Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa

Edited by: **André Bationo**

TSBF

Tropical Soil Biology & Fertility Institute of CIAT

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

RELMA
Regional Land Management Unit

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Soil fertility depletion has been described as the major bio-physical root cause of declining per capita food available in small-holder farms in sub-Sahara Africa (SSA).

In essence, overtime, this has necessitated changes in research approaches. The need has been recognized for integration of socio-economic and policy research besides technical research. Soil fertility can no longer be regarded as a simple issue solved by the issues of organic and inorganic sources of nutrients. Integrated soil fertility management embraces responses to the full range of driving factors and consequences, namely biological, physical, chemical, social, economic and political aspects. The holistic approach encompasses nutrient deficiencies, inappropriate germplasm and cropping system design, pest, disease interaction with soil fertility, linkage between land degradation, poverty and global policies, incentives as well as institutional failure considerations. Such long term and holistic soil fertility management strategies require an evolutionary and knowledge intensive process, participatory research and development focus rather than a purely technical focus. This book espouses such an approach.

This book is written by AfNet members and is divided into three parts. The first part deals with the issue on Integrated soil fertility management. The second part is on belowground biodiversity and the last part is on participatory and scaling up of soil fertility restoration technologies.

The African Network for Soil Biology and Fertility (AfNet) of the Tropical Soil Biology and Fertility Institute of CIAT (TSBF- CIAT) is the single most important implementing agent of TSBF. The Network has the overall goal of strengthening and sustaining stakeholder capacity to generate, share and apply soil fertility management knowledge to contribute to the welfare of farming communities and hence the publication of this book.

This book is edited by AfNet members. It is a synthesis of research results from AfNet and other resources and presents views of African scientists in the critical issue of improving the productivity of the soils of the continent. Further editorial and publishing support has been provided by Prof. Samuel O. Akatch of the Academy Science Publishers at the African Academy of Sciences, Karen, Nairobi and HABRI of the University of Nairobi.

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Dedication

At the African Network for Soil Biology and Fertility (AfNet) scientific committee meeting on the 15th December 2002 at Naivasha, Kenya, the committee members decided to have this book dedicated to Professor Mike Swift and make him an AfNet life member.

It is with much gratitude that AfNet scientific committee wishes to dedicate this book to **Professor Mike Swift** for his many years of dedicated service to the TSBF Institute. Mike, as we have popularly referred to him, served TSBF and established AfNet as the single most important implementing agent of this institute.

Professor Mike Swift has been instrumental in career development and professional growth of many scientists and academicians on the African continent, and beyond. He is committed to the concept that the fertility of tropical soils is controlled by biological processes and can be managed by the manipulation of these processes.

We all wish Professor Mike Swift and his family a happy retirement and success in all their future endeavors.

André Bationo
Susan Ikerra
Stephen Kimani
Daniel Mugendi
Martins Odendo
Mary Silver

Preface

Enormous research has been done within the African continent in various areas including soil organic matter, soil biota, synchrony and resource integration. All this research is geared towards gaining more understanding on soil processes which have direct or indirect influence on soil fertility and land productivity as a whole.

The Tropical Soil Biology and Fertility (TSBF) Institute of CIAT is a research programme whose main aim is to contribute to human welfare and environmental conservation in the tropics by developing adoptable and suitable soil management practices that integrate the biological, chemical and socio-economic processes that regulate soil fertility and optimize the use of organic and inorganic resources available to the land-users. The African Network for Soil Biology and Fertility (AfNet) being a network of scientists in Africa is the single most important implementing agency of TSBF in Africa. AfNet's main goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility management knowledge and skills to contribute to the welfare of farming communities. It is a mechanism to facilitate and promote collaboration in research and development among scientists in Africa for the purpose of developing innovative and practicable resource management practices for sustainable food production in the African continent.

AfNet's overall target outputs are:

1) To exchange information and combine collective experience of professionals in the same field;
2) To achieve economies of scale and efficiency by concentrating scarce human, financial and other resources on key national and regional problems;
3) To carry out collaborative research through network experiments;
4) To minimize duplication;
5) To provide increased bargaining power with external partners; and
6) To undertake joint capacity building.

In order to enhance these objectives of collaborative research, the network members were offered the opportunity to participate in a conference that brought together all partners and stakeholders to share, exchange and publish results emanating from their research activities in soil biology and fertility in Africa. This book on Managing Nutrient Cycle to Sustain Soil Fertility in sub-Saharan Africa is a synthesis of AfNet member research results of the past few years.

Soil fertility degradation still remains the single most important constraint to food production in sub-Saharan Africa and an efficient cycling of nutrients among crops, animals and soil is crucial to the sustained productivity of the farming systems. Emerging evidence indicate that there is considerable consensus on guiding principles for integrated soil fertility management (ISFM) as the more pragmatic and feasible approach to overcome the limitations of past research approaches. As a holistic approach to research on soil fertility, ISFM embraces responses to the full range of driving factors and consequences namely biological, physical, chemical, social, economic and political aspects of soil fertility decline. The approach encompasses nutrient deficiencies, inappropriate germplasm and cropping system design, pest-disease interaction with soil fertility, linkage between land degradation and poverty and global policies, incentives as well as institutional failures. Such long-term soil fertility management strategy requires an evolutionary, knowledge intensive process, participatory research and development focus rather than a purely technical focus.

After the introduction in chapter 1 on new challenges and opportunities of AfNet, this book is divided in three broad parts. Part one ranges from chapter 2 to chapter 28 and deals with the issues on integrated soil fertility management. The second part is from chapter 29 to chapter 34 and is on belowground biodiversity. Part three, from chapter 35 to chapter 42 is on participatory research and scaling up of soil fertility restoration technologies.

AfNet recently published a book on "**Soil Fertility Management in Africa: A Regional Perspective**". AfNet also intends to publish another book on "**Fighting Poverty in Sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management**".

We are grateful to the Rockefeller Foundation for their continual support to AfNet and particularly for financial support towards the successful organization of the conference leading to the publication of this book. AfNet also wishes to acknowledge the financial support from Regional Land Management Unit (RELMA) in the publishing this book.

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The Tropical Soil Biology and Fertility (TSBF) Institute of CIAT is a research programme whose main aim is to contribute to human welfare and environmental conservation in the tropics by developing adoptable and suitable soil management practices that integrate the biological, chemical and socio-economic processes that regulate soil fertility and optimize the use of organic and inorganic resources available to the land users. TSBF research basically targets the empowerment of farmers so as to effectively (i) manage nutrient cycles; (ii) manage below ground biodiversity and (iii) manage ecosystem services, so as to achieve the necessarry sustainable Agro-ecosystem management.

The African Network for Soil Biology and Fertility (AfNet) is the single most important implementing agency of TSBF in Africa. Its main goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility and biology management knowledge and skills to contribute to the welfare of farming communities. It is a mechanism to facilitate and promote collaboration in research and development among scientists in Africa for the purpose of developing innovative and practical resources management interventions for sustainable food production. AfNet has membership from National Agricultural Research and Extension Services (NARES) and universities from various disciplines mainly soil science, social science, agronomy and technology exchange.

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PART I

INTEGRATED SOIL FERTILITY MANAGEMENT

PART II

BELOWGROUND BIODIVERSITY

PART III

PARTICIPATORY RESEARCH AND SCALING UP OF SOIL FERTILITY RESTORATION TECHNOLOGIES

1

The African Network for Soil Biology and Fertility: New Challenges and Opportunities

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Abstract

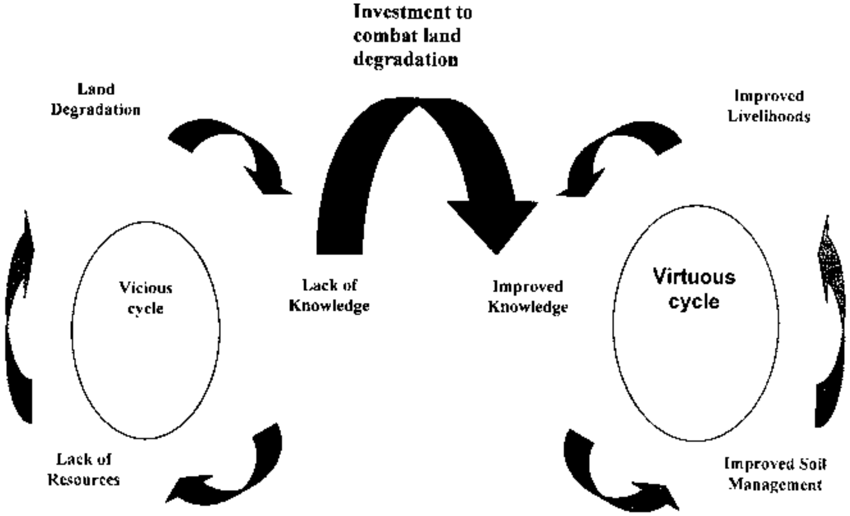
Soil fertility degradation has been described as the single most important constraint to food security in sub-Saharan Africa (SSA). Soil fertility decline is not just a problem of nutrient deficiency but also of 1) Inappropriate germplasm and cropping system design, 2) Interactions with pests and diseases, 3) The linkage between poverty and land degradation, 4) Often perverse national and global policies with respect to incentives, and 5) Institutional failures. Tackling soil fertility issues thus requires a long-term perspective and a holistic approach. The African Network for Soil Biology and Fertility (AfNet) of Tropical Soil Biology and Fertility institute of CIAT whose ultimate goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility management knowledge and skills to contribute to the welfare of farming communities is devoted to overcoming this challenge. This African-wide network has over 200 members from National Agricultural Research and Extension Services (NARES) and universities from various disciplines mainly soil science, social science and technology exchange. This paper is an highlight of AfNet's main activities which include: Network field research activities, information and documentation, training and capacity building.

Introduction

Africa has 340 million people, over a half of its population living on less than USD 1 per day, a mortality rate of children under 5 years of age of 140 per 1000 and life expectancy of only 54 years. The latest figures show that some 200 million people, or 28% of Africa population are chronically hungry. The average African consumes only about 87% of the calories needed for a healthy and productive life. At present, over USD 18 billion is spent annually on food imports and in the year 2000, Africa received 2.8 million tons of food aid, a quarter of the world's total. Over half of the African population is rural, and directly dependent on locally grown crops or foods harvested from the immediate environment. Macro-policy changes imposed externally in the last decade, such as structural adjustment and the removal of fertilizer subsidies, were executed without any clear understanding of the likely consequences at a micro-level and hidden effect on continued erosion of the natural resource base. Structural adjustment policies resulted in the reduction of the use of external inputs, extensification of agriculture through the opening of new lands and the reduction of the farmers' potential for investment in soil fertility restoration. Technological, environmental, socio-cultural, economic, institutional and policy constraints have been identified to hamper agricultural development in Africa. These constraints are: (i) low soil fertility (ii) fragile ecosystems (iii) over dependence on rainfall (iv) aging rural population and thus limited physical energies for production (v) underdeveloped and degraded rural infrastructure (vi) insufficient research due to lack of motivation and inadequate facilities (vii) inadequate training and extension services (viii) high post harvest losses (ix) insufficient market (x) lack of credit and insufficient agri-input delivery systems (xi) limited farmers' education and know-how (xii) continental brain-drain of African intellectuals (xiii) policy instability (xiv) inconsistent agricultural policies and efficient land tenure. This led to the New Partnership for Africa's Development (NEPAD) to recognize that agriculture-led development is fundamental to cutting hunger, reducing poverty, generating economic growth, reducing burden of food imports and opening the way to an expansion of exports. Per capita food production in Africa has been declining over the past two decades, contrary to the global trend. The result is widespread malnutrition, a recurrent need for emergency food and an increasing dependence on food grown outside the region. The average annual increase of cereal yield in Africa is about 10 kg/ha, the rate known as the one for extensive agriculture neglecting external inputs like improved seeds and plant nutrients. The growth rate for cereal grain yield is about 1% while population growth will be about 3%. During the last 35 years, cereals production per capita has decreased from 150 to 130 kg/person, whereas in Asia and Latin America an increase from about 200 to 250 kg/person have been observed. Both labor and land productivity are among the lowest of the world. The Forum for Agricultural Research in Africa (FARA) with its member sub-regional organizations (SRO) has developed a vision for African Agricultural Research, which calls for 6% annual growth in agricultural productivity.

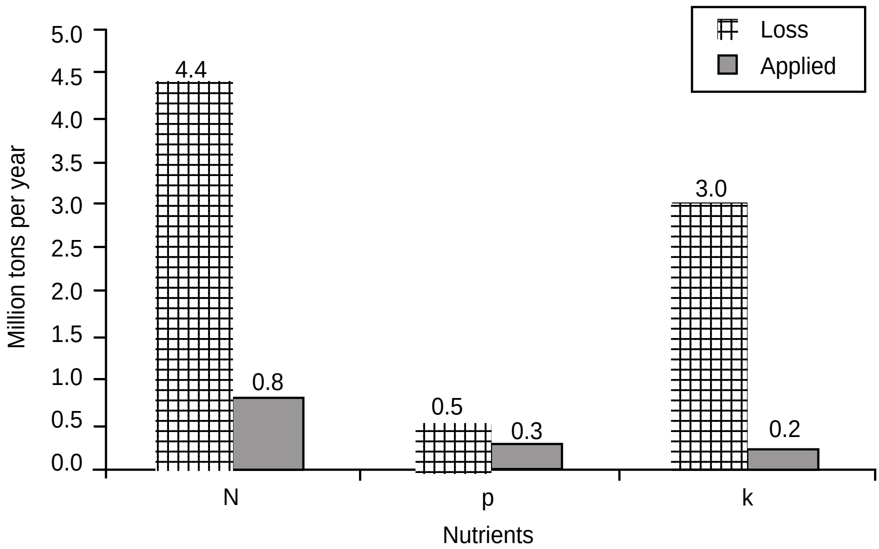
Land degradation is one of the most serious threats to food production in the continent. The population is thus trapped in a vicious poverty cycle between land degradation, and the lack of resources or knowledge to generate adequate income and opportunities to overcome the degradation and it is urgent to invest to combat land degradation to revert this vicious circle (Figure 1.1).

Figure 1.1: Combating land degradation to improve rural livelihoods



Scientists have reported that soil loss through erosion is about 10 times greater than the rate of natural formation, while the rate of deforestation is 30 times higher than that of planned reforestation. Although large areas of forests, wetlands, river valley bottoms and grassland savanna have been put under food crops, the food gap (requirements minus production) keeps widening. Soil nutrient depletion is a major bottleneck to increased productivity in Africa and has largely contributed to poverty and food insecurity. Soil nutrient depletion occurs when nutrient inflows are less than outflows. Nutrient balances for many cropping systems are negative indicating that farmers are mining their soil. The data in Figure 1.2 clearly illustrate the level of nutrient mining in African agro-ecosystems. For nitrogen as an example, whereas 4.4 million tons is lost per year, only 0.8 million tons is applied.

Figure 1.2: Macronutrient application versus loss in Africa



Source: Sanchez *et al.* (1997)

The different biophysical, chemical and socio-economic factors contributing to low soil fertility and poor productivity are reported in Figure 1.3.

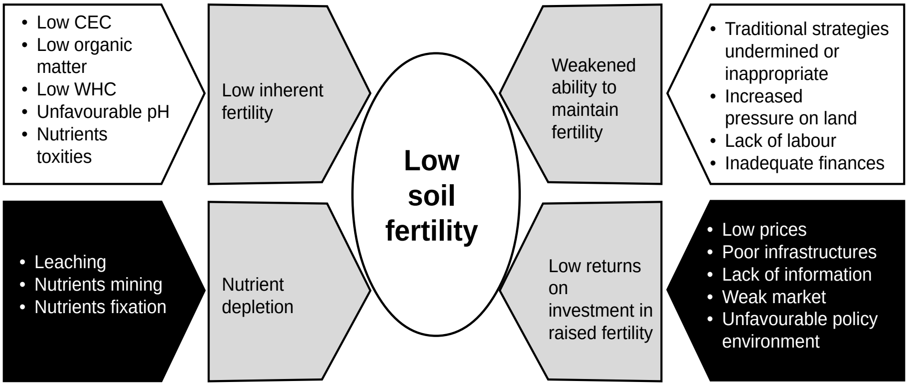
At present, fertilizer use in Africa is about 9 kg ha^{-1} as compared to 87 kg ha^{-1} for the developed countries (Table 1.1). With 9% of the world's population, SSA account for less than 1.8% of global fertilizer use and less than 0.1% of global fertilizer production.

Table 1.1: Population, cropped land and fertilizer use (1961-97) in some African countries as compared to some developed ones

	1961			1997		
	Pop. (Million)	Crop land (Million ha)	Fertilizer use (Kg ha^{-1})	Pop. (Million)	Crop land (Million ha)	Fertilizer use (Kg ha^{-1})
World	3136	1352.0	23.0	5823	1501.0	90
Dev. countries	987	654	42	1294	640.0	87
S.S Africa	219	120	0.15	578	154	9
D.R. Congo	16	7.0	0.04	48	7.9	0.8
Kenya	9	28.8	2.8	28	4.5	29
Nigeria	38	0.6	0.5	104	30.7	4.5
Egypt	29	2.6	93	65	3.2	313
France	46	21.4	113	58	19.5	260
India	452	160.9	21	966	169.8	95
USA	189	182.5	41	272	177.0	114

Source: FAO 1999

Figure 1.3: Biophysical, chemical and socio-economic factors contributing to low soil fertility and poor productivity in Sub-Saharan Africa



Source: Murwira, 2003

The gradual degradation of the land is a menace to rural communities, in terms of food security and a continued exploitation of the fragile resource base depleted from many plant nutrients. There is, therefore, a critical need to develop and implement management options that both mitigate soil degradation, deforestation and biological resources losses and enhance local economies while protecting the natural resource base.

Transforming African Agriculture and expanding its production capacity are prerequisites for alleviating rural poverty, household food deficits and environmental exploitation in the continent. Because opportunities for expanding the cultivated area are rapidly being exhausted, as much as four-fifths of future production increases must come from higher yields. The use of effective strategies to combat land degradation is one of the key components of the higher productivity. The African Network for soil biology and fertility (AfNet) of the Tropical Soil Biology and Fertility Institute of CIAT is established to overcome the challenge of soil fertility degradation in the African continent. In this paper, after a brief presentation of AfNet objective and management, we will present the new challenges and opportunities of this network in field research activities, information and documentation, training and capacity building.

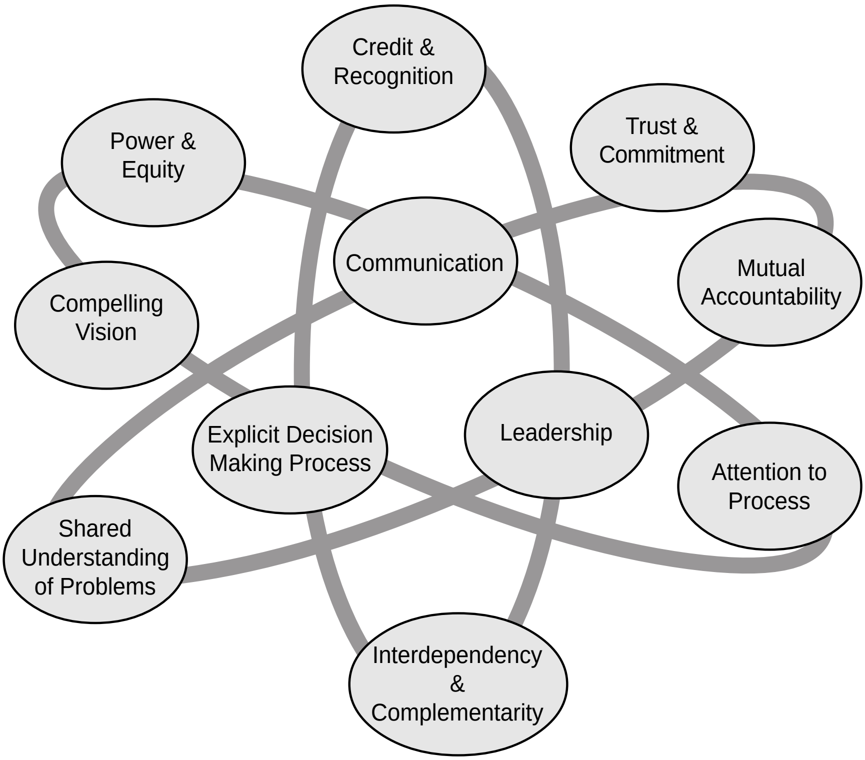
AfNet Objectives and Management

Networking may be defined as a strategy by stakeholders in a given area of interest to work together to achieve a common objective. The building blocks of a network are the participating individuals or institutions. These stakeholders collaborate on the hypothesis that working together is more beneficial and effective than working independently, and that there is a need to go outside the organization in order to accomplish their goals. Through networking, participants (a) build-up their knowledge base, (b) understand the processes through which they can promote values and (c) translate their understanding into action. Several achievements are possible in research through networking. The collaborating institutions or individuals are in a position to exchange information and combine collective experience of professionalism in the same field as partners. Figure 1.4 gives the different elements of partnerships and these elements are considered by AfNet in order to increase the network effectiveness and efficiency.

The advantages of networking include:

i) To achieve economies of scale and efficiency in research by concentrating scarce human, financial and other resources on key national and regional problems;

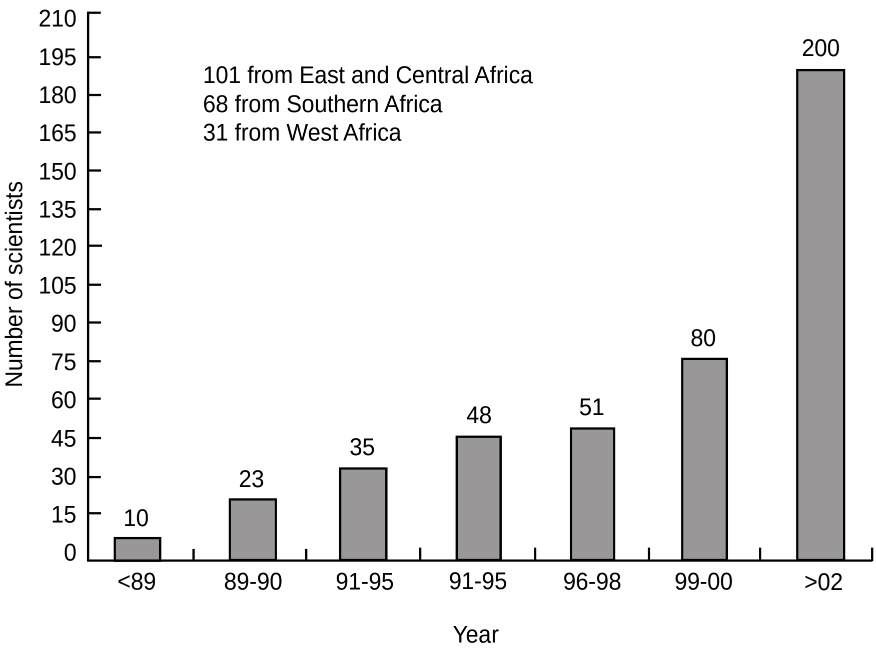
Figure 1.4: Elements of Partnerships



ii) To provide increased bargaining power with external partners;
iii) To minimize duplication;
iv) To exchange information and combine collective experience of professionals in the same field;
v) To carry out collaborative research through network experiments;
vi) To undertake joint capacity building;
vii) To capture research spill-over/ spill-in effects;
viii) To rationalize human resource development;
ix) To mobilize research efforts on trans-national problems that require collaboration between countries;
x) To exploit a larger market for agricultural research technologies through regional collaboration;
xi) To demonstrate impact despite the declining investment in agricultural research through regional cooperation;
xii) To achieve lower transaction costs;
xiii) To facilitate better and more access by all stakeholders of available technologies at regional and international levels.

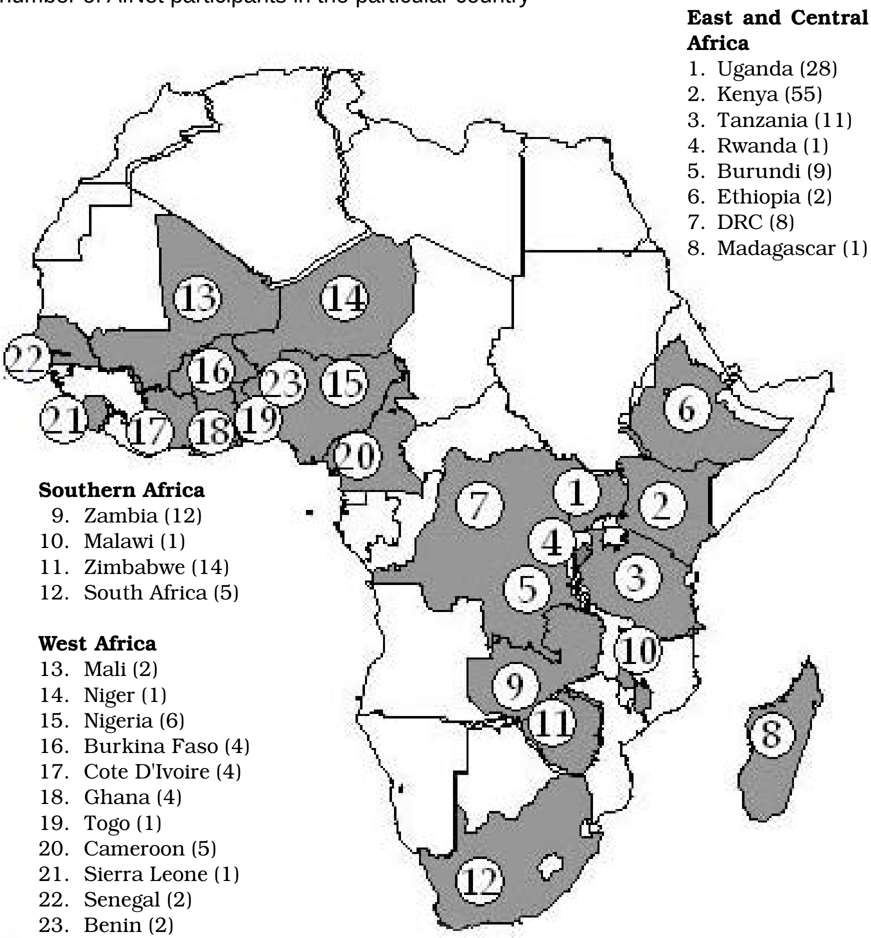
The African Network for Soil Biology and Fertility (AfNet) was established in 1988 and is the single most important implementing agency of TSBF in Africa. Its main goal is to strengthen and sustain stakeholder capacity to generate, share and apply soil fertility and biology management knowledge and skills to contribute to the welfare of farming communities. It is a mechanism to facilitate and promote collaboration in research and development among scientists in Africa for the purpose of developing innovative and practical resource management interventions for sustainable food production. AfNet has membership from National Agricultural Research and Extension services (NARES) and Universities from various disciplines mainly soil science, social science, agronomy and technology exchange.

Figure 1.5: AfNet member registrations since inception



With a total number of 10 researchers in 1989, AfNet has now a total number of over 200 persons in 2003. It is an African-wide network with 101 members from East and Central Africa, 68 from Southern Africa and 31 from West Africa (Figure 1.5). The data in Figure 1.6 gives the AfNet participating countries.

Figure 1.6: AfNet partitipating countries, 2003: Number in parenthesis represent the number of AfNet participants in the particular country



AfNet is under the auspices of the Tropical Soil Biology and Fertility Institute of CIAT, who implement most of its activities in Africa through AfNet. The AfNet members share TSBF goals and approaches. TSBF conduct research in a variety of tropical countries, but always in collaboration with national scientists. This implementation of TSBF agenda through partnership utilizes a range of approaches with particular emphasis on the following:

i) Catalysis: Ensuring that AfNet members are kept at the forefront of conceptual and methodological advances by conducting and promoting review, synthesis and dissemination of knowledge and information. This is done through workshops, training and sabbatical and short exchange visits.

ii) Facilitation: Co-ordinating actions by members to achieve progress and success in research. This is done by providing backstopping support in the preparation, submission, implementation and publication of research results.

iii) Collaboration: Developing appropriate alliances with institutions across the research, educational and development spectrum, including linkages between institutions in the North and those in the South.

AfNet has a coordination unit comprising of a secretariat, research assistants and the coordinator. AfNet is managed by a scientific committee comprising of the director of TSBF, the AfNet coordinator and five members from the national programmes elected during general assemblies by AfNet members.

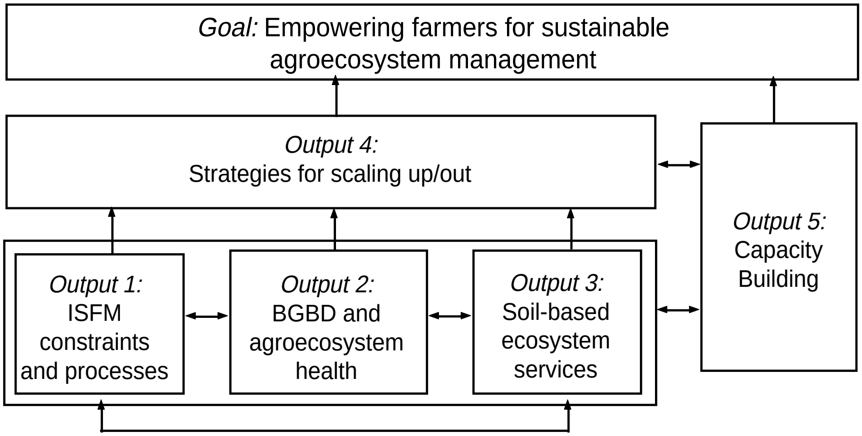
AfNet is dedicated to work more closely with other networks, system-wide ecoregional initiative such as AHI, SoilFertiNet, ANAFE, DMP, SWMNet, ECABREN, MIS and is planning to have an active role in the various challenge programmes of the CGIAR.

Network field activities

Predictive interdisciplinary research across environments, using standard methods and experimental designs, reinforces results, enables the drawing and extrapolation of generalized conclusions and enhances modeling capacity, all leading to accelerate progress in essential research areas. AfNet works with partners to identify key research themes or problems of regional or international importance and then develops appropriate experimental methods and protocols for addressing those topics. There will be a special focus on the use of decision support systems, GIS and modeling for the extrapolation of research results to other recommendation domains.

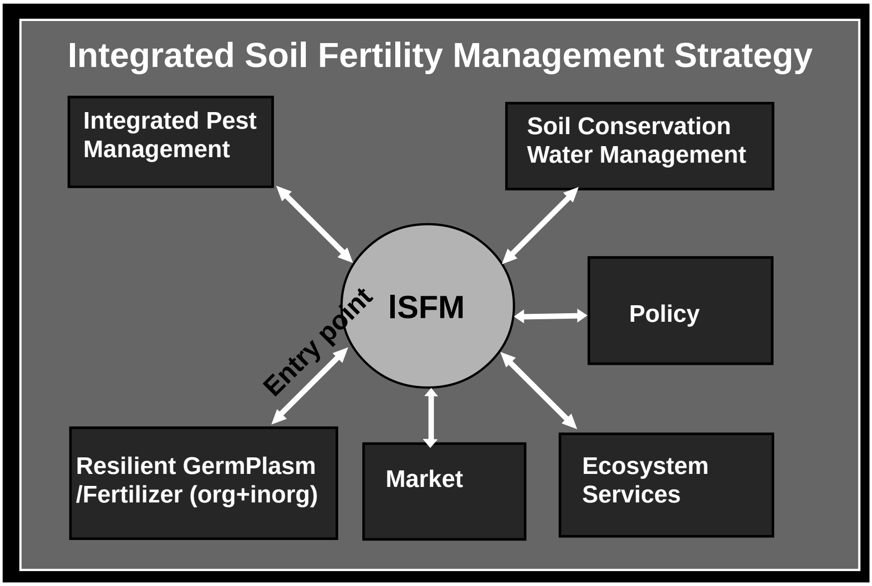
AfNet field research activities addresses the same research outputs of the TSBF institute of CIAT (Figure 1.7) with the overall goal of empowering farmers for sustainable agro ecosystem management. Output 1 on Integrated Soil Fertility Management (ISFM), output 2 on belowground biodiversity and agro-ecosystem health and output 3 on soil-based ecosystem services are the technical outputs for the development of alternative options. In Africa all research institutions are confronted with the challenge of extending their research findings for successful impact on farm. The fourth output on strategies for scaling up/ out will focus on evaluation of management options, on pathways of knowledge interchange and on policies for sustainable soil management by using the technical options developed by the other outputs.

Figure 1.7: The Tropical Soil Biology and Fertility Institute of CIAT research outputs



During the past three decades, the paradigms underlying soil fertility management research and development efforts in SSA have undergone substantial change. From the nutrient replacement paradigm to Low Input Sustainable Agriculture (LISA) AfNet adopted the Integrated Soil Fertility Management (ISFM) paradigm that forms an integral part of the Integrated Natural Resource Management (INRM) research approach with a focus on appropriate management of the soil resource (Figure 1.8).

Figure 1.8: Integrated Soil Fertility Management strategies with wider natural management concerns



In essence, ISFM is the adoption of a holistic approach to research on soil fertility that embraces the full range of driving factors and consequences- biological, physical, chemical, social, economic and political.

The need has been recognized for integration of socio-economic and policy research besides technical research. Soil fertility can no longer be regarded as a simple squared by the issue of organic and inorganic nutrient sources. The holistic approach encompasses nutrient deficiencies, inappropriate germplasm and cropping systems, pest and disease interaction with soil fertility, linkage between land degradation and poverty and global policies, incentives as well as institutional failures. Such long-term soil fertility management strategy requires an evolutionary and knowledge intensive process and participatory research and development focus rather than a purely technical focus.

AfNet will focus in the years to come on the following research topics and projects for the implementation of its field research activities.

Nutrient budgets of agroecosystems

Past research focuses on N, P, and K, there is need to target other macronutrient besides nitrogen, phosphorus and potassium and micronutrients and soil carbon. There will be need to focus more on methodologies for extrapolation of results in the time and space scales. The validation of transfer functions leading to better estimates of leaching losses, gaseous and erosion losses and the need to link nutrient balances data to other soil productivity indicators, total or available nutrient stocks, fertilizer needs and response functions and nutrient budgets to farmers' perception and knowledge systems.

Economic, policy and dissemination issues

In most of the research projects, economic policy and dissemination issues are incorporated with focus of economic analysis of soil fertility technologies with special emphasis on the trade-offs of alternative strategies of soil fertility management (eg food, feed, soil fertility management, social functions), the need to incorporate economic and bio-physical modeling to capture long-term sustainability and risk perspectives.

On adoption and impact assessment, special attention is put on the assessment of socio-economic and agronomic factors affecting farmers' adoption of best bet technologies, the measurement, the understanding of the potential and constraints and the economics of different dissemination channels. Research on ways to increase farmers' access to external input through the establishment of appropriate credit and saving schemes. Policy research and advocacy to create an enabling environment to accelerate adoption of best bet technologies and establishment of policy briefs and studies on economic of different dissemination channels will be emphasized.

Long-term soil fertility management trials

AfNet is contributing with NARS to maintain long-term soil fertility management trials in the sub-humid highlands of Kenya at Kabete (established since 1976), the sub-humid zone of Burkina Faso at Farakoba (established since 1990), the dry savannah of Burkina Faso at Saria (established since 1960) and at Fada (established since 1990) and the Sahelian zone of Niger at Sadore (established since 1982). The overall goal is to access sustainability indicators from the different inputs (organic and inorganic) and cropping systems.

Combining organic and inorganic nutrient sources for increased soil quality

The overall goal of the work on organic-inorganic interactions is to (i) empower farmers (Including extension workers and stakeholders) to use organic and inorganic resources with optimal efficiency; (ii) understand the long-term effects on nutrient recovery efficiencies and (iii) better understand the non-N effects of organic amendments (weed suppression eg striga, other nutrients (Ca, Mg, K, S, P etc…), moisture retention and use).

The role of legumes in soil fertility restoration

The general objective for this network study is to foster strategic research on issues that increase efficiency of legume cover crops (LCCs) for enhancement and sustaining soil fertility and hence crop yields in smallholder farms in the Sub-Saharan Africa. The derived specific objectives are: 1) Review and document current information on the use of LCCs for soil fertility improvement in the Africa region 2) Determine the contribution of above and below ground biomass from LCC on the subsequent food crops 3) Determine the relationship between source and quantity of N from cover crops and its recovery in the subsequent crop 4) Evaluate tradeoffs in gains and losses in food production, land availability, labour constraints and capital that may affect the adoption of LCCs 5) Develop a decision support guide for dissemination of LCC technologies.

Livestock and soil fertility issues

For this research theme we will emphasize on the assessment of manure production, livestock rangeland ratios for sustainable production. Strategies that minimize competition between crops and livestock. The overall objective for the improvement of manure management aims at reviewing past manure work in the individual countries and identifying technologies that could be disseminated without doing basic research; testing and validating, various composting/storage techniques on crop yield, soil fertility maintenance and economics with farmers' participation; and the contribution of manure use to soil organic matter.

Use of rock phosphate as capital investment to replenish soil fertility

The use of fertilizers is a possible option to reverse the soil fertility decline trend but their high costs constitute an handicap mainly to resource poor farmers. There is therefore a need for alternative, affordable P sources. Rock phosphates which are found in most parts of Africa have low reactivity. They, however offer a cheaper source of P for resource poor farmers. For this issue, there is need to extend the agronomic evaluation of suitability of PR to perennial crops and other crops than the traditional cereals and to investigate on the interaction between soil, climate and water conservation on PR effectiveness. The screening of plant species and association with Vascular Arbuscular Mychorrizae (VAM) for efficient use of PR need more attention. The economics of compacted products with PR and development of decision support systems (DSS) need to be emphasized. Solubility of these phosphate rocks can be improved by using combination of the rock and organic/ green manures. Besides their solubilization effects, the organic materials influence soil P availability by altering some processes governing soil P pools such as microbial activities and P sorption. Different organic inputs are likely to impart different effects on rock phosphate dissolution and soil P availability depending on their composition, rate of application, and type of soil and agro- ecological zone. This network research theme therefore is to do on-farm testing of Phosphate rocks P dissolution as influenced by different types and rates of organic materials and the subsequent crop yield. Specifically, the research is intended to identify, characterize and evaluate locally available organic materials for their potential to enhance phosphate rock solubilization under farmer's conditions. Also establish the effect of local organic materials on PR dissolution and its relative agronomic effectiveness. In addition the research will assess the effects of organic and inorganic P sources on soil P dynamics and fractions.

Nutrient and water interaction

African dry lands soils have low inherent fertility, and this combined with high inter-annual variability and erratic rainfall distribution in space result in water limiting conditions and poor crop yields. The use of effective strategies to control nutrient mining and improve water and nutrient use efficiency in dry land Africa is one of the key components for higher productivity. In light of large initial investment in material machinery and labor for water harvesting, there is need to focus research to increase the profitability in the farming systems. Although water and nutrient interaction research is essential for increasing and stabilizing crop production, and for maximizing the returns from investments on fertilizer and water harvesting techniques, far less studies on these interactions have been carried out in the dry lands of Africa, compared to studies on nutrients or those of water separately. A win win situation will occur when water and nutrients are combined as this will increase the efficiency of these inputs and therefore improve their profitability to the small-scale farmer.

Land tenure

Land tenure has a critical impact on market values and thus on economic decision making as to the uses to which land should be put and how to utilize the natural resource. Nature of land rights affects use; duration of right affects nature of long-term investment. World Bank estimates suggest that the capital value of land and natural resources constitutes half to three quarters of a nation's wealth: the less domestic capital and the less developed the economy, the higher this proportion. What is true for the nation is also typically true for the family and individual. Land and natural resources are therefore likely to be by far the largest class of asset in most economies. Its efficient use and management must be one of the keys to successful economic development. Secure land rights will move the key economic resource of land towards the highest and economically most efficient use.

Lack of secure land tenure is associated with overexploitation of resources. In turn, overexploitation of land and natural resources critically affects the economic welfare and food security. With insecure land tenure, farmers have no incentive to commit long-term investments for sustainable farming and livelihood.

The main goal of this research theme is to contribute to poverty reduction through increased land productivity to improve food security, while conserving the natural resource base for sustainable production. The purpose is to provide farming communities, policy-makers and other stakeholders with land tenure policy options that will improve adoption of land management and conservation technologies. The research agenda seek to achieve the following specific objectives: (1) Review and compile existing land and natural resource use and investment policies that has direct implication to smallholder farmers' decision-making process, (2) Identify categories of tenure that play major role in adopting available technologies for integrated land management and natural resource use, (3) Estimate socioeconomic gains associated with secure land tenure through bio-economic modeling/simulation, (4) Suggest policy instruments that would encourage secure land tenure and maximize national goals of improving smallholder farmers' welfare.

Conservation tillage

Combination of soil fertility restoration technologies and conservation tillage practices offer opportunities to sustainable land use. However, little has been done to integrate these approaches within existing crop production systems. It is hypothesized that combining soil fertility technologies with conservation tillage practices is one of the best strategies to increase food security, sustain rural livelihoods in sub-Saharan Africa and maintain soil organic matter.

In this research theme, the following specific objectives are sought to be achieved: (i) Evaluate the productivity of different cropping systems following conservation tillage practices, (ii) Determine the effect of conservation tillage on sustainability and soil health indicators, (iii) Promote conservation tillage practices as a means to restore the productivity of degraded soils.

Belowground biodiversity

The soil biota constitutes a major fraction of global terrestrial biodiversity and is responsible for key ecosystem functions such as decomposition; nutrient acquisition, storage and cycling; soil organic matter synthesis and mineralization; soil structural modification; regulation of atmospheric composition; and the biological control of soil-borne pests and diseases. These functions remain largely under-exploited by humans for services and products in agriculture because little has been understood on the biological processes of soil unlike physical and chemical management of soil.

The strategic research in AfNet to realise this potential by:

- Developing quantitative techniques for monitoring and manipulating key functional groups of soil biota and their relationship to ecosystem service functions and plant health.

- Developing and validate management practices for key groups of beneficial soil organisms for small-scale farms.
- Linking local knowledge about biological indicators of soil quality with scientific knowledge to develop robust soil quality monitoring systems that combine precision and relevance.

This research agenda will also seek to establish the relationship between organic residue quality (resource quality), farmers' management strategies and diversity, populations and activities of biotic community (macrofauna: ecosystem engineers-earthworms, termites, ants and others) associated with biomass transfer technologies. The main aim is to come out with the best-bet approach that promote soil biotic activities, increase and sustain soil productivity and minimize pest incidence in tropical agroecosystems.

Also to sustainably increase crop yield for small-scale farmers in sub-Sahara Africa by using mycorrhiza as bio-fertilizer and build farmers' understanding on the importance of termites and other macro and meso faunal communities in African farming systems.

Low quality organic resource management

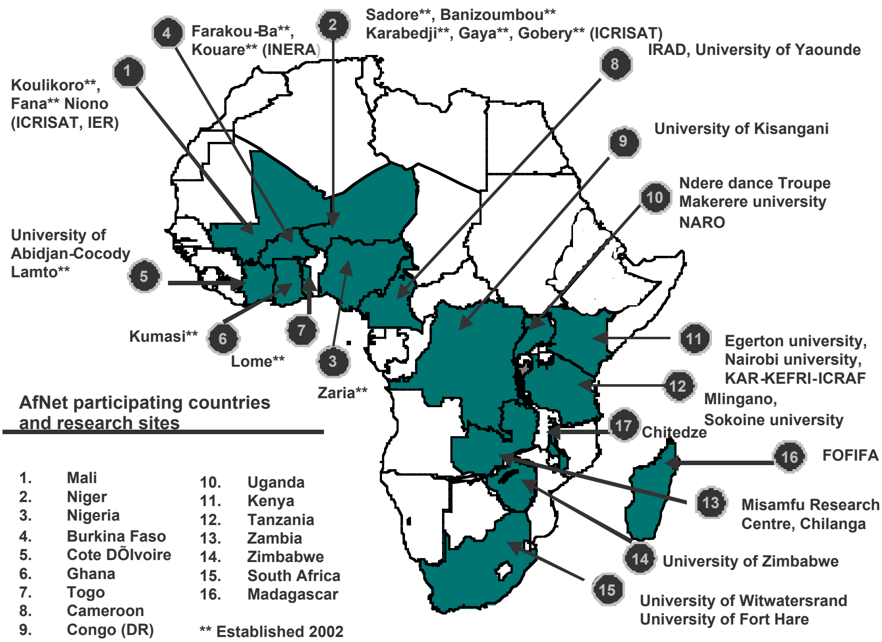
This research theme examines the functional role of low quality organic resources on soil organic matter (SOM) and the ultimate influence in sustaining crop productivity and environmental service functions in tropical agro-ecosystems as affected by management of quality and quantities of low quality organic resources available to smallholder farmers in the sub-Saharan region of Africa. The research will i) Characterize the quantity and quality of organic materials available to smallholder farmers in benchmark areas, and determine how these have influenced SOM status and dynamics under different management practices and biophysical environments; ii) determine the quantitative effects of continuous application of low quality organic inputs on SOM build up, soil nutrient supply patterns and soil physico-chemical properties; iii) quantify the differential contribution of distinct SOM functional pools (fractions) to soil properties essential for maintenance of crop productivity and environmental quality under different management systems, soils types and climatic environments in selected benchmark areas; iv) define the biophysical and socio-economic boundaries within which SOM management can be enhanced for increased soil productivity and environmental services in tropical farming systems in sub-Saharan Africa.

Site selection

The field activities are carried out on benchmark and satellite sites. The benchmark sites are selected according to several factors such as soil types, rainfall regime, farming systems, type of market, land tenure, etc...

At present, AfNet is implementing field research in about 50 representative benchmark sites in Africa. Figure 1.9 gives some selected benchmark sites where experiments were carried out in 2002. AfNet encourages multi-disciplinary approach for the implementation of its field activities but individual research projects are also supported by the network. In addition to the thematic research, focus is put now on the development of country proposals using an holistic approach to Integrate Soil Fertility Management (ISFM).

Figure 1.9: Selected AfNet research sites in 2002



Funding mechanism

The funding of network trials is on a competitive basis and the criteria used for the attribution of funds are based on: (i) the level of contribution to food security and self sufficiency (ii) equity (number of beneficiaries, poverty alleviation, gender/ age consideration) (iii) efficiency (iv) sustainability (v) effectiveness (probability of success, cost of adoption) (vi) regional collaboration.

Information and documentation

One of the main constraints to soil biological research experienced by many national scientists is limited access to current research findings. It is important not only that current research developments are accessible to members of the network but that the results of their own work are effectively disseminated. In addition, farmers in SSA are attempting to improve soils, but their efforts are constrained by limited access to useful information, low resource endowments, and lack of incentives. Wealthier households having access to information and with more options available, are more likely to manage their soils better. Poor households lack knowledge of soil management options, the capacity to invest in soils (especially in fertilizer), and have less ability to bear risk and wait for future payoffs from investment. For example, in Western Kenya, resource-poor households, with no access to information, were found to make only 5% of the farm investments, had over twice the erosion rates as compared to the wealthy farmers, and obtained only 28% of maize yields. Tragically, these resource-poor households constitute about 90% of the population. Compounding the problem are poor price incentives, land and labour constraints, and the weakness or complete lack of rural institutions for supporting information and other services. The network will collaborate with other institutions to develop information easy-to-read by farmers on transferable technologies for soil fertility restoration.

A major function of AfNet is to publish, synthesis and disseminate research results relevant to its programme goals. AfNet is publishing twice yearly the comminutor (TSBF newsletter) as a link between network members. Literature search is done as needed on specific subjects for distribution to network members. In addition to publication to refereed journals, AfNet has committed to produce three books.

(i) Soil Fertility Management in Africa: A Regional Perspective.
(ii) Managing Nutrient Cycles to Sustain Soil Fertility in Africa: Proceedings of the 8th Meeting of The African Network for Soil Biology and Fertility, Arusha, Tanzania.
(iii) Fighting Poverty in sub-Saharan Africa: The Multiple Roles of Legumes in Integrated Soil Fertility Management.

Training and capacity building

The capacity for ISFM research in sub-Saharan Africa is insufficient both in terms of the numbers of professional personnel and the essential laboratory facilities. ISFM is a knowledge intensive approach to soil management. Professional staff and students alike suffer from isolation and lack of access to up-to-date educational opportunities. Networks run by sub-Regional Organisations and CGIAR Centres, such as the TSBF African Network for Soil Biology and Fertility (AfNet) provide a vehicle of opportunity to correct this situation. Priority actions include:

- Strengthen networking to engage a wide range of stakeholders and enhance the efficiency of ISFM research.
- In particular, strengthen links between research and extension (including NGOs) using a "learning by doing" approach, which includes local knowledge and builds on existing networks.
- Develop strategic partnerships in capacity building that identify and utilise the range of comparative expertise.
- Improve the dissemination of knowledge on ISFM through a wide range of methods including electronic sharing and training of trainers.
- Promote programmatic linkages with Universities and other educational institutions to strengthen curricula with appropriate and up-to-date information and teaching materials.
- Raise awareness of ISFM issues with policy and decision-makers at all levels.

Table 1.2 below showing the percentage literacy rates reveals an average (57%) literacy rate in the African continent as compared to 97% in the European continent. In some countries like Niger, the literacy rate is as low as 16%. This is a clear indication that more than half of the African population cannot read neither write hence imposing a great impairment to the implementation and dissemination of the research results.

Table 1.2: Selected education statistics for some countries in Africa and other world regions

Country	Literacy rate (%)	Tertiary school enrolment (%)
Burkina Faso	24	0.9
Kenya	83	-
Uganda	67	1.7
Niger	16	1
World	74	14
SSA	57	5
Europe	97	27

Source: ADB 1999

In sub-Saharan Africa tertiary school enrolment has gone as low as 5% as compared to the European continent, which has 27%. However, in addition to low literacy rate in the African continent, there has been a great concern that institutions of higher learning are not making a significant contribution to the national agricultural research agenda. This is due in part to the limited funding of agricultural higher education (Table 1.3). From 1987-97, World Bank global support to agricultural extension was 46.3% as compared to 2.2% for agricultural higher education. The common trend in the African continent has been decline in support for research in these institutions. This trend has to change especially with the realization that many universities in Africa have a large stock of agricultural scientists with M.Sc. and PhD degrees. For example, in 1995, there were 547 African scientists with a PhD in agriculture employed by universities and 357 in the National Agricultural Research Systems (NARSs) in Eastern and Southern Africa.

Table 1.3: World Bank Global Support for Agricultural Research, Extension and Agricultural Higher Education, 1987-97

	Million $	Percent
Agricultural research	2,482	51.5
Agricultural extension	2,229	46.3
Agricultural higher education	108	2.2
Total	4,819	100

Source: Willett 1998

Lack of administrative, managerial and scientific capacity has been noted as the weak link in African development. Therefore, it is of great importance to launch capacity building initiatives in the African continent. The availability of personnel suitably trained in the appropriate techniques is essential for sustainable agricultural development and research. Since investment in knowledge and human resources is central to sustained development, capacity building should help to rehabilitate and strengthen research and higher education in the African region. TSBF promotes interest in soil biology and fertility among scientists by providing experience and orientation in TSBF methods through short courses, internships and attendance at professional meetings.

Universities and other institutions of higher learning represent the only sustainable option that can, in the long-term, reduce the over dependency on overseas training in the African continent. Therefore, the managers of agricultural research and extension systems in Africa should have a deep concern on improving the quality of local graduate programs because, after phasing out scholarships for overseas training, African universities remain the primary source of human capital for agricultural research and extension agencies in the continent. The African Network for Soil Biology and Fertility (AfNet) has taken this challenge and is in the process of developing a soil biology curriculum support in African Universities. Some of the needs highlighted by 13 African Universities include: lack of critical mass, limited access to information, limited access to teaching material, poor laboratory facilities, and limited examples from African environments.

AfNet will organize short term training courses which will address the following issues: (i) TSBF Standard methods for process and applied research in Soil Biology and Fertility; (ii) data collection, statistical analysis and interpretation; (iii) methodology for on-farm research; (iv) scientific paper writing; and (v) development of research proposals. It will also liase with universities in Europe and the United States of America to have students do their thesis with TSBF officers in Africa for co-supervision of students for MSc and PhD from local universities on topics relevant to TSBF research

Conclusion

Land degradation is one of the most serious threats to food production in the African continent. The population is thus trapped in a vicious poverty cycle between land degradation, and the lack of resources or knowledge to generate adequate income and opportunities to overcome the degradation and it is urgent to invest to combat land degradation to revert this vicious circle. Soil fertility can no longer be regarded as a simple issue squared by the issue of organic and inorganic sources of nutrients. Integrated soil fertility management embraces responses to the full range of driving factors and consequences, namely biological, physical, chemical, social, economic and political aspects. The holistic approach encompasses nutrient deficiencies, inappropriate germplasm and cropping system design, pest, disease interaction with soil fertility, linkage between land degradation and poverty and global policies, incentives as well as institutional failures. Such long-term soil fertility management strategy requires an evolutionary and knowledge intensive process and participatory research and development focus rather than a purely technical focus.

AfNet developed several research projects on Integrated Soil Fertility Management (ISFM), Belowground Biodiversity (BGBD) and agro ecosystem health, soil based ecosystem services and strategies for scaling up/ out to empower farmers for sustainable agro-ecosystems' management. Information and documentation, training and capacity building are among the main strategies of AfNet for sustainable agricultural development in Africa.

References

African Development Bank (ADB). African Development Fund (1999) Education Sector Policy Paper (ESPP), OCOD, December 1999.

FAO (1999) AGROVOC multilingual agricultural thesaurus, Rome, Italy.

Murwira, H.K. (2003) Managing Africa's soils: Approaches and challenges. In: Gichuru, M.P., Bationo, A., Bekunda, M.A., Goma, H.C., Mafangoya, P.L., Mugendi, D.N., Murwira, H.M., Nandwa, S.M., Nyathi, P. and Swift, M. Soil Fertility Management in Africa: A regional Perspective. Academy Science Publishers, Nairobi, Kenya, 306 pp.

Palm, C., Bationo, A. and Waddington, S. (2001). Integration of soil research activities in Eastern and Southern Africa, Nairobi, Kenya, 48 pp.

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Izaac, A.M.N.,Mokwunye, A.Z., Kwesiga, F.R., Ndiritu, C.G., Woomer, P.L. (1997) Soil fertility replenishment in Africa: An investment in natural resource capital. In: Buresh, et al. Replenishing Soil Fertility in Africa. SSSA Special Publication Number 51:1-46.

Willet, A (1998) Agricultural education review: Support for agricultural education in the bank and by other donor executive summary. Washington D.C., World Bank.

2

Integrated Soil Fertility Management Research at TSBF: The Framework, the Principles, and their Application

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Abstract

Integrated Soil Fertility Management (ISFM) has been adopted by the Tropical Soil Biology and Fertility (TSBF) Institute, its African Network (AfNet), and various other organisations as the paradigm for tropical soil fertility management research and development. The development of ISFM is the result of a series of paradigm shifts generated through experience in the field and changes in the overall socio-economic and political environment the various stakeholders, including farmers and researchers, are facing. A first part of the paper illustrates these shifts and sketches how the science of organic matter management has developed in the framework of the various paradigms. The second part focuses on the technical backbone of ISFM strategies by illustrating the roles of organic resources, mineral fertilizer, and soil organic matter (SOM) in providing soil-related goods and services. Special attention is given to the potential occurrence of positive interactions between

these three factors, leading to added benefits in terms of more crop yield, improved soil fertility status, and/or reduced losses of C and nutrients to the environment. A third part aims at confronting the principles and mechanisms for soil fertility management, highlighted in the second section, with reality and focuses on the impact of other realms of capital on soil management opportunities and the potential of decision aids to translate all knowledge and information in a format accessible to the various stakeholders.

Paradigm shifts related to tropical soil fertility management: From a Nutrient Replenishment to an Integrated Soil Fertility Management agenda

During the past 3 decades, the paradigms underlying soil fertility management research and development efforts have undergone substantial change because of experiences gained with specific approaches and changes in the overall social, economic, and political environment the various stakeholders are facing. TSBF has traditionally put a lot of emphasis on the appropriate management of organic resources and the conceptualisation of the role of organic resources in tropical soil fertility management has obviously been adapted to the various underlying paradigms.

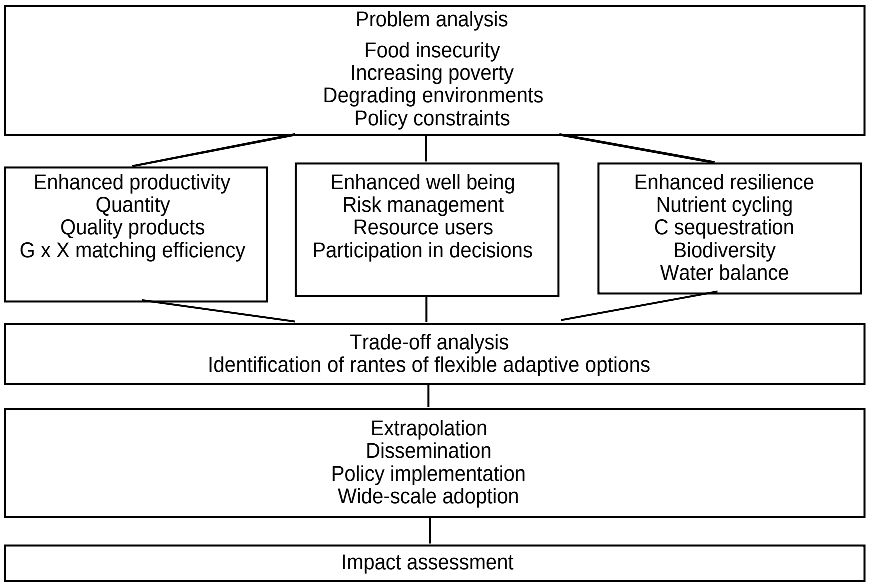
During the 1960s and 1970s, an external input paradigm was driving the research and development agenda. The appropriate use of external inputs, be it fertilizers, lime, or irrigation water, was believed to be able to alleviate any constraint to crop production. Following this paradigm together with the use of improved cereal germplasm, the ‘Green Revolution’ boosted agricultural production in Asia and Latin America in ways not seen before. Organic resources were considered less essential. Sanchez (1976) stated that when mechanization is feasible and fertilizers are available at reasonable cost, there is no reason to consider the maintenance of SOM as a major management goal. However, application of the ‘Green Revolution’ strategy in sub-Saharan Africa (SSA) resulted only in minor achievements because of a variety of reasons (IITA, 1992). This, together with environmental degradation resulting from massive applications of fertilizers and pesticides in Asia and Latin-America between the mid-1980’s and early-1990’s (Theng, 1991) and the abolition of the fertilizer subsidies in SSA (Smaling, 1993), imposed by structural adjustment programs led to a renewed interest in organic resources in the early 1980s. The balance shifted from mineral inputs only to low mineral input sustainable agriculture (LISA) where organic resources were believed to enable sustainable agricultural production.

After a number of years of investment in research activities evaluating the potential of LISA technologies, such as alley cropping or live-mulch systems, several constraints were identified both at the technical (e.g., lack of sufficient organic resources) and the socio-economic level (e.g., labour intensive technologies).

In this context, Sanchez (1994) revised his earlier statement by formulating the Second Paradigm for tropical soil fertility research: 'Rely more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use'. This paradigm did recognize the need for both mineral and organic inputs to sustain crop production, and emphasized the need for all inputs to be used efficiently. The need for both organic and mineral inputs was advocated because (i) both resources fulfil different functions to maintain plant growth, (ii) under most small-scale farming conditions, neither of them is available or affordable in sufficient quantities to be applied alone, and (iii) several hypotheses could be formulated leading to added benefits when applying both inputs in combination. The second paradigm also highlighted the need for improved germplasm, as in earlier days, more emphasis was put on the nutrient supply side without worrying too much about the demand for these nutrients. Obviously, optimal synchrony or use efficiency requires both supply and demand to function optimally.

From the mid-1980s to the mid-1990s the shift in paradigm towards the combined use of organic and mineral inputs was accompanied by a shift in approaches towards involvement of the various stakeholders in the research and development process, mainly driving by the 'participatory' movement. One of the important lessons learnt was that the farmers' decision making process was not merely driven by the soil and climate but by a whole set of factors cutting across the biophysical, socio-economic, and political domain. The Sustainable Livelihoods Approach (DFID, 2000) recognizes the existence of five realms of capital (natural, manufactured, financial, human, and social) that constitute the livelihoods of farmers. It was also recognized that natural capital, such as soil, water, atmosphere, or biota does not only create services which generate goods with a market value (e.g., crops and livestock) but also services which generate amenities essential for the maintenance of life (e.g., clean air and water). Due to the wide array of services provided by natural capital, different stakeholders may have conflicting interests in natural capital. The Integrated Natural Resource Management (INRM) research approach (Figure 2.1) aims at developing interventions that take all the above into account (Izac, 2000). The Integrated Soil Fertility Management (ISFM) paradigm, that forms and integral part of the INRM research approach with a focus on appropriate management of the soil resource, is currently adopted in the soil fertility research and development community. Although technically ISFM adopts the Second Paradigm, it recognizes the important role of social, cultural, and economic processes regulating soil fertility management strategies. ISFM is also broader than Integrated Nutrient Management (INM) as it recognizes the need of an appropriate physical and chemical environment for plant to grow optimally, besides a sufficient and timely supply of available nutrients.

Figure 2.1: The Integrated Natural Resource Management research approach



Source: Izac, 2000

The science of organic matter management as affected by shifts in soil fertility management paradigms

Although organic inputs had not been new to tropical agriculture, the first seminal synthesis on organic matter management and decomposition was written only in 1979 by Swift *et al*. (1979) (Table 2.1). Between 1984 and 1986, a set of hypotheses was formulated based on 2 broad themes, 'synchrony' and 'SOM' (Swift, 1984, 1985, and 1986), building on the concepts and principles formulated in 1979. Under the first theme, especially the O(rganisms)-P(hysical environment)-Q(uality) framework for OM decomposition and nutrient release (Swift *et al*., 1979), formulated earlier, was worked out and translated into hypotheses driving management options to improve nutrient acquisition and crop growth. Under the second theme, the role of OM in the formation of functional SOM fractions was stressed. During the 1990s, the formulation of the research hypotheses related to residue quality and N release led to a vast amount of projects aiming at validation of these hypotheses, both within AfNet and other research groups dealing with tropical soil fertility. This information has been very instrumental for proper evaluation of the sustainability of LISA systems. As such systems did not emphasize the need for mineral inputs, organic resources were merely considered as short-terms sources of nutrients and especially N.

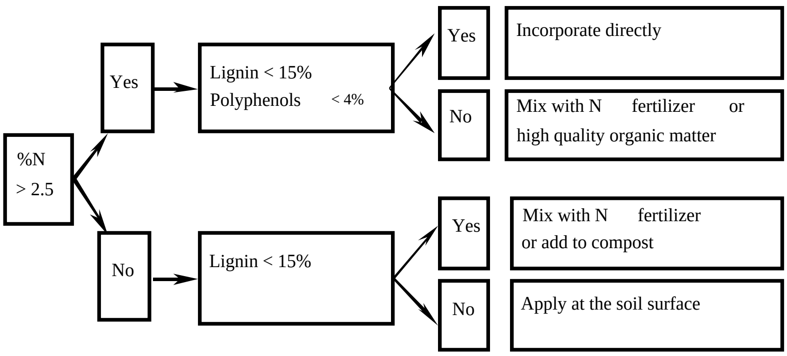
Table 2.1: A brief summary of the science of tropical organic resource management

Period	Observation	Reference
< 1970s	Organic matter as a 'blob'	Palm, personal communication
1979	Organisms - Physical environment – Quality framework for organic matter decomposition	Swift *et al*., 1979
1984-1986	Development of the 'synchrony' research theme within the Tropical Soil Biology and Fertility programme	Swift, 1984; Swift, 1985; Swift, 1986
1990s	Various experiments addressing the 'synchrony' hypothesis	Various
1995	International Symposium on 'Plant Litter Quality and Decomposition'	Cadisch and Giller, 1997
2000	Development of the 'Organic Resource Database' and the Decision Support System for organic N management	Palm *et al*., 2001
> 2001	Quantification of the Decision Support System for organic N management	The current and future publications

Two major events further accentuated the relevance of the topic in tropical soil fertility management. Firstly, a workshop was held in 1995 with the theme 'Plant litter quality and decomposition' resulting in a book summarizing the state of the art of the topic (Cadisch and Giller, 1997). Secondly, TSBF in collaboration with its national partners and Wye College developed the Organic Resource Database (ORD) and related Decision Support System (DSS) for OM management (Figure 2.2) (Palm *et al.*, 2001). The Organic Resource Database contains information on organic resource quality parameters including macronutrient, lignin and polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agroecosystems. Careful analysis of the information contained in the ORD led to the development of the

DSS which makes practical recommendations for appropriate use of organic materials, based on their N, polyphenol, and lignin contents resulting in four categories of materials (Figure 2.2). Recently, a farmer-friendly version of the DSS has been proposed by Giller (2000).

Figure 2.2: The Decision Support System for organic matter management



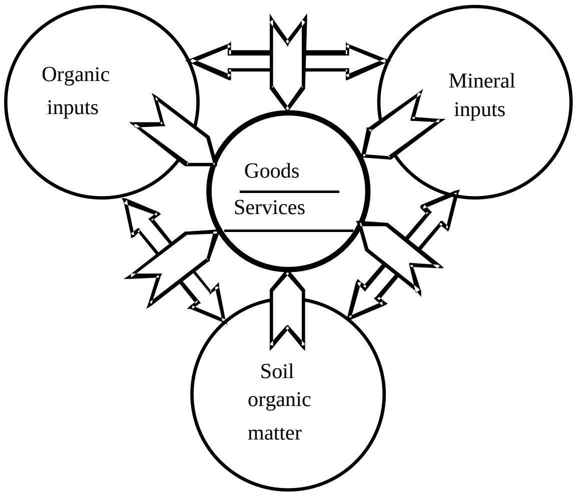
Source: Palm *et al*., 2001

The DSS recognizes the need for certain organic resource to be applied together with mineral inputs, consistent with the Second Paradigm. Organic resources are seen as complimentary inputs to mineral fertilizers and their potential role has consequently been broadened from a short term source of N to a wide array of benefits both in the short and long term (Vanlauwe *et al.*, 2002a). The ISFM paradigm has also led to increased emphasis on the social, economic, and policy dimensions of organic and mineral input management (TSBF, 2002). In this context, it is important to note the full-time involvement of a social scientist in TSBF and the recognition for more social input need in AfNet.

The technical backbone of ISFM: optimal management of organic resources, mineral inputs, and the soil organic matter pool

Optimum management of the soil resource for provision of goods and services requires the optimum management of organic resources, mineral inputs, and the SOM pool (Figure 2.3). Each of these resources contributes to the provision of goods and services individually, but more interestingly, these various resources can be hypothesized to interact with each other and generate added benefits in terms of extra crop yield, an improved soil fertility status, and/or reduced losses of nutrients to the environment.

Figure 2.3: The goods and environmental services generated by the soil are the result of the management of organic resources, mineral inputs, and the SOM pool and the interactions between these various factors

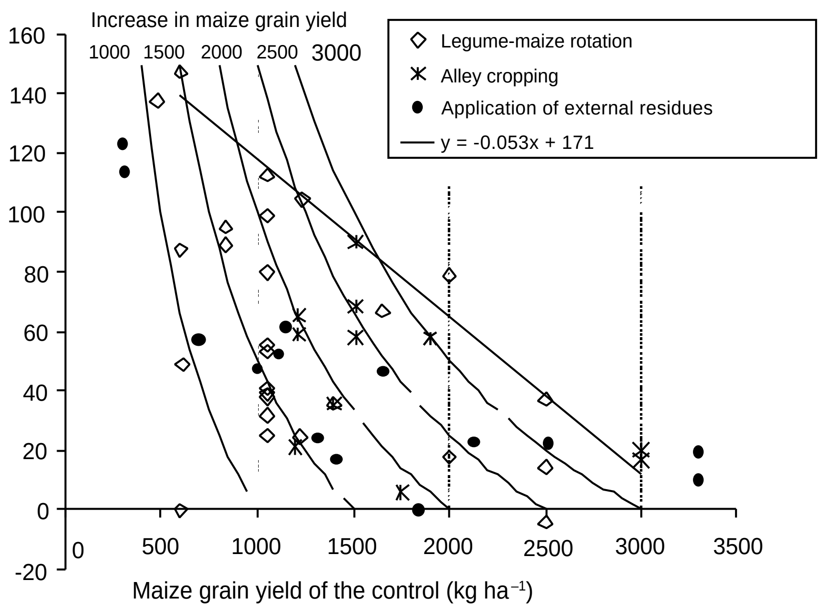


Impact of individual factors on the provision of goods and services

Numerous studies have looked at crop responses to applied fertilizer in sub-Saharan Africa and reported substantial increases in crop yield. Results from the FAO Fertilizer Program have shown an average response of 750 kg maize grain ha^{-1} to medium NPK applications (FAO, 1989). Value–to–Cost ratios (VCR) varied between 1.1 and 8.9, and were usually above the required minimum ratio of 2. National fertilizer recommendations exist for most countries, but actual application rates are nearly always much lower to nil due to constraints of a socio-economic rather than a technical nature. For a variety of reasons, fertilizers are relatively expensive in SSA, certainly if compared to - often subsidized - prices in, for example, Western Europe ($7.5 per 50 kg bag of urea in Germany, 1999, vs $13-17 per 50 kg bag of urea in Nigeria in, 1999, — S Schulz, personal communication, 2000). This is further aggravated by the lack of credit schemes to purchase these inputs as there is often a large time-gap between revenue collection from selling harvested products and fertilizer purchase. In terms of environmental services, mineral inputs have relatively little potential to enhance the SOM status (Vanlauwe *et al.*, 2001a) and may, in the case of N fertilizer, contaminate (ground)water resources when not used efficiently. The production of N fertilizer itself requires a substantial amount of energy, usually derived from fossil fuels, and contributes to the CO_2 load of the atmosphere.

In cropping systems with sole inputs of organic resources, short-term data reveal a wide range of increases in maize grain yield compared to the control systems without inputs (Figure 2.4). With higher soil fertility status, the maximum increases were observed to decrease to virtually nil at control grain yields of about 3000 kg ha^{-1}. Although yields on fields with a low soil fertility status, e.g., with control yields below 1000 kg ha^{-1}, can easily be increased up to 140% after incorporation of a source of OM in the cropping system, this would lead to absolute yields hardly exceeding 1500 kg ha^{-1} (Figure 2.4). In most cropping systems, absolute yield increases in the OM-based treatments are far below 1000 kg ha^{-1}, while significant investments in labour and land are needed to produce and manage the OM. This is partly related to the low N use efficiency of OM to be low (Vanlauwe and Sanginga, 1995; Cadisch and Giller, 1997). Other problems related to the sole use of organic inputs are low and/or imbalanced nutrient content, unfavorable quality, or high labor demand for transporting bulky materials (Palm *et al.*, 1997).

Figure 2.4: Increase in maize grain yield relative to the control in cropping systems based on organic matter management (legume-maize rotation, alley cropping, systems with application of external organic matter) without inputs of fertilizer N as influenced by the initial soil fertility status, expressed as yield in the control plots. The linear regression line shows the estimated maximal increases in grain yield. The curved lines show the absolute yields in the treatments receiving organic matter (in kg ha^{-1})



Source: Vanlauwe *et al.*, 2001a

Although most of the organic resources show limited increases in crop growth, they do increase the soil organic C status (Vanlauwe *et al.*, 2001a) and have a positive impact on the environmental service functions of the soil resource. This is evidenced by the existence of steep gradients in soil organic C status between fields at the farm scale caused by long-term site-specific soil management by the farmer (Table 2.2). Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Figure 2.5). Consequently, the high SOM status in the homestead fields is often observed to be related positively with crop yield (Figure 2.6).

Table 2.2: Soil fertility status of various fields within a farm in Burkina Faso. Home gardens are near the homstead, bush fields furthest away from the homestead and village fields at intermediate distances

Field	Organic C (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})	Exchangeable K (mmol kg^{-1})
Home garden	11 – 22	0.9 – 1.8	20 – 220	4.0 – 24
Village field	5 – 10	0.5 – 0.9	13 – 16	4.1 – 11
Bush field	2 – 5	0.2 – 0.5	5 – 16	0.6 – 1

Source: Prudencio *et al.*, 1993

Figure 2.5: Regulating nutrient supply and soil-based environmental services

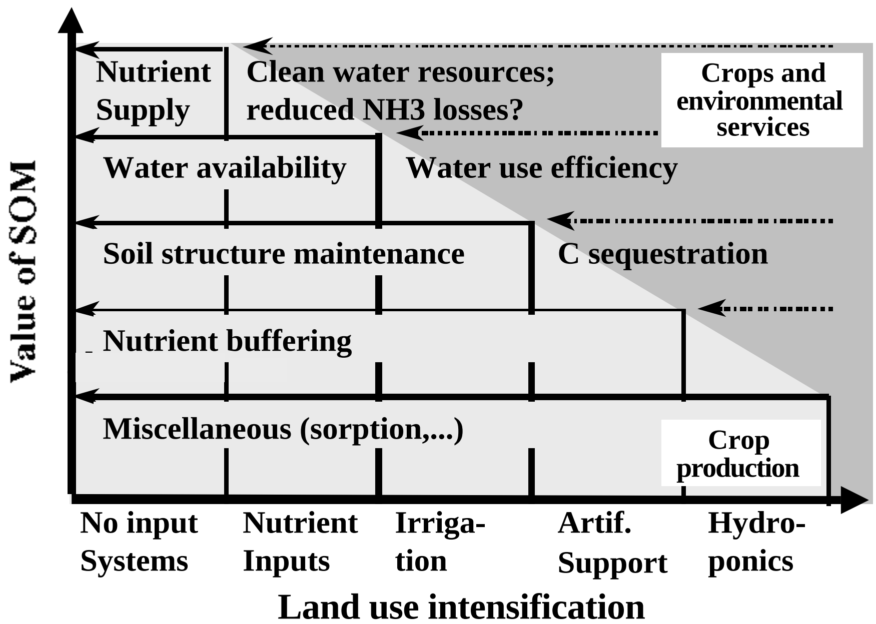
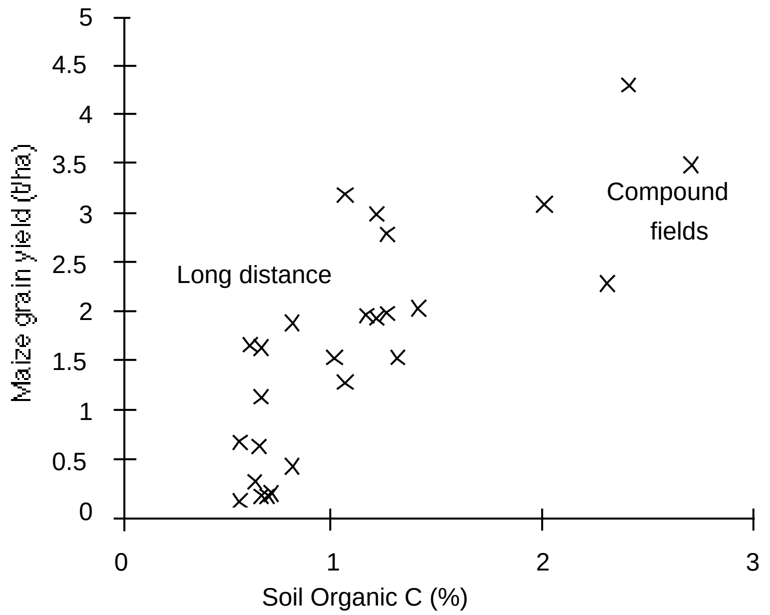


Figure 2.6: Relationship between the soil organic C content and maize grain yield for a set of fields varying in distance to the homestead in Northern Nigeria



Source: Carsky *et al*., 1998

From the crop production point of view, the relevance of SOM in regulating soil fertility decreases (plain horizontal arrows on figure 2.5) as natural capital is being replaced by manufactured or financial capital with increasing land use intensification. From an ISFM point of view, that also considers environmental service functions besides crop production functions, one could argue that the relevance of SOM does not decrease (dashed horizontal arrows on Figure 2.5).

Potential interactions between the various factors on the provision of goods and services

The Second Paradigm initiated a substantial effort on evaluating the impact of combined applications of organic resources and mineral inputs as positive interactions between both inputs could potentially result in added benefits. A *Direct* and *Indirect Hypothesis* which could form the basis for the occurrence of such benefits has been formulated by Vanlauwe *et al*. (2001a). The *Direct Hypothesis* was formulated as: *Temporary immobilization of applied fertilizer N may improve the synchrony between the supply of and demand for N and reduce losses to the environment.* The *Indirect Hypothesis* was formulated for N supplied as fertilizer as: *Any organic matter-related improvement in soil conditions affecting plant growth (except N) may lead to better plant growth and consequently enhanced efficiency of the applied N.* The *Indirect Hypothesis* recognizes that organic resources can have multiple benefits besides the short-term supply of available N. Such benefits could be an improved soil P status by reducing the soil P sorption capacity, improved soil moisture conditions, less pest and disease pressure in legume-cereal rotations, or other mechanisms. Both hypotheses, when proven, lead to an enhancement in N use efficiency, processes following the *Direct Hypothesis* through improvement of the N supply and processes following the *Indirect Hypothesis* through an increase in the demand for N. Obviously, mechanisms supporting both hypotheses may occur simultaneously.

Testing the *Direct Hypothesis* with ^{15}N labelled fertilizer, Vanlauwe *et al*. (2002b) concluded that direct interactions between OM and fertilizer-N not only exist in the laboratory but also under field conditions. The importance of residue quality and way of incorporation in the overall size of these interactions was also demonstrated. In a multilocational trial with external inputs of organic matter, Vanlauwe *et al*. (2001b) observed added benefits from the combined treatments in 2 of the 4 sites, which experienced serious moisture stress during the early phases of grain filling. The positive interaction in these 2 sites was attributed to the reduced moisture stress in the 'mixed' treatments compared to the sole urea treatments because of the presence of organic materials (surface and sub-surface placed) and constitutes evidence for the occurrence of mechanisms supporting the *Indirect Hypothesis*. Although more examples can be found in literature supporting the *Indirect Hypothesis*, it is clear that a wide range of mechanisms could lead to an improved use efficiency of applied external inputs. These mechanisms may also be site-specific, e.g., an improvement in soil moisture conditions is of little relevance in the humid forest zone. Unravelling these, where feasible, as a function of easily quantifiable soil characteristics is a major challenge and needs to be done in order to optimize the efficiency of external inputs. On the other hand, when applying organic resources and mineral fertilizer simultaneously, one hardly ever observes negative interactions, indicating that even without clearly understanding the mechanisms underlying positive interactions, applying organic resources in combination with mineral inputs stands as an appropriate fertility management principle.

Because SOM affects a series of factors supporting plant growth and because of the observed within-farm variability in soil fertility and SOM status, interest has been recently developed in relating the use efficiency of mineral N inputs to the SOM status. A set of hypotheses follows the general principles behind the *Indirect Hypothesis* outlined above and result in positive relationships between SOM content and fertilizer use efficiency. On the other hand, SOM also release available N that may be better synchronized with the demand for N by the plant than fertilizer N and consequently a larger SOM pool may result in lower use efficiencies of the applied fertilizer N. A preliminary investigation, carried out in a long-term alley cropping trial showed a negative correlation between the proportion of maize N derived from the applied fertilizer and the topsoil organic C content and supports the latter hypothesis (Vanlauwe *et al.*, Unpublished data). Other reports show higher use efficiency of N fertilizer (Breman, personal communication) and P fertilizer (Bationo, personal communication) for homestead fields with a higher SOM content.

Finally, application of organic resources is the easiest way to enhance the SOM pool. Although it is only possible in the medium to long term to induce substantial changes in soil organic C content in experimental trials using realistic organic matter application rates, the above-mentioned often drastic differences in SOM between fields within one farm prove that farmers are already managing the SOM status. While residue quality has been shown to significantly affect the short-term decomposition/ mineralization dynamics (Palm *et al.*, 2001), it is unclear whether quality is still an important modifier of the long-term decomposition dynamics. Several hypotheses have been formulated, most of them postulating that slowly decomposing, low quality organic inputs with relatively high lignin and polyphenol content will have a more pronounced effect on the SOM pool than rapidly decomposing, high quality organic inputs (Figure 2.2). The *C stabilization potential* could be an equivalent index to the N fertilizer equivalency index used to describe the short term N release dynamics. The few trials that have shown significant increases in SOM have used farmyard manure as organic input, which may be related to the presence of resistant C in the manure as the available C is digested while passing through the digestive track of the animal.

Production of organic matter in existing cropping systems: the bottleneck in implementing ISFM practices

Although there is a wide range of potential niches to produce organic resources within existing cropping systems (Table 2.3), introducing an organic matter production phase in a cropping system creates problems with adaptability and adoptability of such technologies, especially if this fallow production phase does not yield any commercial product, such as grain or fodder. Although a significant amount of organic matter can potentially be produced in cropping systems with in-situ organic matter production, adoption of such cropping systems by the farmer community is low and often driven by other than soil-fertility regeneration arguments. Dual-purpose grain legumes, on the other hand, have a large proportion of their N derived from biological N fixation, a low N harvest index, and produce a substantial amount of both grain and biomass, have a great potential to become part of such cropping systems (Sanginga *et al.*, 2001). Further advantages besides a substantial amount of N fixation from the atmosphere associated with growing high biomass producing legumes in rotation with cereal are, among others, potential improvement of the soil available P status through rhizosphere processes operating near the root-zone of the legume crop (Lyasse *et al.*, 2002), reduction in pest and disease pressure by e.g., *Striga* spp, (iii) improved soil physical properties. These processes yield benefits to a cereal crop beyond available N but are often translated into N fertilizer equivalency values. Obviously, values greater than 100% should be sometimes expected.

Table 2.3: Place and time of production of organic matter (fallow species) relative to crop growth and the respective advantages/disadvantages of the mentioned organic matter production systems with respect to soil fertility management and crop growth. 'Same place' and 'same time' mean 'in the same place as the crop' and 'during crop growth'

Place and time of organic matter production - example of farming system	Advantages	Disadvantages
Same place, same time - alley cropping	- 'Safety-net' hypothesis (complementary rooting depths) - Possible direct transfer from N_2 fixed by legume species	- Potential competition between crop and fallow species - Reduction of available crop land
Same place, different time - crop residues - legume-cereal rotation - improved tree fallows - manure, derived from livestock fed from residues collected from same field	- 'Rotation' effects (N transfer, improvement of soil P status,...); - Potential inclusion of 'dual purpose' legumes - In-situ recycling of less mobile nutrients - No competition between fallow species and crops	- Land out of crop production for a certain period - Decomposition of organic matter may start before crop growth (potential losses of mobile nutrients, e.g., N, K,...) - Extra labour needed to move organic matter (manure)
Different place - cut-and-carry systems - household waste - animal manure, not originating from same field	- Utilization of land/nutrients otherwise not used - No competition between fallow	- Extra labour needed to move organic matter - No recycling of nutrients on crop land - Need for access to extra land - Manure and household waste often have low quality

Source: Adapted from Vanlauwe *et al*., 2001a

In cut-and carry systems, which involve the transfer of nutrients from one area to another, it is necessary to determine how long soils can sustain vegetation removal before collapsing, especially soils which are relatively poor and where vegetative production can be rapid. Cut-and-carry systems without use of external inputs may be a ‘stay of execution’ rather than a sustainable form of soil fertility management. Of further importance is the vegetation succession that will occur after vegetative removal. It is possible that undesirable species could take over the cut-and-carry field once it is no longer able to sustain removal of the vegetation of the selected species. Where an intentionally planted species is used, the natural fallow species needs to be compared to determine what advantage, if any, is being derived from the extra effort to establish and maintain the planted species.

From theory to practice: Implementation of ISFM practices at the farm level

Having focussed on the principles and technical issues underlying the ISFM research agenda, these need to be put into the wider context this paper started off with. This section aims at looking at ISFM options from the farmer perspective and considers ways to disseminate these options to the various stakeholders.

Beyond the soil: Links with other realms of capital

So far, the paper mainly focussed on the management of natural capital with some inclusion of manufactured capital in the form of mineral inputs. However, as stated above, farmers’ livelihoods consist of various realms of capital which all contribute to their decision-making process regarding soil fertility management. One obvious factor affecting the way farmers manage their soils is related to their wealth in terms of access to other realms of capital, such as cash, labour, or knowledge. Rommelse (2001) reported that in a set of villages in Western Kenya, wealthy farmers spend 102 USD on farm inputs per year compared to 5 USD for poor farmers. Besides having an overall impact on the means to invest in soil fertility replenishment, farmers’ wealth also affects the strategies preferred to address soil fertility decline. In two districts in Western Kenya, Place *et al.* (2002) observed that wealthy farmers do not only use more frequently mineral fertilizers compared to poor farmers, but also a wider range of soil management practices. Farmer production objectives, which depend on a whole set of biophysical, but also social, cultural, and economic factors, also take into account the fertility gradients existing within their farm boundaries. Most soil fertility research has been targeted at the plot level, but decisions are made at the farm level, taking into account the production potential of all plots.

In Western Kenya, e.g., farmers will preferably grow sweet potato on the most degraded fields, while banana's and cocoyam occupy the most fertile fields (Tittonell, personal communication).

Finally, farmers are not the only stakeholders benefiting from proper land management. As stated earlier soils provide and regulate a series of important ecosystem services that affect every living organism and society as a whole and maintaining those ecosystem service functions may be equally or more vital than maintaining the crop production functions. Unfortunately, little information is available on the potential trade-offs between the use of land for either of both functions, on the most appropriate way to create a dialogue between the various stakeholders benefiting from a healthy soil fertility status, and on the role policy needs to assume to resolve above questions. The INRM research approach is aiming at creating a basis for such trade-off analysis and stakeholder dialogue.

Putting it all together: User-friendly decision aids for ISFM

After having obtained relevant information as described above, two extra steps may be required to complete the development of a user-friendly decision aid: (i) all above information needs to be synthesized in a quantitative framework and (ii) that framework needs to be translated in a format accessible to the end-users. The level of accuracy of such quantitative framework is an important point to consider. The generation of a set of rules of thumb is likely to be more feasible than software-based aids that generate predictive information for a large set of environments. The level of complexity is another essential point to take into consideration. For instance, if variation between fields within one farm is large and affects ISFM practices, then this may justify having this factor included in decision aids. Other aspects that will influence the way information and knowledge is condensed into a workable package are: (i) the targeted end-user community, (ii) the level of specificity required by the decisions to be supported, and (iii) level of understanding generated related to the technologies targeted. Van Noordwijk *et al.* (2001) prefer the term 'negotiation support systems' because the term 'decision support systems' suggests that a single authority makes decisions that will then be imposed on the various stakeholders. In an INRM context, it is recognized that different stakeholders may have conflicting interests related to certain specific soil management strategies and that a certain level of negotiation may be required.

The final format of the decision aid should take into account the realities on the field. Some of these realities, among others, are: (i) large scale soil analyses are not feasible, so local soil quality indicators need to be included in decision aids as farmers use those to appreciate existing soil fertility gradients within a farm; (ii) conditions within farms vary as does the availability of organic resources and fertilizer, therefore rules of thumb rather than detailed quantitative recommendations would be more useful to convey the message to farmers; (iii) farmers decision making processes involve more than just soil and crop management; and (iv) access to computers, software and even electricity is limited at the farm level, necessitating hard copy-based products.

References

Cadisch, G. and Giller, K.E. (1997) Driven by nature: plant litter quality and decomposition. CAB International, Wallingford, UK.

Carsky, R.J., Jagtap, S., Tian, G., Sanginga, N. and Vanlauwe, B. (1998) Maintenance of soil organic matter and N supply in the moist savanna zone of West Africa. In: Soil Quality and Agricultural Sustainability (Ed. R Lal), Ann Arbor Press, Chelsea, Michigan, pp. 223-236.

DFID (2000) Sustainable livelihoods guidance sheets. The Department for International Development, London, UK.

FAO (Food and Agriculture Organization) (1989) Fertilizers and Food Production. The FAO Fertilizer Programme 1961-1986. FAO, Rome, Italy.

Giller, K.E. (2000) Translating sience into action for agricultural development in the tropics: an example from decomposition studies. *Applied Soil Ecology* 14: 1-3.

IITA (International Institute of Tropical Agricultue) (1992) Sustainable food production in sub-Saharan Africa: 1. IITA's contributions. IITA, Ibadan, Nigeria.

Izac, A-M.N (2000) What Paradigm for Linking Poverty Alleviation to Natural Resources Management? Proceedings of an International Workshop on Integrated Natural Resource Management in the CGIAR: Approaches and Lessons, 21-25 August 2000, Penang – Malaysia.

Lyasse, O., Tossah, B.K., Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (2002) Options for increasing P availabilitiy from low reactive Rock Phosphate. In: Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice (Eds B Vanlauwe, J Diels, N Sanginga and R Merckx). CABI, Wallingford, UK, pp 225-237.

Palm, C.A., Myers, R.J.K. and Nandwa, S.N. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. P. 193-217. *In* R. J. Buresh, P. A. Sanchez and F. Calhoun (ed.) Replenishing soil fertility in Africa. SSSA, ASA, Wadington, USA.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G. and Giller, K.E. (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment* 83, 27-42.

Place, F., Franzel, S., Dewolf, J., Rommelse, R., Kwesiga, F., Niang, A. and Jama, B. (2002) Agroforestry for Soil Fertility Replenishment: Evidence on

Adoption Processes in Kenya and Zambia, in Barrett,C.B., Place, F., Abdillahi, A.A., (eds.), Natural Resources Management in African Agriculture: Understanding and Improving Current Practices, CABI, Wallingford, UK, 155-168.

Prudencio, C.Y. (1993) Ring management of soils and crops in the West African semi-arid tropics: the case of the mossi farming system in Burkina Faso. *Agriculture, Ecosystems and Environment* 47: 237-264.

Rommelse, R. (2001) Economic analyses of on-farm biomass transfer and improved fallow trials in western Kenya. Natural Resources Problems, Priorities and Policies Programme Working Paper 2001-2, International Centre for Research in Agroforestry, Nairobi.

Sanchez, P.A. (1976) Properties and Management of Soils in the Tropics. John Wiley and Sons, New York, USA.

Sanchez, P.A. (1994) Tropical soil fertility research: Towards the second paradigm. P. 65-88. In Inaugural and state of the art conferences. Transactions 15th World Congress of Soil Science. Acapulco, Mexico.

Sanginga, N., Okogun, J.A., Vanlauwe, B., Diels, J., Carsky, R.J. and Dashiell, K. (2001) Nitrogen contribution of promiscuous soybeans in maize-based cropping systems (Eds G Tian, F Ishida and J D H Keatinge), SSSA Special Publication Number 58, Madison, USA, pp 157-178.

Smaling, E.M.A. (1993) An Agro-ecological Framework of Integrated Nutrient Management with Special Reference to Kenya. Wageningen Agricultural University, Wageningen, The Netherlands.

Swift, M.J. (1984) Soil biological processes and tropical soil fertility: a proposal for a collaborative programme of research, Biology International Special Issue 5, International Union of Biological Sciences, Paris, France.

Swift, M.J. (1985) Tropical soil biology and rertility: planning for research. International Union of Biological Sciences, Paris, France.

Swift, M.J. (1986) Tropical soil biology and fertility : inter-regional research planning workshop, Biology International Special Issue 13, International Union of Biological Sciences, Paris, France.

Swift, M.J., Heal, O.W. and Anderson, J.M. (1979) Decomposition in Terrestrial Ecosystems, Studies in Ecology Volume 5, Blackwell Scientific Publications, Oxfort, UK.

Theng, B.K.G. (1991) Soil science in the tropics - the next 75 years. *Soil Science* 151, 76-90.

TSBF (2002) Soil Fertility Degradation in sub-Saharan Africa: Leveraging Lasting Solutions to a Long-Term Problem. Conclusions from a Workshop held at the Rockefeller Foundation Bellagio Study and Conference Centre, March 4th to 8th 2002.

Vanlauwe, B. and Sanginga, N. (1995) Efficiency of the use of N from pruning and soil organic matter dynamics in *Leucaena leucocephala* alley cropping in Southwestern Nigeria. P. 279-292. *In* R. Dudal and R. N. Roy (ed.) Integrated plant nutrition systems. FAO, Rome, Italy.

Vanlauwe, B., Wendt, J. and Diels, J. (2001a) Combined application of organic matter and fertilizer. In: Sustaining Soil Fertility in West-Africa (Eds G Tian, F Ishida and J D H Keatinge), SSSA Special Publication Number 58, Madison, USA, pp 247-280.

Vanlauwe, B., Aihou, K., Aman, S., Iwuafor, E.N.O., Tossah, B.K., Diels, J., Sanginga, N., Merckx, R. and Deckers, S. (2001b) Maize yield as affected by organic inputs and urea in the West-African moist savanna. *Agronomy Journal* 93, 1191-1199.

Vanlauwe, B., Diels, J., Sanginga, N. and Merckx, R. (2002a) Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice. CABI, Wallingford, UK, 352 pp.

Vanlauwe, B., Diels, J., Aihou, K., Iwuafor, E.N.O., Lyasse, O., Sanginga, N. and Merckx, R. (2002b) Direct interactions between N fertilizer and organic matter: evidence from trials with 15N labelled fertilizer. In: Integrated Plant Nutrient Management in sub-Saharan Africa: From Concept to Practice (Eds B Vanlauwe, J Diels, N Sanginga and R Merckx). CABI, Wallingford, UK, 173-184.

Van Noordwijk, M., Toomich, M.T.P. and Verbist, B. (2001) Negotiation support models for integrated natural resource management in tropical forest margins. *Conservation Ecology* 5, 21.

3

Guidelines for Integration of Legumes into the Farming Systems of East African Highlands

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Abstract

Grain legumes are major protein sources for animals and humans. Given that farmers export both grain and stover from the fields, the amount of residue left to the soil is too small to have a profound effect on soil fertility. Participatory research was conducted to evaluate the performance of six legume cover crops (Vetch, Stylosanthus, Crotalaria, Mucuna, Canavalia, and Tephrosia) and two food crops (Pea and Common bean) in southern Ethiopian Highlands, one of the African Highlands Initiative (AHI) sites called Areka, to be used for soil fertility improvement. Besides evaluating the biomass productivity of legumes, the objective of this research was to learn about the perception of farmers to LCC, feed and food legumes, to identify socio-economic factors affecting adoption and also to identify potential niches for their integration. For short term fallow (three months or less), Crotalaria gave significantly higher biomass yield (4.2 t ha^{-1})

followed by Vetch and Mucuna (2 t ha^{-1}), while for medium-term fallow (six months or more) Tephrosia was the best performing species (13.5 t ha^{-1}) followed by Crotalaria (8.5 t ha^{-1}). The selection criterion of farmers was far beyond biomass production, and differed from the selection criteria of researchers. Farmers identified firm root system, early soil cover, biomass yield, decomposition rate, soil moisture conservation, drought resistance and feed value as important biophysical criteria. Soil moisture conservation was mentioned as one important criterion and decreased in order of Mucuna (22.8%), Vetch (20.8 %), Stylosanthus (20.2 %), bare soil (17.1 %), Crotalaria (14 %), Canavalia (14 %) and Tephrosia (11.9 %), respectively. The overall sum of farmers' ranking showed that Mucuna followed by Croletaria are potentially fitting species. However, Vetch was the most preferred legume by farmers regardless of low biomass, due to its' early growth, high feed value and fast decomposition when incorporated into the soil. The most important socio-economic criteria of farmers for decision-making on which legumes to integrate into their temporal & spatial niches of the system were land productivity, farm size, land ownership, access to market and need for livestock feed. These indicators were used for the development of draft decision guides for integration of legumes into multiple cropping systems of East African Highlands.

Key words: Participatory research; soil degradation; legume cover crops; integration; decision-guide

Introduction

Grain legumes are important components of the farming systems of the East African highlands as they are the sole protein sources for animals and humans. Besides restoring soil fertility, legumes are grown in rotation with cereals mainly because, besides restoring soil fertility, they also accompany the staple cereals in the local dishes. However, as farmers export both grain yield and stover from the field, the amount of legume residue left to the soil is too small to have a profound effect on restoration of soil fertility.

Degradation of arable lands became the major constraint of production in East African Highlands, due mainly to nutrient loss resulting from soil erosion, lack of soil fertility restoring resources, and unbalanced nutrient mining (Amede *et al.*, 2001). However, most farmers in the region have very low financial resources to combat nutrient depletion, and hence research should be directed to seek affordable and least risky, but profitable amendments necessary to keep nutrient balance neutral (Versteeg *et al.*, 1998). In 1999 and 2000, researchers of the African Highlands Initiative (AHI) conducted farmers participatory research on maize varieties on a degraded arable land in Southern Ethiopia, Areka, by applying different inorganic sources of fertilisers. Although the soil is an Eutric Nitisol deficient in nitrogen and phosphorus (Waigel, 1986), high level application of inorganic N and P did not improve maize yield. The land was highly degraded and the organic matter was totally depleted. Lack of response to inorganic fertilisers because of low soil organic matter content was also reported elsewhere (Swift and Woomer, 1993). Organic inputs in the form of green manuring or otherwise could increase the total amount of nutrients added, and also influence availability of nutrients (Palm *et al.*, 1997). However, more than 50% of the organic resource available in the region is maize stalk, of which 80% is used as fuel wood (Amede *et al.*, 2001). The strong competition for crop residues between livestock feed, soil fertility and fuel wood in the area limits the use of organic ferilizers unless a suitable strategy that builds the organic resource capital is designed. Fallowing for restoration of soil fertility is no more practised in the region due to extreme land shortage.

One strategy could be systematic integration of legume cover crops into the farming system. Organic inputs from legumes could increase crop yield through improved nutrient supply/availability and/or improved soil-water holding capacity. Moreover, legumes offer other benefits such as providing cover to reduce soil erosion, maintenance & improvement of soil physical properties, increasing soil organic matter, cation exchange capacity, microbial activity and reduction of soil temperature (Abayomi *et al.*, 2001) and weed suppression (Versteeg *et al.*, 1998). There are several studies in Africa that showed positive effects of Legume Cover Crops (LCCs) on subsequent crops (Abayomi *et al.*, 2001; Fishler & Wortmann, 1999; Gachene *et al.*, 1999; Wortmann *et al.*, 1994). Studies in Uganda with Crotalaria (Wortmann, *et al.*, 1994; Fishler and Wortmann, 1999), and in Benin with Mucuna (Versteeg *et al.*, 1998) showed that maize grown following LCCs produced significantly higher yield than those without green manure. The positive effect was due to high N and P benefits and nutrient pumping ability of legumes from deeper horizons. However, the success rate in achieving effective adoption of LCCs and forage legumes in sub-Saharan Africa has been low (Thomas and Sumberg, 1995) since farmers prefer food legumes over forage or/legume cover crops in that the opportunity cost is so high to allocate part of the resources of food legumes to LCC. Therefore, there is a need to develop an effective guideline that targets different legumes types into different niches of different agro-ecologies and socio-economic strata.

The objective of this paper was, therefore a) to analyse the distribution of legumes in the perennial- based (Enset-based) systems, b) test the performance of legumes under short term and medium term periods, c) identify the potential causes of non-adoption of LCC, and d) develop preliminary decision guides that could be used to integrate LCC in small scale farms with various socio-economic settings.

Materials and Methods

Location, Climate and Soil

The research was conducted at the Gununo site (Areka), Southern Ethiopian Highlands. It is situated on 37° 39' E and 6° 51' N, at an altitude range between 1880 and 1960 m.a.s.l. The topography of the area is characterised by undulating slopes divided by V-shaped valleys of seasonal and intermittent streams, surrounded by steep slopes.

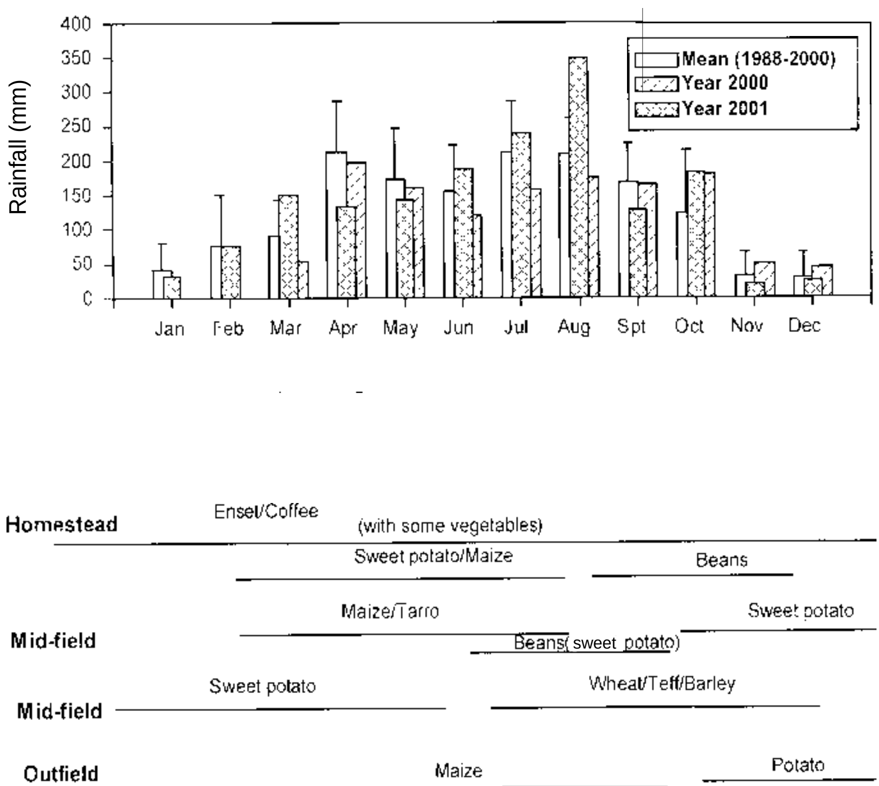
The mean annual rainfall and temperature is about 1350 mm and 19.5°C, respectively. The rainfall is unimodal with extended growing periods from March to the end of October, with short dry spell in June (Figure 3.1). The highest rainfall is experienced during the months of July and August and caused soil loss of 27 to 48 t ha^{-1} (SCRP, 1996).

The dominant soils in the study area are Eutric Nitiosols, very deep (>130 m), acidic in nature, and are characterised by higher concentration of nutrients and organic matter within the top few centimetres of the soil horizon (Table 3.1). These soils originated from kaolinitic minerals which are inherently low in nitrogen and phosphorus (Waigel, 1986). Soil fertility gradient decreases from homestead to the outfield due to management effects. The chemical properties of the Gununo soils are presented in Table 3.1.

Participatory evaluation of LCCs

The research site has relatively very high human population density with an average land holding of 0.5 ha $household^{-1}$. Using LCCs for soil fertility purposes is not a common practise in the area. LCCs were introduced into the system in 2000 following a farmers field school (FFS) approach so as to allow farmers to learn and appreciate various legumes uncommon to the area. The farmers research group (FRG) was mainly composed of men, despite the repeated temptation of researchers to include women. The legumes were planted in two planting dates. The on-farm experiments, also used for FFS, were planted on April 25, 2000 and July 1, 2000 and harvested on October 6, 2000 and January 6, 2001, respectively, using recommended seed rates. The interest of the farmers was to evaluate the effect of planting dates and length of fallow period on biomass productivity of respected species, and to identify the best fitting legumes for a short-term fallow (three months) or medium term (six months) fallow. Long-term fallow became impractical due to land scarcity. Thirty interested farmers, who were organised under one farmers research group (FRG), have studied six different species namely, Stylosanthus (St*ylosanthus guianensis*), Crotalaria (*Crotalaria ochroleuca*), Mucuna (*Mucuna pruriens*), Tephrosia (*Tephrosia vogelii*), Vetch (*Vicia dasycarpa*) and Canavalia (*Canavalia ensiformis*). All LCC were exotic species to the system except Stylosanthus. We also included two food legumes, namely common bean (*Phaseolus vulgaris*) and Pea (*Pisum sativum*), in the study that were existing in the farming system.

Figure 3.1: Crop calendar, rainfall amount and distribution, and crops grown in the farming system of Areka



The FRG studied and monitored growth and biomass productivity in short and long seasons of 2000. The researchers were involved mainly in facilitation of continual visits and stimulation of discussions among farmers. Farmers and researchers were recording their own data independently. After intensive discussion, the FRG identified six major criteria to propose one or the other legume to be integrated into the system. Since farmers considered soil water conservation as one important criterion for selecting LCCs, soil water content was determined under the canopy of each species at top 25-cm depth gravimetrically. Sampling was done in relatively dry weeks of November 2000, five months after planting. We considered four samples per plot, weighed immediately after sampling, oven dried the samples at 120°C for a week before taking dry weight. Legume ground cover was determined using the beaded string method, knotted at 10-cm interval and laid across the diagonals of each plot, 12 weeks after planting.

Table 3.1: Chemical Properties of Nitisols at Gununo site at the depth of top 20 cm

Soil fertility parameters	Analytical value
Total N (%)	0.05
Available P (ppm), Olsen	7
Organic matter (%)	1.2
pH (H_2O)	5.9
CEC (me/100g soil)	15
Exchangeable cations (me $100g^{-1}$ soil)	
Na^+	0.22
K^+	0.96
Ca^{2+}	14.04
Mg^{2+}	2.93

Source: Waigel (1986)

In August 2002, after farmers monitored the introduced legumes, 26 farmers from four villages selected species of their choice LCC and tested them in their farms together with a food legume, Pea. During the growing seasons of 2000 and 2001, we monitored which farmer selected what, how did they manage the LCCs in comparison to the food legume and for what purpose the legumes were used. Biomass production of the various legumes under farmers' management was also recorded. Besides structured questionnaire and formal survey (Pretty *et al.*, 1995), an informal repeated on-field discussion using transect walks were used to identify the socio-economic factors that dictated farmers to choose one or the other option and to prioritise the most important criteria of decision making using pair wise analysis matrix. Moreover, farmers invited non-participating neighbouring farmers for discussion; hence the decision made is expected to represent the community.

We have conducted an additional replicated experiment to evaluate biomass production of LCCs under partially controlled replicated experiment to verify earlier obtained results. It was also meant to identify the most promising species for short term fallow, as farmers were reluctant to allocate land for LCCs beyond three months. The species were planted on October 12, 2001 and harvested on January 10, 2001. The tested species were those most favoured by farmers for further integration namely Crotalaria (*Crotalaria ochroleuca*), Mucuna (*Mucuna pruriens*), Tephrosia (*Tephrosia vogelii*), Vetch (*Vicia dasycarpa*) and Canavalia (*Canavalia ensiformis*) replicated three times arranged in a randomised block design. The plot size was 12 m^2, with one-meter gangway between treatments. The field was weed free throughout the season by hand weeding. In all cases, phosphorus was applied at a rate of 13-Kg ha^{-1} to facilitate growth and productivity. Data on biomass production of the species was analysed by ANOVA using statistical packages (Jandel Scientific, 1998).

Using the qualitative and quantitative data obtained from the site, and by considering the hierarchy of indicators identified by farmers, we developed draft decision guides on the integration of legumes into the farming systems of the Ethiopian Highlands.

Crop management

The technology, green manuring, in Gununo was first tested in a researcher/farmer- managed participatory research on farmers fields, who were interested to try Legume Cover crops and select the appropriate green manure species that could be adapted to their agro-ecology and also fit into their farming systems. Seven species of legume cover crops namely Trifolium (T*rifolium quartinianum),* Stylosanthus (*Stylosanthus guianensis*), Crotalaria (*Crotalaria ochroleuca*), Mucuna (*Mucuna pruriens*), Tephrosia (*Tephrosia vogelii*), Vetch (*Vicia dasycarpa*) and Canavalia (*Canavalia ensiformis*) were planted on April 25, 2000 (Belg season), July 1, 2000 (Meher season) and August 28, 2000 (Birra), to evaluate the performance of those legumes under different planting dates. The legumes were harvested on October 6, 2000, January 6, 2000 and March 5, 2001, for Belg, Meher and Birra planting, respectively. The plot size was 2 x 10m and with 1m gang way between each treatment. The recommended seed rate was used. We have also considered two food legumes, namely common bean (*Phaseolus vulgaris*) and Pea (*Pisum sativum*), in the study but they are already in the farming system. The trial also served as farmers field school to introduce farmer communities to alternative soil improving legume cover crops. The farms used for

Belg planting are known by the community as the most degraded, and hence the fate of the LCCs to be accepted or rejected by the community relied on whether the LCC could improve the productivity of those farms. Short before maturity the LCCs of Belg planting were chopped and incorporated after three weeks time. A sweet potato crop, cultivar Gadisa was planted following the LCCs on October, 15, 2000 and harvested on March 10, 2001.

As soil water conservation was considered by farmers as one of the important criteria of LCCs, we determined soil water content under the canopy of each species at 25 cm depth gravimetrically in the relatively dry weeks of November, five months after planting.

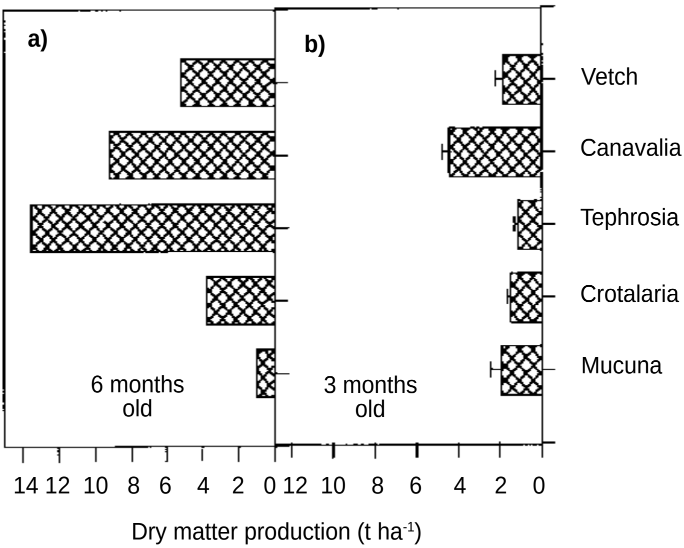
In July 2000, after farmers had repeatedly visited the Belg-planted green manure, we distributed seeds of their choice LCC together with improved Pea variety to 19 interested farmers to see what farmers were doing with those LCCs, where did they grow the food legume (pea) or LCC, and the type of management they were doing for the Pea or LCCs field. Besides structured questionnaires, we used participatory procedures of Pretty *et al* (1995) for data collection and follow-up.

Results and Discussion

Land use and Soil fertility management

Farming communities in Gununo prefer to build their homes on the top of the hills, in scattered hamlets surrounded by plantations of Enset, also called 'false banana' (*Enset ventricosum*) and coffee. The hamlets face towards the open communal fields, which people use for social occasions. The Wollaytas (which also includes Gununo communities) are reputed to be fond of trees for their own sake, growing trees and shrubs around their farm for spices, medicine, aromatic use, shade, farm implements and fuel wood. The farming system is a perennial based (Enset-based system) highly intensive system with a possibility of up to three cropping per year. Enset is a carbohydrate rich perennial crop, with strong spurious stem and edible bulbs and corm. Unlike the land holdings in the northern parts of Ethiopia which is characterised by land fragmentation, land holding in Areka is consolidated. Multiple cropping, in the form of intercropping, relay cropping and crop diversity, are practised by farmers thanks to the long growing season with uni-modal pattern of rainfall distribution (Figure 3.1). The farmers of Wollayta have divided their land into several plots for various purposes (Figure 3.1 and Figure 3.2). Trees are planted on valley bottoms, sloppy area, farm boundaries, in front of house and gully areas. Grazing land (tithering) are found in front of house (Deje). Some plots are left for cut and carry for livestock feeding. These plots have also different inherent soil fertility status (Figure 3.2), that is soil fertility declines with distance from houses (Eyasu, 1998).

Figure 3.2: Biomass production of various legume cover crops grown in Nitisols for three and six months of growing period under highland conditions (n=3)



The major land use systems in the community include homestead farms, (plot A in Figure 3.2) which are characterised by soils with high organic matter content due to continuos application of organic residue. These soils are dark brown to black in colour mainly due to high organic matter content. This part of the farm was used to grow most important crops such as enset, coffee, vegetables, planting materials for sweet potato and raise tree seedlings. In the system our two years survey showed that only about 3% of the homestead is occupied by legumes intercropped under the enset/ coffee plants (data not presented). Farmers are not applying inorganic fertiliser in this part of the farm. Homestead soils (Kareta) are characterised by high organic matter content due to continuous application of organic residue. Soils of the neighbouring field except the Kareta types are red in colour. Even the Kareta soils changed their colour due to organic matter application (PRA report, 1997). Red soils are less fertile and since the organic fertiliser sources are limited they require application of inorganic fertilisers. The homestead field is followed by the main field (plot B), which is characterised by red soils. Red soils are considered by the farmers as less fertile due to limited application of organic inputs, hence require application of inorganic fertiliser to get a reasonable amount of yield. In this part of the farm, farmers grow maize in association with taro, beans and sweet potato. This is also the part of land where legumes are growing most (Figure 3.2). Sweet potato is also planted as sole crop in this part of the land following long maturing maize during the small rainy season. The outfield (plot B in Figure 3.2) is the most depleted and commonly allocated for growing maize or potato using inorganic fertlizers. This plot does not receive any organic manure, legumes are rarely planted and the crop residue is even exported for different purposes. Farmers do not practice intercropping in this part of the land.

Although legumes are the major components of the system, the primary objective of the farmers is production of food grains as sources of protein followed by feed production as a secondary product, and not soil fertility. That is also partly the reason why the amount of land allocated for legumes decreases with distance from the homestead (decreasing soil fertility), excluding the enset field (Figure 3.2).

Participatory Evaluation of Legume Cover Crops

Seven green manuring cover crops were evaluated on-farm under three planting dates at the beginning (Belg), in the middle (Meher) and at the end of the growing season (Birra) of Areka, in 2000/2001. The rainfall amount and distribution is presented in Figure 1. The rainfall distribution was favorable and there was no extended dry spell within the growing season of 2000 and 2001. For the medium-term fallow, Tephrosia produced the highest dry matter biomass yield, 13.5 t ha^{-1} followed by Crotalaria, 9 t ha^{-1} (Figure 3.2). Most of the biomass accumulation in Tephrosia was observed four months after planting. The lowest yield was observed from Vetch, but it showed early vigour and matured much earlier than the other species. For the short-term fallow, Crotalaria was the best performing species followed by Mucuna and Vetch. On individual farmer's field, Crotalaria was the best performing species regardless of soil fertility. Similar results were reported from Uganda (Wortmann *et al.*, 1994). On the other hand, vetch and mucuna were performing best in fertile corners of the farms. For the Belg planting, the highest biomass yield (about 5t of dry matter ha^{-1}) was obtained from Crotalaria followed by Stylosanthsu and Trifolium (Table 3.2). The smallest biomass yield was obtained from Vetch. Crotalaria was the best performing species under this degraded soil. In the Meher planting, the highest dry matter yield (13.5 t ha^{-1}) was obtained from Tephrosia followed by Crotalaria. Like that of the Belg planting, the smallest yield was obtained from Vetch. This did not agree with the findings of Birra planting, when the amount of rainfall sharply declined two months after planting of the green manure, the highest dry matter yield was obtained by Crotalaria and Mucuna (about 2.9 t ha^{-1} dry matter). In this experiment plants were exposed to drought for extended period, and hence the yield obtained from Birra planting was relatively smaller than in the other two experiments. Although the Belg planting and Meher planting received about equal amount of rainfall (Table 3.2) dry matter production was the highest in Meher than in Belg planting. It could be explained by differences in soil fertility status of the two farms, whereby the land of Mr. Demeke (Belg planting) was highly degraded with a slope of about 18%. Unlike the results of Versteeg *et al.*, (1998), which indicated that mucuna performed better than other green manures (including crotalaria) to recover completely degraded soils, our data showed that Crotalaria performed much better than Mucuna in the degraded field of Mr. Demeke. When those species were planted in the driest part of the season, crotalaria and mucuna performed best and produced up to 2.9 t ha^{-1} dry matter within three months of time (data not presented). Although farmers who own livestock considered Stylos and Vetch for integration, resource-poor farmers went for Crotalaria and Canavalia.

Table 3.2: Tuber yield of Sweet potato following LCCs, Soil water content and ground cover of Legume Cover Cropsgreen manure in an on-farm trial, 2000. Data on ground cover (1 the least and 10 the highest) and soil water content (%) was taken when the plants were five months old (n= 4), and soil water was determined at harvesting

Species	Soil water (%)	Ground cover (1-10) rating
Canavalia	13.98	7
Vetch	20.78	5
Tephrosia	11.91	6
Mucuna	22.72	10
Crotalaria	14.05	7
Stylosanthus	20.22	9
Undisturbed soil	17.12	1
Mean	17.25	6.43
SED	4.10	2.94

Besides dry matter yield, we measured soil water content under the canopies of LCCs. The data from Meher planting showed that, the highest soil water content was obtained from mucuna and stylosanthus, which could be due to the self-mulching (Table 3.2). The ground cover (%) was the highest for Mucuna (100 %), and the lowest for vetch (60%). A similar result was obtained for mucuna in western Nigeria (Abayomi *et al.*, 2001). Higher soil water content under mucuna and stylosanthus (Table 3.3) implies that these species could improve soil water availability through reduction of evaporative loss. They also do not compete for water strongly if grown in combination with food crops.

Table 3.3: Farmers' criteria of selection of legume cover crops. According to farmers' ranking 6 was the highest and 1 the lowest (n=25)

Species	Firm roots	Eary soil cover	Bio mass	Rate of decomp-osition	Moisture conser-vation	Drought resista-nce	Feed value	Sum Total
Crotalaria	2	6	6	6	2	2	2	26
Vetch	1	5	5	4	1	1	6	23
Mucuna	6	4	3	3	6	6	4	32
Canavalia	5	3	4	1	4	5	2	24
Tephrosia	3	2	2	2	5	3	2	19
Stylosanthus	4	1	1	5	3	4	5	23

In Belg planting, all tested LCC were chopped and incorporated into the plots where they were grown. Mr. Demeke planted Sweet potato following the green manures with the residual moisture of 2000/2001, and obtained relatively higher tuber yield as an after effect of legumes (Table 3.3). The best performance was observed from those planted after Tephrosia and Mucuna followed by Canavalia & Crotalaria. Interestingly crop yield under the best performed legume (Crotalaria) was not the highest. Organic inputs from green manuring increased tuber yield possibly because it could increase the total amount of nutrients added, improve the soil-water holding capacity and also influence nutrient availability. Palm *et al.*, (1997) indicated that organic fertilisers could serve (i) as sources of carbon and energy to enhance microbial activity (ii) by controlling the net mineralisation - immobilization patterns (iii) as precursors to soil organic matter fractions and (iv) in complexing toxic cations and reducing the P sorption capacity of the soil.

Farmers evaluated the performance of LCCs in the fields individually or in groups through repeated visits. The selection criteria of farmers were beyond biomass production (Table 3.3). After intensive discussion among themselves, the FRG farmers agreed on seven types of biophysical criteria to be considered for selection of LCCs (Table 3.3). However, the criteria of choice had different weights for farmers of different socio-economic categories. None of the farmers mentioned labour demand as an important criterion. They considered firm root system (based on the strength of the plant during uprooting), rate of decomposition (the strength of the stalk and or the leaf to be broken), moisture conservation (moistness of the soil under the canopy of each species), drought resistance (wilting or non-wilting character of the leaf during warm days), feed value (livestock preference), biomass production (the combination of early aggressive growth and dry matter production) and early soil cover. For resource poor farmers (who commonly did not own animal or own few) food legumes green manure crops with fast biomass production (Crotalaria and Mucuna) were the best choices. For farmers who own sloppy lands with erosion problems mucuna and canavalia were considered to be the best: Mucuna for its mulching behaviour and canavalia for its firm root system that reduced the risk of rill erosion. Farmers with exhausted land selected crotalaria, as all the other legumes were not growing well in the degraded corners of their farms. On the other hand, farmers with livestock selected legumes with feed value and fast growth (Vetch and Stylosanths). In general, Vetch was the most favoured legume despite low dry matter production, as it produced a considerable amount of dry matter within a short period of time to be used for livestock feed. It was also easy to incorporate into the soil and found it to be easily decomposable due to its early aggressive growth. None of the farmers mentioned labour shortage as a potential constraint. The overall sum of farmers' ranking, however, showed that mucuna followed by crotalaria are the best candidates for the current farming system of Areka. Since Mucuna is aggressive in competition when grown in combination with other crops (Versteeg *et al.*, 1998) it could be used to increase soil fertility in well established Enset/Coffee fields, while Crotalaria and Canavaia could be used to ameliorate exhausted outfields. Canavalia is found to be best fitting as an intercrop under maize as it has deep root system and did not hang on the stocks of the companion crop (personal observation). The herbaceous LCCs feed and green manure legumes are reported as high quality organic resources (Gachene, *et al.*, 1999) to be used directly as organic fertilizers to improve the grain yield of subsequent crops (Abayomi *et al.*, 2001).

Farmers' management of experimentation with LCCs green manure

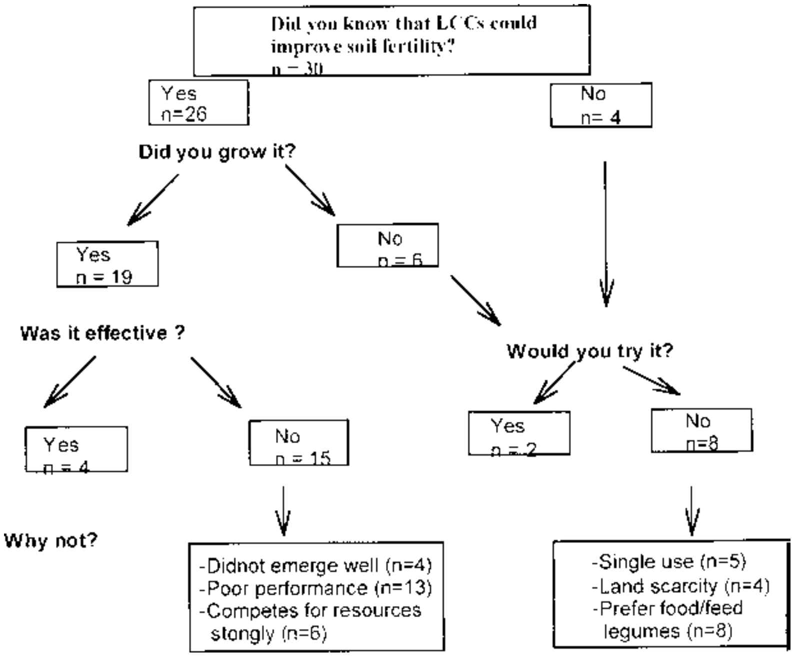
After thorough monitoring about the productivity and growth behaviour of LCCs in the experimental plots, about 19 farmers have tested various LCCs in their own farm. They tried mainly Canavalia, Crotalaria, Mucuna, Stylosanthus and Vetch. We observed that farmers have selected the most degraded corners of the farm for growing the LCCs and the fertile parts of their land for growing Pea (Table 3.4). About 50% of the trial farmers allocated depleted lands (degraded and abandoned) for the LCC. Further discussion with farmers revealed that they took this type of decision partly due to fear of risk, and partly not to occupy land that could be used for growing food crops.

Table 3.4: Spatial niches identified by farmers for growing Legume Cover Crops or Food legumes (Pea) in the growing seasons of 2000. Data shows number of involved farmers (%) grew legumes at different spatial niches (n=26)

Crop type	Sole in fertile soil	Sole in degraded soil	Relay under maize	Steepy Land	Border strips	abandoned land
Legume cover crops	0	28.6	7.1	14.3	21.43	21.42
Pea	64.29	0	35.7	0	0	0

From the total respondents, 86.6% of the farmers knew about the role of green manures as soil fertility restorers (Figure 3.3). However only 63% of them tested LCCs and of those who tested the green manures only 21 % responded LCCs were effective in improving the fertility status of the soil. About 79% believed that LCCs may not fit into their system mainly because they did not emerge well, or showed poor performance under depleted soils or are competing with food legumes for resources (labour, water and, land) (Figure 3.3). This could be explained by the fact that almost all of the farmers planted the LCCs on the degraded corners of their farm (Table 3.4), which in turn caused low biomass production and generally poor performance of LCCs (data not presented), especially at the initial stage of growth.

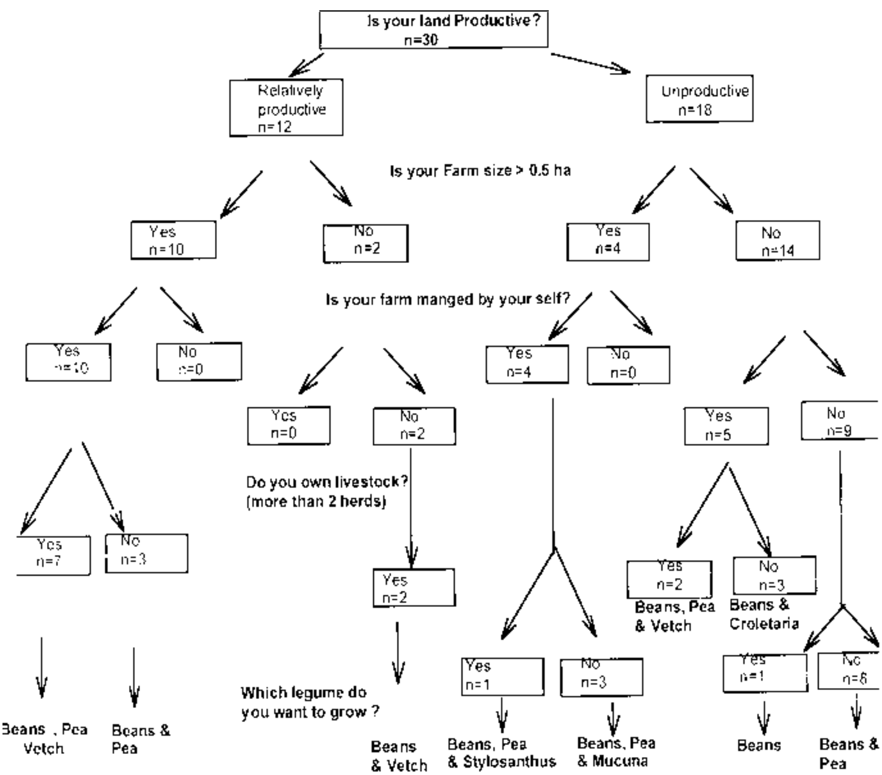
Figure 3.3: Guidelines for identification of factors of adoption or non-adoption of legume cover crops in multiple cropping systems of Areka



Socio-economic factors dictating guidelines for integration of legumes

Results from PRA studies augmented by structured questionnaire showed that there are 21 different factors that affect the integration of legumes. When farmers were asked to prioritise the most important factors affecting integration and adoption of legumes they mentioned a) farm size b) suitability of the species for intecropping with other crops for space and resources c) soil productivity of their land d) suitability for livestock feed e) marketability of the product f) toxicity of the pod to children and animals g) who manages the farm (self or share cropping) h)ownership of the farm i) length of time needed to grow the species and j) risk associated with growing LCCs in terms of introduction of pests and diseases. Earlier works suggested that farm size and land ownership affect integration of LCCs into small holder farms (Wortmann & Kirungu, 1999). After comparing those factors in a pair-wise analysis, four major indicators of different hierarchy were identified (Figure 3.4).

Figure 3.4: Tools for determining degree of integration of legumes into multiple cropping systems of Areka



1) *Degree of land productivity:* Farmers in Gununo associated land productivity mainly with the fertility status of the soil and distance of the plot from the homestead. The homestead field is commonly fertile due to continual supply of organic resources. Farmers did not apply inorganic fertiliser in this part of the farm. They remained reluctant to allocate a portion of this land to grow LCCs for biomass transfer or otherwise, but they grow food legumes, mainly beans, as intercrops in the coffee and enset fields. The potential niche that farmers were willing to allocate for LCCs is the most out field.They are well aware of the role of legumes in crop rotation, though they give priority to food legumes with immediate benefits. When it comes to integration of LCCs solely for the sake of soil fertility maintenance, farmers are unwilling to allocate the land which otherwise could be used to grow food crops.

2) *Farm size:* Despite very high interest of farmers to get alternative sources of inorganic fertilizers, the probability of farmers to allocate land for growing LCCs depended on the size of their land holdings. For Areka conditions, a farm size of 0.75 ha is considered large. Farmers with very small land holdings did not grow legumes as sole crops, but may integrate them into their system as intercrops or relay crops. Therefore, the potential niches for LCCs are partly occupied unless the farm is highly depleted.

3) *Ownership of the farm:* Whether a legume (mainly LCCs) could be grown by farmers or not depended also on the authority of the person to decide on the existing land resources, which is linked to land ownership and management. Those farmers who did not have enough farm inputs (seed, fertilizer, labour and/or oxen) are obliged to give their land for share cropping. In this type of arrangement, the probability of growing LCCs on that farm is minimal. Instead farmers who contracted the land preferred to grow high yielding cereals (maize & wheat) or root crops (sweet potato). As share cropping is an exhaustive profit-making arrangement, the chance of growing LCCs in such type of contract was almost nil. Without ownership or security of tenure, farmers are unlikely to invest in new soil fertility amendment technology (Thomas and Sumberg, 1995)

4) *Livestock feed:* In mixed farming systems of Ethiopia livestock is a very important enterprise. Farmers select crop species/varieties not only based on grain yield but also straw yield (as a crop residue or forage) when evaluating new variety or crop. Similarly legumes with multiple use were more favoured than those legumes that were appropriate solely for green manure purposes.

These socio-economic criteria of farmers together with the productivity experimental data from the field were used to develop decision guides to help farmers in selecting legumes to be incorporated into their land use systems as presented in Figure 3.5 and Table 3.5. As presented in Figure 3.4, farmers considered the degree of land productivity as the most important factor (placed at the highest heirarchy) for possible integration of legumes. Farmers who own degraded arable lands were willing to integrate more LCCs green manures while those who own productive lands of large size wanted to grow food legumes with additional feed values. However, all farmers decided to have food legumes in their system regardless of farm size or land productivity. Beans and Pea are already in the system and farmers found niches to grow them as they are also part of the local dishes. From the feed legumes, farmers favoured stylosanthus and vetch as mentioned above. Those farmers who wanted soil improving LCCs, selected crotalaria, as they found it better performing even under extremely degraded conditions. However, about 45% of the farmers with degraded arable lands are not willing to integrate LCCs, or grow green manures either because they did not manage their own farm, and hence share cropping /contract or have limited options of household income.

Figure 3.5: Guideline for integrating food, feed legumes and legume cover crops in small-scale farms

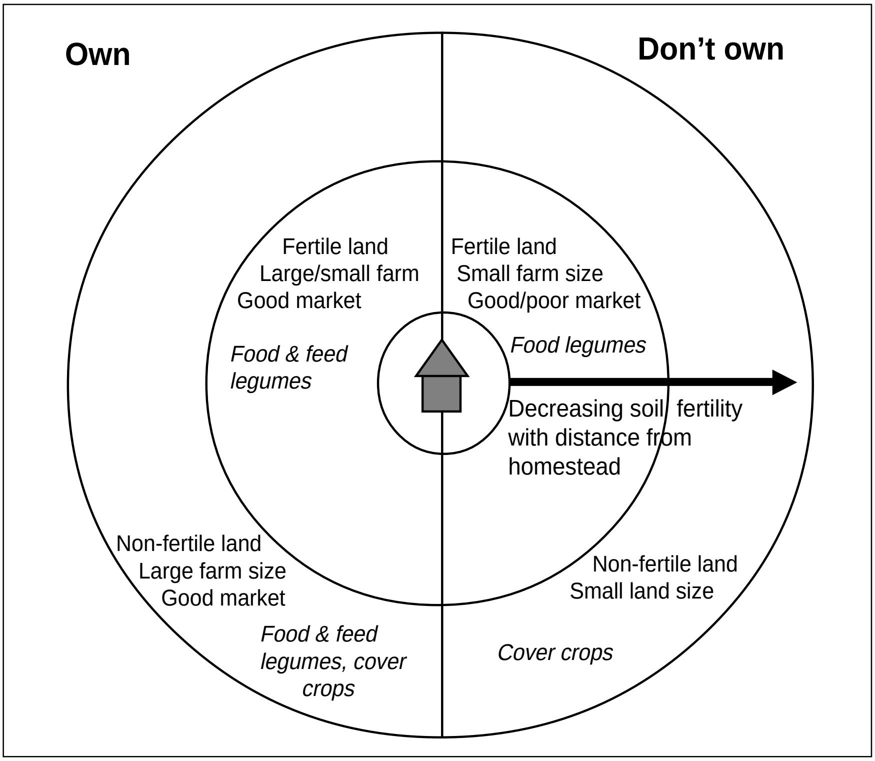


Table 3.5: Tools for identification of potential legume niches for possible integration into the multiple cropping systems of Areka developed in consultation with farmers

Position within the farm	Land size	Soil fertility status	Demand for fodder	Available niche	Best-best
Homestead	Large	Fertile	High	Intercrop under enset/coffee vetch	Stylosanthus Desmodium
			Low	same	Beans/pea
	Small		High	Intercrop under ensey/coffee	Beans/pea
			Low	same	Same
Outfield	Large	Fertile	High	a) Intercrop with maize b) Relay under maize	a) Beans & Peas b)Vetch
			Low	a) Sole b) Intercrop under maize	a) Beans/Pea b)Crotalaria/ Mucuna /Tephrosia
		Less Fertile	High	Relay crop/ short fallow	Vetch Stylosanthus
			Low	a) Relay crop b) Intercrop	a) Crotalaria b)Canavalia/ Tephrosia
	Small	Fertile	High	Relay/Inter Under maize	a) Beans/Pea b)Vetch Stlosanthu
			Low	same	Pea/Beans
		Less Fertile	High	Relay crop Short fallow	Stylosanthus/ Mucuna
			Low	Relay crop Short fallow	Crotalaria/ Canavalia

In general, given very high population pressure and associated land shortage, farmers in Areka may not allocate full season for LCC, but preferred fast growing LCCs for short term fallow. The probability of integrating LCCs into the system became even less when the land is relatively fertile. As the homestead Enset and darkua fields are relatively fertile (Figure 3.2) and used for intercropping/relay cropping purposes, growing LCC on that part of the land may not be the choice of farmers. On the other hand, farmers with large farm size and high degree of land degradation may go for selected LCCs. The potential niche available in the system would be the least fertile most-out field (Figures 3.1 and 3.2) where intercropping is not practised. The most out field is commonly occupied by potato in rotation with maize (Figure 3.1) with relatively less vegetative cover over the years.

The length of the growing period together with the amount and distribution of the rainfall dictates whether the system may allow growing legumes intercroped with maize, intercroped with perennials, or relay cropped with maize or sweet potato. In regions, where the growing season is extended up to eight months, and where the outfield became depleted to sustain crop production, LCCs green manures that could grow under poor soil fertility conditions in drought-prone months would be appreciated. Indeed, crotalaria performed very well under such conditions.

The Decision Guides

We are presenting three guidelines for integration of legumes into the farming systems of multiple cropping, perennial-based systems.

Maize is the major staple crop in the region, and about 45% of the arable land in Areka is allocated for maize. Table 3.3 shows a decision tree developed to improve nutrient availability of Maize with decreasing costs using organic resources in combination with inorganic fertilizers or sole. The decision trees were developed based on the following background information from the site.

1) Farmers preferred food legumes over non-food legumes regardless of soil fertility status of their farm.

2) The above ground biomass of grain legumes (grain & stover) is exported to the homestead for feed and food while the below ground biomass of grain legumes (beans and pea) is small to effect soil fertility. The probability of the manure to be returned to the same plot is less as farmers prefer to apply manure to the perennial crops (Enset & Coffee) growing in the home-stead.

3) The tested legumes may fix nitrogen to fulfil their partial demand (we have observed nodules in all although we did not quantify N-fixation), but in conditions where the biomass is exported, most of the crop residue of legumes or green manure are used as feed sources. Therefore, we did not expect significant effect on soil fertility. It is not clear whether the organic resource circulates back to the field in the form of manure.

4) LCCsGreen manures produced much higher biomass when planted as relay crops in the middle of the growing season than when planted at the end of the growing season as short-term fallows due to possible effects of end-of season drought.

5) The homestead field is much more fertile than the outfield,; hence those legumes sensitive to water and nutrient deficiency will do better in the homestead than in the outfield.

The first guide (Figure 3.3) is intended to assist researchers to get feed back information about technologies that were accepted or rejected by the farmers or farmer research groups. This guide will assist researchers not only to identify the major reasons for the technology to be accepted or rejected, but also to prioritise the reasons of resistance by farmers not to adopt the technology. This type of feed back will help to modify/improve the technology through consultative research to make technologies compatible to the socio-economic conditions of the community.

The second guide (Table 3.5) is intended to assist farmers and researchers in identification of potential legumes that could be compatible to the existing spatial and temporal niches. This guide was developed based on the fact that the outfield is larger in size than the homestead field, and land size, soil fertility status, feed demand and available niches in the system (see also Figure 3.4) determined the best-bets that could fit into the current land use system.

The third guide (Figure 3.5) is developed based on the data presented in Figure 3.4, and by taking into account the market effects. The most important criteria at the lowest level is the presence or absence of livestock in the household followed by who manages the farm, market access, the size of the land holding and the land quality. The factor that dictates the decision at the highest level was land productivity, which was governed mainly by soil fertility status. Growing food legumes was the priority of every farmer regardless of wealth (land size, land quality & number of livestock). Farmers with livestock integrated feed crops regardless of land size, land productivity and market access to products. However, the size and quality of land allocated for growing feed legumes depended on market access to livestock products (milk, butter and meat). Those farmers with good market access are expected to invest part of their income on external inputs, i.e. inorganic fertilisers. Hence farmers of this category did not allocate much land for growing LCCs, but applied inorganic fertilisers. In the homestead field, there was no land allocated for LCCs in the system, not only because farmers gave priority to food legumes, but it also became very expensive for farmers to allocate the fertile plot of the farm for growing LCCs. The most clear spatial niche for growing LCCs is the most out field, especially in poor farmers' field with exhausted land and limited market-driven farm products.

Acknowledgement

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References

Abayomi, Y.A., Fadayomi, O., Babatola, J.O., Tian, G. (2001) Evaluation of selected legume cover crops for biomass production, dry season survival and soil fertility improvement in a moist savannah location in Nigeria. *African Crop Science Journal* 9(4): 615-627.

Amede, T. , Geta, E. and Belachew, T. (2001) Reversing degradation of arable lands in Ethiopia highlands. Managing African Soils series no. 23., IIED, London.

Areka PRA report (1997) Unpublished.

Eyasu, E., 1998. Is soil fertility declining? Perspectives on environmental change in southern Ethiopia.

Managing Africa's Soils, series no. 2, IIED, London.

Fishler, M. and Wortmann, C. (1999) Crotaelaria (C. ochroleuca) as a green manure crop in maize-bean cropping systems in Uganda. *Field Crops Research* 61: 97-107.

Gachene, C.K., Palm, C, Mureithi, J. (1999) Legume Cover Crops for soil fertility improvement in the East African Region. Report of an AHI Workshop, TSBF, Nairobi, 18-19 February, 1999. 26p.

Palm, C., Myers, R.J. and Nandwa, S.M. (1997) Combined use of organic and inorganic sources for soil fertility maintenance and replenishment. SSSA Special publication No. 51: 193-218.

Pretty, J., Guijt, I., Thompson, J., and Scoons, I. (1995) A trainer's guide for participatory approaches. IIED, London.

Soil Conservation Research Program (SCRP) (1996) Data base report (1982-1993), Series II: Gununo Research Unit. University of Berne, Switzerland.

Swift, M.J. and Woomer, P. (1993) Organic matter and the sustainability of agricultural systems: definition and measurement. In: Mulongoy, K. and Merck, R. (eds). Soil organic matter dynamics and sustainablity of tropical agriculture. Wiley-Sayce, Chichester, UK. Pp. 3-18.

Thomas, D. and Sumberg, J. (1995) A review of the evaluation and use of tropical forage legumes in Sub-saharan Africa. *Agriculture, Ecosystem & Environment* 54: 151-163.

Waigel, G. (1986) The soils of Gununo area. Soil Conservation Research Project (SCRP). Research report 8, University of Berne, Switzerland.

Wortmann, C. Isabirye, M., Musa, S. (1994) *Crotalaria ochreleuca* as a green manure crop in Uganda. *Afri. Crop Sci. J.* 2: 55-61.

Wortmann, C. , Kirungu, B. (1999) Adoption of soil improving and forage legumes by small holder farmers in Africa. Conference on: Working with farmers: The key to adoption of forage technologies. Cagayan de oro, Mindano, The Philipines. 12-15 Oct., 1999.

Versteeg, M.N., Amadji, F., Eteka, A., Gogan, A., and Koudokpon, V., 1998. Farmers adaptability of Mucuna fallowing and Agroforestry technologies in the coastal savannah of Benin. *Agricultural Systems* 56 (3)) 269-287.

Effect of Organic and Inorganic Nutrient Sources on Soil Mineral Nitrogen and Maize Yields in Western Kenya

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Abstract

The effects of organic and inorganic fertilizers on soil mineral N and maize yields were evaluated in a Kandiudalfic Eutrodox soil of western Kenya.

Leaf biomass of tithonia (*Tithonia diversifolia* [Hemseley] A. Grey) and senna (*Senna spectabilis* D.C. & H.S. Irwin) at 5 t ha^{-1} dry weight were incorporated into the soil and compared with the response obtained from control without any input and fertilizer at 120 kg N, 150 kg P and 100 kg K ha^{-1} from urea and triple super phosphate (TSP). Soil mineral (inorganic), N, was measured at the beginning of the trial and subsequently at 1, 2, 4, 8 and 12 weeks after applying the treatments. Maize grain and stover yields were estimated at harvest.

Total inorganic nitrogen in the soil at the beginning of the season was at a similar level in all treatments. It increased rapidly after applying the materials and at the onset of rains for all treatments probably because of rapid nitrogen mineralisation in all treatments. After four weeks, inorganic nitrogen decreased progressively until end of the experiment in all the treatments. The highest contribution of mineral N to the soil by the organic residues was noted at four weeks stage and this was significantly higher with tithonia than senna. This could be due to rapid N mineralization by these residues. Senna treatment that had the lowest mineral N during the first weeks of the trial, showed that N mineralization was slow with the mineral N reaching highest level at four-week stage. However, it is interesting to note that while soil N under tithonia was statistically higher than in senna at four weeks, it was higher under senna at later stage observations. Thus tithonia decomposed completely in about four weeks, while senna was still mineralizing at 8 weeks.

Fertilizer use increased maize grain yield by 63% over the control. Although tithonia biomass increased maize grain yield by 38% over the control and did not differ significantly from fertilizer treatment, senna increased maize yield by only 6% over the no input control. Higher yield with tithonia than senna was partly because of higher nutrient concentration and hence greater amounts of nutrients added for the same quantity of material applied. The study indicates that high quality residues such as tithonia can be used as sources of nutrients to improve crop yields.

Keywords: Biomass transfer, *Tithonia diversifolia, Senna spectabilis*, mineral nitrogen, maize yield.

Introduction

Crop yields in large parts of Kenya are low due to declining soil fertility as a result of continuous cropping and non-application of fertilizers by farmers. For example, soils in western Kenya, (Acrisols, Ferralsols and Nitisols)(FAO, 1965) are poor in organic matter content and have low reserves of nitrogen (N), phosphorus (P) and some trace elements

(ICRAF, 1994; ICRAF, 1997; Mwiinga *et al.*, 1994; Mugendi, 1996; Sanchez *et al.*, 1997; Rao *et al.*, 1998). In addition they are easily compacted and are prone to erosion. As soon as the vegetative cover is removed and land intensely cropped with grain crops, the soil's physical, chemical and biological properties are readily degraded (ICRAF, 1993; Sanchez *et al.*, 1997).

With the liberalization of trade and introduction of structural adjustment programmes (SAP), fertilizer costs have increased to a level unaffordable to small-scale farmers. How to increase and maintain crop yields to meet the needs of the growing population has become a major national problem. Agroforestry technologies such as short duration planted tree fallows and green manuring (biomass transfer) with tree residues have been demonstrated to increase crop yields (Niang et al., 1996; ICRAF, 1997). These technologies have also been found to be economically attractive to farmers (Sanchez et al., 1997). In the absence of fertilizers, crop production relies largely on nutrient management through organic residues (Vanlauwe et al., 1996; Rao *et al.*, 1998).

In western Kenya, farmers have live fences around their farms and grow shrub and tree hedges on contours, but rarely use the biomass from these trees and shrubs for soil fertility improvement. Several studies have shown that tree residues can be used as a source of nutrients to crops (Niang *et al.,* 1996; Palm, 1996; ICRAF, 1997). The residues serve mainly as source of organic matter and nitrogen, but may also contribute significant amounts of other essential nutrients. These residues upon incorporation into the soil can help increase crop yields. For example, experiments conducted in western Kenya, have demonstrated that higher yields can be obtained with leaf biomass of *Tithonia diversifolia* (Hemsley) A. Gray than even with commercial urea fertilizer (ICRAF, 1996; ICRAF, 1997; Rao *et al.*, 1998). *Tithonia diversifolia* is a soft and succulent shrub belonging to the family Asteraceae (Compositae), and is commonly referred to as wild sunflower. Tithonia at 5 t ha^{-1} rate (on fresh weight basis) increased maize grain yield about one and half times higher than without inputs (Gachengo, 1996).

The capacity of any agroforestry system to enhance nutrient cycling depends both on soil fauna, environmental conditions (e.g. temperature, moisture, and aeration) and on management factors. Management aspects include the selection of tree species with appropriate phenology, rooting patterns and litter quality. Scientists need to understand the complex interactions among the above in order to realize the potential benefits of introducing agroforestry in a given environment (ICRAF, 1993).

In this study we seek to:

1) compare the effect of adding organic residues from agroforestry trees and shrubs on soil mineral N to that of inorganic source of N (fertilizer).
2) assess how these inputs of organic and inorganic sources of nutrients influence crop yields.

Materials and Methods

Study site description

The study was conducted on farm near Maseno (0°6' N, 34°35' E, and 1560 m above sea level), in Vihiga District of western Kenya. The area receives an average annual rainfall of 1800 mm in two rainy seasons; 'long rains' (March to July) and 'short rains' (September to January). However, during 1997, a total rainfall of 2037 mm was recorded with 1200 mm in the short rains, received because of the El nino phenomenon. Mean monthly temperature ranges between 14.6°C and 30.7°C. The soil at the experimental site was classified as Kandiudalfic Eutrodox (USDA, 1992). At the start of the study, the field had the following soil physical and chemical characteristics at 0-15 cm and 15-30 cm depths respectively: pH (1:2.5 soil water) 5.5, 5.5; organic carbon (g kg^{-1}soil) 15.5, 14.5; extractable soil inorganic P (mg kg^{-1}) 1.3, 0.9; exchangeable calcium (cmolc kg^{-1}) 4.03, 3.85; exchangeable potassium (cmolc kg^{-1}) 0.15, 0.13; clay (%) 41, 42; sand 33%, 33%; silt % 26%, 25%; porosity ranged between 50% and 60%. The soil is considered to be moderately P fixing with a soil P concentration corresponding to 310 mg P kg^{-1} adsorbed by the soil (Nziguheba *et al.*, 1998).

Experimental set-up and management

The present study was superimposed on an on-going larger experiment that was initiated in 1995, during the short rain season to evaluate six organic tree and shrub residues (*Tithonia diversifolia, Lantana camara, Calliandra calothyrsus, Senna spectabilis, Sesbania sesban* and *Croton megalocarpus*), as sources of nutrients in comparison with inorganic nutrients at six different N and P levels. The treatments were replicated four times in a randomized complete block design in plots of 7.5 m wide and 7 m long. The present study was conducted during the 1997 short rains with the following treatments using maize (*Zea mays* L.) hybrid as the test crop:

1) control: with no external inputs (Farmers' practice),
2) fertilizer input at: 120 kg N, 150 kg P and 100 kg K ha^{-1},
3) fresh biomass of *Tithonia diversifolia* at 5 tonnes (dry weight) ha^{-1} and
4) fresh biomass of *Senna spectabilis* at 5 tonnes (dry weight) ha^{-1}.

The trial initially did not include a "no input" control (no N and P), so a farmers' no fertilizer control was randomly assigned to one of the unutilized blank plots in each replicate. The site was relatively flat and there was no particular problem of runoff from plot to plot.

The amount of N and P added by the organic residues, depends on the chemical composition. Chemical composition was determined every season at the time of application. All the selected material contained fairly high N and P, but differed with respect to tannin, lignin, polyphenol levels (Table 4.1). In the fertilized plots, 120 kg N ha^{-1} rate was chosen as it is close to the total N applied for the different materials ranging between 136 kg N ha^{-1} to 183 kg N ha^{-1}. The rate is also sufficient to overcome N limitation to maize growth in these soils. The choice of the two residues (tithonia and senna) was based on the nutrient (N and P) concentration, plant residue quality index (PRQI)(Tian *et al*., 1995) and availability in the region for potential use by farmers.

Table 4.1: Chemical composition and plant residue quality index (PRQI) of tithonia and senna foliage

Plant residue	%N	%P	%Lignin	% Poly-phenols	C/N ratio	PRQI(%)
Senna spectabilis	3.3	0.21	9.0	1.03	10.89	10.26
Tithonia diversifolia	3.5	0.28	9.0	3.20	10.10	10.59

The difference between the two test materials as measured by PRQI, has turned out to be much smaller than initially thought (Table 4.1). However, the experience of many researchers indicate that tithonia decomposes faster than senna and represents high quality residues (Jama and Palm, Personal communications). In western Kenya, particularly around Maseno area, farmers grow tithonia as a part of live fences around their farms to mark boundaries or as hedges on contour. *Senna spectabilis* trees are also common. The two residues were therefore readily available.

Soil sampling

Soil samples were taken using 2-inch wide auger, from five different locations at two depth intervals (0-15 cm and 15-30 cm), within each plot. One composite sample was prepared for each 0-15 cm and 15-30 cm depths and they were analyzed for nitrate-N and ammonium-N contents of the soil using standard methods/procedures (Anderson and Ingram, 1993; Weaver *et al,* 1994). Inorganic N content was measured at the start of season and subsequently at 1, 2, 4, 8 and 12 weeks after treatments were applied.

Maize yield measurements

Maize grain and stover yields were estimated by harvesting the four central rows (3.0 m wide and 5.5 m long) leaving three guard rows on either sides and one metre each on either end. Within each row, two maize plants were left on either end as guard. The maize cobs were harvested, weighed and sub-samples obtained. The sub-samples (about 0.5 kg from each plot) were oven-dried and the cobs threshed. The threshing percentage was used to estimate the maize grain yield in tonnes per hectare. The maize stover from the net plot was harvested, weighed and sub-samples obtained. The sub-samples of stover were chopped into smaller pieces and were then oven-dried at 70°C. The ratio of dry weight to fresh weight and plot fresh weights were used to estimate the maize stover yield in tonnes per hectare.

Data analyses

The data collected were subjected to analyses of variance (ANOVA), to compare treatment effects on soil mineral N and maize yields. ANOVA was conducted using the GENSTAT 5 Committee (1993) statistical package. While sampling was conducted at different periods, the data were analyzed in a split-plot design with the applied treatments as the main plot factor and sampling period as the sub-plot factor. Treatment differences were evaluated using the least significance difference (LSD) at $P<0.05$. Standard error of difference of means (SED) was given.

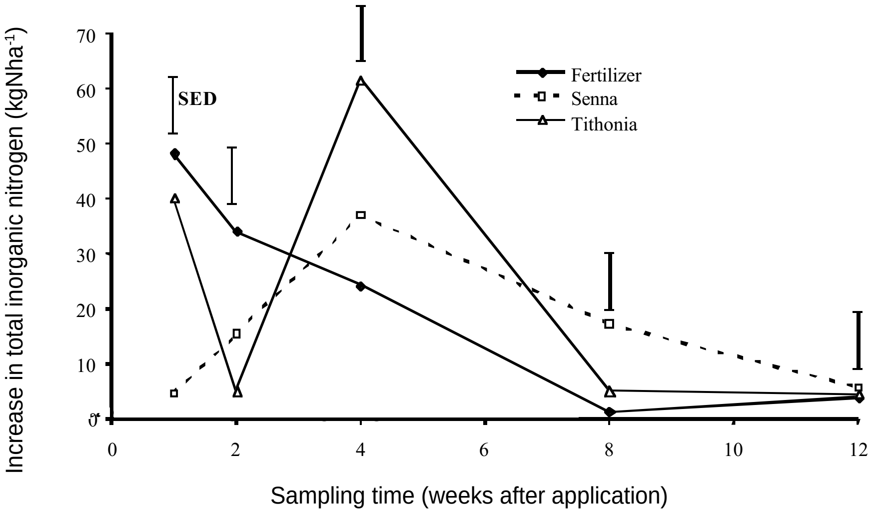
Results

Effect of fertilizer and organic residues on mineral nitrogen (N) in the soil

Total inorganic (mineral) nitrogen in the soil at the beginning of the season was at a similar level in all treatments. It increased rapidly after applying the materials and the onset of rains probably because of rapid nitrogen mineralisation in all treatments. At one week stage after addition of inputs, the highest amount of soil mineral N was observed in the urea fertilized plot (48 kg N ha^{-1}), followed by tithonia treated plots (40 kg N ha^{-1}), but lowest under senna (4.5 kg N ha^{-1}) (Figure 4.1).

After four weeks inorganic nitrogen decreased progressively until end of the experiment in all the treatments. However, for urea-fertilized plots, progressive decrease in mineral N was noted after one week. The highest contribution of mineral N to the soil by the organic residues was noted after four weeks and this was significantly higher with tithonia than senna. This could be due to rapid N mineralization by these residues. However, it is interesting to note that while soil N under tithonia was statistically higher than in senna at four weeks, it was higher under senna at 8 weeks after application (Figure 4.1).

Figure 4.1: Increase in mineral nitrogen (total mineral nitrogen in the top 0-30 cm soil depth) above the control (no input) over 12 weeks under different inputs of organic and inorganic nutrient sources



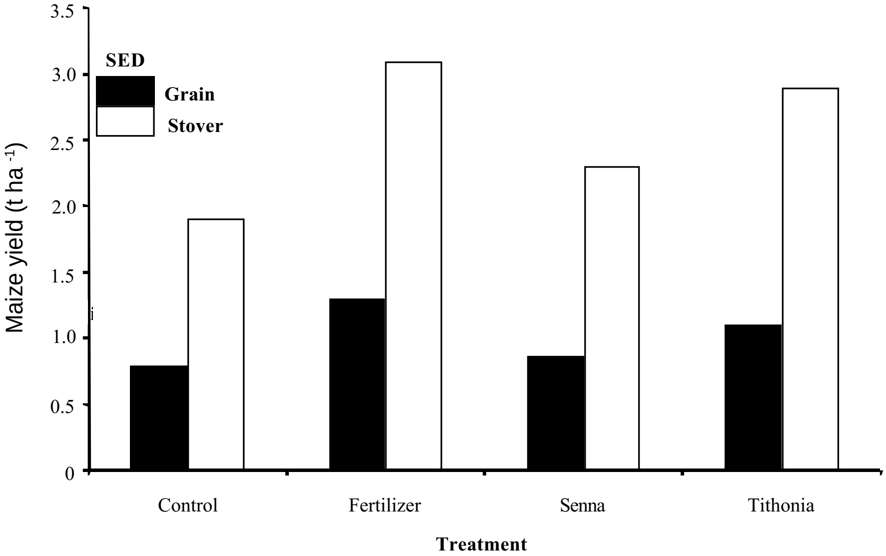
SED- Standard error of difference of means.

Effect of organic and inorganic sources of nutrients on maize yields

The treatments affected maize grain and stover yields in a similar way (Figure 4.2).

Maize without inputs (i.e. control) produced the lowest yields of 0.8 t grain and 1.9 t stover ha^{-1}. Application of senna residue did not increase the yields significantly. However, addition of fertilizer and tithonia biomass increased maize yields significantly over the control (Figure 4.2). Whereas the fertilized maize produced 1.3 t ha^{-1} grain and 3.1 t ha^{-1} stover, which represented about 63% increase over the respective yields in the control, maize yield following application of tithonia biomass yielded 1.1 t ha^{-1} grain and 3.0 t ha^{-1} stover per ha, which represented 38% and 58% respectively over the control. The fertilizer and tithonia treatments did not differ significantly between them. Senna treatment increased grain yield by only 6% over the no input control.

Figure 4.2: Maize yields affected by organic residues and fertilizer compared with no inputs during 1997 short rains in western Kenya



SED- Standard error of difference of means.

Discussion

Effect of organic and inorganic fertilizer inputs on soil mineral nitrogen

Tithonia decomposed and mineralized nutrients faster than senna probably because of its higher N and P concentration and lower C:N ratio (Table 4.1). The overall level of secondary compounds (lignin and polyphenols) in tithonia and senna were low compared with foliage of many trees and shrubs (Chesson, 1997; Palm and Rowland, 1997). It has been shown that tithonia residue has high microbial biomass hence higher microbial activities resulting in higher decomposition rate (Nziguheba and Palm personal communication). The high soluble carbon in the tissue of tithonia provides the necessary substrate for higher microbial activity. Tithonia contains 80% water that further contributes to rapid decomposition. Senna has comparatively high C:N ratio and therefore soil fauna has greater role to play in its decomposition (TSBF, 1996). Thus, decomposition of senna proceeded at a slow rate because of its overall low quality relative to that of tithonia. Senna released more N than tithonia towards the end of the season, i.e. it asynchronized to plant uptake. It has been shown that the presence of a low quality material with low N and P contents at the onset of rains extends the time period of nutrient availability to the plants (Myers *et al.*, 1994). Asynchrony has undesirable effects on the crops because nutrients are released when their demand by crops is low. The benefits of such residues to the crop may be through the long-term build-up of N rather than the direct use of N from the decomposing residues (Palm, 1995). Application of senna and tithonia did not significantly affect the soil mineral N among the treatments (Figure 4.1). Lack of treatment related differences in the soil could be due to:

1) plant uptake of the nutrients during the growing season, and
2) loss of nutrients from the soil by leaching and also by surface run-off after the release of the nutrients following mineralization.

Nitrogen mineralization for tithonia was high at the beginning of the trial and this decreased toward the end of the season. It is possible that this being a high quality residue, the fauna promoted early release of N and leaching took place at the onset of rains.

Effect of organic and inorganic fertilizer inputs on maize yield

The yield differences among treatments could be related to N and P availability to crops and release patterns by the organic residues. Higher yields obtained in the fertilizer treatments could be attributed to the nutrients being readily available from the fertilizers. Nutrients from organic residues must first undergo decomposition before they are available for crop uptake. In the organic residue treatments, nutrient availability depended on nutrient concentration and release in synchrony with crop needs. Tithonia had a higher N and P concentration and underwent rapid mineralization, while senna, which has low concentration of N and P, exhibited slow mineralization and/or immobilization during early stages of maize. Maize yields with tithonia were therefore significantly higher than with senna. Higher yields with use of organic residue have been reported. For instance, experiments conducted in western Kenya have demonstrated that higher yields can be obtained when organic residues have been incorporated (Gachengo *et al.*, 1999; Palm, 1996). Gachengo (1996) showed that tithonia can increase maize yields by one and half times higher than without tithonia input. Furthermore, tithonia was found to reduce P sorption capacity of the soil and increase crop yields particularly in P limited soils by making P available to crops (Nziguheba *et al.*, 1998; Palm, 1996). As the experimental site was deficient in P, the increased yield in tithonia green-manure treatment was probably related to the combined effect of rapid N and P mineralization and their increased availability to crops. Phosphorus availability might have also increased through reduction of P sorption by tithonia (Nziguheba *et al.*, 1998).

Conclusions

This is a one-season study conducted during the 1997 short rains (October 1997 to February 1998). The experimental period was characterized by above normal rainfall due to *El nino* effect. A rainfall of 1200 mm was received during this season and therefore maize did not grow well. Crop yields were low and variable. The results of the study and recommendations made should be considered in the above background of *El nino* effect, poor crop growth and high variability of observations.

Based on the results of this study, foliage of tithonia is a better organic residue for soil nutrient management than that of senna. Resource-poor farmers who cannot afford fertilizers may be encouraged to plant tithonia in hedges or in contours and use this organic residue to improve the soil nutrient status.

Organic residues such as senna, which release nutrients slowly, can be considered for long-term build up of soil fertility. It should preferably be incorporated into the soil much before crop sowing to synchronize nutrient release with the crop needs.

Because only two organic residues, tithonia and senna, were studied, there is still need to investigate and test more organic residues to identify potential alternatives to tithonia for different agroclimatic condition.

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References

Anderson, J.M. and Ingram J.S.I. (1993) Tropical Soil Biology and Fertility: A Handbook on Methods, CAB International, Wallingford UK.

Chesson, A. (1997). Plant degradation by ruminants: Parallels with litter decomposition in soils. *In:* Cadisch, G. and Giller, K.E. (eds.), *Driven by* *nature: Plant litter quality and Decomposition*. CAB International, Wallingford, U.K, pp. 47-66.

Food and Agricultural Organization (FAO). (1965) *Guidelines for soil description.* Soil Survey and Fertility Branch, Land and Water Development Division.

Gachengo, C.N. (1996). Phosphorus (P) release and availability on addition of organic materials to phosphorus fixing soils. M.Phil. thesis, Moi University, Eldoret, Kenya.

Gachengo, C.N., Palm, C.A., Jama, B. and Othieno, C. (1999) Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. Agroforestry Systems 44: 21-36.

Genstat 5 Committee (1993) *Genstat release reference manual,* Oxford University Press, Oxford UK.

ICRAF., (1993). *International Council for Research in Agroforestry*. Annual Report, ICRAF., Nairobi, Kenya, 185pp.

ICRAF. (1994) *International Council for Research in Agroforestry*. Annual Report, ICRAF, Nairobi, Kenya, 185pp.

ICRAF. (1996) *International Council for Research in Agroforestry*. Annual Report, ICRAF, Nairobi, Kenya, 286pp.

ICRAF. (1997) *International Council for Research in Agroforestry.* Annual Report, ICRAF, Nairobi, Kenya, 165pp.

Mugendi, D.N. (1996) Resource integration: productivity aspects of alley cropping *Calliandra calothyrsus* and *Leucaena leucocephala* with maize in the highlands of Kenya. *Annual Report of the Tropical Soil Biology and Fertility Programme* (TSBF), Nairobi, Kenya.

Mwiinga, R.D., Kwesiga, F.R. and Kamara, C.S. (1994) Decomposition of leaves of six mulitipupose tree species in Chipata, Zambia. *Forest Ecology and Management* 64: 209-216.

Myers, R.J.K., Palm, C.A., Cuevas, E., Gunatilleke, I.U.N. and Brossard, M. (1994) The synchronization of nutrient mineralization and plant nutrient demand. *In:* Woomer, P.L. and Swift, M.J. (eds.). *The Biological Management of Tropical Soil Fertility,* pp. 81-116.

Niang, A., Amadalo, B., Gathumbi, S. and Obonyo, C. (1996) Maize yield response to green manure application from selected shrubs and tree species in Western Kenya: A preliminary assessment. *In:* Mugah, J.O. (ed.), *People and Institutional Participation in Agroforestry for Susainable Development,* KEFRI, Nairobi, Kenya, pp. 35-358.

Nziguheba, G., Palm, C.A., Buresh, R.J. and Smithson, P.C. (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. *Plant and Soil* 198: 159-168.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agroforestry Systems* 30: 105-124.

Palm, C.A. (1996) Nutrient management: Combined use of organic and inorganic fertilizers for increasing soil phosphorus availability. *Annual Report of Tropical Soil Biology and Fertility Programme* (TSBF), Nairobi, Kenya.

Palm, C.A. and Rowland, A.P. (1997) A minimum dataset for characterization of plant quality for decomposition. *In* Cadisch, G. and Giller, K.E. (eds.). *Driven by nature: Plant litter quality and Decomposition*. CAB International, Wallingford, U.K, pp. 379-392.

Rao, M.R., Niang, A., Kwesiga, F.R., Duguma, B., Franzel, S., Jama, B. and Buresh, R. (1998) Soil fertility replenishment in sub-Saharan Africa: New techniques and the spread of their use on farms. Agroforestry Today, 10(2): 38.

Sanchez, P.A., Shepherd, K.D., Soule, M.J., Place, F.M., Buresh, R.J., Anne-Marie, N.I., Mokwunje, A.U., Kwesiga, F.R., Ndiritu, C.G. and Woomer, P.L. (1997) Soil fertility replenishment: An investment in Natural Resource Capital. *In:* Buresh, R.J., Sanchez, P.A. and Calhoun, F. (eds.). *Replenishing Soil Fertility in Africa. Soil Science Society of America (SSSA). Special publication, No. 51*.

Tian, G., Kang, B.T. and Brussard, L. (1995) An index for assesssing the quality of plant residues and evaluating their effects on soil and crop in the sub-humid tropics. *Applied Soil Ecology* 2: 25-32.

TSBF. (1996) *Tropical Soil Biology and Fertility programme*. Annual Report, pp 48, Nairobi, Kenya.

USDA. (1992) Soil taxonomy. Agricultural Handbook no. 294, Washington D.C.

Van den Bosch, S. (1994) The influence of residue quality on nitrogen dynamics in the litter fraction. An MSc. Thesis abstract, Catholic University Leuven, Belgium.

Vanlauwe, B., Dendooven, L., Merckx, R., Vanlangenhove, G., Vlassak, K. and Sanginga, N. (1996) Residue quality and decomposition under controlled and field conditions. *International Institute of Tropical Agriculture (IITA) Research Highlights and Annual Report,* 12, 1-6.

Weaver, R.W., Angle, J.S. and Bottomley, P.S. (1994) *Methods of Soil Analyses: Microbiological and Biochemical Properties,* 5, 2.

5

Long Term Effects of Mineral Fertilisers, Phosphate Rock, Dolomite and Manure on the Characteristics of an Ultisol and Maize Yield in Burkina Faso

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Abstract

The effects of soil liming, mineral and organic fertilisation on soil characteristics and maize *(Zea mays)* productivity was studied in an Ultisol in the South Savannah zone of Burkina Faso. The experiments were carried out in Farakô-ba research station located in the South Sudanian zone at 11°6' N latitude, 4°20' W longitude and 405 m altitude. Two experimental designs were used. In a long-term experiment with different treatments of fertilizers, a single rate of 571 kg ha^{-1} of the local Kodjari phosphate rock (PR) containing 200 kg ha^{-1} CaO and 143 kg ha^{-1} P was applied the first year (1983). The liming effect of organic fertilisation was also evaluated with an application of 5 t ha^{-1} of manure every two years. In the second experiment, the liming effect of a local dolomitic limestone was tested with 3 rates of potassium (0, 30 and 60 kg ha^{-1} K_2O) in a split-plot design. The results of the long term experiment showed that mineral fertilisers might increase maize yield from 250 to 350% during the first 5 years indicating that nutrient deficiency is one of the main constraints that limit crop productivity. However, mineral fertilisers induced soil acidification and became less efficient after 5 years of cultivation. Manure increased and maintained mineral fertiliser effectiveness during 6 years of cultivation. Manure had a significant liming effect on soil acidity by increasing pH and reducing exchangeable acidity and Al saturation. PR increased exchangeable Ca, and base saturation. Soil liming with PR increased P availability, maize yield and mineral fertiliser effectiveness during 6 years of cultivation indicating that P deficiency is an important limiting factor in this soil. The critical soil fertility limit of available P (Bray I) for maize using Cate and Nelson graphical method was found to be 15.9 mg kg^{-1} soil. Dolomite also increased base saturation and soil pH and reduced Al saturation and exchange acidity. However, a significant interaction between dolomite and potassium fertiliser was observed. Dolomite effectiveness was affected by K rate. The higher yield of maize was obtained with 370 kg ha^{-1} of dolomite combined with 42 kg K ha^{-1} indicating that Ca, Mg and K ratios have to be considered when dolomite is used for soil liming.

Keywords: acidity, soil, phosphorus, manure, phosphate rock, dolomite, maize

Introduction

Agriculture in sub-Saharan Africa (SSA) is characterized by its poor productivity. Several factors related to soil fertility limit agricultural production. Many factors such as soil type, farmer's practices, crop residues and mineral fertilizers management influence crop yields. Alfisols, Oxisols and Ultisols dominate sub-Saharan Africa zones. The Sahel zone of West Africa is particularly covered with sandy acidic soils with low buffering capacities. Acidity in these soils is probably a consequence of parent sands derived from acid continental terminal deposits, strong paleoclimate and contemporaneous leaching and base-cycling processes (Wilding and Hossner, 1989). Majority of West African soils belong to the Alfisols soil order according to the United State Soil Taxonomy and Ferruginous tropical group in the French classification (Pieri, 1985). In the savannah zone with low rainfall (500 - 1000 mm annually), base leaching is limited; hence soils have relatively high soil pH and base saturation (Ssali *et al.*, 1985). Particularly Alfisols of

Savannah zone have a low inherent acidity (pH 6.0 to 6.5). Considering the pH values, West African soils are not excessively acid. However, soil acidity may rapidly increase with farmers cultural practices (Pieri, 1985). Traditional fallow system reduction due to population growth, intensive cropping, nutrient losses by erosion and runoff, cations Ca^{2+} and Mg^{2+} losses with nitrate leaching, all tend to induce acidification in low-buffered soils. So, the acidification of cultivated soils and P deficiency due to high P fixation could significantly affect crop yields.

Considering P deficiency and soil acidification induced by farmers practices, organic amendments, rock phosphates and dolomite are interesting alternatives that could be exploited to improve traditional farming system productivity in SSA. The objective of this study was to test PR and dolomite ability to alleviate both P deficiency and soil acidity constraints.

Materials and Methods

Two trails were established in the research station of Farakô-ba in Burkina Faso. The site is located in the South Sudanian zone at 11°6' N latitude, 4°20' W longitude and 405 m altitude. The average annual rainfall varies from 900 to 1000 mm. Ultisols and Alfisols are the main soil types of Farakô-ba. The two experiments were established on Ultisols. These soils have a low inherent acidity (pH 6.0 to 6.5), which may rapidly increase with cultural practices. The major properties of the soil are presented in Table 5.6. Before the establishment of the experiments, the land was under several years of fallow.

The dolomite effectiveness was studied in a randomised block design in a split-plot arrangement with six replications. The main plot treatments were four levels of dolomite (0, 100, 200 and 400 kg CaO ha^{-1}). The potassium was applied in the sub plots. Three levels of K (0; 21 and 42 kg K ha^{-1}) were applied. All plots received 16 kg P ha^{-1} in the form of triplesuperphosphate except the control. A uniform rate of 90 kg N ha^{-1} was applied on all subplots except the control. The N was applied in the form of urea and was split. Three splits were applied, with one third at the sowing, one-third 30 days after planting (DAP) and the last third 60 DAP. An improved maize variety SR 22 (120 days) was used at the recommended planting density of 62500 plants ha^{-1}.

PR liming effect was studied in a long-term experiment started in 1983. The experimental design was a randomised complete block design in a split-plot treatment arrangement with six replications. The main plot treatment was six levels of mineral, organic and organo-mineral fertilisers. The PR was applied in the sub plots. Two levels of mineral fertilisers (weak annual mineral fertilizer: 60N-10P-10K-6S-1B (fm) and high annual mineral fertiliser: 90N-15P-36K-9S-1.5B (FM) was applied alone or in combination with 5 tonnes ha^{-1} of manure every two years (fmo and FMO). The nutrients P, K, S and B were applied as NPKSB fertiliser and KCl. Nitrogen in the form of urea and NPKSB fertiliser was split. Three splits were applied, with one third at the sowing, one-third 30 days after planting (DAP) and the last third 60 DAP. Each main plot was split in two subplots and one of them received a basal application (1983) of 571 kg ha^{-1} of PR corresponding to 200 kg ha^{-1} CaO and 62 kg ha^{-1} P. The main characteristics of PR are presented in Table 5.1. On the two experiments all fertilisers were broadcast and incorporated.

An improved maize variety, IRAT 171 (120 days) was used at the recommended planting density of 62,500 plants ha^{-1}. The dates of planting varied according to the start of the rains. In general, plating was in June and harvesting occurred in November. The monthly rainfall distribution during the experimentation is showed in Table 5.2. Maize gain and stover yield were measured. Consistent with traditional practices, the crop residues were removed each year.

Table 5.1: Element content (%) of phosphate rock and dolomite

	Phosphate rock *	Dolomite
P_2O_5	25.5	-
Al solubility (HCl)	3.1	-
Fe_2O_3solubility HCl	3.4	-
CaO	34.5	35.5
F	2.5	-
SiO_2	26.24	-
MgO	0.27	19.0

* Source: Mc Clellan *et al* (1986)

Table 5.2: Monthly rainfall (mm) distribution during the crop cycle of the experiments

	Month						
Year	May	June	July	August	September	October	Total
1983	122	104	166	194	131	3	720
1984	102	104	123	274	157	13	773
1985	112	290	272	429	169	57	1329
1986	118	83	215	233	168	53	870
1987	43	151	199	372	74	22	861
1988	83	99	194	196	305	62	939
1989	59	126	155	366	144	41	891

In 1989, soil samples were taken after harvest from the top 20 cm depth of all subplots for chemical characterisation. Organic carbon was measured by the procedure of Walkley & Black (1934). Soil pH was measured in 1 N KCl using 2:1 solution to soil ratio and exchangeable acidity was measured using McLean method (1982). Exchangeable bases (Ca, Mg and Na) were displaced with NH_4O. Ca and Mg were determined by atomic absorption spectrometry, while K and Na were determined using flame photometry. The data were analysed as split-plot with SYSTAT using analysis of variance.

Results and Discussions

The effects of fertilisers and PR on maize yield are presented in Tables 5.3 and 5.4. Compared to the control, all treatments increased the maize yields. All Fertilisers improved maize grain and stover yields during the eight years of experimentation. The mineral fertilisers highly increased maize grain and stover yields particularly during the first four years. The highest yields of maize were obtained with the application of mineral fertilisers associated with organic manure. As showed by other works (Berger *et al.*, 1987; Pichot *et al*, 1981; Sedogo, 1981; Bationo and Mokwunge 1991; Bado *et al.*, 1997) these high responses to fertilisers may be explained by the poverty in nutrients and the low content in organic mater of west African weakly acidic Ultisols. So, all additions of fertilisers or high quality organic mater can significantly increase crop yields. As showed on Table 5.6, mineral fertilisers reduced soil base saturation and pH. They increase exchangeable acidity and Al saturation. Mineral fertilisers not only increased nutrients availability in soil but also increased soil acidity at the same time. This acidification effects of the mineral fertilisers are reduced or suppressed when manure was simultaneously applied with mineral fertilisers (Table 5.6), explaining the beneficial effect of organic and mineral fertilisers on soil fertility and maize yields. Similar results relative to the beneficial effect of the simultaneous application of organic amendments and mineral fertilisers on crop yields were also obtained by Sedogo (1981) and Bado *et al.* (1997).

The basal application of PR in the first year (1983) had a significant effect (<0.01) on maize grain yield, particularly during the first two years (Table 5.3). The PR also increased maize stover yield during the first three years (Table 5.4). The beneficial effect of the PR on maize yields may probably be due to it's effect on P availability and soil acidity. PR application involved an increasing of soil available P (Table 5.6). As indicated by the relationship between soil available P and maize yield calculated in 1989 using the data of all treatments, maize yield was significantly affected by soil P availability (Figure 5.1). Maize yields and P-Bray are related by positive correlations (<0,01) indicating that 94 % of maize yield variations were due to soil P availability. By using the graphical methodology of Cate and Nelson (1965) we saw that the critical limit of P-Bray I for maize production in this soil was 15.9 mg P kg^{-1} and 16.5 mg P kg^{-1} respectively for grain and stover yield indicating that P is an important limiting factor for maize yield in this soil as shown by Saharawat *et al* (1997) in Côte d'Ivoire.

Table 5.3: Effect of organic and mineral fertilizers and basal application of rock phosphate (only in 1983) on maize grain yield over six years (1983-1989)

			Organic and mineral fertilisers			
Year		Control	Weak mineral fertiliser (fm)	High mineral feriliser (FM)	fm + 5 t ha^{-1} manure	FM + 5 t ha^{-1} manure
	0 PR	505	1766	2159	1566	2175
1983	571 kg PR	1353	2413	1889	1775	2230
	PR (a)			*		
	Fertiliser(b)			**		
	a*b			*		
	0	294	2036	1901	1812	2486
1984	PR	1185	2730	3089	2397	3240
	PR*(a)			**		
	Fertiliser(b)			**		
	a*b			ns		
	0	847	2276	2994	2861	3242
1985	PR	1386	2247	2903	3224	3641
	PR*(a)			NS		
	Fertiliser(b)			**		
	a*b			ns		
	0	679	2413	2543	2758	3538
1986	PR	1263	2233	2985	2873	3428
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	453	2285	2796	1673	2857
1987	PR	1022	2310	3223	1867	2708
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	64	1108	1734	1308	2923
1988	PR	284	1160	2438	1745	3024
	PR*(a)			**		
	Fertiliser (b)			**		
	a*b			ns		
	0	35	472	869	479	1069
1989	PR	227	657	878	733	1203
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		

*, **, ns: indicate significant at 0.05, 0.01 probability or not significant (> 0.05)

Table 5.4: Effect of organic and mineral fertilizers and basal application of rock phosphate (only in 1983) on maize stover yield over six years (1983-1989)

		Organic and mineral fertilisers				
Year		Control	Weak mineral fertiliser (fm)	High mineral feriliser (FM)	fm + 5 t ha^{-1} manure	FM + 5 t ha^{-1} manure
	0 PR	1595	3328	3762	3086	4099
1983	571 kg PR	3424	4581	4292	3617	3906
	PR (a)			**		
	Fertiliser(b)			**		
	a*b			**		
	0	1109	3376	2893	2894	3906
1984	PR	1591	4003	3810	3231	3762
	PR*(a)			**		
	Fertiliser(b)			**		
	a*b			ns		
	0	1254	4128	4417	4552	4630
1985	PR	2083	4109	4900	4687	5112
	PR*(a)			*		
	Fertiliser(b)			**		
	a*b			ns		
	0	-	-	-	-	-
1986	PR	-	-	-	-	-
	PR*(a)	-	-	-	-	-
	Fertiliser (b)	-	-	-	-	-
	a*b		-	-	-	-
	0	1234	4687	4784	3974	4321
1987	PR	2180	4649	5035	3569	5343
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			ns		
	0	249	1742	2656	2098	3583
1988	PR	532	1835	3351	2264	3313
	PR*(a)			NS		
	Fertiliser (b)			**		
	a*b			NS		
	0	260	1138	1428	776	1726
1989	PR	583	1205	1755	1635	2030
	PR*(a)			**		
	Fertiliser (b)			**		
	a*b			ns		

*, **, ns: indicate significant at 0.05, 0.01 probability or not significant (P> 0.05)

On the soil acidity parameters, the basal application of PR significantly reduced aluminium saturation (Table 5.6). The basal application of PR in 1983 had a residual effect on the reduction of Al saturation until 1989. By using the data of all treatments we found that soil pH and soil exchange acidity are related by a significant ($P<0.05$) exponential relationship (Figure 5.2).

Figure 5.1: Relationship between P-Bray I and maize grain yield

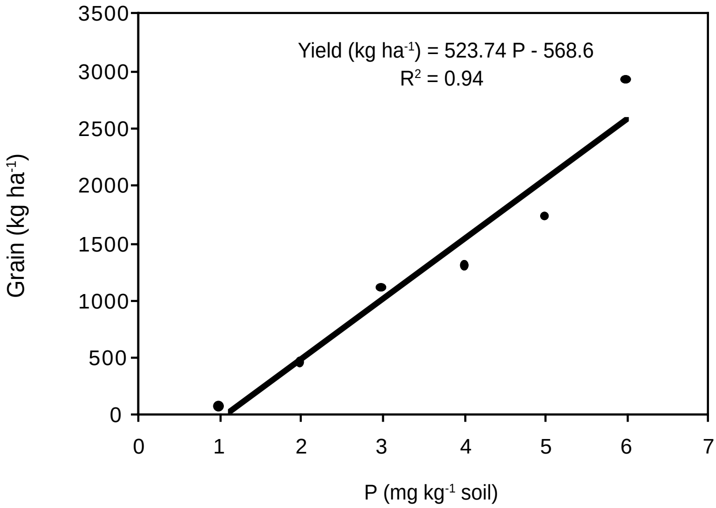
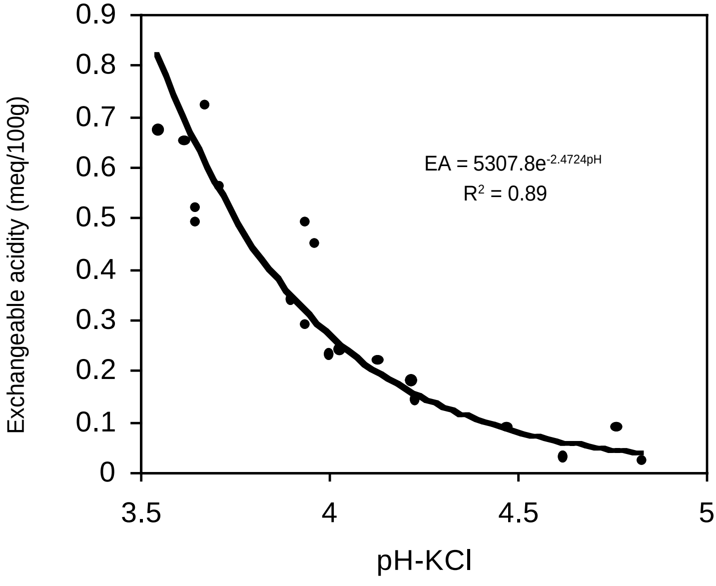


Figure 5.2: Relationship between soil pH and exchangeable acidity



The effects of dolomite and potassium on maize yields are presented in Table 5.5. Dolomite increased maize yields. The efficiency of dolomite was affected by potassium rates. When potassium wasn't applied, the highest yield of maize was obtained with 200 kg CaO ha^{-1}. Potassium had a significant effect on maize yield when it was applied at 42 kg K ha^{-1} indicating that Ca, Mg and K ratios are to be considered for a better use of dolomitic limestone as observed by Bado *et al*. (1993). The best combination of dolomite and potassium providing highest yield is 100 kg ha^{-1} CaO as dolomite combined with 42 kg K ha^{-1}.

Table 5.5: Effect of dolomite and potassium on maize grain yield (kg ha^{-1})

	Potassium (kg K ha^{-1})		
Dolomite (kg CaO ha $^{-1}$)	0 kg ha^{-1}	21 kg ha^{-1}	42 kg ha^{-1}
0	3557 a	3284 a	3143 a
100	3831 a	3509 a	4736 b
200	4286 b	4293 b	3309 a
400	4140 b	4234 b	4493 b

Yields affected by the same letter are significantly different (P< 0.05).

Table 5.6: Effects of organic and mineral fertiliser and phosphate rock on soil characteristics after 9 years of maize cultivation.

	P-Bray I	pH-KCl	Al+H	Al sat. (%)	Ca	Mg	K	Bases	CEC
Control	4.9	4.2	0.22	11	0.38	0.32	0.12	0.98	1.20
Control + PR	10.5	4.2	0.16	8	0.40	0.28	0.12	0.96	1.12
fm	13.1		0.32		0.32	0.21	0.11	0.82	1.14
fm + PR	15.7		0.20		0.33	0.17	0.10	0.77	0.97
FM	19.4	3.8	0.38	26	0.18	0.19	0.14	0.68	1.06
FM+PR	23.2	3.8	0.35	20	0.33	0.21	0.16	0.86	1.20
fmo	14.5		0.22		0.32	0.27	0.14	0.91	1.13
fmo+PR	25.1		0.17		0.41	0.27	0.16	1.00	1.18
FMO	16.1	4.0	0.24	13	0.30	0.26	0.23	0.96	1.20
FMO+PR	24.4	4.1	0.20	8	0.39	0.29	0.18	1.00	1.23
Original Soil	4.4	4.3	-	9	0.63	-	-	1.48	1.71

Conclusion

In this weakly acid soil, low organic matter content and low nutrient content soil, particularly for P, mineral and organic fertilisers are the main constraints limiting maize yield. This explains the good response of maize to mineral fertilisers and organic manure applications. Mineral fertilizers alone may induce soil acidification, a decrease in exchangeable cations and an increase in aluminium dissolution. Thus, the decrease in productivity is associated to soil acidification as a consequence of soil organic matter declining due to long-term cultivation and crop residues exportation, bases absorption by plants and bases leaching over years. To solve these problems, an economic solution may be to use local agro mineral resources (rock phosphate and dolomite) to supply P and to correct soil acidification over time.

References

Bado, B. V., Dakyo, D., N'Dayegamiye, A. and Cescas, M. (1993) Effet de la dolomie sur la production et les propriétés chimiques d'un sol ferralitique. *Agrosol*. VI (2): 21-24.

Bado, B. V., Sedogo, M. P., Cescas, M. P., Lompo, F. and Bationo., A. (1997) Effet à long terme des fumures sur le sol et les rendements du maïs au Burkina Faso. *Agricultures*. Vol. 6 No 6 : 571 - 575.

Bationo, A. and Mokwunye, A.U. (1991) Role of manures and crop residue in alleviating soil fertility constraints to crop production with special reference to the Sahelian and Sudanian zones of West Africa. In: A. U. Mokwunye (Ed.) *Alleviating soil fertility constraints to increase crop production in West Africa.*. Kluwer Academic Publishers, 217 - 225.

Berger, M., Belem, P. C., Dakouo, D., and Hien, V. (1987) Le maintien de la fertilité des sols dans l'Ouest du Burkina Faso et la nécessité de l'association agriculture élevage. *Cot. et Fib. Trop.*; vol. XLII Fasc 3 pp 10.

Cate, R.B., and Nelson, L.A. (1965) *A rapid method for correlation of soil test analyses with plant response data.* North Carolina State Univ. Int. Soil Testing series Tech. Bull. 1.

Pichot J., Sédogo, M. P., and Poulain, J.F. (1981) Évolution de la fertilité d'un sol ferrugineux tropical sous l'influence des fumures minérales et organiques. *Agronomie Tropicale* N° 36: 122-133.

Pieri, C. (1985) Management of Acid Tropical Soils in Africa. In: *Management of Acid Tropical Soils for Sustainable Agriculture.* 41-61, Proc. Of an IBSRAM Inaugural Workshop. Yurimaguass, Peru.

Sahrawat, K. L., Jones, M. P., and Diatta, S., (1997) Extractable phosphorous and rice yield in an Ultisol of the humid forest zone in West Africa. *Comm. Soil Sci. Plant Anal.* 28: 711-716.

Sédogo, M.P. (1981) Contribution à l'étude de la valorisation des résidus culturaux en sol ferrugineux et sous climat tropical semi-aride. Matière organique du sol, nutrition azotée des cultures. Thèse de Docteur Ingénieur, INPL Nancy. 135 P.

Ssali, H., Ahn, P.M. and Mokwunye, U. (1985) Fertility of soils of tropical Africa: a historical perspective. In: Mokwunye, A.U., Vlek, L. G., (Eds), *Management of nitrogen and phosphorus fertilizers in Sub-Saharan Africa*. 59-82.

Walkley, A., and Black, J.A. (1934) An examination of the Detjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37: 29-38.

Wilding, L. P., Hossner, L.R. (1989) Causes and effects of acidity in Sahelian Soils. In: *Soil, Crop and Water Management in the Sudano Sahelian Zone*. 215-227. Proc of International Workshop. ICRISAT, Sahelian Center, Niamey, Niger.

6

Changes in Soil Properties and their Effects on Maize Productivity Following *Sesbania Sesban* and *Cajanus Cajan* Improved Fallow Systems in Eastern Zambia

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Abstract

Changes in soil properties and their effects on maize productivity following *Sesbania sesban* and *Cajanus cajan* improved fallow system were measured on a Typic kandiustalf in eastern Zambia. The treatments used in the study were two-year planted improved fallows of *Sesbania sesban* (L.)

Merr. (sesbania) and *Cajanus cajan (L.)* Millsp (pigeonpea); natural fallow and continuous fertilized (m+f) and unfertilized maize (m-f) (*Zea mays* L.) mono culture. At the end of 10-week incubation period, the cumulative N mineralization of sesbania (fresh leaves + litter), reached 59.4 mg N kg^{-1} soil as compared to 5.1 mg N kg^{-1} soil for pigeonpea litter. Grass fallow litter had a cumulative net immobilization of 0.8 mg N kg^{-1} soil. Maize with fertilizer had the highest pre-season soil nitrate-N at all soil depths. A polynomial regression model between maize grain yield and pre-season inorganic nitrate-N for 0-20 cm, 0-40 cm and 0-60 cm soil layers showed that the amount of pre-season inorganic nitrate-N in the soil layer accounted for 71%, 68% and 71%, respectively of the maize yield. Total inorganic N in the top 0-20 cm soil depths was in the order of: m+f > cajanus > sesbania > m-f > natural fallow. As was the case with pre-season soil nitrate-N, total inorganic N in 0-20 cm, 0-40 cm and 0-60 cm soil depths was significantly correlated to grain yield (R^2 = 0.70, 0.67 and 0.71). DM accumulation ranged from 0.2 t ha^{-1} to 9.5 t ha^{-1} for m-f (at 4 WAP) and m+f (at 24 WAP), respectively. The maximum N accumulation in maize tops at 24 weeks after planting (WAP) averaged 156.9 kg N ha^{-1} and 77.0 kg N ha^{-1} for m+f and sesbania land use system (LUS), respectively, with grain yields of 5.51 and 3.02 t ha^{-1}, correspondingly. The lowest penetrometer resistance measured at 4 WAP for 0 -40 cm soil depth was recorded in sesbania LUS (2.2 Mpa). On the other hand fertilized maize had the highest resistance of 3.9 Mpa. The highest percentage of water stable aggregates > 2.00 mm at fallow termination was recorded in sesbania LUS (83.3 %), followed by pigeonpea LUS (80.8 %). At crop harvest the highest percentage of water stable aggregates > 2.00 mm was recorded in pigeonpea LUS (76.9 %), followed by natural fallow LUS (65.8 %). At fallow termination, the average cumulative water intake after 3 hours was 233, 315, 465, 485 and 572 mm for continuous maize without fertilizer, continuous maize with fertilizer, sesbania, pigeonpea and natural fallow, respectively. Soil water sorptivity at fallow termination was in the order of pigeonpea > natural fallow > sesbania > m+f > m-f. On the other hand soil water sorptivity at crop harvest was in the order of sesbania > natural fallow > pigeonpea > m+f > m-f. At crop harvest the average cumulative water intake at 3 hours was 173, 184, 221, 246 and 399 mm for unfertilized maize, fertilized maize, pigeonpea, natural fallow and sesbania, respectively. The improved soil condition and nitrogen contribution of sesbania

and pigeon pea fallows to subsequent crop was evidenced by increased maize yields after these fallows as compared with no tree treatments. Mixing of litter (low quality) with fresh leaves (high quality) from the same tree species at fallow termination had an effect on maize N uptake. Therefore there is need to carefully manipulate the quantities of materials (fresh leaves and litter) at fallow termination so as to get the maximum N utilization by maize plants in improved planted fallow systems.

Key words: Mineralization, immobilization, stable aggregates, penetration resistance, cumulative water intake

Introduction

Under traditional farming methods, farmers have relied on short natural or shrub fallows to grow maize and other crops. In eastern part of Zambia this fallow system is known locally as 'cisala' (Kwesiga *et al.* 1997). Nye and Greenland (1960) also reported that natural fallows have long been a way to overcome soil fertility depletion that results from continuous cropping with no nutrient inputs. The fallow period may vary from five to twenty years. However, long fallow periods have become impractical because of increasing human and livestock populations. Losses of mineral nutrients during the cultivation phase, through runoff, erosion, leaching and crop removal, can no longer be restored by short periods of bush fallow (Brady, 1996). The processes of natural soil fertility restoration are not completed with bush short duration fallows of between 1-5 years and this has necessitated the need for improved fallows.

Intensive cultivation and cropping may have negative effects on the chemical, physical, and biological properties of the soil due to the induction of changes in temperature, water, and aeration fluxes, decreasing organic matter content and increasing aggregate disruptions and soil erosion (Migliena *et al.* 1988). Nitrogen limits crop production over large areas of Zambia and the main sources of plant-available N are mineralization of soil organic matter (SOM), biological N_2 fixation, fertilizers and organic inputs (e.g., plant residues, composts and manures (Giller *et al.* 1997). The improvement in soil physical properties could be another reason for yield improvement but little quantitative data exist on these changes. Recent reviews (Rhoades, 1997 and Young, 1997) on the soil improvement effects of trees have largely concentrated on studies of soils under forest stands or along transects under individual trees. Studies by Mafongoya and Nair (1997) under field conditions showed that lignin, polyphenols and nitrogen content had a significant effect on N release and maize yield. Research on mixing of legume tree prunings from different species of high quality with low quality has been done by many researchers

(Handayanto *et al*. 1995 and Mafongoya *et al*. 1997). The residual effect on nutrient release and long-term changes in soil fertility resulting from mixing of prunings of different quality from the same tree legume species is a subject, which has received little attention to date.

Soil physical properties, such as aggregate stability and infiltration, are difficult, time consuming, and expensive to measure, hence their importance often receives insufficient research attention. Whilst the response of maize growth and yield in improved fallow systems has received much attention, the processes in tree and post fallow phase have not been understood. Therefore, the objectives of the study were: 1) To quantify some changes in soil properties that are responsible for improvement in crop productivity under fallow cultivation systems compared to the continuously cropped maize system. 2) To quantify the nitrogen mineralization patterns of mixing litter and fresh leaves from the same tree species.

Materials and Methods

The study was conducted in Eastern province of Zambia at Msekera research station during 1996/97 to 1998/99 season. Msekera research station is situated between latitudes $13^{0}38'$ S and longitudes $32^{0}34'$ E. The soils at experimental site in 0-20 cm soil layer are composed of 1.2% carbon content, pH ($CaCl_2$) of 4.5, 25% clay, 67% sand and receives an average rainfall of 1092 mm per annum. In general, the surface texture for the experimental site is sandy clay loam with reddish brown top and subsoils, classified as Typic kandiustalf (USDA, 1975) or Haplic luvisols (FAO, 1988).

A randomised complete block design (RCBD) comprising of five land-use systems (LUS) replicated three times was used, with gross plots of 10 m x 10 m. The LUS were *Sesbania sesban* (L.) Merr. (sesbania) and *Cajanus cajan* (L.) Millsp (pigeonpea); natural fallow and maize (*Zea mays* L.) monoculture with and without fertilizer. *Sesbania sesban* (prov. Chipata dam) fallow trees were planted from nursery raised bare rooted seedlings at the age of 5 weeks at a spacing of 1.0 m x 1.0 m (10 000 plants ha^{-1}). While *Cajanus cajan* (cv. ICP 9145) was direct seeded in the plots at the same time the *Sesbania sesban* seedlings were transplanted into the field in November 1996 at a spacing of 1.0 m x 0.50 m (20 000 plants ha^{-1}). Trees were clear felled at collar (ground) level in November 1998 after 2 years of fallow, while stumps and root system were left below ground.

Data collection and observations

Total above ground biomass of trees (leaves, twigs and wood) was measured at fallow clearing by separating the biomass components into foliage (leaves and twigs), branches and stems. These components were then weighed as green after which samples of each component were collected on plot basis and oven dried at 70°C to equilibrium moisture content. This data was used to estimate dry weight on plot basis and extrapolated to a hectare basis. The tree biomass (leaf + twig) and natural grass fallow of *hyparrhenia* sp. was incorporated in the soil by hand hoeing. After land preparation, hybrid maize (*Zea mays* L.) (variety MM 604) was sown by hand at 30 cm within-row and 75 cm between-row spacing (44 444 plant ha^{-1}). Fertilizer was applied to the fertilized control plots at the recommended rates of 20 kg N ha^{-1}, 40 kg P_2O5 ha^{-1}, and 20 kg K_2O ha^{-1} of Compound-D at sowing and 92 kg N ha^{-1} as urea at 4 weeks after sowing (WAS). All the plots were managed following the recommended agronomic practices for weeding and harvesting.

Soil ammonium and nitrate nitrogen

Soil sampling for soil ammonium and nitrate was done at fallow clearing (pre-season, November 1998) using a metal sampler (4.2 cm diameter G. I. Pipe) from 0-20, 20-40 and 40-60 cm soil depths. For determination of ammonium and nitrate nitrogen, about 20 g of field moist soil was extracted with 100 ml of 2 *M* KCl. The samples were shaken on a horizontal shaker for 1 hour at 150 oscillations min^{-1} followed by gravity filtering with pre-washed Whatman No. 5 filter paper. A second sub-sample of soil was dried at 105 °C for 24 hours to determine the dry weight of the extracted soil. Ammonium was determined by colorimetric method (Anderson and Ingram, 1993). Nitrate and nitrite concentrations were determined by cadmium reduction (Dorich and Nelson, 1984). The sum of inorganic ammonium-N and inorganic nitrate-N constituted the total inorganic nitrogen.

Laboratory incubation

Laboratory incubation was done to characterize the nutrient release patterns of sesbania (fresh leaves + litter), sesbania litter alone, pigeonpea (fresh leaves + litter), pigeonpea litter alone and dry grass littter. Chemical compositions of the organic materials used are shown in Table 6.2. Fresh leaves collected from the two species were sun dried for 2-3 days and oven-dried at 65 ^{0}C for 48 hours to determine the dry matter (DM) content. Soil was air-dried and sieved through a 2-mm mesh screen. The soil was first leached with deionised water at a water-to-soil ratio of 1 to 3 and left to drain until 50 % water holding capacity was achieved by constant weighing. 1.35g of ground organic material was mixed with 270g of soil in 350 ml aluminium moisture cans. This rate is equal to 5 t ha^{-1}, which is applied in the field. The treatments were 1) Soil + sesbania (fresh leaves + litter). 2) Soil + sesbania litter alone. 3) Pigeonpea (fresh leaves + litter). 4) Pigeonpea litter alone. 5) Soil + dry grass. 6) Soil alone (control). Fresh leaves and litter were mixed in a 1:1 w/w basis. Moisture cans were covered with aluminium foil that was perforated to allow air movement and put in the incubator at 28 ^{0}C throughout the experiment period. Soil moisture content in the cans was maintained at 50% water holding capacity throughout the experimental period by periodic additions of deionised water using a syringe and constant weight adjustment. Each treatment was replicated three times in a completely randomised design. Sub samples (20g) were analyzed for exchangeable NH_4^-N and NO_3^-N immediately after addition of plant material (at week 0) and once every week for 10 weeks. Ammonium was analysed by the modified calorimetric method of Dorich and Nelson (1984) and nitrate by the method of Cataldo *et al*. (1975). Results were reported as cumulative net mineralizable total inorganic nitrogen (ammonium-N + nitrate-N).

Soil penetration resistance

Penetration resistance was measured with a hand penetrometer, Bush soil penetrometer SP1000, version 1.0, supplied by ELE International, England. The penetrometer probe of 12.83 mm diameter with a cone semi-angle of 60^0 was pushed to a depth of 50 cm, and the resistance offered by the soil was recorded at 2 cm interval by a digital balance. Five insertions in the net plot were measured at 4 WAP and 24 WAP.

Cumulative water intake

Cumulative water intakes were monitored at fallow clearing and at crop harvest during the dry season. Two standard infiltrometer rings (double ring) per plot were used according to the procedure described by Bouwer (1986). Water measurements were recorded for three hours at 0, 5, 10, 15, 20, 30, 45, 60, 90, 120, 150 and 180-minute intervals. The average readings were used to calculate cumulative water intake per plot using Kostiakov (1932) and Philip (1957) models.

The Kostiakov (1932) model is described by equations 1 and 2:
1) Equation for cumulative depth is described by:
$z = kt^a$
2) Equation for infiltration rate is described by:
$i = akt^{a-1}$

Where: z = cumulative depth infiltrated
t = time
i = infiltration rate
a and k are constants determined empirically.
The Philip's model is described by equations 3 and 4:
3) Equation for cumulative depth is described by:
$z = St^{1/2}+At$
4) Equation for infiltration rate is described by:
$i = {}_{1/2}St^{-1/2}+ A$
Where: z = cumulative depth infiltrated
t = time
i = infiltration rate
S =sorptivity which indicates the capacity of a soil to absorb water.
A = transmissivity

Aggregate size distribution

Aggregate size distribution and stability was determined by the methods of De Leenheer and De Boodt (1958). Soil clods were dug at random from 0-20 cm depth at fallow clearing and at crop harvest using a hand hoe. Soil clods were hand broken to a maximum aggregate size of 50 mm then each soil sample was air dried at room temperature to stimulate some forces involved in aggregation. These forces are those related to cultivation, erosion (wind and water), and wetting of soils, respectively. The sample was allowed to pass through 9.50 mm and retained on the 0.30 mm opening sieve. A Yoder (1936) type-sieving machine, which raises and lowers the nests of sieves, through water with a stroke length of 1.5 inches approximately 30 cycles per minute was used with a set of 4.75, 2.0, 1.0, 0.50 and 0.30 mm openings sieves with a receiver at the bottom. An air-dry sample of 500g was placed gently in the sieve with 4.75 mm opening. The set of sieves were lowered in water of sieving machine and the machine was made to run for five minutes. Fractions obtained on each sieve and retainer was oven dried at 105°C for 48 hours and weighed. The oven dry aggregates were expressed as mean weight diameter (MWD) of aggregates and percent of aggregates retained on each sieve.

Trees, natural grass and crop biomass

Total above ground biomass of natural grass and tree components including leaves, twigs and litter were measured at fallow clearing. Total inorganic N in grass, leaves and litter was analysed by micro-kjeldahl digestion followed by distillation and titration (Anderson and

Ingram, 1993). Nitrogen uptake was assessed in the plant dry matter (DM) measured at 4, 6, 8 and 24 WAP (at harvest in grain and stover). Five plants were cut at ground level and oven-dried at 70°C for 72 hours for DM determination. N in the plant tissue was analysed by micro-kjeldahl digestion followed by distillation and titration (Anderson and Ingram, 1993). Maize grain and stover yields were measured at harvest (24 WAP).

Data analysis

The data were subjected to analysis of variance using GENSTAT version 5 (Genstat 5 committee, 1988). For all mean comparisons significance was tested at $P \leq 0.05$, using Duncan's Multiple Range Test (Gomez and Gomez, 1984). Simple linear and curvilinear regressions were used to determine the relationship between maize grain yield and pre-season soil inorganic nitrate-N and total inorganic N.

Results

Tree growth

Significant differences ($P \leq 0.05$) were observed in the survival rates. The highest survival rates were recorded in sesbania (91.7%), while pigeonpea had only 31.0%. As was the case with survival, high total biomass was recorded in sesbania fallows (Table 6.2).

Table 6.1: Growth performance of *Sesbania sesban* and *Cajanus cajan* fallow species at 24 months after fallow establishment at Msekera, Chipata-Zambia (November 1998)

Land-use system	Survival (%)	Leaf + Twig ($t\ ha^{-1}$)	Total biomass ($t\ ha^{-1}$)
Pigeonpea	31.0b	0.19a	8.50
Sesbania sesban	91.7a	0.23a	16.8
Mean	61.30	0.21	12.6
SED	10.68	0.18	2.94

Nitrogen mineralization and immobilization

The organic materials used had C-to-N ratio ranging from 14.7 to 69 for sesbania fresh leaves and natural grass, respectively (Table 6.1). The N concentration ranged from 0.62 to 3.09% for natural grass and sesbania, respectively (Table 6.1). The quality of leaves and litter significantly affected the N release pattern throughout the 10-week incubation period. After 10 weeks of incubation, the cumulative net N mineralization ranged from 5.1 to 59.4 mg N kg^{-1} soil for pigeonpea litter only and sesbania (fresh leaves + litter) mixture, respectively (Figure 6.1). Cumulative net immobilization of 0.8 mg N kg^{-1} soil was observed at end of the incubation period in natural grass litter (Figure 6.1). Between week 1 and 4 there was net immobilization in pigeonpea (fresh leaves + litter) mixture and sesbania litter alone. Pigeonpea litter alone had a cumulative net immobilization from week 1 to 5.

Table 6.2: Chemical compositions of organic materials used for incubation study at Msekera, Chipata-Zambia

Land-use system	Carbon (%)	Nitrogen (%)	Carbon to Nitrogen ratio
Pigeonpea fresh alone	45	2.98	15.1
Pigeonpea litter alone	45	1.36	33.1
Pigeonpea (fresh leaves + litter) mixture	45	2.10	21.4
Sesbania fresh leaves alone	45	3.09	14.7
Sesbania litter alone	45	1.28	35
Sesbania (fresh leaves + litter) mixture	45	2.4	18
Natural grass litter alone	43	0.62	69

Pre-season soil mineralizable nitrogen

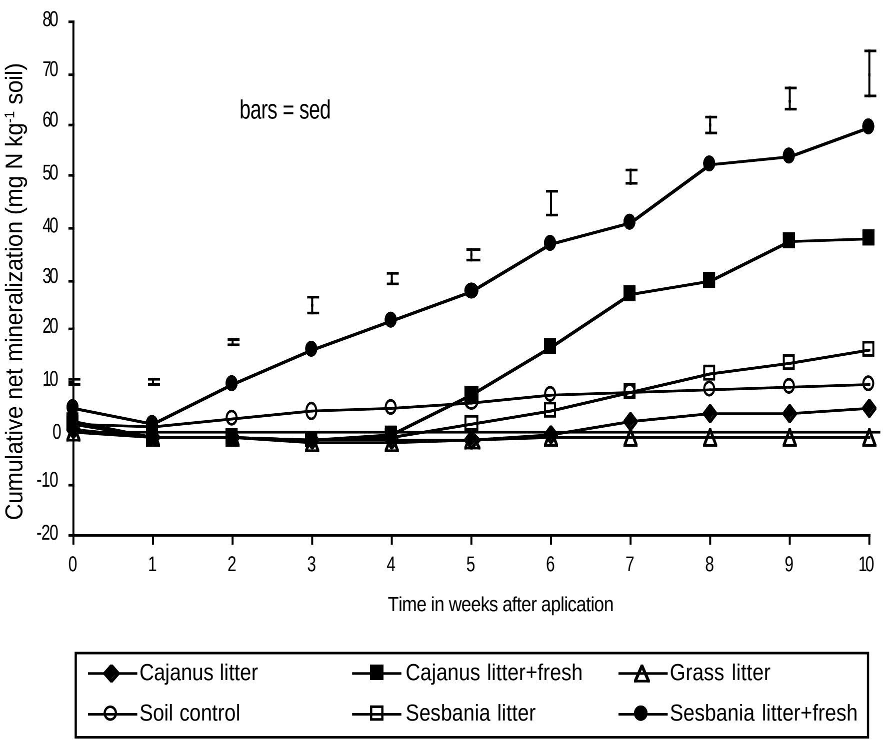
Pre-season nitrate-N and total inorganic N was significantly ($P \leq 0.05$) affected by soil depth and LUS (Table 6.3). Ammonium-N was not significantly affected by either soil depth or LUS (Table 6.3). Maize with fertilizer had the highest soil nitrate-N in all soil depths, which was not significantly different from pigeonpea and sesbania LUS. At 40-60 cm soil depth soil nitrate-N had the following trend: m+f > sesbania > m-f > pigeonpea > natural fallow (Table 6.3). A polynomial regression model between maize grain yield and pre-season inorganic nitrate-N for 0-20 cm, 0-40 cm and 0-60 cm soil layers showed that the amount of pre-season inorganic nitrate-N in the soil layer accounted for 71%, 68% and 71%, respectively of the maize yield. Total mineral N in the top 0-20 cm soil depths was in the order of: m+f > pigeonpea > sesbania > m-f > natural fallow (Table 6.3). As was the case with pre-season soil nitrate-N, total mineral N in 0-20 cm, 0-40 cm and 0-60 cm soil depths was significantly correlated to grain yield (R^2 = 0.70, 0.67 and 0.71).

Table 6.3: Pre-season soil mineralizable nitrogen as affected by Land-use system and soil depth at Msekera, Chipata-Zambia (November 1998)

Treatment	Ammonium (mg N kg^{-1})			Nitrate (mg N kg^{-1})			Total N (mg N kg^{-1})		
	0-20	20-40	40-60	0-20	20-40	40-60	0-20	20-40	40-60
Pigeonpea	3.65[a]	2.52[a]	2.10[a]	3.49[ab]	2.37[ab]	1.25[bc]	7.14[ab]	4.88[ab]	3.36[b]
Natural fallow	3.09[a]	2.14[a]	1.64[a]	1.49[b]	0.74[c]	0.59[c]	4.58[b]	2.88[b]	2.23[b]
Maize +fert	3.11[a]	2.53[a]	1.59[a]	4.24[a]	3.52[a]	4.74[a]	8.32[a]	5.52[a]	7.73[a]
Maize – fert	4.07[a]	2.00[a]	2.99[a]	2.18[b]	1.70[bc]	1.81[bc]	5.29[ab]	4.23[ab]	3.41[b]
Sesbania	4.21[a]	1.85[a]	1.97[a]	2.49[ab]	1.52[bc]	2.07[b]	6.70[ab]	3.37[ab]	4.04[b]
Mean	3.36	2.21	2.06	2.78	1.97	2.09	6.40	4.18	4.15
SED	0.83	0.71	0.62	0.84	0.58	0.56	1.29	0.94	0.98

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test

Figure 6.1: Cumulative amount of net N mineralised as affected by quality of multipurpose tree leaves and litter during 10-week incubation period at Msekera, Chipata-Zambia



Dry matter and seasonal nitrogen accumulation in maize topmass

DM accumulation during the growing season ranged from 0.2 t ha^{-1} to 9.5 t ha^{-1} for maize without fertilizer (at 4 WAP) and with fertilizer (at 24 WAP), respectively (Figure 6.2). High N accumulation in maize above ground biomass was observed from 4 to 6 WAP in sesbania LUS (13.9 kg N ha^{-1}), as compared to fertilized plot that only accumulated 2.4 kg N ha^{-1} (Figure 6.3). Between 6 WAP to 8 WAP, there was a sharp rise of N accumulation in fertilized maize. Fertilized maize accumulated the highest amount of N (39 kg N ha^{-1}). On the other hand, sesbania and pigeonpea had only 7.0 kg N ha^{-1} and 15.8 kg N ha^{-1}, respectively (Figure 6.4). The maximum N accumulation in maize aboveground biomass at 24 WAP averaged 156.9 kg N ha^{-1} and 77.0 kg N ha^{-1} for maize with fertilizer and sesbania LUS, respectively. A polynomial regression model between maize dry matter accumulation and nitrogen uptake at 8 WAP and 24 WAP showed that the amount of nitrogen uptake accounted for 93% and 98%, respectively of the dry matter accumulation in maize plant.

Figure 6.2: Maize dry matter (DM) accumulation during the growing season under different land-use systems at Msekera, Chipata-Zambia (1998/99 season)

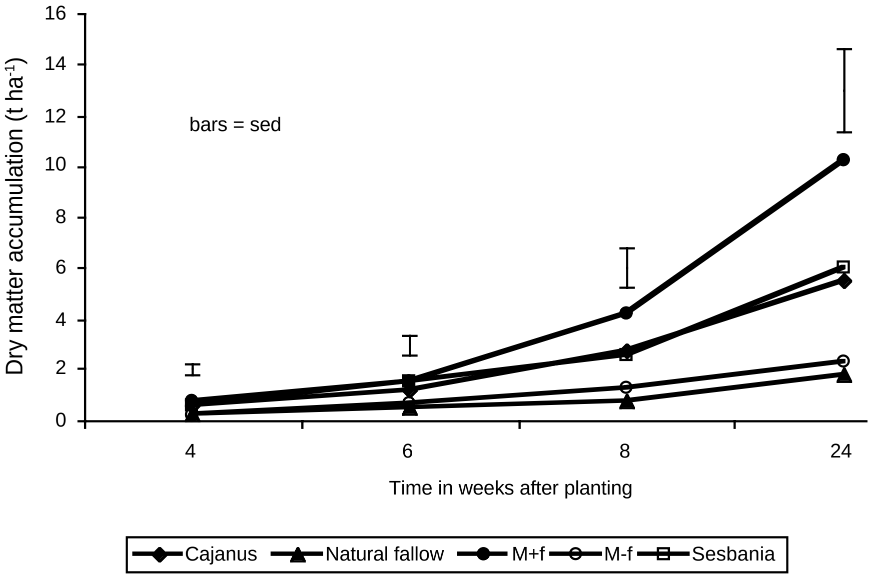


Figure 6.3: Seasonal Nitrogen accumulation in maize above ground biomass during the growing season under different land-use systems

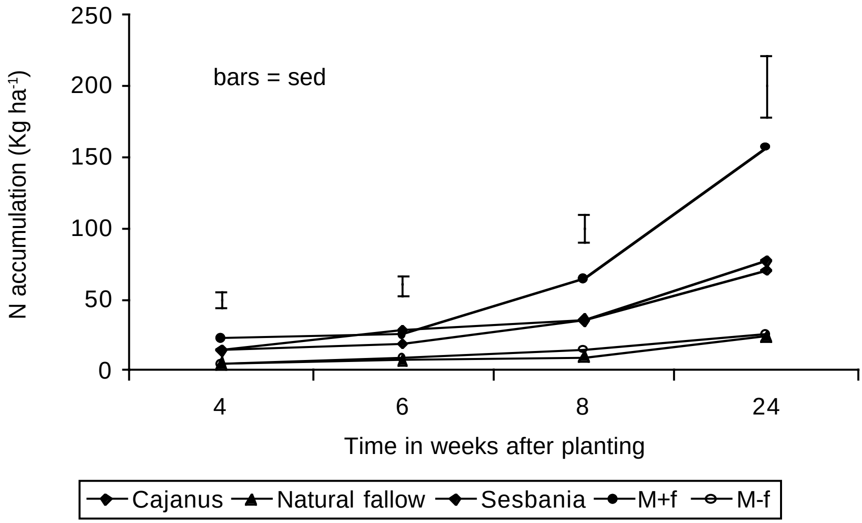
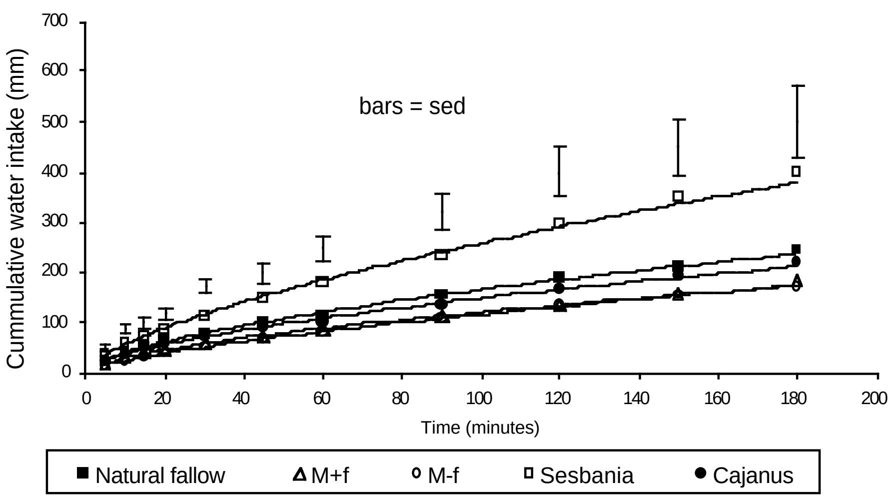


Figure 6.4: Effects of Land-use system on cumulative water intake (mm) of the soil at Msekera, Chipata-Zambia (at crop harvest May 1999)



Maize yields

Analysis of variance of maize stover, grain yield and total biomass showed significant differences ($P \leq 0.05$) due to land-use systems. The highest stover yield of 4.01 t ha^{-1} was in continuous maize with fertilizer followed by sesbania (3.01 t ha^{-1}) and the least was in natural fallow (0.93 t ha^{-1}). As was the case with stover, the highest grain yield of 5.51 t ha^{-1} was recorded in maize with fertilizer followed by sesbania (3.02 t ha^{-1}) and the least was in natural fallow (0.85 t ha^{-1})(Table 6.4).

Table 6.4: Maize yields as affected by different land-use system at Msekera, Chipata-Zambia (May 1999)

Land-use system	Stover yield (t ha^{-1})	Grain yield (t ha^{-1})	Total biomass (t ha^{-1})
Sesbania sesban	3.01[a]	3.02[a]	6.02[b]
Cajanus cajan	2.79[a]	2.69[bc]	5.48[bc]
Natural fallow	0.93[a]	0.85[c]	1.78[d]
Cont. M+F	4.01[a]	5.51[a]	9.52[a]
Cont. M-F	1.25[b]	1.01[c]	2.26[cd]
Mean	2.40	2.61	5.01
SED	0.67	0.82	1.46

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test

Penetration resistance

Average cone penetrometer resistance measured at both 4 WAP (November 1998) and 24 WAP (May 1999) was significantly affected by the LUS. Average cone penetrometer resistance measured at 4 WAP ranged from 2.2 to 3.9 Mpa for sesbania and maize with fertilizer LUS, respectively (Table 6.5). At 24 WAP no significant difference was observed in cone penetrometer resistance among the LUS (Table 6.5).

Table 6.5: Effects of Land use system on some soil physical properties after 2 years of improved fallow system at Msekera, Chipata-Zambia (November 1998 and May 1999)

Land-use system	Average penetrometer resistance at at 40 cm soil depth (Mpa)		Average water stable aggregates >2.00mm (%)		Average cumulative water intake at 3 hours(mm)	
	Nov. 1998	May 1999	Nov. 1998	May 1999	Nov. 1998	May 1999
Sesbania sesban	2.2[c]	3.3[a]	83.3[a]	65.1[b]	465[ab]	399[a]
Cajanus cajan	2.9[b]	3.0[a]	80.8[a]	76.9[a]	485[ab]	221[b]
Natural fallow	2.9[b]	4.3[a]	65.7[b]	65.8[b]	572[a]	246[ab]
Continuous M+F	3.9[a]	4.0[a]	65.6[b]	58.4[c]	315[bc]	184[b]
Continuous M-F	3.2[b]	3.3[a]	61.2[a]	44.0[d]	233[c]	173[b]
Mean	3.1	3.6	71.5	62.0	414	245
SED	0.19	0.57	3.13	2.74	93.3	72.5

Means in a column followed by the same letter or letters are not significantly different at $P \leq 0.05$ based on the Duncan's Multiple Range Test

Aggregate stability

The percentages of aggregates bigger than 2.00 mm (aggregates > 2.00 mm) were significantly affected by the LUS at fallow termination ($p \leq 0.05$). The highest percentage of water stable aggregates > 2.00 mm at fallow termination was recorded in sesbania LUS (83.3 %) followed by pigeonpea LUS (80.8 %). The least was recorded in maize without fertilizer (61.2 %) (Table 6.5). The highest percentage of aggregates at crop harvest (May 1999) greater than 2.00 mm was recorded in pigeonpea LUS (76.9 %) followed by natural fallow LUS (65.8 %). The least was recorded in maize without fertilizer (44.0 %) (Table 6.5).

Infiltration rate and cumulative water intake

Significant differences ($P \leq 0.05$) were observed at both fallow termination and crop harvest stages in cumulative water intake. At fallow termination, the highest average cumulative water intake at 3 hours was 572 mm in natural fallow followed by pigeonpea (485 mm). The lowest cumulative water intake was recorded in maize without fertilizer (233 mm) (Table 6.5). At crop harvest, the maximum (399 mm) and least (173 mm) average cumulative water intake were recorded in Sesbania and continuous maize without fertilizer, respectively (Table 6.5). Soil water sorptivity at fallow termination was in the order of: pigeonpea > natural fallow > sesbania > m+f > m-f (Table 6.6). On the other hand soil water sorptivity at crop harvest was in the order of: sesbania > natural fallow > pigeonpea > m+f > m-f (Table 6.6).

Table 6.6: Prediction Equations and Correlation Coefficients (r^2) relating to equilibrium infiltration rate (i) in mm min^{-1} with the time (t) in minutes at fallow termination and crop harvest at Msekera, Chipata-Zambia (November 1998 and May 1999)

Land-use system	Kostiakov's model of infiltration rate (mm min^{-1}) $i = akt^{a-1}$			Philip's model of infiltration rate (mm min^{-1}) $i = {}_{1/2}St^{-1/2} + A$		
	a	k	r^2	S	A	r^2
Sesbania (Nov 1998)	0.67	13.52	0.99	15.92	1.44	0.98
Sesbania (May 1999)	0.65	13.02	0.99	14.97	1.09	0.99
Cajanus (Nov 1998)	0.63	18.50	0.99	22.30	1.12	0.88
Cajanus (May 1999)	0.59	9.76	0.99	10.92	0.40	0.95
Natural fallow(Nov 1998)	0.66	16.89	0.99	19.05	1.66	0.98
Natural fallow(May 1999)	0.61	10.26	0.99	11.68	0.49	0.95
M+F(Nov 1998)	0.63	10.97	0.99	12.41	0.79	0.96
M+F(May 1999)	0.66	7.98	0.99	8.82	0.34	0.98
M-F (Novy 1998)	0.69	6.25	0.99	7.74	0.72	0.94
M-F (May 1999)	0.67	5.42	0.99	6.64	0.50	0.96

S= Sorptivity
A= Transmissivity

Discussion

Tree growth

Results on the growth performance of pigeonpea fallows showed that survival was very poor and this was probably due to the method of establishment and drought. Pigeonpea was directly seeded as compared to sesbania that was raised from nursery seedlings. Soon after sowing of pigeonpea there was a period of drought that might have contributed to high mortality. Kwesiga *et al.* (1993) reported similar results of poor establishment and high mortality in pigeonpea fallow under similar environmental conditions.

Nitrogen mineralization and immobilization

The large C-to-N ratio (69) and low N (0.62%) in grass litter resulted in immediate immobilization of all N available in the soil. All the treatments, which had litter, showed some form of immobilization except for Sesbania (fresh leaves + litter) mixture. This was because of the low C-to N ratio of 18. Palm *et al.* (1997) showed that sesbania fresh leaves which have 3-4 % N decompose faster than those species with high C-to-N ratio. The increased growth and grain yield in the sesbania LUS can be attributed to the high concentrations of N, fast nutrient release and decomposition of the fresh leaves and litter. The 4 weeks of N immobilization in pigeonpea (fresh leaves + litter) delayed the release of N to the maize crop. Sakala *et al.* (2000) also reported that senesced cajanus leaves have a short period of N immobilization despite having a narrow C-to-N ratio. Similarly, Mafongoya *et al.* (2000) reported low quality materials initially immobilize nutrients, but later they mineralise and make the nutrients available to the crop for uptake. Therefore a mixture of pigeonpea fresh leaves and litter will only start adding N to the maize crop after a period of 4 weeks as compared to the mixture of sesbania fresh leaves and litter. The other reason of high N mineralization for sesbania fresh leaves + litter could be ascribed to low lignin content as compared to other materials used in this study (Mafongoya *et al.* (1998).

Plant materials with high lignin concentration decompose more slowly than those with low lignin (Melillo *et al.* 1982). Similarly, the low release of nitrogen in natural grass fallow litter or pigeonpea litter could be as a result of high lignin and low N contents in these materials. While Mafongoya *et al.* (2000) reported that nutrient release from these organic inputs depends on their chemical composition and soil properties. However, work done by Mafongoya *et al*. (1998), Handayanto *et al*. (1995) and Constantinides and Fownes (1994) on nitrogen release patterns of MPT leaves say that the ratios of NDF-N:N, Soluble polyphenols:N, and (Lignin + polyphenol):N are a good predictor of net N release patterns on MPT leaves. Whilst Palm and Sanchez, (1991) showed that nitrogen concentration, lignin and polyphenolic contents are considered to control N release rates of decomposing plant residues. Our results indicate that mixing of litter of low quality with fresh leaves at fallow termination will cause the nitrogen to immobilize for a few weeks except for those species, which have low C-to- N ratio. Under field conditions there is either more of the litter or fresh leaves depending at what time you terminate the fallow. In most cases fallows are terminated in November or December at that time there is less fresh leaves on the trees. Therefore, the N mineralization patterns will depend on the ratios of these organic materials (fresh leaves to litter). Athough no data is available on the polyphenols and lignin composition of these organic inputs used, our results suggest that not only the C-to-N ratio played a major role in the N mineralization pattern, but also other chemical characteristics of these materials as reported by many workers (Mafongoya *et al*. 1998, Handayanto *et al*. 1995 and Constantinides and Fownes 1994).

Pre-season soil mineralizable nitrogen

Our results show that pre-season soil nitrate-N and total inorganic N at lower depths was higher in fertilized plots than the tree or natural fallow plots. This is because most of the nitrate-N in the top layers is bound to be leached to lower depths quickly after heavy rains as compared to the tree based system which releases nitrogen slowly. Buresh (1995) also reported that most of the nitrate-N in the top layers is bound to be leached to lower depths that are beyond the rooting depth of most annual crops. Tree fallows are best since trees are able to capture lost nutrients and transfer them back to surface soil in form of litterfall and leafy biomass which subsequently is made available to the maize crop as compared to the natural fallow (Mekonnen *et al*. 1997). Higher nitrate-N in the topsoil was observed under pigeonpea and sesbania fallow than the natural fallow. Mekonnen *et al*. (1997) and Onim *et al*. (1990) also reported similar results. They attributed this higher topsoil nitrate in pigeonpea and sesbania as being due to faster mineralization under N-fixing trees than under natural fallow. The high level of nitrate-N in the lower depth of maize with fertilizer was probably due to leaching. Similarly, Hartemink *et al*. (1996) and Mekonnen *et al*. (1997) found greater accumulation of subsoil nitrate under maize monoculture on the Oxisol and they attributed this to higher rainfall and leaching of nutrients to lower depths. Low levels of subsoil nitrate were also observed in natural fallow and sesbania LUS.

Dry matter and seasonal nitrogen accumulation in maize topmass

The high N accumulation in maize with fertilizer above ground biomass was probably due to the addition of mineral fertilizer and rapid assimilation of nutrients by the maize plants. Low N accumulation in sesbania, pigeonpea, natural fallow and maize without fertilizer was probably due to low rate of inorganic-N mineralization and lack of synchrony of N release to N demand by the crop. On the other hand, Mafongoya *et al.* (2000) attributed the mechanism contributing to synchrony as being the action of chemical constituents in organic inputs which slow or delay the release of nutrients, thus reducing leaching and asynchrony between nutrient release and crop uptake. The other reasons for low N accumulation in maize without fertiliser and natural fallow LUS could be: 1) low levels of soil nutrients to influence plant uptake and growth, and 2) the limited utilization of soil nitrate from the subsoil by maize due to poorly developed root system resulting from the rapid deterioration of soil physical properties (high penetration resistance, low infiltration rate, and low aggregate stability). A polynomial regression model between maize dry matter accumulation and nitrogen uptake at 8 WAP and 24 WAP showed that the amount of nitrogen uptake accounted for 93% and 98%, respectively of the dry matter accumulation in maize plant.

Maize yields

The increase of grain yields in the sesbania and pigeonpea fallow system was a result of plant-available N from decomposing aboveground biomass (fresh leaves and litter). Other sources of nitrogen was probably from the decomposition of root biomass of sesbania and pigeonpea fallow species. Similar results of increased maize yields after 2 years of sesbania fallows and pigeonpea fallows have been reported (Kwesiga and Coe, 1994; MacColl, 1989). Maroko *et al.* (1997) attributed increase in crop yield after sesbania fallow to rapid release of plant-available N from sesbania litter and leaves resulting in an increased supply of inorganic N at crop planting after fallow period, and increased soil N mineralization rates. On the other hand, the decline in yield in unfertilised and natural fallow plots could be soil fertility depletion and deterioration of soil physical properties such as resistance to root penetration, aggregate stability and infiltration. The other reason for yield component decline is water stress during pollination (Claassen and Shaw, 1970). Sanchez (1976) also reported that the main reason for the decline in yield is soil fertility depletion, increased weed infestation, deterioration of soil physical properties, and increased insect and disease attacks. Similarly, the data from this experiment confirms the decline in yield of continuously cropped maize without fertilizer as being due to soil fertility depletion and deterioration of soil physical properties.

Penetration resistance

The major reason for low penetration resistance in natural fallow, sesbania and pigeonpea LUS at fallow termination, can be attributed to addition of aboveground biomass during fallow phase and improved soil aggregation. On the other hand Harris *et al.* (1996) attributed low penetration resistance to the addition organic matter to soil which increases soil microbial activity and together with the decomposed soil organic matter, this microbial activity promotes aggregation, hence the soil is more porous and as a result, soil penetration resistance is decreased. Decrease in penetration resistance under agroforestry systems have been reported by Torquebiau and Kwesiga (1996), Lal (1989) and Dalland *et al*. (1993). There was an increase in penetration resistance after cropping. This could be as a result of reduced pore space and loss of soil aggregation.

Aggregate stability

The high percent of water stable aggregates >2.00 mm in pigeonpea sesbania and natural fallow at both fallow termination and at crop harvest was probably due to high organic matter content as compared to maize with and without fertilizer LUS. Mapa and Gunasena (1995) and Yamoah *et al*. (1986) reported similar results in hedgerow inter cropping. The importance of soil organic matter in stabilizing soil has been well documented (Tisdall and Oades 1983, and Chaney and Swift 1984). Continuous cultivation breaks large aggregates into smaller aggregates as was evidenced at crop harvest of this experiment. There was a decrease in percent of water stable aggregates >2.00 mm after cropping at crop harvest. The improved size aggregation in sesbania, pigeonpea and natural fallow LUS has an effect on increased water infiltration and water holding capacity, which reduces surface water runoff and hence decreased erosion as compared to the maize mono cropping system.

Infiltration rate and Cumulative water intake

The high cumulative water intake in the natural fallow, sesbania and pigeonpea could have been due to the improvement in the soil physical properties (improved soil aggregation and decreased resistance to penetration). Mapa and Gunasena, (1995) reported that higher wet stable aggregates facilitate higher macro-porosities, higher infiltration rate and reduce soil erosion which is a major contributing factor in degrading soil physical properties under shifting cultivation. Similar results in hedgerow intercropping were reported by Lal, (1989), and Hulugalle and Ndi, (1993). Soil water sorptivity in November 1998 and May 1999 was highest in tree-based system than maize with and without fertilizer. These results show that pigeonpea and sesbania tree based LUS will have a higher affinity for water by soil matrix. Which means that during periods of water stress maize under pigeonpea and sesbania LUS will perform better than the maize with and without fertilizer.

Conclusion

This study shows the importance of improved fallow technology in maintaining soil fertility. Sesbania and pigeonpea have a potential to supply inorganic soil nitrogen through leafy biomass and litter. The nitrogen contribution of sesbania and pigeonpea fallows to subsequent crop was evidenced by increased maize yields after these fallows as compared to no tree treatments. Improved fallows have the potential of improving soil physical conditions as compared to maize mono-cropping systems as shown from high soil aggregation, greater water infiltration, higher soil water sorptivity and reduced resistance to penetration. Continuous cultivation causes the breakdown of numerous soil processes associated with crop productivity.

The results from the incubation study under laboratory condition indicate that mixing of litter (low quality) with fresh leaves (high quality) from the same tree species at fallow termination had an effect on maize N uptake. Maize planted after sesbania fallows will have an immediate benefit from the prunings than maize planted after pigeonpea. This is because pigeonpea mixture (fresh leaves +litter) starts to release nitrogen to the crop after a period of 4 weeks. However there is need to carryout this study under field condition to support the results found under laboratory condition.

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References

Anderson, J. M. and Ingram, J. S. I. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. 2nd edition. CAB International, Wallingford, UK. pp 221.

Bouwer, H. (1986) Intake rate: Cylinder infiltrometer. p825-844. In: Klute, A.(ed). Methods of soil analysis, part 1, Physical and mineralogical methods-Agronomy Monograph Number 9. *Am. Soc. Agr*. Madison, Wisconsin, USA.

Brady, N. C. (1996) Alternatives to slash-and burn: a global imperative. *Agriculture Ecosystems and Environment* 58: 3-11.

Buresh, R. J. and Tian, G. (1997) Soil improvement by trees in sub-Saharan Africa. *Agroforestry systems* 38: 51-76.

Buresh, R.J. (1995) Nutrient cycling and nutrient supply in agroforestry systems p155-164. In: Dudal, R. and Roy, R.N.(Eds). Integrated plant nutrition systems. FAO fertilizer and plant nutrition Bulletin number 12. Rome, Italy.

Cataldo, D. A., Harron, M., Schrader, L. E. and Youngs, V. L. (1975) Rapid colorimetric determination of nitrate in plant tissue by nitration of salicylic acid. *Commun Soil Sci. Plant Anal*. 6: 71-80.

Chaney, K. and Swift, R. S. (1984) The influence of organic matter on aggregate stability in some British soils. *Journal of Soil science* 35: 223-236.

Claassen, M. M. and Shaw, R. H. (1970) Water deficit effects on corn: II. Grain components. *Agron. J*. 62: 652-655.

Commissaris, A.L.T.M. (1975) Detailed Soil Survey of Msekera Research Station. *Soil Survey report no.* 19.

Constantinides, M. and Fownes, S. H. (1994) Nitrogen mineralization from leaves and litter of tropical plants. Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biol. Biochem* 26: 49-55.

Dalland, A., Våje, P. I., Mathews, R. B. and Singh, B. R. (1993) The potential of alley cropping in improvement of cultivation systems in the high rainfall areas of Zambia III. Effects on soil chemical and physical properties. *Agroforestry Systems.* 21: 117-132.

De Leenheer, L. and De Boodt, M. (1958) Determination of aggregate stability by the change in mean weight diameter. pp.260-300. In: Proceedings of International Symposium of Soil Structure. Ghent, Belgie.

Dorich, R. A. and Nelson, D. W. (1984) Evaluation of manual cadmium reduction methods for determination of nitrate in potassium chloride extracts of soil. *Soil Sci. Soc. Am. J*. 48: 72-75.

FAO (1988) Soil Map of the World-Revised Legend. World Soil Resources *Report* 60 FAO/UNESCO, Rome.

Genstat 5 Committee. (1988) Genstat 5 reference manual. Oxford Univ. Press, Oxford, England. 749pp.

Giller, K. E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W. D. and Mafongoya, P. L. (1997) Building soil nitrogen capital in sub-Saharan Africa. In: Buresh, R. J., Sanchez, P. A. and Calhoum, F. (Eds) Replenishing Soil Fertility in Africa p 151-192. SSSA Special Publication 51. SSSA and ASA, Madison, WI, USA.

Gomez, K. A. and Gomez, A. A. (1984) Statistical procedures for agricultural research 2nd edition. Jony Wiley and Sons Inc.

Handayanto, E. Cadisch, G. Giller, K. E. (1995) Manipulation of quality and mineralization of tropical legume tree prunings by varying nitrogen supply. *Plant Soil* 176: 149-160.

Harris, R. F., Chesters, G. and Allen, O. N. (1996) Dynamics of soil aggregation. *Adv. Agron* 18: 107-169.

Hartemink, A. E. Buresh, R. J. Jama, B. Janssen, B. H. (1996) Soil nitrate and water dynamics in sesbania fallows, weed fallows and maize. *Soil Sci Soc Am J.* 60: 568-574.

Hulugalle, N. R. and Ndi, J. N. (1993) Effects of no-tillage and alley cropping on soil properties and crop yields in a Typic Kandiudult of Southern Cameroon. *Agroforestry Systems.* 22: 207-220.

Kostiakov, A. N. (1932) On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. *TRANS. Sixth Intnl. Society of Soil Science*, *Russian* Part A: 17-21.

Kwesiga F. and Coe, R. (1994) The effect of short rotation Sesbania sesban planted fallows on maize yield. *Forest Ecology and Management* 64: 199-208.

Kwesiga, F., Phiri, D. M. and Rauno, A. (1997) Improved fallows with Sesbania in Eastern Zambia. Summary proceedings of a consultative workshop 22-26 April, 1996, Chipata, Zambia. ICRAF Nairobi, Kenya pp. 101.

Kwesiga, F., Phiri, D. M., Simwanza, C. P. and Mwanza, S. (1993) Zambia/ICRAF Agroforestry Research Project, 1993 Annual report. AFRENA Report no. 71.

Lal, R. Wilson, G. F. and Okigbo, B. N. (1978) No-tillage farming after various grasses and leguminous cover crops in tropical Alfisols I. Crop performance. *Field Crops Res.* 1: 71-84.

Lal, R. Wilson, G. F. and Okigbo, B. N. (1979) Changes in properties of an Alfisol produced by various crop covers. *Soil Sci.* 127: 377-382.

Lal, R. (1989) Agroforestry systems and soil surface management of a tropical Alfisol: IV. Effects on soil physical and mechanical properties. *Agroforestry systems* 8: 197-215.

MacColl, D. (1989) Studies on maize (*Zea mays* L.) at Bunda, Malawi: II. Yield in short rotation with legumes. *Exp. Agric.* 25: 367-374.

Mafongoya, P. L. and Nair, P .K. R. (1997) Multipurpose tree prunings as a source of nitrogen to maize (*Zea mays* L.) under semiarid conditions in Zimbabwe. I. Nitrogen recovery rates in relation to pruning quality and method of application. *Agroforestry system* 35: 31-46.

Mafongoya, P. L., Barak, P. and Reed, J. D. (2000) Carbon, nitrogen and phosphorus mineralization of tree leaves and manure. *Biology Fertility Soils* 30: 298-305.

Mafongoya, P. L., Nair, P. K. R. and Dzowela, B. H. (1997) Effect of multipurpose trees, age of cutting and drying method on pruning quality. In: Cadisch, G. and Giller, K.E. (Eds) Driven by nature: plant litter quality and decomposition. CAB International, Wallingford, UK, pp 167-174.

Mafongoya, P. L., Nair, P. K. R. and Dzowela, B. H. (1998) Mineralization of nitrogen from decomposing leaves of multipurpose trees as affected by their chemical composition. *Biology Fertility Soils* 27: 143-148.

Mapa, R. B. and Gunasena, H. P. M. (1995) Effect of alley cropping on soil aggregate stability of a tropical Alfisol. *Agroforestry systems* 32: 237-245.

Maroko, J. B., Buresh, R. J. and Smithson, P. C. (1997) Soil nitrogen availability as affected by fallow-maize systems on two soils in Kenya. *Biol. Fert. Soils.* 26: 229-234.

Mekonnen, K., Buresh, R. J. and Jama. (1997) Root and inorganic nitrogen distributions in sesbania fallow, natural fallow and maize fields. *Plant and soil* 188: 319-327.

Melillo, J. M., Aber, J. D. and Muratone, J. F. (1982) Nitrogen and Lignin control of hard wood leaf litter decomposition dynamics. *Ecology* 63: 621-626.

Migliena, A. M., Rosell, R. A. and Glave, A. E. (1988) Changes of chemical properties of a Haplustoll soil under cultivation in Semi-arid Argentina. p 421-425. In: Unger, P. W. Jordan, W.R. Sneed, T. V. and Jensen R. W. (Eds). Challenge in dryland agriculture- Grobal perspective- proceedings of the International Conference on Dryland Farming, August 15-19, 1988. Texas, USA.

Nye, P. H. and Greenland, D. J. (1960) The soil under shifting cultivation. *Technical Communication* No. 51. Commonwealth Bureau of Soils, Harpenden, UK.

Onim, J. F. M., Mathuva, M., Otieno, K. and Fitzhugh, H. A. (1990) Soil fertility changes and response of maize and deans to green manures of leucaena, sesbania and pigeonpea. *Agroforestry Systems.* 12: 197-215.

Palm, C. A., Myers, R.J. K. and Nandwa, S. M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Replenishing Soil Fertility in Africa. Buresh, R. J., Sanchez, P. A. and Calhoun, F. G. (Eds). pp196-217. SSSA Special Publication No.5!: Soil Science society of America, Madison, WI, USA. Proceedings of an International Symposium.

Palm, C. A. and Sanchez, P. A. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem* 23: 83-88.

Pereira, H. C., Wood, R. A., Brzostowski, H. W. and Hosegood, P.A. (1958) Water conservation by fallowing in semi-arid tropical East Africa. *Emp. J. Exp. Agr*. 26: 203-228.

Philip, J. R. (1957) The theory of infiltration: 4. Sorptivity and algebraic infiltration equations. *Soil Science* 84: 257-264.

Rhoades, C. C. (1997) Single-tree influences on soil properties in tropical agroforestry systems. *Agroforesty Systems* 38: 3-50.

Sakala, W. D., Gadish, G. and Giller, K. E. (2000) Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. *Soil Biology and Biochemistry.* 32: 679-688.

Sanchez, P. A. (1976) Properties and management of soils in the tropics. New York: John Wiley, pp 618.

Tisdall, J. M. and Oades, J. M. (1983) Organic matter and water stable aggregates in soils. *Journal of Soil Science* 33: 141-163.

Torquebiau, E. F. and Kwesiga, F. (1996) Root development in *Sesbania sesban* fallow-maize system in eastern Zambia. *Agroforestry systems* 34: 193-211.

USDA (United States Department of Agriculture) (1975) Soil Taxonomy, agricultural handbook number 436, Soil Conservation Service, USA.

Yamoah, C. F., Agboola, A. A., Wilson, G. F. and Mulongoy, K. (1986) Soil properties as affected by the use of leguminous shrubs for alley cropping with maize. *Agriculture Ecosystems and Environment*. 18: 167-177.

Yoder, R. E. (1936) A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *J. Am. Soc. Agron*. 28: 337-351.

Young, A. (1997) Agroforestry for soil management. CAB International, Wallingford, UK and ICRAF, Nairobi, Kenya. pp 276.

7

Tillage Effects on Soil Organic Carbon and Nitrogen Distribution in Particle Size Fractions of a Red Clay Soil Profile in Zimbabwe

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Abstract

The long-term tillage effects on soil organic C and N distribution in particle size fractions of a chromic luvisol (FAO soil classification) soil profile was evaluated. Three treatments, conventional tillage, mulch ripping and weedy fallow from a long-term tillage experiment established in 1988/89 season were compared.

Relative to the weedy fallow, conventional tillage showed a more marked decline in organic C and total N than mulch ripping. There was a general decline in organic C, total N, and C and N in the soil organic matter fractions with depth for mulch ripping and the weedy fallow while there was a more or less uniform distribution with depth under conventional tillage. The decline in organic C and total N was more pronounced in the surface horizons with about 20% and 50% decline for mulch ripping and weedy fallow, respectively, from the 0-2 cm to the 2-5 cm depths. There were no treatment differences in organic C and total N distribution below the plough layer (30 cm).

For conventional tillage and mulch ripping, the largest decline in organic C was in the coarse sand fractions (212-2000 µm), whereas the least decline in organic C was observed in the clay fractions of 22% and 13% for conventional tillage and mulch ripping respectively, when compared with the weedy fallow. There was a decline in total N in the organic matter fractions with depth. The sand fractions had the least organic C and total N at all depths than silt and clay fractions for conventional tillage and mulch ripping, and the silt fractions had intermediate concentrations. All the size fractions from the weedy fallow had high N content in the 0-2 cm soil layer where silt, medium sand and coarse sand fractions, had even higher N contents than the clay fraction. We concluded that mulch ripping promotes soil organic matter accumulation and reduces soil organic matter loss. This build up in soil organic matter from the decomposition of residue mulch is significant when compared with conventional tillage. It was also concluded that higher organic C losses under conventional tillage were due to intensive cultivation and associated soil losses through erosion.

Keywords: soil organic matter, conventional tillage, mulch ripping and weedy fallow

Introduction

Type and length of tillage practice influence the amount of soil organic matter (SOM), present in the soil and the rate of SOM turnover and its distribution among size fractions down the profile (Cambardella and Elliot, 1994). Conventional tillage mixes upper and lower horizon soils and disrupts aggregate protected organic matter (Hassink, 1995; Jastrow, 1996). This results in faster decomposition and loss of organic matter and more or less uniform distribution of organic matter in the plough layer (Etana *et al.*, 1999; Stockfisch et al., 1999).

The change in total organic C pool size as affected by soil management practice can be expressed using the carbon pool index (CPI), which is calculated from sample total C expressed as a fraction of the reference total C (Blair *et al.*, 1997). The higher the organic C loss, the lower the carbon pool index and the more difficult it is to rehabilitate, especially for soil which has a small initial total carbon pool.

Conventional tillage systems are known to increase organic matter losses from the soil whereas no till practices can improve soil aggregation thus increasing physical protection and maintenance of SOM (Doran *et al.*, 1987; Feller and Beare, 1997). Accumulation of SOM under minimum tillage is limited to the surface while conventional tillage, which incorporates organic inputs, may affect SOM and other properties to a greater depth (Fernandes *et al.*, 1997). Work done by Beare *et al.* (1994) showed that under similar management, soil organic carbon content of no till surface soils (0-5 cm) was 18% higher than that of conventional tillage after eleven years of continuous treatment.

The objective of this experiment was to assess the effects of conventional and conservation tillage in relation to a reference point (weedy fallow) on:

a) total N and reduction of organic C as reflected by the C pool index (CPI);
b) SOM content and distribution of C among SOM fractions; and
c) distribution of organic C, N and SOM fractions down the profile.

It was hypothesised that conservation tillage results in the accumulation of SOM especially in the surface horizons whereas conventional tillage results in lower SOM amounts that is uniformly distributed down the profile.

Materials and Methods

Measurements for this experiment were taken from a tillage experiment, which was established in 1991/92 season at the Institute of Agricultural Engineering (IAE), Harare, Zimbabwe (17°45'S; 31°10'E). The IAE site is in an agro-ecological zone that receives an annual rainfall of 800-1000 mm and is on a red clay soil derived from gabbro parent material and is classified as rhodic paleustalf (USDA) or chromic luvisol (FAO).

Runoff plots of 10 m x 30 m planed at 4.5% slope were laid out for five treatments; conventional tillage, mulch ripping, clean ripping, no till tied ridging and no till strip cropping. Work reported in this paper is from two treatments, mulch ripping and conventional tillage, and from a weedy fallow found close to the treatment plots for use as a reference point. Conventional tillage consisted of annual ox-mouldboard ploughing to 25 cm depth. Mulch ripping involved ripping between rows into residues to a depth of about 27 cm. Perennial grass was growing naturally with no tillage operations and no fertiliser additions for the weedy fallow. However, the weedy fallow had been cropped since 1980 up to the onset of the experiment when it was converted to be a grass fallow. There were annual fertiliser additions of 115 kg N ha^{-1}, 22 kg P ha^{-1} and 25 kg K ha^{-1} to mulch ripping and conventional tillage. Maize was grown annually as the test crop.

Soil samples were collected from the treatment plots and from a weedy fallow in July 1999 at the following depths; 0-2, 2-5, 5-10, 10-20, 20-30 and 30-60 cm. Another set of samples was collected from the 0-30 cm depth (plough layer) from the treatment plots and the weedy fallow, using an auger. Soil was sieved through a 2 mm sieve and analysed for organic C using the Walkley Black method and total N using the Kjeldahl analysis method (Anderson and Ingram, 1993).

Soil was fractionated according to the method by Feller *et al.* (1996). Fifty grams of soil was shaken overnight in 200 ml of 0.5% sodium hexametaphosphate after soaking the soil in water overnight. Soil was wet sieved through a series of sieves to separate 212-2000 µm (coarse sand), 53-212 µm (medium sand) and 20-53 µm (fine sand) fractions. The 0-2 µm (clay) and 2-20 µm (silt) fractions, were separated by the sedimentation method based on Stoke's Law (Hillel, 1982). The fractions were dried in an oven at 50°C and analysed for organic C using the modified Walkley-Black method and total N using the Kjeldahl analysis method. Statistical analysis was done using Genstat for analysis of variance (ANOVA).

Results

Tillage effects on total organic C, C pool index and total N

Conventional tillage and mulch ripping resulted in a decrease in soil organic C content, compared with the weedy fallow (Table 7.1).

Table 7.1: Tillage effects on total organic carbon (%), total nitrogen (%) and CPI in the 0-30 cm depth of a red clay soil from the Institute of Agricultural Engineering, Harare, Zimbabwe

Tillage practice	Total organic C (%)	Total N (%)	C/N ratio	CPI
Conventional tillage	1.49	0.11	13.6	0.53
Mulch ripping	1.72	0.15	11.5	0.62
Weedy fallow	2.79	0.19	14.7	1.00

Soil under conventional tillage had smaller amounts of % organic C and % total N compared with mulch ripping (Table 7.1). Weedy fallow had almost twice as much total organic C and total N contents as conventional tillage and mulch ripping. The C/N ratio was highest under the weedy fallow while it was lowest for the mulch ripping treatment. Conventional tillage had a lower soil organic carbon pool index than mulch ripping, reflecting a higher reduction in the total C pool under conventional tillage compared with mulch ripping (Table 7.1). The carbon pool index (CPI), of conventional tillage was almost half that of the weedy fallow as was shown by a 47% decline in organic C. There were however no significant differences in maize yield under mulch ripping and conventional tillage over the seasons (Figure 7.1).

Conventional tillage caused higher surface runoff losses over the seasons compared with mulch ripping which had low surface runoff losses even in years with high rainfall (Figure 7.2). Surface runoff and soil erosion are other pathways in which soil organic matter was lost.

Figure 7.1: Tillage effects on maize yield over nine seasons at the Institute of Agricultural Engineering, Harare, Zimbabwe

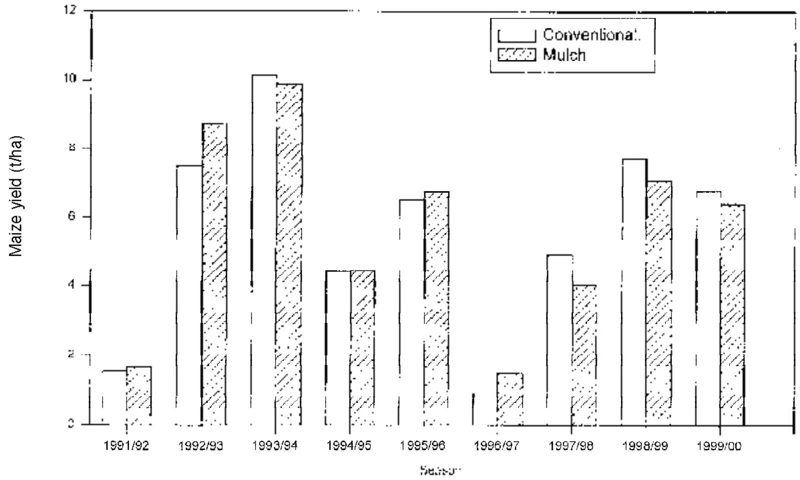
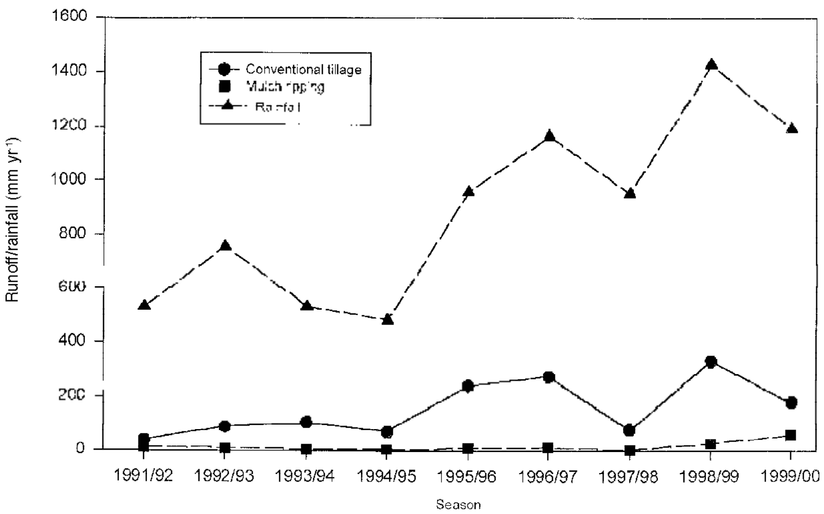


Figure 7.2: Tillage effects on runoff over nine seasons at the Institute of Agricultural Engineering, Harare, Zimbabwe



Tillage effects on organic C in the SOM fractions

Soil under mulch ripping had higher organic C content in the organic matter size fractions compared with conventional tillage except for the coarse sand organic matter fractions which was not significantly different for conventional tillage and mulch ripping (Table 7.2).

Table 7.2: Tillage effects on organic carbon distribution in soil organic matter size fractions of a red clayey soil in Harare, Zimbabwe

Tillage	Organic C in SOM size fractions (mg C g^{-1} soil)							
treatment	212-2000 µm coarse sand	53-212 µm Medium sand	20-53 µm Fine sand	5-20 µm Silt	0-5 µm Clay	Sum	Total measured	% Recovery
Conventional tillage	0.97	0.95	0.84	1.69	8.1	12.6	14.9	84.6
Mulch ripping	1.04	1.34	1.00	2.09	9.0	14.5	17.2	84.3
Weedy fallow	4.47	3.57	1.90	3.15	10.4	23.5	27.9	84.2
SED	0.167	0.187	0.091	0.118	0.242			

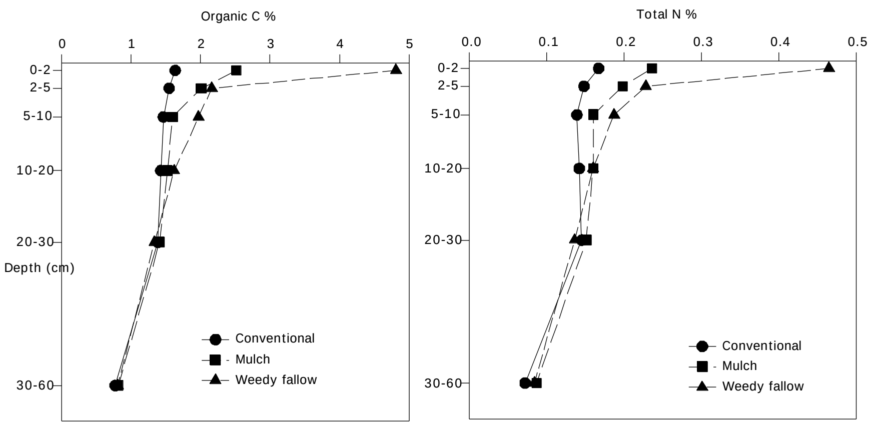
NB n=3 except for the weedy fallow where n=1

There was however more than a four fold decrease in organic C in the coarse sand organic matter fraction for mulch ripping (1.04 mg C g^{-1} soil) and conventional tillage (0.97 mg C g^{-1} soil), when compared with the reference point, the weedy fallow (4.47 mg C g^{-1} soil) (Table 7.2). The smallest decline in organic C was in the clay fractions. Relative to the weedy fallow, conventional tillage caused a larger decline in organic C in the clay (22%) and silt (46%) fractions compared with mulch ripping which caused a 13% and 34% decrease in organic C in clay and silt fractions, respectively (Table 7.2). There were no complete recoveries of organic C for all the treatments indicating that the fractionation method does not account for the entire C in the soil (Table 7.2). Some of the soluble organic C was lost during fractionation.

Tillage effects on total organic C and total N distribution down the soil profile

There was a general decline in total organic C and N with depth for all the treatments but this was less pronounced for conventional tillage (Figure 7.3).

Figure 7.3: Tillage effects on a) organic C and b) total N distribution down the profile of a red clayey soil at the Institute of Agricultural Engineering, Harare, Zimbabwe



The decrease in total N and organic C was more pronounced in the surface horizons (0-10 cm) of mulch ripping and weedy fallow, where there was about 20% decline in organic C and total N from 0-2 cm to 2-5 cm depth for the mulch ripping treatment. Total N and organic C contents decreased by about 50% from the 0-2 cm to the 2-5 cm depth for the weedy fallow. In the upper 20 cm weedy fallow had the highest total N and organic C contents while mulch ripping had higher total N and organic C contents than conventional tillage (Figure 7.3). At depths below 20 cm, there were no treatment differences on total N and organic C content. The 30-60 cm depth had the lowest organic C and total N contents for all the treatments. The C/N ratio did not change with depth.

Tillage effects on organic carbon and nitrogen distribution in size fractions down the profile

There were no significant differences in the distribution of organic C and N in the coarse, medium and fine sand fractions for the conventional tillage and mulch ripping treatments at all depths (Figures 7.4 and 7.5).

Figure 7.4: Effects of a) conventional tillage, b) mulch ripping and c) weedy fallow on the distribution of organic C in the organic matter size fractions down the profile of a red clay soil from Harare, Zimbabwe

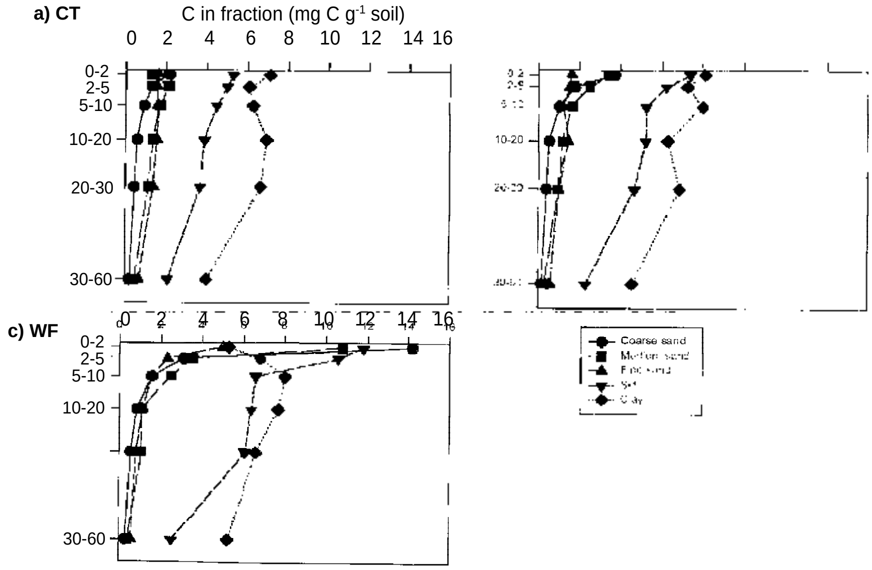
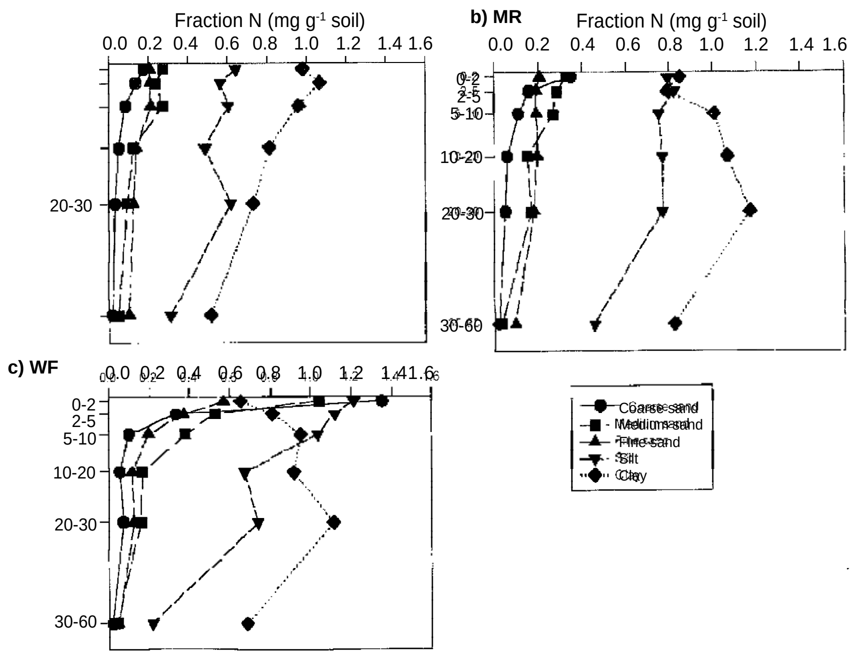


Figure 7.5: Effects of a) conventional tillage, b) mulch ripping and c) weedy fallow on the distribution of N in the organic matter size fractions down the profile of a red clay soil from Harare, Zimbabwe



There were no significant changes in organic C and N in the sand fractions with depth for mulch ripping and conventional tillage. The sand fractions had the lowest amounts of organic C and N at all depths followed by silt, while clay had the highest for the conventional and mulch ripping treatments. Total N and organic C in the silt fractions of conventional tillage and mulch ripping did not change significantly with depth in the upper 30 cm (Figure 7.4 and Figure 7.5). There was a decline of organic C and N in the silt fraction from the 20-30 cm to 30-60 cm depth by about 40% and 50% for conventional tillage and mulch ripping respectively (Figure 7.4 and Figure 7.5). There were increases in the organic C and N content of the clay fraction from the 0-2 cm depth to the 5-10 cm depth for conventional tillage and from 0-2 cm depth to 20-30 cm depth for mulch ripping followed by a decline at depths below (Figure 4 and Figure 5). The biggest decline was from the 20-30 cm depth to the 30-60 cm depth where there was almost a 50% decline for mulch ripping and conventional tillage (Figure 7.4 and Figure 7.5).

For the weedy fallow, all the fractions had high organic C and N contents in the surface layer (0-2 cm) (Figure 7.4 and Figure 7.5). Unlike the other treatments the coarse sand and the silt fractions for the weedy fallow had high organic C and N contents in the 0-2 cm depth. Organic C and N contents in the silt fraction were almost twice that in the clay fraction in the 0-2 cm depth for the weedy fallow. There was almost a four-fold decline in organic C and N contents in the coarse sand fraction, from the 0-2 cm to the 2-5 cm depth. At depths below 2 cm, there were no differences in organic C and N contents in the sand fractions. The organic C and N contents in the sand fractions did not significantly change with depth. There was a decrease in organic C and N contents in the silt fraction with depth with the biggest decline from the 20-30 cm depth to the 30-60 cm depth. There was an increase in organic C and N contents in the clay fraction from the 0-2 cm depth to the 2-5 cm depth followed by a decline at depths below. Organic C and N contents were higher than in the silt fraction in the clay fraction in the depths above 5 cm and was lower at depths below for the weedy fallow.

Discussion

Tillage effects on total organic C, total N and CPI

The lower organic C and total N for conventional tillage was probably a result of high organic matter decomposition enhanced by disruption of aggregates (Table 7.1) (Hassink, 1995). This could have been enhanced by the removal of residues under conventional tillage compared with mulch ripping where residues are left on the surface increasing organic matter inputs. The lower CPI for conventional tillage means that conventional tillage stimulates organic matter decomposition while mulch tillage enhances organic matter retention (Table 7.1) (Blair *et al*., 1997). Conventional tillage also had lower total N than mulch ripping most probably due to low organic matter content under conventional tillage (Table 7.1).

The additions of organic matter due to litter fall and lack of tillage resulted in higher organic C under the weedy fallow than cultivated soil (Table 7.1). The weedy fallow had the highest total N value but its C/N ratio was much higher than that of mulch tillage. This was probably because tillage enhances soil organic matter decomposition lowering the C/N ratio of cultivated soil. Under the weedy fallow, there is predominantly grass litter, which could have resulted in a high C/N ratio. The lack of differences in maize yield under conventional tillage and mulch ripping could have been due to annual fertilizer additions such that there were no nutrient limitations (Figure 7.1). The higher surface runoff losses under conventional tillage could have been a result of disruption of soil aggregates, increasing the susceptibility of soil to raindrop detachment and associated runoff and soil erosion (Figure 7.2).

Tillage effects on SOM fractions

The higher organic C in the soil organic matter size fractions under mulch ripping compared with conventional tillage, was caused by higher additions of soil organic matter through returning of residues and reduced tillage intensity (Table 7.2). Organic C in the coarse sand fraction in mulch ripping was expected to be higher than conventional tillage because of additions of organic residues to the soil. The lack of difference could have been due to the fact that sampling was done at the end of the season such that much of the added litter had broken down into smaller sizes. The decrease of organic C in the coarse sand fraction from the weedy fallow to conventional tillage and mulch ripping was probably a result of little organic residue additions under cultivated soil when compared with all year round additions of organic residues under the weedy fallow (Table 7.2). Lower organic C contents in the fine sand, silt and clay fractions in conventional tillage compared with mulch ripping resulted from disruption of aggregates (Table 7.2) (Hassink, 1995) and the resulting decomposition of organic matter and dilution of organic matter due to mixing of plough layer.

Tillage effects on organic C and total N distribution down the soil profile

The higher organic C and total N in the soil surface was a result of additions of organic residues on the soil surface for mulch ripping and weedy fallow (Figure 7.3). Total N and organic C was low in the surface horizon for conventional tillage because of little or no organic residues added in the soil and tillage disrupts aggregate protected organic matter (Hassink, 1995). Beare *et al* (1994), found that there was 18% more organic C for a no tillage treatment than conventional tillage after 11 years of continuous treatment. There was a uniform distribution of organic C and total N in the upper 20 cm of soil under conventional tillage caused by mixing of upper and lower horizon soil (Etana *et al*., 1999).

In this study, the sharp decline in organic C and total N under the weedy fallow from the 0-2 cm to the 2-5 cm depth, was probably because of the large additions of litter to the surface horizon (Figs. 3 and 4). Soil under the weedy fallow was not tilled, such that there was no mixing of the litter layer with the subsurface horizon. For depths below 20 cm, there were no treatment differences even for the conventional tillage treatment because there was little or no mixing of soil beyond that depth. The 30-60 cm depth had the lowest organic C and total N contents for all the treatments. This is because, at this depth there are limited additions of organic residues. The C/N ratio was not affected by depth for all the treatments because as organic C content decreased down the profile so did the total N content.

Tillage effects on organic carbon and nitrogen distribution in size fractions down the profile

The high C and N contents in the clay fractions for the conventional tillage and mulch ripping treatments was probably due to the high clay content in the soil, which could have protected organic matter from microbial decomposition and hence high C and N. The decline in organic C and total N contents in the silt fractions from the 20-30 cm depth to the 30-60 cm depth reflected changes in total N with depth.

High litter fall under the weedy fallow resulted in high organic C and total N contents associated with all the fractions in the surface layer. Litter on the soil surface was probably in different stages of decomposition, such that all the fractions had high organic C and N contents. Organic C and total N in the clay fraction was lower in the silt than coarse and fine sand fractions on the soil surface probably because of high litter content such that there was a lower proportion of organic matter associated with the clay fraction compared to the other fractions.

Conclusion

Conventional tillage results in faster decomposition and loss of soil organic matter than mulch ripping, as was shown by the 47% decline in organic carbon under conventional tillage, compared to 38% organic carbon decline under mulch ripping. Mulch ripping promotes physical protection and soil organic matter accumulation in the plough layer, compared with conventional tillage. Conventional tillage results in the mixing of the surface soil horizon, diluting the organic layer and resulting in a more uniform distribution of organic matter in the plough layer. Mulch ripping on the other hand involves minimum tillage and promotes organic matter in the surface horizons.

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References

Anderson, J. M. and Ingram, J. S. I. (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods*. Second edition. CAB International, Wallingford, UK.

Beare, M., Cabrera, M. L., Hendrix H., P. F. and Coleman, D. C. (1994) Aggregate-protected and unprotected pools of organic matter in conventional and no-tillage soils. *Soil Sci. Soc. Am. J.* 58:787-795.

Blair, G. J., Lefroy, R. D. B., Singh, B. P. and Till, A. R. (1997) Development and use of a carbon management index to monitor changes in soil C pool size and turnover rate. In: Cadisch, G. and Giller, K. E. (eds) *Driven by Nature: Plant Litter Quality and Decomposition.* CAB International.

Cambardella, C. A. and Elliot, E. T. (1994) Carbon and nitrogen dynamics of soil organic matter fractions from cultivated Grassland soils. *Soil Sci. Am. J.* 58: 123-130.

Doran, J. W., Mielke, L. N. and Power, J. F. (1987) Tillage/Residue management interactions with the soil environment, organic matter and nutrient cycling. In Cooley J. H. (ed), *Soil Organic Matter Dynamics and Soil Productivity*. INTECOL Bulletin. 1987:15.

Etana, A., Hakansson, I., Zagal, E. and Bucas, S. (1999) Effects of depth on organic carbon content and physical properties in five Swedish soils. *Soil & Tillage Research* 52:129-139.

Feller C., Albrecht, A.. and Tessier, D. (1996) Aggregation and organic matter storage in kaolinitic and smectitic tropical soils. In Carter, M. R. and Stewart, B. A. (eds), *Structure and Organic Matter Storage in Agricultural Soils*. Lewis Publishers, London.

Feller, C. and Beare, M. H. (1997) Physical control of soil organic matter dynamics in the tropics. *Geoderma* 79: 69-116.

Fernandes, E. C. M., Motavalli, P. P., Castilla, C. and Mukurumbira, L. (1997) Management of soil organic matter dynamics is tropical land-use systems. *Geoderma* 79:49-67.

Hassink, J. (1995) Density fractions of soil macroorganic matter and microbial biomass as predictors of C and N mineralization. *Soil Biol. Biochem.* 27:1099-1108.

Hillel, D. (1982) *Introduction to Soil Physics.* Second edition. Academic Press, London.

Jastrow, J. D. (1996) Soil aggregate formation and the accrual of particulate and mineral-associated organic matter. S*oil Biol. Biochem.* 28: 665-676.

Stockfisch, N., Forstreuter, T. and Ehlers, W. (1999) Ploughing effects on soil organic matter after twenty years of conservation tillage in Lower Saxony, Germany. S*oil & Tillage Research* 52: 91-101.

8

Combating Nutrient Depletion in East Africa – the work of the SWNM program

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Introduction

A workshop was held 11-16 February 1996 at CMRT, Egerton University to launch the Combating Nutrient Depletion (CND) theme of the Soil, Water, and Nutrient Management Program (SWNMP) of the CGIAR. The meeting at Egerton, convened by Tropical Soil Biology and Fertility Programme (TSBF), brought together partners from national institutions of the countries participating in the African Highlands Program, Ethiopia, Kenya, Madagascar, and Uganda as well as international centers collaborating in the region, and expertise from outside the region. The project is a joint action of the African Highlands Initiative (AHI) and the Soil Water and Nutrient Management Programme (SWNMP) of the CGIAR. The project is implemented by a consortium of national, regional and international agencies with a wide range of expertise and experience in nutrient management research, farmer participatory research, agricultural problem-solving and development actions. The project is co-ordinated by TSBF on behalf of the SWNMP and represented within AHI through the technical support group.

The objective of the CND – East Africa Consortium are:

1. Integrating nutrient management practices that redress nutrient imbalances and environmental degradation.

2. Enabling policies for combating nutrient depletion.
3. Assisting farmers to adopt improved nutrient management practices.

Erosion and nutrient depletion are major causes of land degradation and loss of productivity in the infertile, mainly acid soils of the humid and sub-humid tropics. These two constraints threaten the livelihood and food security of up to 630 million people who occupy most of the 1.8 billion ha of marginal or fragile areas where nutrient depletion and soil erosion are most prevalent.

Unlike soil erosion nutrient depletion is generally a reversible constraint because diverse nutrient resources are usually available to resource poor farmers but are often underutilised because of a lack of knowledge or other constraint such as labour. Available resources may include commercial fertilizers, agro-mineral deposits, agro-industrial by-products and locally produced or harvested organic materials.

Income generation by smallholders, and subsequent investment in soil amendments and erosion control measures, are essential components to combating soil depletion and erosion. Nutrient access operates at the national level and is policy-driven while nutrient availability operates at local levels and is strongly influenced by farmer opportunities and decision-making. Improvements in both nutrient access and availability require innovative solutions achieving nutrient recapitalization, better fertilizer distribution and marketing, better integrated nutrient management technologies and refinements in farmer participatory techniques. Erosion control measures generally need to provide a product of immediate financial or other benefit in order to be accepted, adopted and adapted by land users.

Project purpose

The stated purpose of the project was to develop for use by farmers, researchers and policy makers, effective decision support systems for the integrated management of nutrient resources and soil erosion, including a simple cost-benefit analysis for their on and off-site effects.

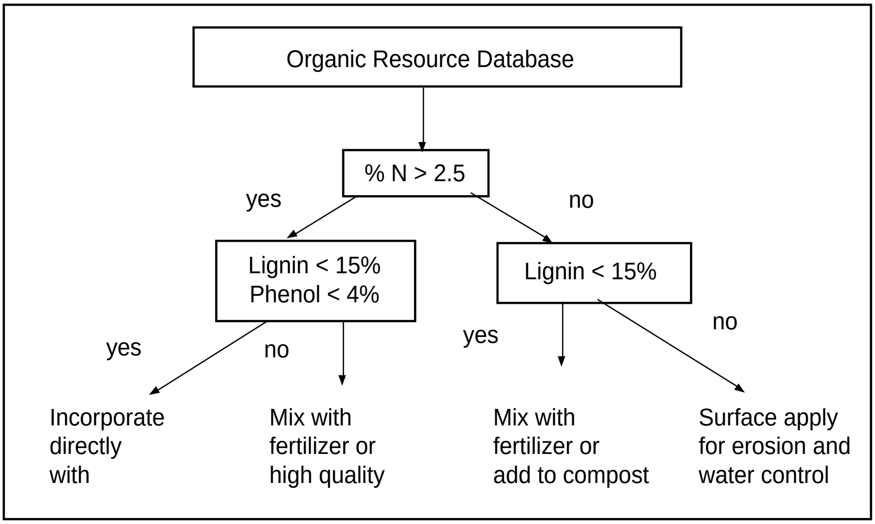
Development of Decision Support Tools

Fertilizer equivalency of organic materials

Research over the past century has related N release patterns to the resource quality, or chemical characteristics of organic materials (Heal *et al.*, 1997). The N concentration and the C-to-N ratio of the material still probably serve as the most robust indices when all plant materials are concerned (Constantinides and Fownes, 1994). Lignin and polyphenols are, however, important modifiers of N release for the fresh, non-senescent leaves of high-quality materials (Constantinides & Fownes, 1994). The delayed N release resulting from polyphenolics, particularly condensed tannins, may be much longer than the temporally N immobilization resulting from high C-to-N ratios in cereal crop residuals (Giller *et al.*, 1997). Beneficial effects of the individual and combined use of organic and inorganic nutrients on soil fertility, crop yields, and maintenance of SOM have been repeatedly shown in laboratory and field trials, yet there are no predictive guidelines for their management, such as those that exist for inorganic fertilizers.

A set of hypothesis has been placed in a decision tree for selecting organic materials for soil N management based on their quality (Palm *et al.*, 1997). Organic materials with N content above 2.5%, lignin and polyphenol contents less than 15% and 4%, respectively can be incorporated directly with annual crops. The recommendation for organic materials with N content above 2.5% and lignin and polyphenol contents more than 15% and 4% is to mix with N fertilizer or high quality organic material. For organic materials with N content <2.5% and lignin content <15%, the recommendation is to mix with N fertilizer or add to compost. Organic materials recommended for surface application for weed, erosion, and water control are those with N content <2.5% and lignin content >15% (Figure 8.1).

Figure 8.1: Decision Tree for Selecting Organic Imputs for Nitrogen Management



Network trials using a wide range of mainly high quality organic materials in combinations with inorganic N fertilizers were established in eastern and southern Africa. The objectives of the trials were (i) establishing fertilizer equivalency values of organic materials based on quality and (ii) to investigate benefits and trade-offs of combining organic and inorganic N sources. Field trials were carried out in five countries in sub-Saharan Africa to establish fertilizer equivalency values of organic materials based on their resource quality and to investigate the effects of combining organic and inorganic N sources on maize yield. Organic materials used were leaves of Tithonia, Senna, Calliandra, Sesbania, Tephrosia, and pigeon pea litter. Tithonia, Senna and Tephrosia (all with %N > 3.5%) had percent fertilizer equivalencies of about 100% and would be classified as high quality organic materials that can be recommended for direct application as N sources. The good performance of Tephrosia in increasing maize yield indicates that the lignin content of 18 to 19% may be a good critical value. The fairly poor performance of Calliandra, Sesbania, pigeon pea litter and Neem (all with %N > 2.5) was due to high levels of polyphenols and/or lignin. The management recommendation that is suggested for these materials is to mix with N fertilizer or high quality organic material. Following application of maize stover (%N < 1.5), yields were lower or comparable to that from the control (no inputs) and hence, can be best used when mixed with N fertilizer or added to compost. The fertilizer equivalencies for organic materials with %N > 2.5 were positively correlated (r = 0.86, P = 0.01) to their N content, showing the dependency of the fertilizer equivalency of an organic material on its N content. The linear function indicated that with an increase of 0.1% N in the tissue of the plant material, there is 8% increase in the fertilizer value. The critical level of N content of organic materials for the transition for increasing crop yield relative to 0 N was 2.4% (Figure 8.2). There were positive interactions when Sesbania and Tephrosia were applied in combination with inorganic fertilizers, while it was more beneficial to apply Tithonia and Senna than both the N fertilizer and the organic-N fertilizer combinations. Better returns were obtained with the addition of inorganic N fertilizer rather than pigeon pea litter. More organic materials need to be tested against a set of hypothesis that has been placed in a decision tree for selecting organic materials for soil N management and to improve the predictability of the relationship between fertilizer equivalencies and N content of organic inputs.

These quality parameters were further tested against data held in the Organic Resource Database. It was found for a wide range of incubation experiments and organic resource quality that there was very close agreement to this initial decision tree (Figure 8.3).

Figure 8.2: The relationship between percent fertilizer equivalencies and N content of organic materials (Regression lines excludes Calliandra and maize stover)

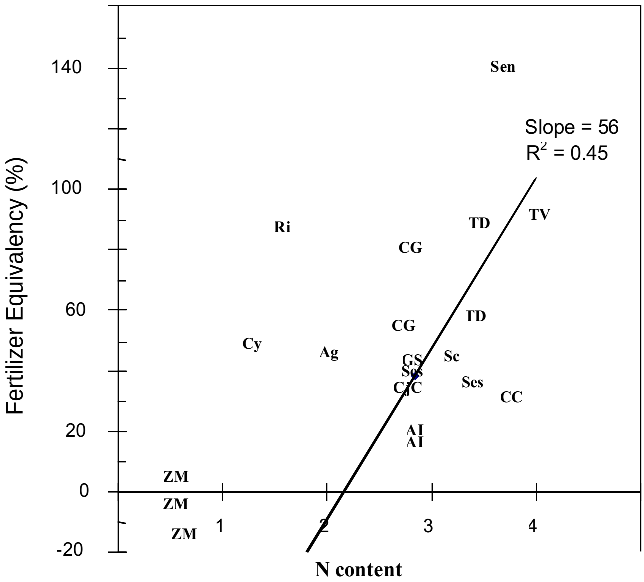
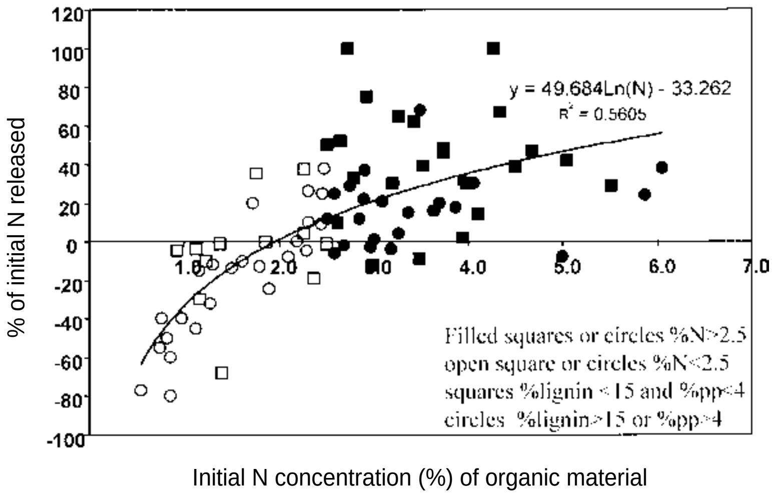


Figure 8.3: Nitrogen mineralized or immobilized after 8 weeks from organic materials from 11 incubation studies as determined by the N concentration of the materials and modified by high lignin or polyphenol concentrations. The regression equation is for all materials. Filled squares or circles represent materials with %N > 2.5m open square or circles %N < 2.5; squares represent materials with % < lignin and %polyphenol 4; circles represent materials with %lignin > 15 or %polyphenol > 4

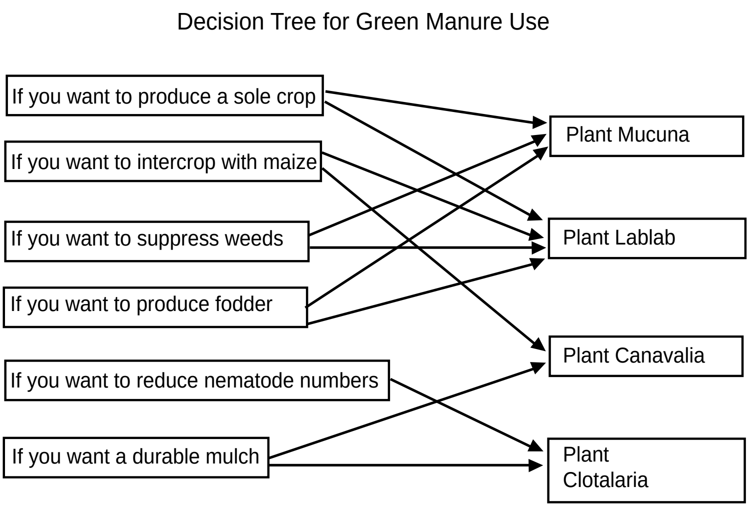


(Palm *et al.*, 2001)

Management of legume cover crop and biomass transfer species

The above example shows how we can select a particular type of management practice depending on the organic resource quality. Farmers also need to know that once they have selected a technology based on these criteria how do they manage that technology. For example, if they have a high quality resource how much of it should they incorporate it directly into the soil. Or, which species should they choose given their production objectives and available resources? Much on-farm evaluation of legumes in central Uganda has led to the production of a legume use decision guide (Figure 8.4). This selects a particular legume species based on the intended benefit the farmer wants from using a legume.

Figure 8.4: Decision aid for LCC use to allow farmers to select the best species for their production system and to address their production objectives



Adaptive research to test and refine decision support tools

The above decision guide on selecting a legume has been tested in eastern Uganda since 1999 through adaptive research with a range of governmental, non-governmental and research partners. This work has just started and the results will be used to update the decision guide as more data is collected. In addition, other organic resources were investigated, e.g. Tithonia for biomass transfer. Some research highlights are:

- Incorporation of 50% and 100% of one season Mucuna and canavalia fallow biomass was assessed to look at the fallow management options. Both incorporation rates of Mucuna and 100% incorporation of canavalia increased grain yields by more than 200% compared to the control in two areas of eastern Uganda (Figure 8.5 and Figure 8.6). Incorporation of 100% rather than 50% of the biomass produced in the plot did not significantly increase maize grain yields compared to the control. This would allow the farmer to produce the biomass in one place and to apply the biomass over twice the area, i.e. to use one part for incorporation and the other for biomass transfer or livestock feed. This is crucial where land sizes and fallow areas are limited, and little area is available for non-food crop production.

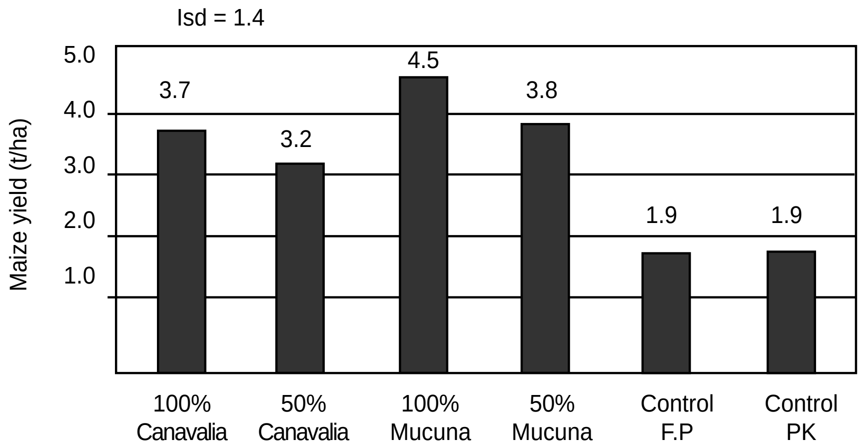
- Tithonia biomass, which is abundant in the district on roadsides and farm boundaries, can increase yields considerably over no input situation (Figure 8.7). In this trial, the treatments were balanced to add 60 kg N ha^{-1}.

- A mechanism for on-farm seed production has been implemented. As a back-up, seed stands at the DFI /DATIC have also been established for the seeds in greatest demand. Over 200 kg of starter seeds of legumes has been supplied to the farmers between 1999 and 2000, with a further 1200 kg distributed so far in 2001. Seeing the potential of this work, NARO's Outreach programme is now funding seed production at the DFI and in all the ARDCs in Uganda in order to get enough seeds for Tororo and other districts where it wants to promote the technologies. These figures do not include the amount that farmers themselves have used from their own stands.

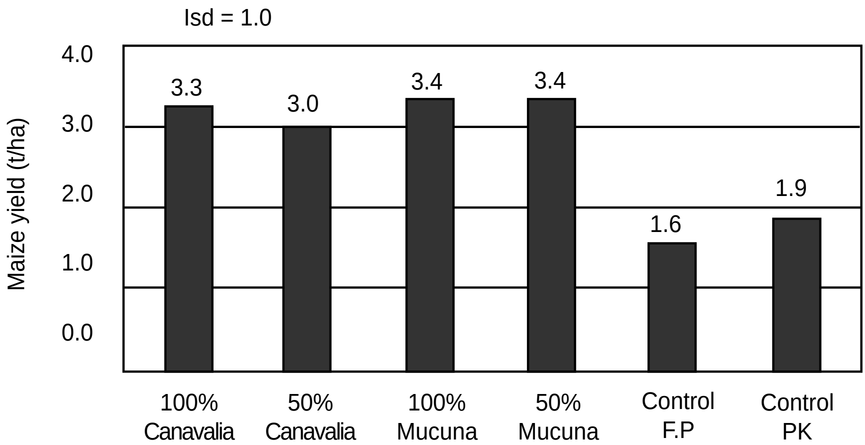
- Strong linkages with National Agricultural Research Organisation (NARO) for transfer of knowledge and materials to other parts of the country have been developed.

- A strong partnership for scaling up impact to the whole district and other neighbouring districts in eastern agroecological zone of Uganda. This has been through distribution of seed to farmers through government extension staff and field exchange visits.

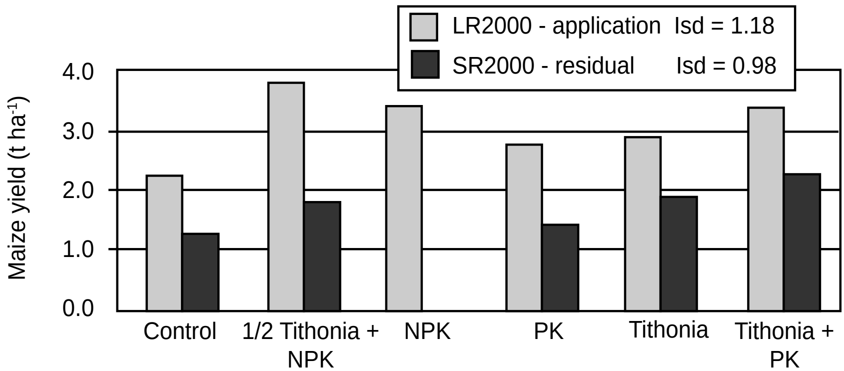
Figures 8.5: Maize grain yield following a one season fallow in Kisoko sub-county



Figures 8.6: Maize grain yield following a one season fallow in Osukuru sub-county



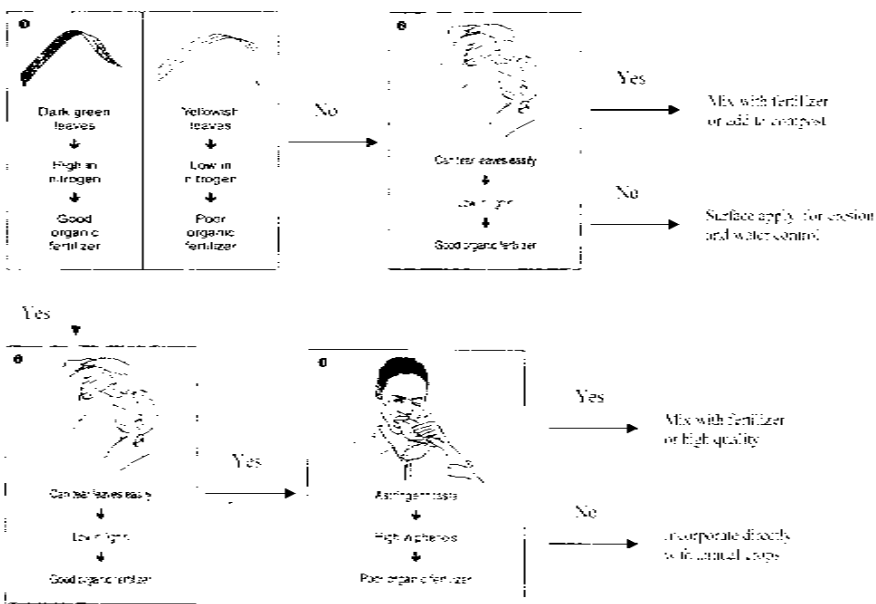
Figures 8.7: Maize grain yield following biomass transfer with Tithonia



The Way Forward

The challenge now is to revise the decision aids in response to on-farm adaptive research and feedback from the farmer evaluations of the technologies and this will form the major research work for the next couple of seasons. One of the key success factors for this will be to translate these decision aids and information into formats that can be used by extension agents and understood by farmers. An example, is where Figure 8.1 has been translated into simple assessments of resource quality to be used in Farmer Field Schools and farmer training (Figure 8.8).

Figures 8.8: Farmer decision guide for selecting organic resource management options



Other areas of on-going research to ensure effective research to extension linkages are:

(a) Mobilisation and training of more farmers and extension staff
(b) Mobilising resources to synergise partnership, farmer to farmer exchange visits from neighbouring districts and countries and to keep the secretariat at A2N running
(c) Development and packaging of information to aid dissemination for farmers, NGOs, extension agents and policy makers
(d) Enhancing the ability of NARS scientists to conduct relevant and participatory on-farm research
(e) Strengthening research to extension linkages

References

Constantinides, M. and Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: Relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biol. Biochem.* 26, 49-55.

Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W.D. and Mafongoya, P.L. (1997) Building soil nitrogen capital in Africa. In: Buresh, R.J., *et al.* (Eds.) Replenishing soil fertility in Africa. SSSA Spec. Publ. 51. SSA, Madison, WI, USA, pp. 151-192.

Heal, O.W., Anderson, J.M. and Swift, M.J. (1997) Plant litter quality and decomposition: An historical overview. In: Cadisch, G., Giller, K.E., (Eds.), Driven by Nature: Plant liter quality and decomposition. CAB International, Wallingford, UK. pp 3-30

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: In: Buresh, R.J., Sanchez, P.A., Calhoun, F. (Eds.), Replenishing soil fertility in Africa, SSSA, American Society of Agronomy, Madison, Wisconsin, USA, pp 193-217.

9

Effects of Farmyard Manure, Potassium and their Combinations on Maize Yields in the High and Medium rainfall Areas of Kenya

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Abstract

A national Fertilizer Use Recommendation Project (FURP), conducted trials in 71 sites in 32 districts of Kenya to monitor the effects of potassium (K) and farmyard manure (fym) on maize yields. The trials were in 36 sites in different agro-ecological zones with widely varying soil characteristics. Out of 36 sites, 8 responded to K, with 4 sites responding positively and an equal number negatively. Maize yield increases due to K ranged between 0.6 to 1.0 t ha^{-1}. Farmyard manure significantly increased yields in 13 sites by about 0.46 to

1.3 t ha^{-1} (P= 0.01 – 4.58). The yields were significantly improved by a combination of fym and K in only 4 sites (P=2.5 - 4.95). Response to inorganic K was in most cases reduced by manure application probably due to excessive K resulting from the additional K supplied from the manure. Results from one site that received linear K levels from 0 to 75 kg K_2O ha^{-1} indicated that K response to 50 kg K_2O ha^{-1} was almost equaled by 5t ha^{-1} FYM. This suggests a supplemental effect of K by manure, hence no yield benefits of applying K fertilizers and manure in combination.

Introduction

In Kenya, like many other sub-Saharan African countries, soil fertility and hence productivity is declining at an alarming rate because areas of high agricultural potential are densely populated and in most cases farm holdings are less than 1 ha. Farmers practice intensive continuous cropping with limited or no replenishment of nutrients through fertilizer application due to the high cost of the inorganic fertilizers. This has resulted in high nutrient depletions. For example, in Kisii, western Kenya, an annual depletion of –112 kg N ha^{-1}, -3 kg P ha^{-1} and -70 kg K ha^{-1}, was reported (Smaling, 1993).

Although K is depleted at such high rates, it has long been assumed by most Kenyans that potassium is non-limited in most Kenyan soils. However, results from a long-term cropping experiment at Kabete indicated a decline in soil K with time, but crop residue return or manure application helped to decelerate the depletion (Kanyanjua *et. al.*, 1999; Kapkiyai *et al.*, 1999). Besides, limited amounts of K containing fertilizers have been used in the country. Potassium fertilizers constitute only 7% of NPK fertilizers imported into the country (Ministry of Agriculture Annual Reports). This may result in K mining in soils, leading to K deficiencies, particularly in food crops that rarely receive K fertilizers. Low K levels and in some cases K deficiency symptoms were observed in Vihiga, Kakamega and Bungoma districts of Western Kenya (Gikonyo *et al.*, 1998, unpublished data; Gikonyo *et al.*, 2000; Kanyanjua unpublished data; Sambili, personal communication). Potassium deficiency symptoms were also extensively observed in maize (*Zea mays* L.) in Bungoma. Application of K fertilizers in maize resulted in good response to K (Sambili, 1998, personal communication). Potassium fertilization is therefore emerging as an important crop production constraint in Kenyan agriculture.

Due to economic hardships, the small-scale farmers cannot afford the potash fertilizers making it important to conduct research on organic resource utilization as an alternative or complementary source of plant potassium. It has been adequately demonstrated that application of organic manures can improve crop yields and soil properties (Probert *et al*., 1995; Kihanda, 1996; Nandwa *et al*., 2000). However, most manure experiments have been conducted in just a few sites. Manures contain about 2.6 cmol. kg^{-1} of potassium and could therefore supplement K in K deficient soils.

Research on manure is by no means exhaustive. Manure has been shown to decelerate K depletion but the interaction between manure and potassium fertilizers has not been addressed. This is becoming important due to the fact that soils are becoming more K deficient and at the same time, manure use is increasing. This paper discusses the effects of farmyard manure and potash fertilizers and their interactions on maize performance in different soils and agro-ecological zones.

Materials and Methods

Data used in this study were generated from the Kenya-wide Fertilizer Use Recommendation Project (FURP), conducted from 1987 to 1993. The project conducted trials in 71 sites in 31 districts of Kenya. Most of these trials were conducted on farmers' fields and represented different agro-ecological zones and soil types. Detailed descriptions of the sites were presented in 30 district volumes (FURP, 1987).

At each site three crop sequences were tested. The sequences were designated as modules 1, 2 and 3. Module 1 involved growing maize in monoculture continuously, season after season on the same plot. An intercrop of maize with beans (*Phaseolus vulgaris* L.), cowpeas (*Vigna unguiculata* (L.) Walp) or pigeonpea (*Cajanus cajan* (L.) Millsp.), formed module 2. Area specific crops such as potatoes (*Solanum tuberosum* L.), cabbages (*Brassica oleracea* L.), sorghum (*Sorghum bicolor* L.) and millet (*Pennisetum americanum* (L.) Leeke), were tested in seasonal rotations in module 3.

Two experiments, designated as trials 1 and 2, were carried out concurrently at each site. Trial 1 was a 4-level N by P factorial experiment laid out in a randomized complete block design with two replications and will not further be discussed in this paper. Trial 2 investigated the effects of presence/absence of N, P, K, S, lime and farmyard manure (FYM) in various combinations in different sites. A total of 36 sites included K and manure in the experimental design.

Table 9.1: Selected sites and soil data from Kenya FURP trials

Site	District	Soil Classification (According to FAO)	pH (H_2O)	Modified Olsen K (cmolc kg^{-1})	Organic Carbon (Walkley-Black) (%)
Otamba	Kisii	*Mollic Nitisol*	5.8	1.21	2.7
Kiamokama	Kisii	*Humic Nitisol*	5.3	0.46	1.8
Kisii NARS	Kisii	*Mollic Nitisol*	5.4	0.50	1.8
Ukwala	Siaya	*Orthic Acrisol*	5.0	0.16	0.6
Siaya Obambo	Siaya	*Chromic Luvisol*	6.3	0.86	1.3
Yala Swamp	Siaya	*Humic Gleysol*	4.8	0.66	1.7
Bukiri Buburi	Busia	*Ferralo-chromic Acrisol*	5.6	0.62	1.3
Alupe ARS	Busia	*Ferralo-orthic Acrisol*	5.4	0.47	1.4
Kamakoiwa	Bungoma	*Rhodic Ferralsol*	4.9	0.19	1.6
Tongaren	Bungoma	*Ferralo-chromic Acrisol*	4.9	0.41	1.0
Mumias	Kakamega	*Ferralo-orthic Acrisol*	4.8	0.12	2.1
Kakamega ARS	Kakamega	*Dystro-mollic Nitisol*	5.2	0.42	2.5
Vihiga Maragoli	Kakamega	*Nito-humic Ferralsol*	5.3	0.19	1.9
Mwihila	Kakamega	*Dystric Nitisol*	5.3	0.20	1.7
Baraton	Nandi	*Humic Nitisol*	5.3	0.21	3.1
Chepkumia	Nandi	*Humic Acrisol*	5.6	0.82	3.6
Sosiot	Kericho	*Dystro-mollic Nitisol*	5.6	0.12	3.3
Eldoret Moi TTC	Uasin Gishu	*Ferralic Cambisol*	5.3	1.15	1.4
Turbo	Uasin Gishu	*Ferralo-chromic Acrisol*	5.2	0.48	1.3
Kapenguria	West Pokot	*Humic Cambisol*	5.9	1.85	2.7
Charagita	Nyandarua	*Nito-chromic Luvisol*	5.0	0.64	3.0
Tulaga	Nyandarua	*Eutric Planosol*	5.4	0.25	2.2
Kandara Kareti	Muranga	*Humic Nitisol*	5.8	0.24	2.2
Makuyu	Muranga	*Dystric Nitisol*	5.6	0.72	2.0
Chehe	Nyeri	*Ando-humic Nitisol*	4.6	0.73	3.1
Kerugoya	Kirinyaga	*Humic Nitisol*	5.6	0.07	1.4
Kavutiri	Embu	*Ando-humic Nitisol*	4.0	0.20	3.0
Gachoka	Embu	*Rhodic Ferralsol*	5.8	0.92	1.7
Embu NARS	Embu	*Humic Nitisol*	5.6	0.97	2.2
Kaguru FTC	Meru	*Humic Nitisol*	5.6	1.07	1.2
Tunyai	Meru	*Nito-rhodic Ferralsol*	5.9	0.52	1.1
Mitunguu	Meru	*Nito-rhodic Ferralsol*	5.5	0.65	1.5
Mpeketoni	Lamu	*Chromic Luvisol*	7.0	0.34	0.7
Mtondia Tezo	Kilifi	*Chromic Luvisol*	7.7	0.49	0.7
Weruga	Taita-Taveta	*Chromic Acrisol*	5.4	0.23	1.6
Kichakasimba	Kwale	*Humic Nitisol*	6.4	0.20	0.5

Nitrogen and potassium were applied at 0 and 50 kg N and K_2O ha^{-1} in all sites except Kerugoya, where K levels of 0, 25, 50 and 75K_2O kg ha^{-1} were applied. Farmyard manure was applied at two levels of 0 and 5 t ha^{-1} in all the sites, except Embu Regional Research Center where manure was applied at linear rates of 0, 2.5, 5.0 and 7.5 t ha^{-1}. The experiment was laid out in a randomized complete block design. The plot sizes were 6 m x 6 m and maize was planted at 0.75 m x 0.60 m. The ultimate aim was to have two plants after thinning at knee-height to have a population of 44,000 plants ha^{-1}. Harvesting was done from an area of 21.6 m^2 and was used to compute the yields in kg ha^{-1}.

Maize varieties grown differed from one area to the other depending on agro-climatic conditions. The "late maturing" Kitale Hybrids were planted in the highlands and humid midlands at altitudes about 1500 – 2300 m. These in descending order were H614, H 622, and H625. The "medium maturing" Embu Hybrids were grown in the sub-humid midlands with lengths of growing periods between 130 - 160 days at 1200 m–1800 m (i.e. H512 and H511). The "early maturing" composites (Katumani composite B (KCB) and Makueni Composite (MC), were grown at the semi-arid Midlands to Lowlands (0-1600 m). Makueni replaced Katumani composite if the length of growing period was less than 85 days. The "early to medium maturing lowland maize"(Coast composite (CC) and Pwani hybrid), were grown at the coastal lowlands. Experimental details are available in the Final FURP Methodology (FURP, 1988). The experiment was conducted from 1987 to 1992, though most sites were not studied for all years of the FURP study.

Statistical analysis was done by analysis of variance using the Statistical Analysis System (SAS Institute, 1990). Reference to statistical significance refers to a probability level of 0.05 unless otherwise noted.

Results

In majority of the sites, 29 out of the 36 trial sites maize responded positively to NP application. Maize responded positively to manure application in 14 sites while response to K was recorded in only 8 out of 36 sites (Table 9.2). Maize responses to manure, K fertilizers and K fertilizer and manure combinations, varied from site to site but a few generalized categories are presented (Figures 9.1a-1f). In some, there were no significant responses to K (1d and 1e) while significant responses to K were observed in others. Some responded to K but not N or NP (1a and 1b) while others responded to K, manure and NP combinations.

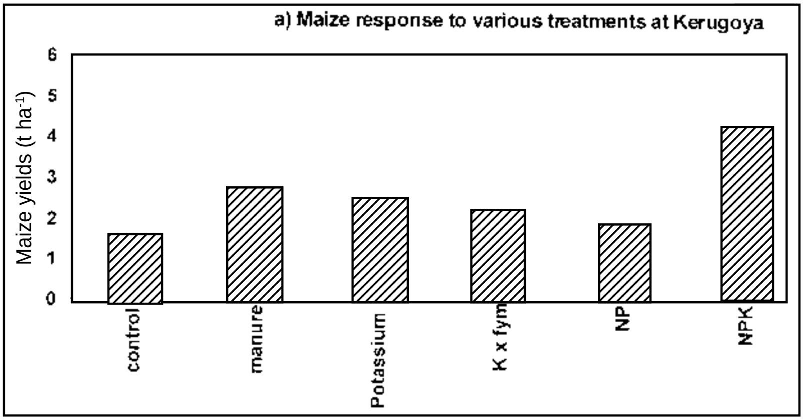
Table 9.2: Sites and respective maize response to Farmyard manure (FYM), Potash fertilizer (K) and N/NP applications

Site	Maize Responses (t ha^{-1}) to		
	FYM	Potassium (K)	Nitrogen X Phosphorus
Kisii NARS	Ns	-1.02	1.2
Ukwala	Ns	ns	1.2
Bukiri Buburi	Ns	ns	0.9
Kamakoiwa	0.94	ns	2.9
Tongaren	1.07	ns	1.9
Mumias	0.51	0.45	1.5
Kakamega ARS	1.3	ns	0.78
Vihiga Maragoli	0.7	ns	1.93
Chepkumia	Ns	ns	1.67
Sosiot	1.0	ns	ns
Turbo	0.58	ns	2.2
Kapenguria	Ns	-0.66	ns
Charagita	Ns	ns	1.21
Tulaga	Ns	0.4	ns
Makuyu	1.3	-0.33	1.15
Chehe	0.83	ns	0.28
Kerugoya	Ns	+vea	1.4
Kavutiri	0.46	0.61	1.1
Gachoka	0.54	ns	0.88
Kaguru FTC	Ns	-0.44	1.64
Tunyai	0.47	ns	1.06
Mpeketoni	0.56	ns	0.56
Mtondia Teso	0.7	ns	1.7
Weruga	Ns	ns	0.7

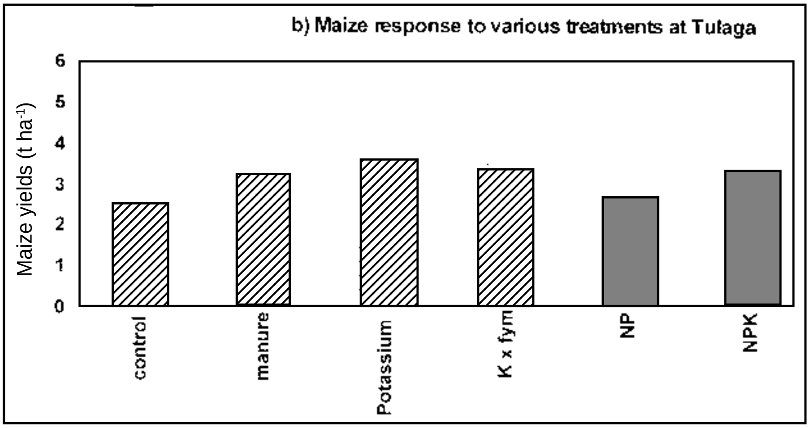
Manure increased maize grain yields in all the manure responsive sites. Manure increased yields by 0.46 - 1.3 t ha^{-1} compared to the control plots. The highest yield increases were from Kakamega ARS and Makuyu site, while the lowest were from Kavutiri site. It was noted that all the manure responsive sites with an exception of Sosiot, were NP responsive. However, out of 10 manure non-responsive sites, only Kapenguria and Tulaga were not responsive to NP. Maize yield increases due to NP application was much higher (0.56 – 2.9 t ha^{-1}) than that resulting from manure application. In Embu, a site with linear manure applications (Figure 9.2), it was observed that yields increased linearly with manure applications from 3.2 t ha^{-1} at zero manure rate to 4.5 t ha^{-1} at manure rate of 7.5 t ha^{-1}. When NP was applied, the yields were shifted at each level of manure application by about 2t ha^{-1}. Potash fertilizer increased yields particularly at zero manure rate, but yields decreased

Figure 9.1 (a - c): Typical patterns of responses to various fertilizer additions at selected sites in multi-locational fertilizer trials in Kenya

(a)



(b)



(c)

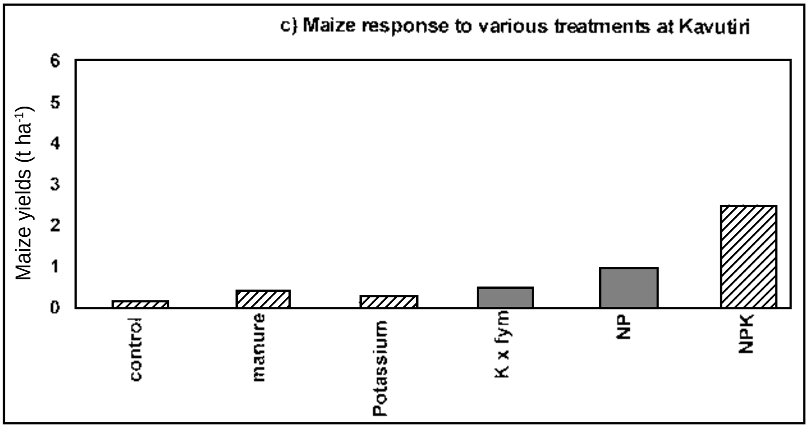
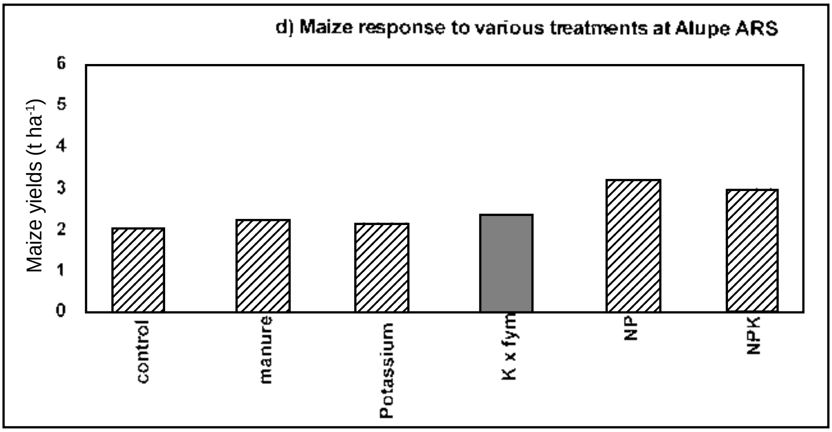
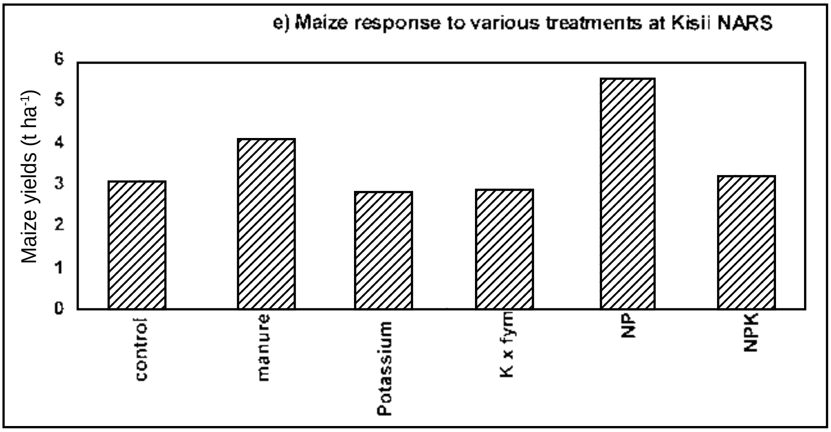


Figure 9.1 (d - f): Typical patterns of responses to various fertilizer additions at selected sites in multi-locational fertilizer trials in Kenya

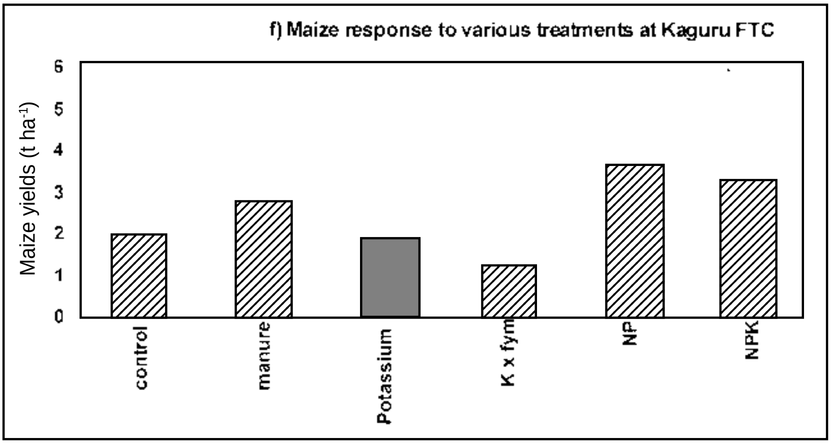
(d)



(e)



(f)



with increasing manure rates in combination. With NP application there was a large yield increase that was further improved by Potash fertilizer application alone, but addition of manure to that combination lowered the yields. This implies that in both cases, i.e. Potash fertilizer alone or in combination with NP fertilizer, inclusion of manure to K had negative effects on maize yields. Manure and Potash fertilizer combinations resulted to no increases or depressed yields in all the sites tested (Figure 9.1a-f).

Maize responded significantly to potash fertilizer application in only 8 sites. However, both negative and positive responses to K were observed, with an equal number of sites showing positive and negative responses (Table 9.2). Four out of thirty five sites (11%) responded positively while four responded negatively. Maize yields increased by up to 0.66t ha^{-1}, but apparently real decreases of up to 1 t ha^{-1} were also recorded. Positive K responses were observed in Mumias, Tulaga, Kerugoya and Kavutiri sites all with extractable modified Olsen K levels of 0.20 cmol kg^{-1}. The four sites showing negative responses were Kisii NARS, Kapenguria, Makuyu and Kaguru FTC and they all had Olsen K levels of 0.5 cmolc kg^{-1} soil. Negative K responses were also reported in maize on granitic and phonolithic soils that were slightly acidic to acidic (Weiss, 1973).

In Kerugoya, an extremely K-deficient site at which linear levels of K were applied in the presence and absence of NP and FYM, response to K alone was quadratic with the maximum yields occurring at K rates around 50 kg K_2O ha^{-1} (Figure 9.3).

Figure 9.2: Effect on maize yields of linear rates of manure or manure + NP fertilizer, plus or minus K at 50 kg K_2O ha^{-1}, at Embu site

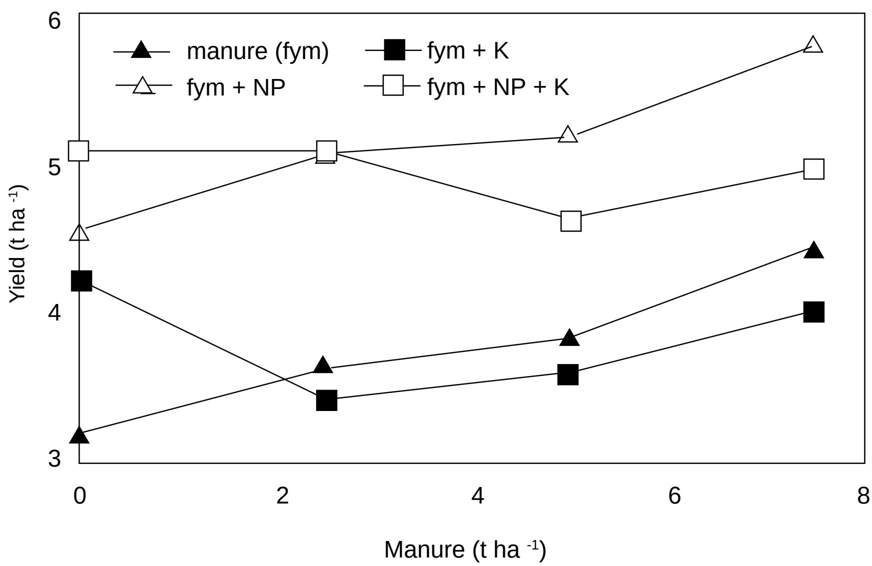
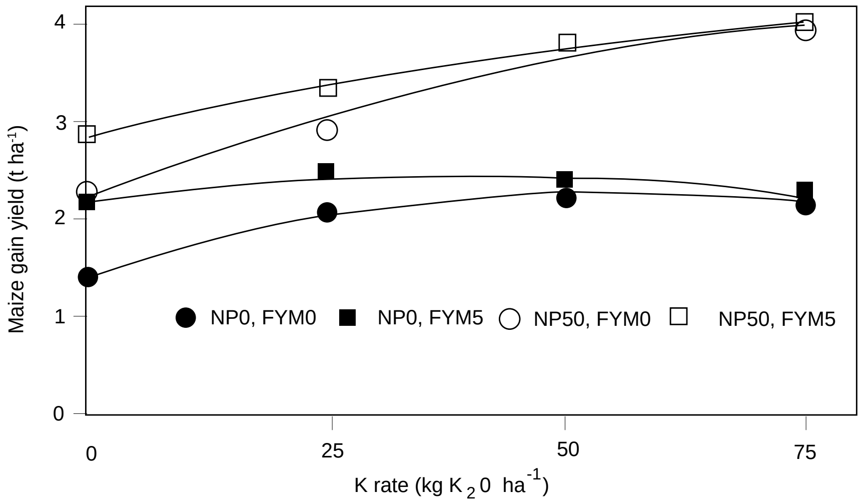


Figure 9.3: Effect on maize yields of linear rates of K fertilizer (0 to 75 kg K_2O ha^{-1}), plus or minus manure at 5 t ha^{-1} at Kerugoya site



In the same site, K response was greatly reduced to almost 0 by application of 5t ha^{-1} FYM suggesting that manure supplied K to the maize. Manure alone gave slightly higher yields than the potash fertilizer. Addition of NP fertilizer together with potash fertilizer increased yields by more than double (Figure 9.3). Such a synergistic effect was also observed in legumes in Western Kenya where beans, groundnuts and soybeans, gave greater responses when K was applied in the presence of P (Qureshi, 1979).

Discussion

Most Kenya soils are N and P deficient, which, probably explains why most sites responded to NP application. The benefits of manure as a source of soil nutrient is well documented.

Besides addition of nutrients, manure increases the water holding capacity, PH and infiltration of water and decreases bulk density of the soil (Azevedo and Stout, 1997). Maize response to manure was probably an indirect response to NP and sometimes K in K deficient soils and this is probably why most of the NP responsive sites also responded to manure application. However in a number of sites maize did not respond to manure but responded to inorganic NP application. This is probably due to the variable quality of manure used in terms of nutrients content (Wanjekeche *et al.*, 1999; Micheni *et al.*, 2000; Lekasi *et al.*, 1997).

Higher maize yield increases were obtained with NP as compared to manure probably due to low nutrients in low quality manure as shown in SMP (1996, 1997) that supplementing some fertilizers for some manure produced a response in cases where manure alone had no response. In Embu site, addition of NP to manure increased yields by twofold, maybe due to the improved nutrient status with addition of NP fertilizers. Some soils were non-responsive to manure but they were responsive to N or NP (Table 9.2). This is probably due to the low nutrient content of some of the manures used (Micheni *et al*., 2000), hence, manure quality should therefore be considered in manure recommendations.

Response to K was observed in only a few sites since as indicated by soils analysis, most sites had high K levels. They were above the K critical level for most crops (> 0.2 cmol kg^{-1}) and therefore, response to K was unlikely (Gikonyo *et al*., 2000). The negative responses at high soil K may be associated with Mg to K ratio imbalance. Considerable evidence indicates that heavy applications of potash fertilizer or high level of K in the soil can lead to low-magnesium content in the plant. Doll and Hossner (1964), reported that fertilizer K decreased potato (*Solanum tuberosum* L.) yields at every level of magnesium fertilization. Differential absorption of K was the controlling factor in the uptake of magnesium in corn seedlings (Stout and Baker, 1981). Mg deficiency was observed in plants growing in soils well supplied with Mg as a result of K-induced Mg deficiency (Messing, 1974).

Lack of response or negative response resulting from manure and potash fertilizer application is probably due to excessive K from the two sources. Manure at 5t ha^{-1} seems to supply the maize crop's K requirement and the application of the two sources not beneficial in all cases.

Acknowlegement

The authors wish to express their gratitude to; the German Agency for Technical Cooperation (GTZ), for providing funds for the FURP studies (1987-1993); staff members of the Kenya Agricultural Research Institute (KARI), for collecting and compiling the original field and laboratory data; P. Angala of ICRAF for providing computer training and logistical support during the attachment of the first author; the European Union-funded Soil Fertility and Plant Nutrition Research Programme, KARI for providing funds to allow the first author's attachment during which data for this work was analysed; TSBF/AfNet for sponsoring my attendance to this conference; Last and not least God almighty for his continued grace and everlasting love.

References

Azevedo, J. and Stout, P.R. (1997) F*arm animal manures. An overview of their role in the agricultural environment.* Califonia Agricultural Experiment station, Extension service.

Doll, E.C., and Hossner. (1964) Magnesium deficiency as as related to liming and potassium levels in acid sandy podzols. *Int.Congr. Soil Sci.*, Trans 8th,1964. 4: 907 – 912.

FURP. (1987) The Fertilizer Use Recommendation Project, Final Report Annex1: Fertilizer Trial Documentation (FERDOC). Min. of Agriculture, Nairobi, Kenya.

FURP. (1988) The fertilizer Use Recommendation Project (Phase 1). Main Repoort,

Methodology and inventory of existing Information. Fertilizer Trial Documentation (FERDOC). Min. of Agriculture, Nairobi, Kenya.

Gikonyo, E.W., Smithson, P.C., Nandwa, S.M., Lijzenga, M. and B. Janssen. (2000) Effects of potassium fertilizer on some major food crops in Kenya. A paper presented at the 18th AGM of Soil Science Society of East Africa meeting held in December 2000 at Mombasa, Kenya.

Kanyanjua, S.M., Buresh, R.J., Recke, H. and Nandwa, S.M. (1999) Potassium status in Kenyan soils and its influence on crop yields: A study to challenge the convention that soils in Kenya have adequate potassium to sustain productivity of major crops. A poster paper presented at the conference on Managing Plant Nutrition: Towards Maximum Resource Efficiency, Barcelona, Spain, 29th July 1999.

Kapkiyai, J. J., Karanja, N.K., Qureshi, J.N., Smithson, P.C. and Woomer, P.L. (1999) Soil organic matter and nutrient dynamics in a Kenyan Nitisol under long-term fertilizer and organic input management. So*il Biol. Biochem.* 31, 1773-1782.

Kihanda, F.M. (1996) The role of farmyard manure in improving maize production in sub-humid highlands of central Kenya. Ph. D. Thesis. University of Reading. UK.

Lekasi, J. C., Tanner, J.C., Kimani, S.K. and harris, P.J.C. (1998) Ma*nure management in the Kenya highlands: Practices and potential.* ADRA Publications. Pp. 35.

Messing, J.H.L. (1974) Long term changes in potassium and calcium content of banana plants and soils in the Windward Islands. *Trop. Agric.* (Trinidad) 51: 154-160.

Micheni, A. Mugendi, D., Mugwe, J., kung'u, J. and Gitari, J. (2000) Low cost soil fertility amendment strategies for improved food production in maize cropping systems in Central highlands of Kenya. Paper presented in the SSSEA, Dec. 2000, Mombasa, Kenya.

Ministry of Agriculture. A*nnual reports of fertilizer imports to Kenya.* Kenya Ministry of Agriculture, Nairobi.

Nandwa, S.M., Thuranira, E.G., Wamaitha, J., Gikonyo, E., Kibunja, C.N. and Onyango, J. W. (2000) Changes on soil fertility and crop yields in a continuous maize-based cropping system with low-and-high external nutrient inputs at semi humid site, Kabete (Nairobi) in Kenya. Paper presented at the International Symposium on balanced Nutrient Management Systems for moist savana and Humid Fores Zones of Africa, Cotonou, Republic of Benin, Oct. 2000.

Probert, M. Okalebo, E., Simpson, J.R. (1995) The use of manure on smallholders in semi-arid eastern Kenya. *Experimental Agriculture* 31: 371-381.

Qureshi, J.N. (1979) Potassium workshop organized by the International Potash Institute in Nairobi, Kenya.

SAS Institute (1990) SAS/STAT User's Guide, Vol. 2. Version 6.1.

SAS Institute, Cary, NC, USA

Smaling, E.M.A. (1993) Soil nutrient depletion in sub-Saharan Africa. In: Th*e role of plant nutrients for sustainable food production in sub-Saharan Africa* pp. 53-67. In Van Reuler, H. and Prins W.H. (eds). Leidschendam: VKP, The Netherlands.

Stout, W.L and Baker, D.I. (1981) Effect of differencial absorption of potassium and magnesium in soils on magnesium uptake by corn. *Soil Sci. Soc. Am. J.* 45: 996 – 997.

SMP 1996, (1997) S*oil Management Project Annual Report.* Wanjekeche, E., Mwangi, T., Powon, P. and Khaemba, J. (1999) Survey of management practices of Boma manure and its nutrient in West Pokot district in Kenya. SSSEA, 17th conference, pp. 335-359.

10

Effects of Nitrogen and Phosphorus Fertilizer Addition on Wheat Straw Carbon Decomposition in a Burundi Acidic Soil

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Abstract

Two laboratory incubation studies were conducted for 56 days in an acidic high altitude Burundi soil, to evaluate the effect of increasing application rates of N and P fertilizers on carbon (C) decomposition from wheat straw (*Triticum aestivum* L.). Nitrogen was applied as NH_4NO_3 at 0, 40, 80 and 120 kg N ha^{-1}, while P was applied at 0, 17.6, 35.2 and 52.8 kg P ha^{-1} as K_2HPO_4. Carbon dioxide (CO_2) evolution was regularly monitored using the alkali absorption method. At the completion of the studies, % C decomposition from wheat straw was equal to 18.8, 34.1, 45.4 and 48.1 % for straw + 0, straw + 40, straw + 80 and straw + 120 kg N ha^{-1}, respectively. Comparatively, similar values were 21.4, 40.4, 51 and 58.6 % for straw + 0, straw + 17.6, straw + 35.2 and straw + 52.8 kg P ha^{-1}, respectively. Straw C decomposition kinetics was described by a simple exponential model and decomposition rate constants (k), half-lives ($t_{1/2}$), together with the time periods required for 90 and 99 % straw C mineralization were evaluated. The data indicated that % straw C mineralization increased with increasing application rates of N and P fertilizers. The highest decomposition rates were obtained with P fertilizers. The investigations illustrated the benefit of the combined use of low-quality organic materials and inorganic nutrient sources in enhancing decomposition and implicitly increasing total available nutrients for plant uptake.

Introduction

Carbon (C) decomposition from organic residues is controlled by as many factors as soil environmental conditions (temperature, moisture, aeration, soil pH, nutrient availability, etc), substrate quality (chemical composition) and quantity, soil residue pre-treatment, application methods and their potential interactions (Marion and Black, 1987).

Organic materials are used in many conflicting ways in developing countries in general and in Burundi in particular. They can serve as cooking fuel, livestock feed, building materials, animal litter, substrate for edible mushroom production or mulch, when they are not used in soil fertility replenishment either by direct application or through composting. Subsistence agriculture in Burundi is very much dependent on organic materials (which include crop residues, animal manure and agroforestry species biomass) to replenish soil organic matter and supply nutrients.

Fertilization could offset the negative effects of low-quality organic materials (Palm *et al.*, 1997) and accelerate their decomposition, thereby releasing over a relatively short time nutrients, which normally would be cycled over a more extended period (Kelly and Henderson, 1978). These released nutrients added to those contributed by fertilizer applications, would increase total available nutrients for plant uptake (Palm *et al.*, 1997).

The objective of the present laboratory studies was to evaluate the short-term effects of N and P mineral fertilizer addition on the decomposition of wheat straw incorporated in a Burundi acidic soil.

Materials and Methods

Soil

The soil used in the studies was collected in April 1999 from the Ruzibazi Seed Center in Mukike District, Rural Bujumbura Province. Selected physical and chemical properties of the soil are given in Table 10.1. Niyongabo (1986) described a similar soil.

Table 10.1: Physical and chemical properties of the soil used in the study

Parameter	Value
% clay	64.9
% sand	24.5
pH_{water}	4.7
pH_{KCl}	4.0
Electrical conductivity (dS/m)	0.0845
% C	5.65
% N	0.61
C/N	9.18
CEC ($cmol_c$ kg^{-1} soil)	33.38
Al^{3+} ($cmol_c$ kg^{-1} soil)	4.91
Exchangeable acidity ($cmol_c$ kg^{-1} soil)	5.50
% Al saturation	4.71
P-Olsen (mg kg^{-1} soil)	

Wheat straw

Wheat straw was collected after crop harvest. The material was dried at 70° C to a constant weight and subsamples were ground in a Wiley mill before chemical analyses were performed. Total N was determined by a Leco N analyser model FP 428 (Leco Corporation, St Joseph, MI). Total C was determined by dry combustion (Nelson and Sommers, 1982). Total P, S, K, Ca and Mg were analyzed by ICP spectrometry after digestion of a 0.2-g sample with HNO_3 and H_2O_2 at 120° C for 3 hours (Zarcinas *et al.*, 1987). Selected properties of the wheat straw used in the study are shown in Table 10.2.

Incubation Procedure

Each incubation vessel (250-mL) was fitted with 2 test tubes each containing 5 mL of 2 N NaOH to capture evolved CO_2.

The laboratory incubations were conducted at room temperature (25 ± 1° C) in the soil laboratory facilities of the Faculty of Agricultural

Sciences, University of Burundi. Soil samples (50 g d.w. basis) were mixed with wheat straw to approximate a field application of 3000 kg ha^{-1}, corresponding to wheat straw production in the wheat producing region of Mugamba, where wheat straw is used as animal litter or composting materials (Niyongabo, 1986). Plant materials were cut into approximately 0.5 cm-long sections and were incorporated in soil in combination with N and P fertilizers. In the first study, N was applied as NH_4NO_3 at 0, 40, 80 and 120 kg N ha^{-1}. In the second study, P was applied at 0, 17.6, 35.2 and 52.8 kg P ha^{-1} as K_2HPO_4, which simultaneously brought 0, 44.3, 88.6 and 132.9 kg K ha^{-1}, respectively. In the latter investigation, fertilizer K was adjusted in all treatments using KCl in order to nullify the effect of K on straw decomposition.

Table 10.2: Chemical Composition of the wheat straw used in the study

Parameter	g kg^{-1}
C	420
N	5.5
P	0.4
S	0.9
K	10.4
Ca	2.9
Mg	0.6
C/N	76.4
C/P	1050
C/S	466.7
N/P	13.8
N/S	6.1

CO_2 sampling was performed at 3, 7, 14, 21, 28, 42 and 56 days of incubation. All incubation vessels were opened and aerated for about 5 minutes at each sampling period to maintain aerobic conditions, while test tubes containing the alkali solution were simultaneously changed and titrated (Stotzky, 1965; Zibilske, 1994).

Control soils without straw and fertilizer were run, and empty incubation vessels were used as controls for CO_2 absorbed from the atmosphere during the incubation procedure. Soil moisture was adjusted to 60 % water holding capacity (WHC). The total quantity of CO_2 collected in the dilute NaOH solution was determined by titration to a phenolphthalein indicator endpoint with standardized HCl following addition of $BaCl_2$, according to the following reactions (Stevenson, 1986):

$$2NaOH + CO_2 \quad - \quad Na_2CO_3 + H_2O \qquad (1)$$
$$Na_2CO_3 + BaCl_2 \quad - \quad BaCO_3\,(\_) + 2\,NaCl \qquad (2)$$
$$NaOH\ (exc.) + HCl \quad - \quad NaCl + H_2O \qquad (3)$$

Calculations

Carbon evolved as CO_2 was estimated by the following formula (Stotzky, 1965):

$$(\text{mg C as } CO_2 = (B - V) \times N \times E \qquad (4)$$

where;
B = mL of standard acid for the blank;
V = mL of standard acid for amended treatments;
N = normality of standard acid;
E = equivalent weight of C (= 6).

The evolution of wheat organic C evolved as CO_2 from soils amended with straw was determined by subtracting the quantity of CO_2–C evolved from control samples from the quantity of CO_2–C evolved, from wheat-amended soils. This is the usual method of determining decomposition of unlabelled substrate in soils. As in many other studies of this nature, the decomposition rate of native soil organic matter C in the presence of wheat straw was assumed to be the same for each treatment, meaning that there was no priming effect (Ajwa and Tabatabai, 1994).

Percentage decomposition was estimated by calculating the percentage of C added evolved as CO_2 after correction for the CO_2 evolved from unamended soils according to the following equation:

$$(\%\ \text{C decomposition} = [(X - Y) / Z)] \times 100 \qquad (5)$$

where
X = mg of C evolved as CO_2 from wheat-fertilizer treatments;
Y = mg of C evolved as CO_2 from unamended soil (control);
Z = mg of C added in the wheat straw.

Decomposition model

Numerous mathematical models have been tested to describe C mineralization from soil organic matter or plant materials. Most models follow the first-order kinetics, for which the magnitude of decomposition is assumed proportional to the quantity of mineralizable C. The simple or one-component exponential model is the oldest (Stanford and Smith, 1972). The model assumes that only one form of potentially mineralizable C exists and mineralizes at a rate proportional to its concentration.

Statistical analyses

The incubation studies were conducted in a completely randomized design (CRD). Experimental treatments consisted of a blank, a control (soil only) and wheat-amended treatments. In each one of the two studies, each treatment was replicated three times to make a total of 18 experimental units. Straw C decomposition can be described by the following equation:

$$dt = -k\ C \tag{6}$$
$$C_t = C_o \exp(-kt) \tag{7}$$

where
C_t = carbon content at time t (day),
C_o = initial C content,
k = first-order rate constant,
t = time, days.

Decomposition rate constants (k) were estimated by using the Linear Least Squares (LLS) procedure by plotting the natural logarithm of % C remaining versus time of incubation in days. The software used to evaluate the fitness of different models of C decomposition kinetics from wheat straw was version 3.2 of SAS JMP IN (SAS, 1996). Mean separation of % C decomposition was performed with the Newman and Keuls test. The 0.05 level of probability was used as the criterion for accepting or rejecting null hypotheses in all statistical analyses.

Using decay coefficient (k) values and assuming constant decay rates for specific treatments, half-lives ($t_{1/2}$) together with the time periods required for 90 and 99 % straw C mineralization were estimated according to equations 8, 9 and 10, respectively.

$$t_{0.5} = \ln 2 / k = 0.693 / k \tag{8}$$
$$t_{0.9} = \ln 10 / k = 2.303 / k \tag{9}$$
$$t_{0.99} = \ln 100 / k = 4.605 / k \tag{10}$$

Results and Discussion

Data were fitted to the simple (one-component) exponential model and decomposition rate constants, $t_{0.5}$, $t_{0.9}$ and $t_{0.99}$ were estimated. For convenience, the results obtained from the two laboratory studies are discussed separately.

Effect of N fertilizer on straw C Mineralization

The addition of N fertilizer significantly increased wheat straw C decomposition. At the completion of the study, % straw C decomposition as affected by N fertilizer ranged from 18.8 with no N addition to 48.1 % with 120 kg N ha^{-1} as shown in Table 10.3. No significant differences were observed between treatments fertilized with 80 and 120 kg N ha^{-1}. Overall, % straw C decomposition followed the order: Straw + 120 kg N ha^{-1} = Straw + 80 kg N ha^{-1} > Straw + 40 kg N ha^{-1} > Straw alone.

Table 10.3: Percent wheat straw decomposition as affected by N fertilizer rates

Treatment	% Decomposition	% Increase
Straw + 120 kg N ha^{-1}	48.10 ± 1.53^{a*}	+ 155.9
Straw + 80 kg N ha^{-1}	45.40 ± 2.28^{a}	+ 141.5
Straw + 40 kg N ha^{-1}	34.11 ± 1.47^{b}	+ 81.4
Straw + 0 kg N ha^{-1}	18.80 ± 2.41^{c}	–

*Values followed by the same letter are not significantly different at 5 % probability level.

Table 10.4: Decomposition model and rate constants of wheat straw fertilized with N

Treatment	Decomposition Model	Prob.	R^2	Decomposition Time (days) $t_{0.5}$	$t_{0.9}$	$t_{0.99}$
Straw + 0 kg N ha^{-1}	Y = 4.576626 (± 0.009675) – 0.003497 (± 0.000320)	< 0.0001	0.86	198	658	1317
Straw + 40 kg N ha^{-1}	Y = 4.536913 (± 0.001655) – 0.006944 (± 0.005480)	< 0.0001	0.89	100	332	663
Straw + 80 kg N ha^{-1}	Y = 4.492028 (± 0.002539) – 0.009955 (± 0.008410)	< 0.0001	0.88	70	231	463
Straw + 120 kg N ha^{-1}	Y = 4.474588 (± 0.002411) – 0.010637 (± 0.007990)	< 0.0001	0.90	65	216	433

Table 10.4 shows that N application hastened straw decomposition. When compared to straw alone, addition of 40 kg N ha^{-1} doubled the decomposition rate, while application of higher N rates (80 and 120 kg N ha^{-1}) tripled it (Table 10.4).

Effect of P fertilizer on straw C Mineralization

At the completion of the study, % wheat straw C decomposition as affected by P fertilizer ranged from 21.4 with no P addition to 58.6 % with 52.8 kg P ha^{-1}) as shown in Table 10.5. Overall, percent straw C decomposition followed the order: Straw + 52.8 kg P ha^{-1} > Straw + 35.2 kg P ha^{-1} > Straw + 17.6 kg P ha^{-1} > Straw alone.

It can be observed that P addition brought about higher percent straw C decomposition when compared to N fertilizer addition. When compared to straw alone, addition of 17.6 kg P ha^{-1} doubled the decomposition rate, while application of 35.2 and 52.8 kg P ha^{-1} tripled and quadrupled it, respectively (Table 10.6).

Table 10.5: Percent wheat straw decomposition as affected by P fertilizer rates

Treatment	% Decomposition	% Increase
Straw + 52.8 kg P ha^{-1}	58.6 ± 0.2^{a*}	+ 173.8
Straw + 35.2 kg P ha^{-1}	51.0 ± 3.3^{b}	+ 138.3
Straw + 17.6 kg P ha^{-1}	40.4 ± 0.6^{c}	+ 88.8
Straw + 0 kg P ha^{-1}	21.4 ± 3.4^{d}	–

Table 10.6: Decomposition model and rate constants of wheat straw fertilized with P

Treatment	Decomposition Model	Prob.	R^2	Decomposition Time (days) $t_{0.5}$	$t_{0.9}$	$t_{0.99}$
Straw + 0 kg P	Y = 4.567626 (± 0.151300) – 0.004290 (± 0.000500)	< 0.0001	0.78	162	537	1073
Straw + 17.6 kg P	Y = 4.546650 (± 0.016548) – 0.009040 (± 0.005480)	< 0.0001	0.91	77	255	509
Straw + 35.2 kg P	Y = 4.531140 (± 0.030420) – 0.012942 (± 0.001008)	< 0.0001	0.89	54	178	356
Straw + 52.8 kg P	Y = 4.522903 (± 0.037912) – 0.016430 (± 0.001260)	< 0.0001	0.89	42	140	280

Results obtained in this study were in agreement with those found by Smith and Douglas (1971), who reported greater decomposition of wheat straw with N than without it. Also, in a study conducted in a Kenyan ferralsol, Munyampundu *et al*. (1997) reported that the combination of wheat straw and increasing rates of inorganic N and P enhanced growth and yields of *Leucaena leucocephala*, *Sesbania sesban*, maize grain and stover.

However, conflicting results have also been reported elsewhere. For example, Kelly and Henderson (1978) found that urea application had little effect and superphosphate addition depressed the decomposition of white oak leaves (*Quercus alba* L.) in litter bags. Also, recent field experiments conducted in India (Goyal *et al*., 1992) and in Malawi (Jones *et al.*, 1997), have shown mixed results with regard to the effect of combining organic and inorganic inputs on yield and nutrient uptake (Palm *et al.*, 1997). In a 4-year experiment using pearl millet [*Pennisetum glaucum* (L.) R. Br.], Goyal *et al.* (1992), indicated that inorganic N addition to wheat straw did not improve yields, N uptake and N recovery by the test plant. On the contrary, Jones *et al.* (1997) reported a significant increase in yields and N-use efficiency when Leucaena [*Leucaena leucocephala* (Lam.) de Wit.] leaf residues were combined with urea in the 1: 3 ratio (Palm *et al.*, 1997).

The study reported in this paper concerned CO_2 evolution. One can argue that this parameter does not have a practical agronomic meaning. However, it has been proved that C decomposition controls nutrient release from organic materials. In particular, Clark and Gilmour (1983) and Castellanos and Pratt (1981) proposed CO_2 evolution as a means of providing a general estimate of net N mineralization. In fact, Gilmour *et al.* (1985) and Moorhead *et al.* (1987) showed significant linear relationships between N mineralization (g kg^{-1} N) and carbon dioxide evolution (g kg^{-1} C) for a number of organic substrates (Table 10.7).

Table 10.7: Selected linear relationships between carbon evolution as carbon dioxide (C) and N mineralization (N) for some organic substrates.

Substrate	Equation	Correlation coefficient
Sewage sludge	N = 1.01 C + 48	r = 0.90
Alfalfa	N = 0.98 C + 79	r = 0.96
Clover	N = 0.97 C + 84	r = 0.995
Bermudagrass	N = 0.43 C + 396	r = 0.94
Ryegrass	N = 0.53 C + 291	r = 0.97
Low-N plant biomass		
Fresh	N = 0.15 C - 36	r = 0.73
Digested	N = 0.32 C + 15	r = 0.94
High-N plant biomass		
Fresh	N = 0.52 C + 89	r = 0.77
Digested	N = 0.30 C + 9	r = 0.95

Source: Gilmour *et al*., 1985 Moorhead *et al*., 1987

Conclusion

The two laboratory studies have indicated that N and P fertilizers significantly increase percent straw C decomposition and decomposition rate. The response of straw C decomposition to N fertilizer addition followed the order: Straw + 120 kg N ha^{-1} = Straw + 80 kg N ha^{-1} > Straw + 40 kg N ha^{-1} > Straw alone. On the other hand, straw C decomposition as affected by P fertilizer rates followed the order: Straw + 52.8 kg P ha^{-1} > Straw + 35.2 kg P ha^{-1} > Straw + 17.6 kg P ha^{-1} > Straw alone. Straw C decomposition was higher in P- than N-fertilized treatments, presumably because P is generally the most limiting nutrient in acid, weathered soils of the subhumid and humid tropics in general (Buresh *et al.*, 1997) and in Burundi high altitude soils in particular (Ntiburumusi *et al.*, 1998).

Although our results could not simultaneously be validated under field conditions, they are in agreement with field experiments conducted with similar organic materials and soils in Kenya (Munyampundu *et al.*, 1997). Both studies illustrate the benefit of the combined use of low-quality organic materials and inorganic nutrient sources in enhancing organic material decomposition and increasing total available nutrients for plant uptake.

References

Ajwa, H.A. and Tabatabai, M. A (1994) Decomposition of different organic materials in soils. *Biol. Fert. Soils* 18**:** 175-182.

Buresh, R.J., Smithson, P.C. and Hellums, D.T. (1997) Building soil phosphorus capital in Africa. p. 111-149. In. R.J. Buresh e*t al*. (eds.). *Replenishing soil fertility in Africa* SSSA Spec. Publ. 51. SSSA, Madison, WI.

Castellanos, J.Z., and Pratt, P.F. (1981) Mineralization of manure nitrogen-correlation with laboratory indexes. S*oil Sci. Soc. Am. J.* 45: 354-357.

Clark, M.D. and Gilmour, J.T. (1983) The effect of temperature on decomposition at optimum and saturated water content. So*il Sci. Soc. Am. J.* 47: 927-929.

Gilmour, J.T., Clark, M.D. and Sigua, G.C. (1985) Estimating net nitrogen mineralization from carbon dioxide evolution. S*oil Sci. Soc. Am. J.* 49: 1398-1402.

Goyal, S., Mishra, M.M., Hooda, E.S. and Singh, R. (1992) Organic mater-microbial relationships in field experiments under tropical conditions: effects of inorganic fertilization and organic amendments. S*oil Biol. Biochem*. 24: 1081-1084.

Jones, R.B., Snapp, S.S. and Phombeya, H.S.K. (1997) Management of leguminous leaf residues to improve nutrient use efficiency in sub-humid tropics. p. 239-250. In Cadisch, G. and Giller, K.E. (ed.). Driven by nature: Plant litter quality and decomposition CAB Int., Wallingford, England.

Kelly, J.M., and Henderson, G.S. (1978) Effects of nitrogen and phosphorus additions on deciduous liter decomposition. So*il Sci. Soc. Am. J.* 42: 972-976.

Marion, G.M., and Black, C.H. (1987) The effect of time and temperature on nitrogen mineralization in Arctic Tundra soils. *Soil Sci. Soc. Am. J.* 1501-1508.

Moorhead, K.K., Graetz, D.A. and Reddy, K.R. (1987) Decomposition of fresh and anaerobically digested plant biomass in soil. *J. Environ. Qual.* 16: 25-28.

Munyampundu, A., Okalebo, J.R., Othieno, C.O., Wesonga, J. and Njoroge, R. (1997) Maize, Leucaena leucocephala, Se*sbania sesban growth and yield improvement through combination of crop residues with nitrogen fertilizer in a Kenyan ferralsol.* 13. Paper presented at the 7th TSBF – AfNet Workshop. 10-15 September. Kampala, Uganda.

Nelson, D.W., and Sommers, L.E. (1982) Total carbon, organic carbon, and organic matter. p.539-579. In A.L. Page e*t al.* (ed.). Methods of soil analysis. Part 2. 2nd ed. *Agronomy 9.* ASA, Madison, W.I.

Niyongabo, D. (1986) Etude d'un système cultural: cycle de la biomasse et des éléments biogènes. Cas de la colline de recensement de Nyarushanga. Mémoire. Faculté des Sciences Agronomiques. Université du Burundi.

Nivyiza, J.C. (2001) Effet de l'application des engrais phosphatés sur la décomposition de la paille de blé appliquée dans un sol de haute altitude du Burundi. Mémoire. Faculté des Sciences Agronomiques. Université du Burundi.

Ntiburumusi, F., Ntibashirwa, S. et Nzohabonayo, Z. (1998) Guide sur la fertilisation des cultures au Burundi. Publication ISABU. p. 95.

Olsen, C.R., C.V. Cole, F.S. Watanabe, and L.A. Dean. (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circ. 939. Washington, DC. USDA.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. p. 193-217. In. R.J. Buresh et *al.* (ed.). *Replenishing soil fertility in Africa.* SSSA Spec. Publ. 51. SSSA, Madison, W.I.

SAS. (1996) A *guide to statistical and data analysis using JMP and JMP IN software.* Statistical Analysis System Institute, Inc., Cary, NC.

Sibomana, L. (2001) Effet de l'application des engrais azotés sur la décomposition de la paille de blé dans un sol d'altitude du Burundi. Mémoire. Faculté des Sciences Agronomiques. Université du Burundi.

Stanford, G., and Smith, S.J. (1972) Nitrogen mineralization potentials of soils. *Soil Sci. Soc. Am. Proc.* 36: 465-472.

Stevenson, F.J. (1986) *Cycles of Soil. Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients.* John Wiley & Sons, New York, NY.

Stotzky, G. (1965) Microbial respiration. p. 1550-1569. In Black, C.A. e*t al.* (ed.), *Methods of soil analysis.* Part 2. Agronomy 9. ASA, Madison, WI.

Zarcinas, B.A., Cartwright, B. and Spouncer, L.R. (1987) Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. C*ommun. Soil Sci. Plant Anal.* 180: 131-146.

Zibilske, L.M. (1994) Carbon decomposition. In: Weaver e*t al.* (ed.). *Methods of soil analysis.* Part 2. Microbial and biochemical properties. SSSA. Madison, WI.

11

Evaluation of Crop Availability of K and Mg in Organic Materials under Greenhouse Conditions

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Abstract

A greenhouse investigation using sorghum sudan [(*Sorghum bicolor* (L.) Moench] was conducted to evaluate the availability of K and Mg added in organic materials applied to a Leadvale (fine-silty, siliceous, thermic typic Fragiudult) and Taloka (fine, mixed, thermic mollic Albaqualf) soil series. Organic materials were compared to an N-P_2O_5-K_2O (13-13-13) fertilizer during a 70 days greenhouse study. They were added based on two N rates: 25 and 50 mg N kg^{-1} soil. Percent Mg recovery from added organic materials was substantially lower than that of K. Soybean, corn and wheat residues were found to be important sources of K, as about 40-50 % of K was available from these residues in a 70 days period. Therefore, we recommend that the contribution of these organic materials should be taken into account when formulating K fertilizer programs.

Introduction

Most studies on organic residue decomposition have been done on N, and to some extent P and S mineralization (Kaboneka *et al.*, 1997; Blackmer and Green, 1995; Aoyama and Nozawa, 1993; Janzen and Kucey, 1988; Enwezor, 1976). The few studies on K and Mg release have been performed on foliar litter decomposition in forestry (Bockheim and Leide, 1986; Blair, 1988). Little is known on the availability of K and Mg from organic materials applied to soils of different fertility levels.

The objectives of this greenhouse study were:

i) to evaluate plant uptake of K and Mg from soil-incorporated cattle manure, soybean [*Glycine max* (L.) Merr.], wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) residues;
ii) to evaluate the effect of soil fertility status on K and Mg release from added organic materials.

Materials and Methods

Soil physical and chemical properties have been described elsewhere (Kaboneka *et al.*, 1997; Kaboneka and Sabbe, 1995) and are summarized in Table 11.1. The Leadvale soil was limed with 9.0 g of limestone per pot (2.5 metric tons ha^{-1}) and pots were regularly watered to approximately field capacity for three weeks prior to sorghum-sudan planting to activate the added limestone. Characterization of residues was done by analyzing them for total N by digestion with H_2SO_4 and H_2O_2, followed by steam distillation of appropriate aliquots (Bremner and Mulvaney, 1982). Total plant P, S, Ca, Mg and K were analyzed by inductively coupled plasma (ICP) spectrometry after digestion with HNO_3 and H_2O_2 of a 0.2 g sample at 120° C (Zarcinas *et al.*, 1987). Ash content of residues was determined by dry combustion in a muffle furnace at 550° C for 4 hours.

Results of the analyses expressed on a dry weight basis are presented in Table 11.2. Of these organic materials, cattle manure provided the highest total amount of Ca and Mg, whereas corn and wheat residues provided the highest amount of K.

Polyethylene pots were filled with 3.53 kg of 2-mm sieved air-dried Taloka and Leadvale soil series. Residues were added based on two N rates: 25 mg N kg^{-1} soil and 50 mg N kg^{-1} soil (56 and 112 kg N ha^{-1}, respectively). They were compared to an N-P_2O_5-K_2O (13-13-13) fertilizer. A control (soil only) treatment was also included.

Table 11.1: Selected physico-chemical properties of Taloka and Leadvale soil series

Parameter	Soil	
	Taloka	Leadvale
PH (H_2O)	5.9	4.6
K (mg kg^{-1})	121	20
Ca (mg kg^{-1})	976	188
Mg (mg kg^{-1})	63.5	46.5
Clay (%)	5.9	6.7
Silt (%)	68.8	75.4
Sand (%)	25.3	17.9
O.M. (g kg^{-1})	20	20

Source: Kaboneka and Sabbe, 1995.

Table 11.2: Chemical composition of the plant residues, manure and inorganic fertilizer

Parameter	manure	wheat	soybean	corn	Fertilizer
		Material			
			g kg^{-1}		
N	3.43	9.03	28.47	15.98	130.00
P	0.97	1.33	3.19	2.29	56.80
S	0.49	1.38	2.33	1.24	130.00
K	1.75	9.75	17.40	15.45	107.90
Ca	6.40	4.30	15.30	3.70	9.00
Mg	1.70	0.80	2.65	1.75	3.00

Two successive sorghum-sudan crops were harvested from each pot after 35 days of growth, corresponding to a total of 70 days of nutrient uptake. Twenty seeds of sorghum-sudan were planted each time. Plants were thinned to 10 plants after germination. During plant growth, pots were regularly watered to approximately field capacity. After 35 days, above-ground plant tissues were harvested, dried for 48 hours at 70° C and the dry weight recorded. Dry plant samples were ground for chemical analyses. Experimental treatments consisted of a control (soil only) and five sources of nutrients (chemical fertilizer, manure, corn, wheat, and soybean residues). Treatments were applied to Leadvale and Taloka soil series in a completely randomized design with three replications. Statistical analyses were performed on each of the two sorghum-sudan harvests and on their combination by using the SAS-GLM procedures of the Statistical Analysis System (SAS, 1985). Treatment mean separation was performed by using LSD at the 0.05 level of probability. The LSD values indicated in different tables were used to compare treatments within and across soil series.

Total plant uptake of K and Mg was estimated by multiplying the respective concentration of nutrients by above ground dry matter yield. Net uptake of the two cation nutrients were estimated by difference between the nutrient uptake from respective materials and the control treatment. Percentage recovery of each nutrient was estimated as follows :

Recovery (%) = [(X - Y) / Z] x 100

where
X = Nutrient uptake from fertilized or amended treatments;
Y = Nutrient uptake from the control treatment;
Z = Total amounts of nutrients added in organic or mineral fertilizer materials.

Results and Discussion

Nutrient uptake and recovery did not include nutrients in roots. It was assumed that addition of root biomass and their nutrient content would not affect treatment differences, as was suggested by Broadbent and Nakashima (1965). Effects of soil series, residue type, rate of residue application and their interactions on K and Mg uptake were evaluated by using orthogonal contrast comparisons (Table 11.3).

Table 11.3. Selected orthogonal contrast comparisons and effect of soil, residue, application rate and their interactions on total K and Mg uptake from added residues.

	Pr > F	
Contrast	K	Mg
NPK vs residue	0.0001	0.0001
Control vs others	0.0026	0.6440
Soil	0.0001	0.0001
Residue	0.5420	0.0001
Rate	0.0001	0.3970
Soil * residue	0.0001	0.2490
Soil * rate	0.2310	0.4600
Residue * rate	0.8320	0.5920
Soil * residue * rate	0.0340	0.3050

Potassium Uptake

Potassium uptake for individual and combined harvests are presented in Table 11.4, which indicates higher K uptake in the first harvest. A two-to three-fold decrease between the first and the second harvest was observed for both soils, with the greater decrease occurring in Taloka soil. A similar trend was recorded with sorghum-sudan dry matter yields (Kaboneka and Sabbe, 1995). Analysis of variance and orthogonal contrast comparisons performed on combined K uptake showed significant effects of soil series, residue application rate, soil series × residue type and soil × residue type × application rate interactions on total K uptake. Total K uptake from chemical fertilizer was significantly higher than that from residue treatments. Both fertilizer and residue effects on total K uptake were significantly higher in Taloka than in Leadvale soil. These differences were probably due to the initial exchangeable high K levels in Taloka soil, which was originally six times higher than that of Leadvale soil. K net uptake from all added materials was uniformly positive in Leadvale soil, suggesting an important K release from residues in this soil series. On the contrary, the only positive net K uptake values in Taloka soil occurred with chemical fertilizer and with the higher manure and soybean residue rates.

Table 11.4: Effect of plant residues, manure and chemical fertilizer on K uptake by sorghum-sudan

			Harvest I		Harvest II		Total Harvest	
Material	N rate	K applied	Leadvale	Taloka	Leadvale	Taloka	Leadvale	Taloka
Control	0	0	50.5	199.9	29.5	62.9	80.0	262.8
NPK	25	75.4	126.1	253.4	40.3	61.8	166.4	335.2
	50	150.8	148.3	290.5	59.5	68.5	208.8	359.0
Corn	25	87.8	87.8	168.4	29.7	64.1	117.5	232.5
	50	175.6	108.1	185.9	53.6	71.9	161.7	257.8
Manure	25	46.3	74.3	184.6	26.7	60.3	101.0	244.9
	50	92.6	80.7	232.8	27.8	69.8	108.5	302.6
Soybean	25	55.0	79.7	170.9	29.9	91.1	109.6	262.0
	50	110.0	96.1	185.6	39.7	88.4	135.8	274.0
Wheat	25	98.0	78.0	154.6	38.0	68.7	116.0	223.3
	50	196.0	122.6	145.5	54.0	61.8	176.6	207.3
LSD (5 %)			41.5		23.5		40.4	

The high K uptake in the limed Leadvale soil could be due to the complementary effect of the two cation nutrients on soil cation exchange sites. It has indeed been demonstrated that lime and the Ca ion in general increases soil solution K by exchanging K from soil exchange sites (Tisdale *et al.*, 1985).

Total K recovery from the lower fertilizer rate was 96 % or more in both soils, with the higher percent in Leadvale soil (115 %). K recoveries were 85 % and 64 % with the higher fertilizer rate, respectively. No K was recovered from the lower manure rate nor from other residues in Taloka soil, with the exception of the higher manure rate (43 %). K percent recovery occurred in all residue treatments in Leadvale soil. However, it decreased from 45 to 31 % from the lower to the higher manure application rates. A similar trend was observed with the soybean residues where K recovery decreased from 54 to 51 % from the lower to the higher residue application rate. On the contrary, the opposite trend was observed with corn and wheat residues in the same soil, where high K recoveries occurred with higher residue rates. As a matter of fact, K recovery from corn residue was 43 and 47 % in Leadvale soil, whereas 37 and 49 % of wheat K were taken up by sorghum-sudan from the same soil. However, the data were not significantly different.

Magnesium Uptake

Similarly to K, total Mg uptake decreased from the first to the second harvest, particularly in Taloka soil. Analysis of variance and orthogonal contrast comparisons performed on combined Mg uptake showed significant effects of soil series and residue application on total Mg uptake (Table 11.3). Total Mg uptake from chemical fertilizer was significantly higher than that recorded from residue treatments. Fertilizer effect on total Mg uptake was significantly higher than residue treatments in Leadvale soil. Net Mg uptake was positive with manure in both soils and with the higher soybean rate in Leadvale soil. All other treatments were characterized by negative net Mg uptake, suggesting that Mg immobilization possibly occurred during microbial degradation of added residues. Residue Mg was recovered from manure at both application rates in Leadvale soil and with the lower soybean application rate in the same soil. In particular, as much as 24 and 6 % Mg were recovered from the lower and the higher manure rates in Leadvale soil, respectively. Substantial Mg (31%) was also recovered from the lower soybean residue rate in Leadvale soil. No Mg was recovered from Taloka soil from either applied organic material. In general, percent Mg recovery from added organic materials was substantially lower than that of K.

Although the chemical fertilizer contained little Mg (Table 11.5), the highest Mg uptake was observed with the fertilized treatments as compared to treatments receiving organic materials. One can hypothesize that fertilizer application released Mg from available forms into soil solution. The competition theory as discussed for K can also be applied to Mg. K applied in the chemical fertilizer could have displaced Mg from soil exchange sites into soil solution, where it would have been actively absorbed by the sorghum-sudan crops. The same competition theory could also explain the higher Mg uptake from the fertilizer in Leadvale soil, since this soil received Ca from applied lime. Therefore, we suspect that a double competition between Mg and both Ca and K for exchange sites would have resulted in higher available Mg in soil solution in fertilized and limed Leadvale soil series (Tisdale *et al.*, 1985).

Table 11.5: Effect of plant residues, manure and chemical fertilizer on Mg uptake by sorghum-sudan

			Harvest I		Harvest II		Total Harvest	
Material	N rate	Mg applied	Leadvale	Taloka	Leadvale	Taloka	Leadvale	Takola
Control	0	0	13.8	19.7	22.1	7.8	35.9	27.5
NPK	25	2.1	38.6	21.2	21.8	8.0	59.4	29.2
	50	4.2	29.9	31.2	27.0	5.5	6.9	36.7
Corn	25	9.9	17.3	12.0	12.7	4.9	30.0	16.9
	50	19.8	16.1	10.3	19.3	7.6	35.4	17.9
Manure	25	45.0	6.5	17.3	20.1	6.6	46.6	23.9
	50	90.0	25.1	19.9	16.4	8.8	41.5	28.7
Soybean	25	8.5	17.4	12.4	21.1	8.7	38.5	21.1
	50	17.0	16.9	15.1	12.7	7.9	29.6	23.0
Wheat	25	8.0	10.5	11.7	11.2	5.2	21.7	16.9
	50	16.0	3.9	10.0	13.6	5.9	27.5	15.9
LSD (5 %)			9.6		8.6		10.6	

From our data, we observed that K and Mg release from applied residues followed the order K > Mg. Our results agree with those reported by other investigators. For example, in a decomposition study of dogwood (*Cornus florida* L.), red maple (*Acer rubrum* L.) and chestnut (*Quercus prinus* L.) forest litter, Blair (1988) found that 91 % of K and 58 % of Mg were released after 2 years of decomposition. For all three species, nutrients were released in the order K > Mg. In a similar study on foliar litter and forest floor dynamics in a *Pinus resinosa* stand, Bockheim and Leide (1986) found that cation nutrients were also released in the order K > Mg.

The difference in the two cation nutrient release pattern from plant materials is governed by their structural nature in the plant matrix. Whether a nutrient is a structural or non-structural component of plant tissues will affect its release dynamics during residue decomposition (Blair, 1988; Budelman, 1988). Among the six major plant nutrients, namely N, P, K, Ca, Mg and S, K is the only non-structural component of plant tissue. It is present as a cation freely moving in the cell fluid. Therefore, K release from crop residues is less correlated with biotic factors as compared to other nutrients. Thus, it is easily leached out and rendered available to crops when the cell membranes disintegrate during residue decay.

Conclusion

This study indicated that direct soil application of organic materials could provide substantial amounts of K. In particular, soybean, corn and wheat residues were found to be important sources of K, as about 40-50 % of K was available from these residues in a 70 days period. From the findings of this study, we recommend that K added as crop residues is readily available for plant uptake and should definitely be taken into account when formulating K fertilizer programs.

References

Aoyama, M. and Nozawa T (1993) Microbial biomass nitrogen and mineralization – immobilization processes of nitrogen in soils incubated with various organic materials. *Soil Sci. Plant Nutr*. 39: 23-32.

Blackmer, A.M. and GreenC.J. (1995) Nitrogen turnover by sequential immobilization and mineralization during residue decomposition in soils. Soil *Sci. Soc. Am. J.* 59: 1052-1058.

Blair, J.M. (1988) Nutrient release from decomposing foliar litter of three species with special reference to calcium, magnesium and potassium dynamics. *Plant Soil* 110: 49-55.

Bockheim, J.G. and Leide, J.E. (1986) Litter and forest floor dynamics in a *Pinus resinosa* plantation in Wisconsin. *Plant Soil* 96: 393-406.

Bremner, J.M. and Mulvaney, C.S. (1982) Nitrogen - Total. In Page A.L. *et al*. (ed.). *Methods of soil analysis*. Part 2. 2nd ed. *Agronomy*. 9: 595-624.

Broadbent, F.E. and Nakashima T. (1965) Plant recovery of immobilized nitrogen in greenhouse experiments. S*oil Sci. Soc. Am. Proc.* 29: 55-60.

Budelman, A. (1988) The decomposition of the leaf mulches of L*eucaena leucocephala*, *Gliricidia sepium* and *Flemingia macrophylla* under humid tropical conditions. *Agroforestry Systems* 7: 33-45.

Enwezor, W.O. (1976) The mineralization of nitrogen and phosphorus in organic materials of varying C: N and C:P ratios. Pl*ant Soil* 44: 237-240.

Janzen, H.H. and Kucey R.M.N. (1988) C, N, S mineralization of crop residues as influenced by crop species and nutrient regime. Pl*ant Soil* 106: 35-41.

Kaboneka, S., Sabbe W.E. and Mauromoustakos A. (1997) Carbon decomposition kinetics and N mineralization from corn, soybean and wheat residues. Co*mmun. Soil Sci. Plant Anal.* 28: 1359-1373.

Kaboneka, S., and Sabbe W.E. (1995) Evaluation of the fertilizer value and nutrient releasefrom corn and soybean residues under laboratory and greenhouse conditions. Co*mmun. Soil Sci. Plant Anal.* 28: 1359-1373.

SAS Institute. (1985) S*AS user's guide: Statistics*. Version 5 ed. SAS Institute, Cary, NC.

Tisdale, S.L., Nelson W.L, and Beaton J.D (1985) S*oil fertility and fertilizers*. MacMillan Publishing Company. New York.

Zarcinas, B.A. and Cartwright B, and Spouncer L.R. (1987). Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry. Commun. *Soil Sci. Plant Anal*. 18: 131-146.

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The Influence of Goat Manure Application on Crop Yield and Soil Nitrate Variations in Semi-Arid Eastern Kenya

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Abstract

The effect of manure on crop yield and soil nitrate -N was measured during the 1994-5 cropping season at three sites in Mbeere and Tharaka-Nithi districts of eastern Kenya. The sites were Machang'a in Mbeere district and Mutuobare and Kajiampau in Tharaka Nithi district. The treatments were goat manure applied at rates of 0,5 and 10 t ha^{-1} (dry weight basis), annually since 1989, and 5 and 10 t ha^{-1} annually from 1989 to 1992. The plots were intercropped with sorghum (*Sorghum bicolor*) and cowpea (*Vigna unguiculata*). The grain yields of sorghum varied widely from 0.3 to 3.9 t ha^{-1}, depending on site and manuring. Differences were most marked at Machang'a site. For example, where manure was continuously applied at10 t ha^{-1}, sorghum yield of more than 3 t ha^{-1} was realized as compared to 1.5 t ha^{-1} from the residual plots. Topsoil nitrate concentrations were highest at the start of the season and within about 15 days, most nitrate had been lost. For example, at the Mutuobare site, nitrate N concentration at the start of the season was about 78 mg kg^{-1} in the recently manured plots but decreased to less than 10 mg kg^{-1} 20 days after onset of the rains. A high manure rate of 10 t ha^{-1} resulted in surplus nitrate at the end of the season, hence a maximum manure rate of 5 t ha^{-1}, is suggested to reduce losses of N. Nitrate N correlated well with N taken up by crops at Kajiampau, where N was the main limiting nutrient, but not at Mutuobare and Machang'a, where P was the limiting nutrient. The wide variations of measured nitrate between sites and sampling dates make it unsuitable as a practical indicator of N requirements for crops. Total soil N was correlated with N taken up by the sorghum at all sites and is an appropriate parameter to assess crop requirement to N.

Key words: Goat manure, sorghum, cowpea , yields, soil nitrate

Introduction

It has long been recognized that manure application is one of the most effective ways of improving soil fertility and crop production in tropical African conditions (Dennison, 1961; Watts-Padwick, 1983). For example, in the Nigerian savanna, application of farmyard manure (FYM) at 2.0 t ha^{-1} increased cotton yield by more than 100 % (Hartley, 1937). Similarly, it has been observed that the production, distribution and application of manure has been a vital role in sustaining small-holder arable farming around Kano in northern Nigeria, which is a semi-arid area with a high population and a long history of arable farming.

In semi-arid Kenya, inadequate soil nitrogen (N) and phosphorus (P), restrict crop production (Siderius and Muchena, 1977), so manure and fertilizers can give yield increases in this climate (Ikombo, 1983). Improved cropping systems are needed, which will be both more efficient with plant nutrients and more attractive to farmers. In many areas, such as the semi-arid zones of eastern Kenya, little use has been made of this resource until recently (Gibberd, 1995a). Development projects to improve agricultural production have been undertaken in this region (Gibberd, 1995b) and a part of this program was a multi-location field experiment with manure initiated in nine sites in the semi-arid eastern Kenya.

Nitrate is the main form in which plants take N from soil. It is released from soil organic matter by mineralization, but is then subject to several processes by which it can be lost before plant roots can take it up. In semi-arid climates, nitrate-N concentration is normally highest at the start of the season (Semb and Robinson, 1969; Wong and Nortcliff, 1995). The purpose of carrying out this study was firstly to determine the effect of manure (residual or continuous application) on sorghum and cowpea grain yield. The second purpose was to monitor changes in nitrate concentration in the different manuring regimes and thirdly to establish whether a relationship exists between soil N (total or NO_3- N) and crop yield. The results presented in this paper are part of a long-term trial on soil fertility improvement conducted in several locations in Mbeere and Tharaka- Nithi districts in semi-arid Kenya.

Materials and Methods

Field experiment

The sites were located in Mbeere and Tharaka-Nithi Districts of eastern Kenya. Information on their location, climate and soil is given in Table 12.1.

Table 12.1: Selected characteristics of the sites and unmanured soils in september 1994

	Machang'a	Mutuobare	Kajiampau
Latitude	0°45'S	0°45'S	0° 15'S
Longtude	37°40'E	37° 45'E	37° 45'E
Altitude (m)	1050	900	750
Rainfall (mm)			
Mean Annual	740	809	1040
October to January season	423	497	683
October 1994 to Jan.1995	439	616	862
pH (water)	6.55	6.84	7.10
pH ($CaCl_2$)	5.75	6.18	6.39
Total N (Kjeldahl)(%)	0.066	0.092	0.059
Olsen –P (mg/kg)	0.98	26.3	10.2
Texture	Sandy clay loam	Sandy clay loam	Sandy loam

Rainfall was bimodally distributed with peaks in November and April, exceeding evaporation only in November and December. The soils are classified as Chromic Cambisols. Machang'a and Mutuobare sites both in Mbeere district were cleared from long-term bush, while Kajiampau in Tharaka-Nithi district had been under arable cropping for five years. The field experiment was set up in 1988, but the measurements described in this study were made in 1994/95 season. There were nine sites altogether but three sites were selected for this investigation because of their contrasting soil properties. Machang'a had low extractable soil P (0.98 mg kg^{-1}, Table 12.1), Kajiampau had adequate extractable P but the lowest total soil N, while Mutuobare had adequate N and P. In the season under study, the crops grown were

(i) sorghum (s*orghum bicolor*, var.954066) planted in rows 0.7 m apart of 5 m long and 0.25 m within rows
(ii) cowpea (*Vigna unguiculata*, var. M66) planted at the same spacings in rows placed midway between sorghum rows.

There were seven rows of sorghum of 5.0 m long. The treatments were:

Code Treatments
A1 Goat manure applied annually since 1989 to 1994 at 5 t ha^{-1}
A2 Goat manure applied annually since 1989 to 1994 at 10 t ha^{-1}
B1 Goat manure applied annually from 1989 to 1992 at 5 t ha^{-1}
B2 Goat manure applied annually from 1989 to 1992 at 10 t ha^{-1}
C Control (no manure)

The five treatment were arranged in a randomised complete block design replicated three times. Treatments A1 and A2 therefore, had continuous manuring whereas treatments B1 and B2 showed residual effects of manure. The goat manure was obtained from the Ministry of Agriculture (Marimanti station) in September each year and broadcast and incorporated immediately. The cumulative amount of manure applied from 1989 to October 1994 were 30, 60, 20 and 40 t ha^{-1} in treatments A1,A2, B1 and B2, respectively. The manure applied in September 1994 was analyzed and it was found that the amounts of N, P and K applied with 10 t ha^{-1} manure were 189, 47 and 372 kg ha^{-1}, respectively.

Soil sampling and analysis

The characterisation data of soils presented in Table 12.1 were for bulk samples collected to a depth of 20 cm in September 1994, before cultivation, manure application and sowing. The first sampling was done before the onset of rains while subsequent sampling were done at intervals of 25 days and continued for a period of three months. For measurements of nitrate during the season, five soil cores from 0 to 15 cm were taken using an auger in each plot. This soil was mixed by hand in a bucket, a sample of about 1kg taken and placed in a polyethylene bag. Fresh soil (45 g), was weighed into a polypropylene bottle (250 ml), 1M KCI (200 ml) added and shaken end-over-end (10 revolutions/ minute) for 1 hour on a rotary shaker. Nitrate was measured with a "Heloflow" portable flow injection analyser (WPA Ltd., Ware, UK), using the Griess-Llosvay procedure (Keeney, 1982). In this method, nitrate-N is reduced to nitrate by copperised Cd metal, reacted with N- (1-naphthyl) ethylene diamine dihydrochloride (NEDD) and measured colorimetrically (at 540 nm). The rest of the soil sample was air-dried (25-30°C), for 2 to 5 days in a freely ventilated shed at Machang'a. Dried soils for Machang'a, Mutuobare and Kajiampau under these conditions contain approximately 2% water on an oven-dry basis. Results here are presented on the basis of air dry soil.

Crop harvests

Cowpeas were harvested in January 1995 and sorghum in February 1995. For each crop, the above-ground residues (leaves, stalk and threshing residues) were collected separately. The grains and residues were air-dried (25-30°C) for each plot separately, weighed and sub-samples taken for anlaysis.

Statistical analyses

Initially, data for each site was treated separately. Where required comparisons between sites were made by pooling Standard Errors. Grain yields, N uptakes and soil nitrate at each sampling time was analyzed by ANOVA (Manure treatment × Replicate blocks in the field). Correlations were made between N uptake by sorghum and cowpea in each plot and measured soil total N and soil nitrate at each sampling time. Statistical calculations were done using INSTAT version 5.31.

Results

Crop yields and N uptake

The yields of sorghum depended on site and manuring. In general, yields and N uptake increased in the order of treatments C<B1< B2<A1<A2 (Tables 12.2 and 12.3). Differences were most marked at Machang'a, where, for continuously applied manure, 10 t ha^{-1} manure, whereas for residual manure the earlier application of 10 t ha^{-1} was no more effective than

5 t ha^{-1} for increasing yield. Differences were least marked at Kajiampau, where the manured treatments A1, A2 and B2 slightly differed in yield. However, Kajiampau was the only place cowpeas responded significantly to manure.

Table 12.2: Grain yield (kg ha^{-1}) of sorghum and cowpeas at the three sites

Treatment	Machang'a	Mutuobare	Kajiampau
Sorghum			
C	360	920	627
B1	1580	2267	853
B2	1560	1853	1360
A1	3153	2067	1480
A2	3893	2653	1920
(SE; df=8)	(248)	(124)	(259)
Cowpea			
C	73	1653	1147
B1	400	1733	1133
B2	233	1653	1307
A1	113	1720	1347
A2	527	1827	1520
(SE;df=8)	(190)	(87)	(85)

Standard errors are given in paretheses

Table 12.3: Total nitrogen uptake in grain plus above-ground residues (kg N ha^{-1}) by sorghum and cowpeas at the three sites

Treatment	Machang'a	Mutuobare	Kajiampau
Sorghum N uptake			
C	24.4	53.7	34.9
B1	68.6	114.8	53.4
B2	64.8	101.6	81.3
A1	123.4	111.0	74.2
A2	140.0	141.1	85.3
(SE;df=8)	(15.3)	(12.3)	(10.4)
Cowpea N uptake			
C	5.27	79.5	54.9
B1	24.47	81.5	52.5
B2	12.96	77.2	56.9
A1	8.65	89.4	68.3
A2	29.42	92.0	76.2
(SE;df=8)	(11.85)	(8.3)	(4.5)

Standard errors are given in parentheses

Temporal variations in soil nitrate

Machang'a site

Nitrate concentrations were high at the start of the season and declined in the next 15 days (Figure 12.1), due to leaching or more probably, denitrification. The concentration was higher at day 56, but remained generally low for the rest of the season. It rose again towards harvest time, suggesting that soil N was being mineralized but no longer required by the crop. Although nitrate values were higher in manured soil at the beginning and end of the season, there were no significant differences between treatments on any one occasion (Table 12.4).

Figure 12.1: Nitrate N concentration at Machang'a for different sampling dates

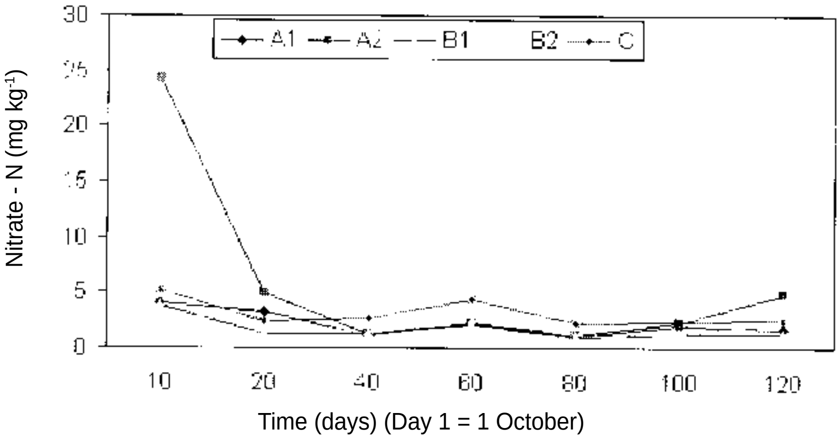


Table 12.4: Effect of manure treatment on soil nitrate N (mg kg^{-1}) in the three sites at the final soil sampling of the season

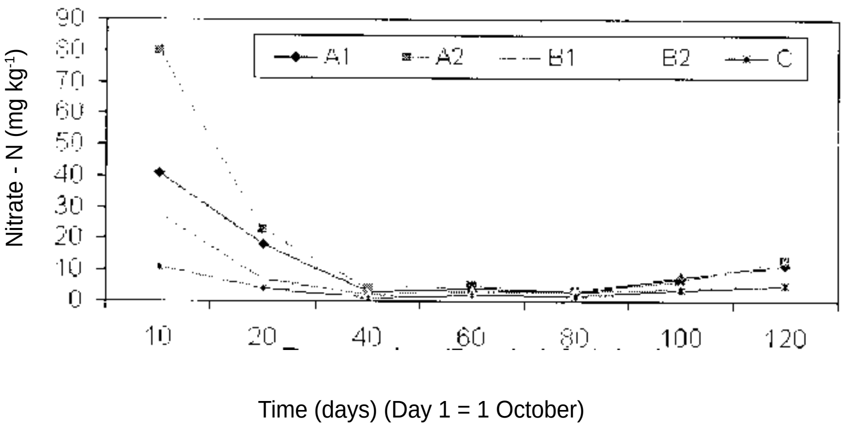
Treatment	Machang'a	Mutuobare	Kajiampau
C	2.89	4.39	1.03
B1	1.29	4.51	0.62
B2	2.10	6.11	0.59
A1	1.66	7.09	1.15
A2	4.56	9.90	1.93
(SE;df=8)	(0.79)	(1.08)	(0.16)

Standard errors are given in parentheses

Mutuobare site

Nitrate was highest at the start of the season and followed a pattern similar to that at Machang'a. At the first two samplings, soil nitrate concentration increased in the order of treatments: C<B1<B2<A1<A2 (Figure 12.2). As would be expected, the higher the manure rate, the more nitrate in recently manured soil (A1 and A2) than in the residual manure plots (B1 and B2). At the second sampling, the difference between treatment groups were significant as follows: C<B<A. In addition, nitrate was significantly less in the control (C) than the other treatments on days 75 and 120. By the end of the season, nitrate was still significantly higher in treatment A2 compared to C (Table 12.4).

Figure 12.2: Nitrate N concentration at Mutuobre for different sampling dates



Kajiampau site

Nitrate was highest at the start of the season and changed in a pattern similar to that at Mutuobare. At the first two samplings, soil nitrate concentration increased as follows: C<B<A (Figure 12.3). As at Mutuobare, the differences were not significant at the first sampling, but were, at the second sampling. Freshly manured soil (treatment A) also contained significantly more nitrate than other soils at days 75 and 116. By the end of the season, the differences between treatments appeared small (Table 12.4), but the difference between A2 and the other treatments was highly significant (P=0.01).

Figure 12.3: Nitrate N concentration at Kajiampau for different sampling date

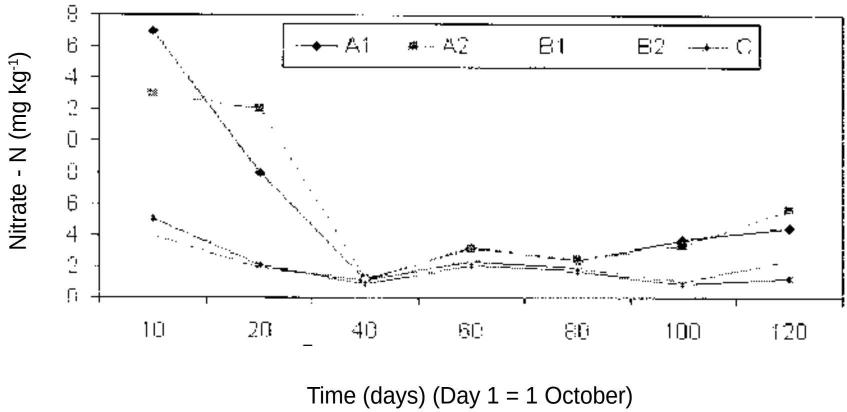


Table 12.5: Correlation coefficients between (i) total N uptake (grain plus residues) by sorghum or cowpeas and (ii) soil nitrate or soil total N

Sorghum N uptake (kg N ha^{-1})			
Planned Sampling Day	Machang'a	Mutuobare	Kajiampau
0	0.628*	0.657**	0.760***
10	0.166	0.423	0.444
25	0.326	0.656**	0.645**
50	-0.337	0.406	0.397
75	-0.503	0.640*	0.678*
100	0.102	0.450	0.310
120	0.077	0.442	0.328
Cowpea N uptake (kg N ha^{-1})			
Planned Sampling Day	Machang'a	Mutuobare	Kajiampau
0	0.171	-0.049	0.524*
10	0.608*	0.345	0.578*
25	0.609*	0.253	0.603*
50	-0.102	0.147	0.641**
75	-0.035	0.359	0.762**
100	0.355	0.374	0.544*
120	0.163	0.137	0.764**

Correlations between N uptake and soil total N and nitrate N

At Machang'a, there were no good correlations of N uptake with soil nitrate although significant correlations at the 5% level were found for cowpeas on day 20 (Table 12.5).

At Mutuobare, N uptake by sorghum and total N uptake were correlated highly significantly with total soil N and nitrate measured at days 26 and 76. Cowpea N uptake did not correlate with soil nitrate. For Kajiampau, N uptakes by both sorghum and cowpeas, total N uptake, correlated significantly with soil total N and also with soil nitrate on many sampling days (Table 12.5). For sorghum N uptake, the closeness of correlation with soil total N increased in the order Machang'a <Mutuobare< Kajiampau, and this correlation was always better than with any nitrate measurements.

Discussion

Temporal variation in soil nitrate

At all sites, large losses of nitrate were observed between the first and second sampling. In the companion experiment at Machang'a, denitrification seemed the most likely loss mechanism, because of the speed of loss (Warren *et al.* 1997). The possibility of substantial denitrification in Kenya soils is supported by laboratory measurements made on a Vertisol and a Phaoezem from western Kenya (Sigunga 1997). Denitrification occurred when the soils were maintained at 60% water holding capacity for four days. Because of periods of prolonged rainfall, these conditions were almost certainly achieved during the season of the field experiment here. The general pattern of nitrate concentration was high at the start of the season, followed by rapid losses at the onset of rain, low levels for a couple of months and a rise towards the end of the season. This is of a particular relevance to the timing of fertility improvement. Mineral fertilizers applied soon before a time of high losses will also be subject to rapid loss and low efficiency. For this reason, basal applications of mineral N are inappropriate, but if manure is used in conjunction with late applied mineral N fertilizer, some synchrony of supply and demand can be achieved as suggested by Murwira and Kirchmann (1993).

Effect of manuring history on soil nitrate

Analyses of the manure applied in October 1994 showed that treatments A1 and A2 received 94 and 189 kg N ha^{-1}. Similar amounts would have been applied in previous years because the source of the manure was the same every year from October 1989. Recently manured soil was able to supply nitrate throughout the growing season as indicated by the often higher amounts of nitrate in manured soils. The clearest evidence came at the end of the season, when at Mutuobare and Kajiampau, nitrate remained significantly higher in treatment A2 compared to C and A1. For the other treatments, there were no significant treatment differences, but the yields and N uptakes, especially for sorghum, were improved in treatments A1, B1 and B2. This suggested that by the end of the season, the readily mineralised N had been taken up by the crops and only more resistant organic matter remained.

For treatment A2, surplus available N was left over at the end of the season, indicated by the raised nitrate concentration. Probably it would be lost at the next rains as mentioned in the preceeding sub-section and two further facts supported this hypothesis. First, measurements of soil total N for all plots in 1993 after 4 years' manuring, showed that the higher rate of manure gave little extra soil N over the low rate (Warren et al., 1997). Second, in the season from October 1994, there was no significant difference between treatments B1 and B2 in yield or N uptake suggesting the same reserve of available N in these two treatments. It is therefore proposed that manure applications may not provide more than 94 kg N ha^{-1} per year (the amount in this experiment) because the extra N is lost.

Transport of manure to the fields presents a problem to farmers. For this reason, there has been several examinations of the relative benefits of applying a small amount of manure frequently or a larger amount at intervals of several years. Grimes and Clark (1962), concluded that in Coast Province, Kenya, an annual application of 3 t ha^{-1} every 3 years were equally effective. In contrast, Gatheca (1970), concluded that 5 or 6 t ha^{-1} every year was better than 20 to 30 t ha^{-1} every 4 or 5 years at Embu, although the latter was a particularly high rate. In the present work, the residual manure did provide extra yield in the fifth season after the last application. We suggest that as long as the maximum rate applied in one season is not so large as to result in losses in the current season, then the rest will be stabilized in soil organic matter. Therefore, it does not matter whether manure is applied every season or in some seasons only.

Differences between sites

Concentrations of nitrate generally increased in the order Kajiampau <Machang'a<Mutuobare (Table 12.3) and since non-leguminous plants obtain most N via nitrate, this confirms that Kajiampau had the lowest available soil N. Differences between soils in the importance of N as a

fertility constraint, were also indicated by the closeness of correlations between N uptake and nitrate or total soil N. Particularly for sorghum, crop N uptake was best related to soil N at Kajiampau but least at Machang'a, suggesting that N was the main deficiency at Kajiampau unlike Machang'a. At Machang'a the unexpected situation arose where soil nitrate was consistently highest in the unmanured treatment from days 49 to 80. Extractable P was very low here (0.98 mg kg^{-1}, Table 12.1) and it is postulated that because P was so deficient, there was surplus N in treatment C. But when extra P was added in manure, the crops were able to utilise N from both manure and soil. Although sorghum N uptake was increased significantly by manure (Table 12.4), the N uptake was not strongly related to soil N.

An intercropped system had been chosen because this is the normal farming practice in most localities of the region. However, this makes interpretation of results more difficult, since the cowpeas would be able to supply at least a part of the N by fixation from the atmosphere. Nevertheless, cowpeas at Kajiampau gave the most significant correlations between nitrate and yield (Table 12.5) and the potential for N fixation here would not be restricted by lack of P. These results indicates that legumes are not net providers of N to soil but also utilise mineralised soil N.

Prediction of N requirements

Worldwide, there is no generally accepted method to test soil for avilable N. In dry climates, the soil nitrate at the start of the season can be a major contributor to the N supply. If measured, the rest of the N required as fertilizer can be calculated , ignoring mineralization. The method was successfully used in the dry climate of southwest USA (Dahnke and Johnson 1990). However, this measurement is of little help in assessing requirements for manure or fertilizer in the circumstances of agriculture in semi-arid Kenya. Nitrate is still the major fraction of soil N that plants can take up, but because of large losses at the start of the rains, nitrate-N had no relationship to the available N later on.

In contrast, the total soil N at the start of the season was always significantly correlated with yield and N uptake for sorghum at every site and is therefore the most reliable indicator of available soil N in these soils. There is a paradox here in that much of the plants N should have been supplied by the manure applied in October, but this N was not included in the total N, which was measured in samples taken in September. The situation may be explained because the manured soils had a supply of N built up by previous manure applications. Each season, a relatively constant proportion of soil organic N is mineralised, between 1 and 3% (Bremner 1967). This is substituted by freshly immobilised N from organic residues. Provided the manuring regime is maintained, total soil N remains proportional to the "steady state" mineralised N which feeds the plants.

Conclusions

The effect of manure on sorghum and cowpea yield depended on the initial soil fertility status of the sites. The highest yield response was recorded in Machanga where soil P was very low. To conserve the fertility value of manure, it is suggested that no more than 5 t ha^{-1} per year of manure should be applied, because at higher rates there was surplus nitrate at the end of the season and this nitrate would probably be lost at the start of the next season. At lower application rates, manure had significant effects in the fifth season after application, so the frequency of application should be of little consequence for overall efficiency. This gives opportunities for labour saving management in scheduling of applications.

At Kajiampau, the crops responded mainly to N in the manure, indicated by close correlations of soil N with crop N uptake, whereas at Machang'a, the crops responded mainly to P in the manure. Although N is supplied from soil to plant roots in the form of nitrate, the amounts of nitrate at any time were not well related to yield and N uptake. Total N is the better indicator of the fertility of soil with regard to N.

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References

Bremner, J.M. (1967) Nitrogenous compounds. In: Mc Laren, A.D., Peterson, G.H. (eds), *Soil Biochemistry Vol. 1*. Marcel Dekker, New York.

Dahnke, W.C., Johnson, G.C. (1990) Testing soils for available nitrogen. In: *Soil Testing and Plant Analysis*, 3rd edition RL Westerman (Ed). Soil Science Society of America, Madison, USA. pp 127-139.

Dennison, E.B. (1961) The value of farmyard manure in maintaining fertility in northern Nigeria. *Empire Journal of Experimental Agriculture* 29: 330-336.

Gatheca, T.W. (1970) The maintenance and improvement of soil fertility under arable crops and grass leys in the first and second rotation cycles of a fertiliser trial at Embu. *East African Agriculture and Forestry Journal* 35:264-252.

Gibberd, V. (1995a) A farmer-friendly research project in semi-arid Kenya. Tropical Science 35:308-320.

Gibberd, V. (1995b) Yield responses of food crops to animal manure in semi-arid Kenya. *Tropical Science* 35:418-426.

Grimes, R.C., Clarke, R.T. (1962) Continuous arable cropping with the use of manure and fertilisers. *East African Agriculture and Forestry Journal* 28:74-80.

Hartley, K.T. (1937). An explanation of the effect of farmyard manure in northern Nigeria. Empire Journal of Experiment*al Agriculture* 19: 244-263.

Ikombo, B.M. (1983) Effects of FYM and fertilisers on maize in semi-arid areas of Eastern Kenya. *Dryland Farming Research in Kenya, East African Agriculture and Forestry Journal* (Special Issue) 44:266-274.

Keeney, D.R. (1982) Nitrogen availability indices. In: *Methods of Soil Analyses*, Part 2. Page, A., Miller, R.H. and Keeney, D.R. Agronomy Monograph No.9 (2nd Edition). American *Society of Agronomy*. Madison, W1, USA.

Murwira, H.K., Kirchmann, H. (1993) Nitrogen dynamics and maize growth in a Zimbabwean sandy soil under manure fertilization. *Communications in Soil Science and Plant Analysis* 24:2343-2359.

Semb, G., Robinson, J.B.D. (1969) The natural nitrogen flush in different arable soils and climates in East Africa. *East African Agricultural Forestry Journal* 34:350-370.

Siderius, W., Muchena, F.N. (1977) Soils and environmental conditions at agricultural research stations in Kenya. Miscellaneous paper no.M5, Ministry of Agricultural University.

Sigunga, D.O. (1997) Fertilizer nitrogen use efficiency and nutrient up take by maize (Zea mays L.) in Vertisols. Chapter 5. PhD Thesis, Wageningen Agricultural University.

Warren, G.P., Atwal, S.S., Irungu, J.W. (1997) Soil nitrate variations under grass, sorghum and bare fallow in semi-arid Kenya. *Experimental Agriculture* 33:321-333

Watts-Padwick, G. (1983) Fifty years Experimental Agriculture.II. The maintenance of soil fertility in tropical Africa: A review. *Experimental Agriculture* 19: 293-310.

Wong, M.T.F., Nortcliff, S. (1995) Seasonal fluctuations of available N and soil management implications. *Fertilizer Research* 42:13-26.

13

Managing Manures Throughout their Production Cycle Enhances their Usefulness as Fertilisers: A Review

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Abstract

Per capital food production lags behind population growth in most parts of sub-Saharan Africa. One of the reasons for this situation is the decline in soil fertility, arising from continuous cultivation where the levels of soil replenishment, by whatever means, are too low to redress the process of nutrient mining. One of the ways to address the problem of the low and declining soil fertility is by using inorganic fertilisers, but use of these inputs in most of sub-Saharan Africa is currently low. High costs, unavailability, marketing problems, poor infrastructure, and the absence of enabling policy environment are major reasons for the low use of inorganic fertilisers. The use of other resources available on farm is therefore increasingly gaining importance. These include green manures, farmyard manure, crop residues and composts. Of these resources, farmyard manure is by far the most important. However, a major limitation in the effectiveness of organic resources is the quality and quantity of these materials. This review paper attempts to define cattle manure quality and discusses some management factors that influence its quality. The paper also suggests some way forward in better use of cattle manures for enhanced crop production.

Introduction

Per capital food production lags behind population growth in most parts of sub-Saharan Africa. One of the reasons for this situation is the decline in soil fertility. The low and declining soil fertility arises from continuous cultivation where the levels of soil replenishment, by whatever means, are too low to mitigate the process of soil mining, whereby the soil fertility is not replaced by new inputs. One of the effective ways to address this problem is by using inorganic fertilisers. This is, however, beset by several problems. Africa's average annual fertiliser use is only 20 kg ha^{-1} against a world average of 96 kg ha^{-1} (Heisey and Mwangi, 1996). In central highlands of Kenya, farmers who use inorganic nitrogen (N) fertilisers do so at rates between 15-25 kg N ha^{-1}, which is far below recommended rates at 40 kg N ha^{-1} and above (Kimani *et al*, 2001). High costs, marketing problems, and poor infrastructure are major reasons for the low use of inorganic fertilisers. The use of other resources available on farm is therefore increasingly gaining importance. These resources include green manures, farmyard manure, crop residues and composts.

Of these resources, farmyard manure is by far the most important. In most farms in central Kenya the manure used is mainly cattle (65%) with the rest comprising sources such as shoats (6%) and poultry (4%) (Kimani *et al.*, 2000). Most of the manures are from own sources (83%) with a very small proportion of farmers (2%) purchasing manure (Kimani *et al.*, 2000). Manures, or other organic inputs applied to the soil control the rate, pattern and extent of growth and activity of soil organisms and provide the source of carbon, energy and nutrients for the synthesis of soil organic matter. Manure can increase the humus content of soils by 15-50%, depending on soil type, in addition to increasing soil aggregate stability and root permeability (Klapp, 1967). In the longer term, as shown in an ongoing experiment (20 years by 1996) in Kabete, Kenya

(Swift *et al*., 1994; Kapkiyai *et al*., 1996), manuring restocks the particulate organic matter fraction better than fresh crop residues. Manure also acts as a buffer, thus improving nutrient uptake for crops grown in acid soils. Using manures alleviates aluminium toxicity and improves the availability of nutrients such as P, particularly in soils with a high P fixation, and sulphur (S) (Simpson, 1986). Manure also supplies essential elements such as Mg, and trace elements which may not be available in commonly used inorganic fertilisers (Simpson, 1986).

However, the use of manure has several drawbacks. Firstly, the farmers cite quantity as a problem, that the manure is usually not enough. Secondly, the quality of manure with regard to nutrient release and crop uptake is poor. In some instances manure has alternative uses such as fuel and house construction material. Despite these drawbacks, manure continues to be an important source of nutrients.

This paper attempts, firstly, to define manure quality. This is followed by a discussion on the improvement of manure quality through better management of animal feed, coupled with improved collection and storage methods. The paper also provides a brief discussion on the effects of combining manures with inorganic fertilisers.

What is manure quality?

Manure quality may simply be defined as the value of manure in improving soil properties and enhancing crop yields. Scientists have used laboratory analysis for nutrient contents as a measure of quality. The perception has been that the higher the nutrient levels, the better the manure quality. More recently the use of nutrient release patterns, using laboratory incubations of manures, and how the nutrient release can be synchronised with crop uptake has been considered a better measure of manure quality. On the other hand farmers have traditionally used their own yardsticks to determine what quality manure is. The challenge is therefore to match the scientist and farmer perceptions to come up with simple decision making tools for defining quality manure without expensive laboratory analysis. An example of laboratory analysis for manure quality determination is given in Table 13.1. While the values given are means, the range is quite variable and wide. For instance, N contents for cattle manures from Kenya range from 0.20-2.2%N, whilst P contents range from 0.08-0.95%.

The farmers of central Kenya use texture, longevity of composting, homogeneity, presence of fungi spores/hyphae, as some of the quality characteristics (Lekasi *et al.*, 1998; Wanjekeche *et al.*, 1999). In Ethiopia, Tigray region farmers distinguish between two types of manure, the ‘husse’ and ‘aleba’, based on the degree of decomposition. The ‘husse’ is well-decomposed and rich in plant nutrients while 'aleba' is less decomposed and has less nutrients (Kihanda and Gichuru, 1999). Table 13.2 shows indicators of manure quality as determined by farmers in West Pokot district, northern Kenya.

Table 13.1: Nutrient contents of farmyard manure samples collected from different countries.

	Nutrient content (%)				
Country	N	P	K	Ca	Mg
UK	1.76	0.24	1.29	0.74	0.34
Kenya	1.62	0.50	1.34	0.26	0.26
Zimbabwe	0.80	0.20	0.85	0.25	0.15
Madagascar	1.10	0.80	0.86	0.85	0.40

Source: Manure management for soil fertility improvement (Kihanda and Gichuru, 1999)

Table 13.2: Indicators of good quality manures used by farmers in Cheptuya village, West Pokot district, northern Kenya.

Indicator	Frequency of farmers
Fine soil-like texture	10
Black-grey colour	12
Longer time of composting	3
Appearance of white caterpillars	5
Lack of heat in the manure	2

Source: Wanjekeche *et al*., 1999

Management factors influence manure quality: Effects of animal feed

Animals fed on high quality supplements produce high quality manures. The high quality supplement would range from feeds concentrates (Lekasi, 2000; Odongo, 1999), to high N content legumes (Delve *et al.*, 1999). Tables 13.3 and 13.4 show the effects of diet supplementation on manure quality, with regard to P and N. The practicality of these findings at the smallholder farm level is doubtful. This is because in most situations farmers feed their livestock opportunistically. This is the feeding situation where a farmer feeds the livestock with whatever feed may be available at a particular time. In general, feeds fluctuate with the rain patterns, where large quantities of high quality are available during wet periods, and low quantities of poor quality dominating during the dry periods. The improved quality associated with improved diets is therefore more practical in the more intensive systems for instance under Zero-grazing units, which are generally associated with farmers with medium to high income.

Table 13.3: Effect of feeding different P supplements on manure P contents.

Diet	% P of the collected manure
Basal diet (Napier grass)	0.24
Busumbu Rock Phosphate	0.70
Mijingu Rock Phosphate	0.45
Bone meal	0.50
Unga commercial feed	0.95

Source: Odongo, 1999, (unpublished)

Table 13.4: Total N content and C:N ratio of faeces obtained from feeding supplemented diets. Percentages indicate supplementation in relation to the total dry matter offered as feed

Faecal sample	Nitrogen (%)	C:N ratio
Barley straw basal diet	0.9	27
15% C. calothyrsus diet	1.4	23
30% C. calothyrsus diet	1.7	22
15% M. axillare diet	1.1	20
30% M. axillare diet	1.2	23
15% poultry manure diet	1.2	27
30% poultry manure diet	1.3	23

Source: Delve *et al*., 1999.

Collection and Storage methods

In the extensive systems, where animals graze freely manuring is done in-situ as the animals graze. Where they are confined overnight at the 'Kraal', the manure collected usually comprises faeces only. The dung is heaped besides the kraal as a continuous process throughout the year. This system is common in pastoral areas of Kenya, such as Maasai land and West Pokot (Wanjekeche *et al., 1999).* Similar methods of manure collection have been reported for the communal grazing areas of Zimbabwe *(Nzuma et al.*, 1998). A limitation in this method of manure collection is that most of the urinary N is leached down the soil profile.

It is also suffices to say that a considerable amount of N is lost via volatilization. During the wet season, the soggy anaerobic conditions may result in denitrification. Where possible, there is therefore need to improve on composting methods, for instance in areas characterised by intensive farming.

Methods of Composting

The purpose of composting is to allow further microbial decomposition. Methods of composting include surface heaps, pitting and deep litter systems. In Zimbabwe, Nzuma *et al*., (1998) compared pit and heap composting, with or without straw additions. They showed that manures composted for three months using pit method was of higher quality (N content) than the surface heap. These differences of N contents in the manure could be related to the pH of the manures during the composting process. In the heaps, where conditions are aerobic, the manure pH is normally high (8-9). This tends to stimulate N losses via volatilization. On the other hand, manure stored under anaerobic conditions tends to produce organic acids that lead to a lower pH (<7), and therefore fewer losses of N via volatilization (Kihanda and Gichuru, 1999). A threshold moisture content of 40-60% is recommended for composting with a view to enhancing fertiliser value. Table 13.5 shows different composting methods and the effects on quality. Farmer cattle manure from a traditional system of central Kenya has manures with a lower N concentration compared with improved composting systems, other than the Maasai manure. The stable system is where the animal is confined throughout. Feed is provided on the stable floor, and the animal feeds on what is necessary and tramples on the rest, mixing it with the urine and faeces. In faeces, urine and feed refusals (F+U+FR), the animal is fed from a trough and the refusals are collected on a daily basis and put in the zero-grazing unit, where they are mixed by the animal through trampling. F+FR refers to the system where animals are fed from a trough. The feed refusals and faeces are collected daily and heaped in a covered storage area, outside the stable, where they are mixed manually. F+U refer to the system where the faeces and urine only are mixed by the animal in the stable. Faeces alone (F) is the system where only the faeces are composted, in a heap outside the stable, with no urine. Other than the farmer practice and the Maasai, the other composting systems were done at a research station, where composting period was 90 days. Details of the procedures of all these systems are provided by Lekasi (2000).

Table 13.5: N and C:N ratios of manures under different composting systems

Type of manure/composting	N%	C:N ratio
Farmer cattle manure	1.1	31
Stable	1.6	23
F+U+FR	1.7	21
F+FR	1.9	19
F+U	1.5	24
F	1.6	25
Maasai cattle manure	0.8	32

Source: Lekasi, 2000. Faeces (F), Urine (U) and Feed Refusals (FR)

The results show that composting process affects C:N ratios. Subsequent work in the field showed that manures with high N contents resulted in higher N mineralisation and a better crop performance, with the exception of Maasai kraal manure (Lekasi, 2000).

Composting in Zero-grazing Systems

In zero grazing units, it is important to manage manures to enhance fertiliser quality. Where animals are confined this way, the land sizes are generally small, for some of them as small as 0.01 ha, for instance in Kiambu and Muranga districts of central Kenya. In the high potential areas, manures combined with feed refusals are of superior quality compared with faeces alone (Table 13.5). The added feed refusals help to conserve urinary N, by minimising leaching losses, apart from providing a conducive environment for aerobic decomposition. This composting method thus reduces environmental problems associated with leaching of nutrients.

According to studies by Lekasi (2000), a small scale farm can produce cattle manures that are able to supply 100 kg N within a period of six months, and this supply may be in excess of the farm requirement for a 0.01 ha small farm in densely populated Kiambu district of central Kenya. This raises a question as to why farmers in the central Kenya highlands continue to indicate that they do not have enough manures (Makokha *et al*., 2001). It is probable that manures produced may be of low quality, rather than quantity, and therefore not effective in raising crop yields, to the satisfaction of farmers. The finding thus highlight the possibility that what may be required in the high potential areas of central Kenya may be a better focus on manure quality and management. Such results also indicate the possibility of selling the excess manures elsewhere, thus providing a source of income to those farmers with surplus manure.

The studies by Lekasi (2000) also bring another dimension to manure quality. For instance, Maasai cattle manure with a low N concentration 0.8% was more superior to increasing maize yields when compared to feedlot Zero-grazing manure produced under experimental conditions (N = 1.6%) . The Maasai manure is usually collected from a kraal, where animals stay overnight after grazing. It is usually dry and dusty and of a finer tilth compared with the manure collected from zero-grazing units which is wet (usually 70% moisture), and aggregated into clods. It is possible that the fine tilth of the Maasai cattle manure provides a high surface area of application (when the manure is broadcast). The higher microbial activity releases nutrients readily for crop uptake in these Maasai manures compared to the feedlot ones , which comprise of moist clods and are more difficult to distribute in the soil. This raises questions as to whether farmers need to dry and grind manure for enhanced effectiveness.

Improving manure effectiveness by placement methods

The placement method also influences the effectiveness of manures. In a trial conducted at Thika, central Kenya, placing manure in a planting hole, as farmers commonly do, resulted in higher maize yields compared with broadcast manures. The yields were 3.5 t ha^{-1} and 1.3 t ha^{-1} for hole and broadcast treatments respectively (Kimani, 1999); Lekasi, 2000), where manures had been applied at an iso-N level of 75 kg ha^{-1}.

Improving manure effectiveness by combining with mineral fertilisers

The interaction between manures and inorganic fertilisers is increasingly becoming an important subject of research. A combination of organic-inorganic nutrient sources is thought to improve the synchronization of nutrient release and subsequent uptake by the crop. For example, the synchrony between N release and uptake is thought to be best achieved under a combined application of manures and inorganic fertilisers. This is particularly so when the manures are available on-farm, where only modest application of inorganic fertiliser are applied. The concept of organic-inorganic combinations (Table 13.6) has been demonstrated in central Kenya by Kimani *et al.*, (2001), where the combinations resulted in higher maize grain yields. The increased maize yields above an unfertilised control were 60%, 50% and 40% for mineral fertiliser alone, fertiliser-manure combination, and manure alone, respectively, in a single season (Table 13.6). Manure 1 and 2 had N contents of 1.8% and

1.6% respectively, and differed in composting methods whereby manure 1 consisted of faeces (F) alone plus feed refusals (FR) and was manually turned in a heap. On the other hand manure 2 consisted of faeces and feed refusals and was mixed by the animal via trampling in the animal housing. Both manures were composted over a period of four months and were applied at the rate of 75 kg N ha^{-1}. The small differences in N contents may therefore not result in significant differences in grain yields associated with the two manures, though both differed significantly compared with the control.

Table 13.6: Effects of manures when applied singly or in combination with mineral fertilisers on maize yields in Kariti, central Kenya long rains 1998. Manures were applied to supply 80 kg N ha^{-1}

Treatment	Grain yields t ha^{-1}
Control (no soil amendments)	2.53
100 kg N ha^{-1}	7.51
40 kg N ha^{-1}	5.36
20 kg N ha^{-1}	5.09
Manure 1 (F+FR manual mix)	4.82
Manure 2 (F+FR animal mix)	5.08
Manure 1 + 20 kg N ha^{-1}	5.64
Manure 1 + 40 kg N ha^{-1}	6.01
Manure 2 + 20 kg N ha^{-1}	5.75
Manure 2 + 40 kg N ha^{-1}	6.33
Lsd 0.05	1.03

Source: Kimani *et al.*, 2001. F, faeces alone; FR, feed refusals, either manually mixed or mixed by the animal in the stable, and composted for 4 months

Conclusions

This review shows that managing manures, through animal feed sources, or by composting can enhance fertiliser value. Quality parameters, based on laboratory measurements are available, although there is dire need to relate them to on-farm management systems. This would lead to production of simple extension manuals that relate management factors with quality, on-farm. Manure placement method will influence its effectiveness as a fertiliser. Hill placement produces a higher yield, at least during the first season of application. Recent studies indicate that in small farms (less than 1 ha), there is possibly excess manure, which is an opportunity to increase the financial situation of farmers through off-farm sales for the better-managed manures. There is need to monitor effects of excess nutrients with regard to environmental conservation.

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References

Delve, R.J., Tanner, J.C., Kimani, S.K., Giller, K.E., Cadisch G. and Thorne, P.J. (1999) Effects of dietary nitrogen source fed to steers on faecal nitrogen, its mineralisation, and the vegetative responses in maize to the incorporation of the faeces in soil. 1999. In: CIMMYT and EARO 1999. Maize production Technologies for the future: Challenges and Opportunities. Proceedings of the 6th Regional maize conference for Eastern and Southern Africa. Addis Ababa, Ethiopia September 21-25, 1998. pp. 282-285.

Heisey, P.W. and Mwangi, W.M. (1996) Fertiliser use and maize production in sub-Saharan Africa. Economics Working Paper 96-10. CIMMYT, Mexica.

Kapkiyai J., Woomer, P. Qureshi, J., Smithson, P. and Karanja N. (1996) Effects of Fertiliser and Organic Inputs on Soil Organic Matter and Nutrient Dynamics in Kenyan Nitisol. Paper presented to the International Symposium "Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems", Harare, Zimbabwe, 29 April-4 May 1996.

Kihanda, F.M. and Gichuru, M. (1999) Manure management for soil fertility improvement. TSBF/AHI Report.

Kimani, S.K. (1999) Integrated use and effects of manures with modest application of inorganic fertiliser in maize production on central Kenya. Progress Report No. 3 to the Rockefeller Foundation, Nairobi.

Kimani S.K., Odera M.M and Musembi, F. (2000) Factors influencing adoption of integrated use of manures and fertilisers in central Kenya. Proceedings of KARI Scientific Conference. November, 2000.

Kimani SK, Mangale, N. Gichuru, M., Palm, C.and Wamuongo, J. (2001) Integrated Use and Effects of Manures with modest Application of Inorganic Fertiliser on soil properties and maize production in the central Kenya Highlands. Final Technical Report to the Rockefeller Foundation. May 2001.

Klapp, E. (1967) Lehbuch des Acker- und Pflanzenbaus. 6. Aufl. Parey, Berlin. 603 pp. As cited in Karl *et al*., (1994). pp. 381-437.

Lekasi, J.K., Tanner, J.C., Kimani, S.K. and Harris P.J.C. (1998) Manure management in the Kenya highlands: Practices and Potential. Emmerson Press, Kenilworth, UK.

Lekasi, J.K. (2000) Manure management in the Kenya highlands: collection, storage and composting strategies to enhance fertiliser quality. PhD Thesis. Coventry University, UK

Makokha, S, Kimani, S.K., Mwangi, W., Verkuijl H. and Musembi, F. (2001) Determinants of fertiliser and manure use in maize production in Kiambu district, Kenya. Mexico, D.F.: International Maize and Wheat Improvement Centre (CIMMYT) and Kenya Agricultural Research Institute (KARI).

Nzuma, J.K., Murwira, H.K., and Mpepereki,J. (1998) Cattle manure management options for reducing nutrient losses. Farmer perception and solutions in Magwanda, Zimbabwe. In: Waddington, S.R., Murwira, H.K., Kumwenda, J.P.T., Hikwa, D. and Tagwira, F. (eds). The soil fertility research for maize-based systems in Malawi and Zimbabwe. CIMMYT. Pp. 183-190.

Odongo, N. (1999) Effects of Rock P fed to cattle as supplement and the resultant manure quality. Unpublished PhD study. University of Guelph, Canada.

Simpson, K. (1986) Manures. In: Fertilisers and Manures. Longman, London pp. 83-108.

Swift, M.J., Seward, P.G.H., Frost, J.N., Qureshi, J. and Muchena, F.N. (1994) Long-term experiments in Africa: developing a database for sustainable land use under global change. p. 229-251. In: R.A. Leigh and A.E. Johnson (eds.). Long-term Experiments in Agricultural and Ecological Sciences. CAB International, Wallingford, UK.

Wanjekeche, E., Mwangi, T., Powon, P. and Khaemba, J. (1999) Management practices and their effects on nutrient status of farmyard manure in West Pokot district, Kenya. Paper presented at the 17th Conference of the Soil Science Society of East Africa, Kampala, Uganda. 6th -10th August 1999.

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Simulated Partitioning Coefficients for Manure Quality Compared With Measured C:N Ratio Effects

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Abstract

Livestock manures comprise an important source of nutrients in many farming systems. However, the quality of manure is generally variable depending on composting, storage and handling. This in turn results in different manure responses with regard to the release of nutrients for crop uptake. Recent studies have shown that there is a wide scope to better manage manures to improve quality, and the field performance. Simulation modelling, for example using APSIM, is a useful tool in exploring improved strategies for management of manures, with regard to enhancing fertiliser quality. This paper discusses some concepts behind APSIM Soil-N module and attempts to simulate responses for different quality manures. The manures were collected from farmer's fields in central Kenya and compared with a feedlot-managed manure. The C:N ratios of these 9 manures ranged from 13 to 32. Fresh organic matter (FOM) in manures was partitioned into different pools of carbohydrate, cellulose and lignin fractions. Simulations on net N mineralisation for C:N ratios of 10, 15 and 25, using APSIM were done. The measured responses were compared for manures with different C:N ratios of these manures, against net N mineralisation as determined in a laboratory incubation study. Whilst the measured responses showed an initial nitrogen immobilisation, the simulated responses showed net N mineralisation from time 0 up to 100 days, for manures with a C:N ratio of 13-22. Manures with C:N ratio above 30 showed net immobilisation throughout the experimental period for the simulated responses.

Introduction

The use of inorganic fertilisers can overcome most of the soil fertility decline in Kenya but the use of inorganic fertilisers in smallholder farms is associated with several constraints. A survey in Kiambu district, Central Kenya listed high cost of fertiliser and unavailability as major constraints to fertiliser use in maize production (Makokha *et al.*, 2001). An alternative to inorganic fertilisers is the utilisation of farm-derived sources of crop nutrients such as crop residues, composts and farmyard manure. In most smallholder farms of central Kenya cattle manure is the most widely used organic fertiliser, at approximately 80% of the households (Makokha *et al.*, 2001). This arises from the higher livestock populations in these areas. About 90% of farmers use manure from their farms, while 10% either purchase or are given free. However, in majority of farms, the manure is not enough to fertilise the farms (Makokha *et al.*, 2001; Kihanda and Gichuru, 2000; Kagwanja, 1996). These manures are usually of poor quality and are particularly low in total N, with most having less than 1% N . In comparison, legume cover crops can have over 3% N (Palm *et al.*, 2000). Animal manures are of major importance in nutrient cycling but generally of poor quality to supply plant nutrients (Giller *et al.*, 1997). In addition other factors, for example, improvement in soil physical conditions such as improved moisture retention and addition of nutrients, in addition to N, play an important role in farming systems (Kihanda and Gichuru, 2000). Simulation models can be useful in predicting, designing and evaluating effects of applied treatments. However, quality data is required in order for simulation models to be validated. This work was an attempt to use Agricultural Systems Simulation Model (APSIM) for defining manure quality, with regard to N release.

This study compared simulated partitioning coefficients for manure quality compared with measured C:N ratio effects, using APSIM model

Simulation modelling

The residue module of APSIM has provision for surface residues to be incorporated into the soil, or to decompose *in situ*. This enabled the simulation of the laboratory incubation experiment. Manures vary in composition, being a complex mixture of animal excreta and plant residues that has undergone varying degrees of composting/ decomposition and may be mixed with varying amount of soil. Some of the nutrients contained in manure will be in forms that are immediately available for crop uptake, and some will undergo further decomposition before they become available. This concept of nutrient availability has a time dimension, therefore nutrients in manure show a wide range of availabilities.

In this study, the manure fresh organic matter pools were fractionated into three components, carbohydrate-like, cellulose-like and lignin-like fractions. These components depicted nutrient compositions ranging from those that are water soluble to very recalcitrant. The APSIM residue module fractionates the manure pools into percentages of 20:70:10 respectively for carbohydrate, cellulose and lignin.

For our study, low quality manure was fractionated at 0:1:99 respectively for carbohydrate, cellulose and lignin. Improved quality manure was fractionated at 0:50:50, and best quality manure had 33:33:34 respectively for carbohydrate, cellulose and lignin. These three partitioning coefficients were used as a scenario to simulate net N mineralisation at C:N ratios of 10, 15 and 25. The model showed a higher sensitivity to C:N ratio of organic inputs, compared with the fractionated components (Figures 14.1 and 14.2). The model also simulated immobilisation of N for C:N ratio of 25 up to 100 days of incubation. However, the model did not simulate the initial mineral N immobilisation, commonly observed in incubation experiments (Figure 14.3).

Figure 14.1: Partitioning coefficient effect on simulated net mineral N (Treatment – Unfertilised control). Part 1 (0:1:99), Part 2 (0:50:50), Part 3 (33:33:34), at CN ratios of 10 (CN10), 15 (CN15) and 25 (CN25).

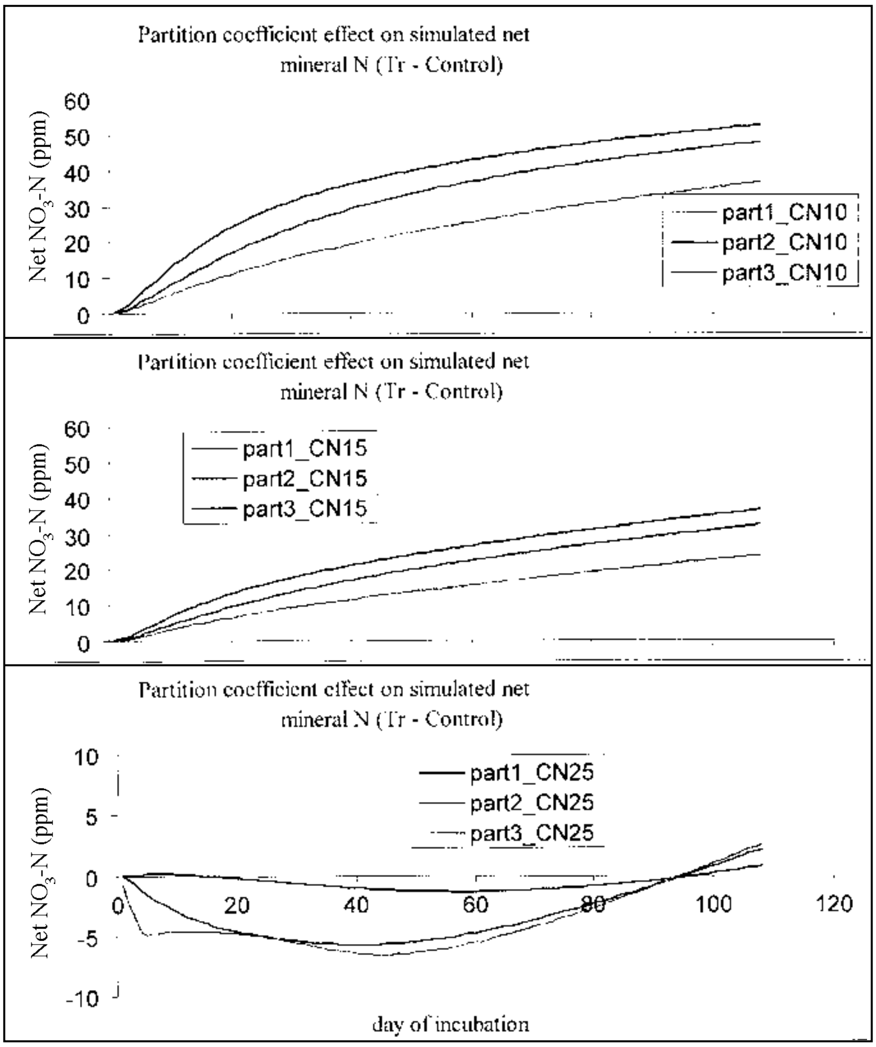


Figure 14.2: Simulated net mineral N (Treatment-unfertilised control) for partition 2 (0:50:50), at CN ratios of 10, 15 and 25

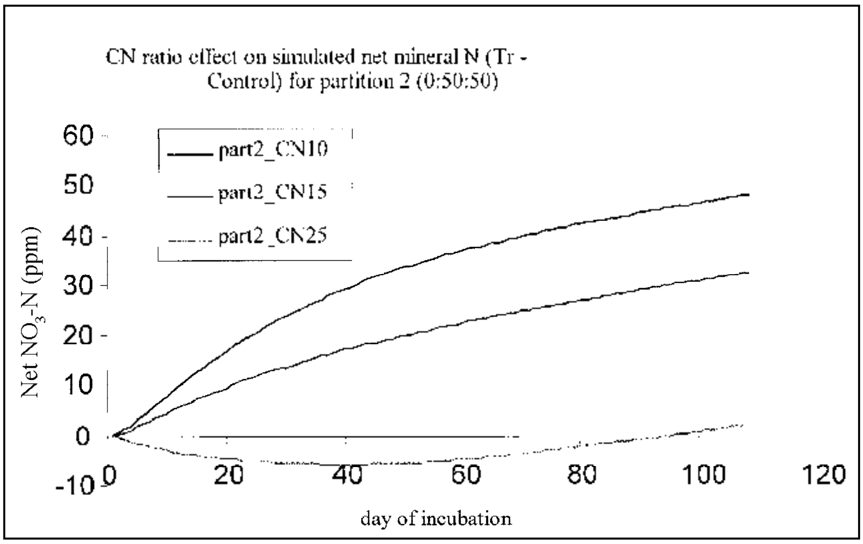


Figure 14.3: Measured responses for N release in the Muguga incubation experiment

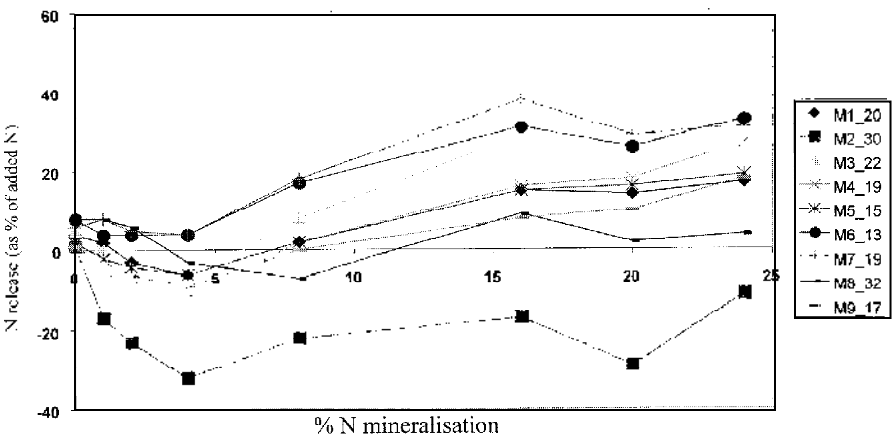
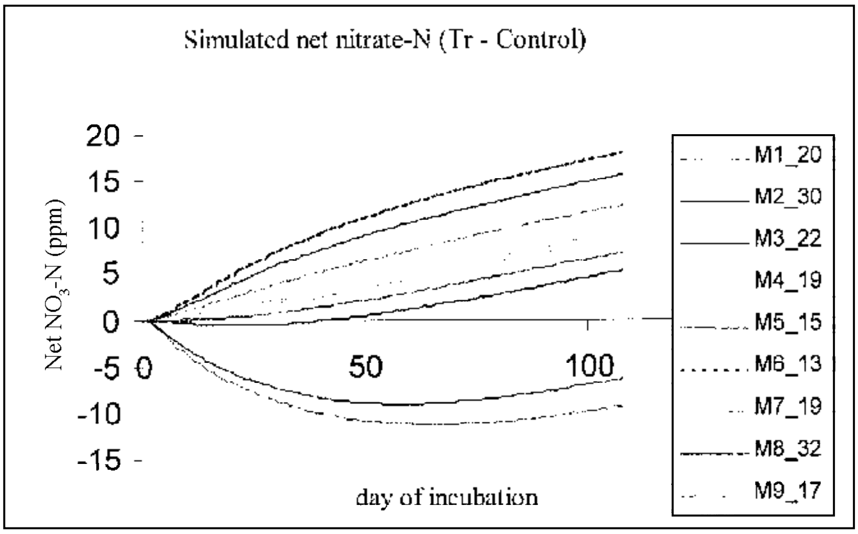


Figure 14.4: Simulated net nitrate N (Treatment – Unfertilised control) for the Manure incubation experiment at Muguga



APSIM simulation of an incubation experiment conducted at Muguga

Nine manures were selected for this study. Their characteristics are briefly described in Table 14.1. Carbon and Nitrogen were measured at various extraction times during the incubation using methods described by Anderson and Ingram (1993). The simulated responses showed net N mineralisation from time 0 up to 100 days, for manures with a C:N ratio of 13-22. Manures with C:N ratio above 30 showed net immobilisation throughout the experimental period for the simulated responses.

Table 14.1: Manures used in the simulation of the Muguga incubation study

Manure	Description	% N	% C	C:N ratio
M1	on-station	1.7	34.6	20
M2	on-farm	1.1	32.7	30
M3	on-farm	1.3	28.4	22
M4	on-farm	1.5	29.1	19
M5	on-farm	1.2	17.7	15
M6	on-farm	1.9	24.9	13
M7	on-farm	1.6	30.3	19
M8	on-farm	0.9	28.5	32
M9	on-farm	1.8	30.6	17

% N mineralisation

Manures with the high C:N ratio immobilised N throughout the 100 days of incubation (Figure 14.4). There was again no initial N immobilisation for these runs, suggesting the need to make some improvements on the model parameters.

Conclusions

APSIM is a model that has been widely used, for instance to analyse management options and help improve farmers' and scientists' understanding of the soil-crop system (McCown *et al.*, 1998). It is likely that the wider application of APSIM has been for field data, for example in New South Wales, Australia (Turpin *et al.*, 1998), and other areas in Australia (Probert *et al.*, 1995; Probert *et al.*, 1998). For these laboratory experiments, whilst the measured responses showed an initial nitrogen immobilisation, the simulated responses showed net N mineralisation from time 0 up to 100 days, for manures with a C:N ratio of 13-22. Manures with C:N ratio above 30 showed net immobilisation throughout the experimental period for the simulated responses. This probably suggests the need to improve the model to show some initial N immobilisation.

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References

Anderson, J.M. and Ingram, J.S.I. (1993) Tropical Soil Biology and Fertility. A Handbook of Methods. C.A.B. International. Wallingford, U.K. Bull. No.9. The Sulphur Institute, Washington, U.S.A.

Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W.D., and Mafongoya, P.L. (1997) Building soil nitrogen capital in Africa, In: Buresh, R.J., *et al.*, (Eds.). Replenishing Soil Fertility in Africa. SSSA Special Publication No. 51. SSSA, Madison, WI, pp. 151-192.

Kagwanja, J.C. (1996) Determinants of Farm Level Soil Conservation Technology Adoption: Lessons from the High rainfall, Highly Populated, Steep Sloped Mt. Kenya Highlands, Embu, Kenya. PhD Thesis, University of Missouri, Columbia.

Kihanda, F.M. and M. Gichuru. (2000) Manure management in East and Southern Africa: A synthesis report. AHI/TSBF.

Makokha, S., S. Kimani, W. Mwangi. H. Verkuijl, and F. Musembi. (2001) Determinants of Fertilizer and Manure Use in Maize Production in Kiambu District, Kenya. Mexico, D.F.: International Maize and Wheat Improvement Centre (CIMMYT) and Kenya Agricultural Research Institute (KARI).

McCown, R.L., Hammer, G.L., Hargreaves, J.N.G., Holzworth, D.P., and Freebairn, D.M. (1996) APSIM: a novel software system for model development, model testing and simulation in agricultural systems research. Agric. Systems 50:255-271.

McCown, R.L., Carberry, P.S., Foale, M.A., Hochman, Z., Coutts, J.A. and Dalgeish, N.P. (1998) The FARMSCAPE approach to farming systems research. In: Michalk, D.L. and Prately, J.E. (eds.) Agronomy – Growing a greener future. Proceedings of the 9th Australian Agronomy Conference. Charles Sturt University, Wagga Wagga, pp. 633-666.

Palm, C.A., Giller, K.E., Mafongoya, P.L., and Swift, M.J. (2000). Management of organic matter in the tropics: translating theory into practice *Nutr. Cyc. Agroecosystems*. In Press:

Probert, M.E., Keating, B.A., Thomson, J.P. and Parton, W.J. (1995) Modelling water, nitrogen and crop yield for a long-term fallow management experiment. *Australian Journal of Experimental Agriculture* 348:941-950.

Probert, M.E., Carberry, P.S., McCown, R.L. and Turpin, J.E. (1998) Simulation of legume-cereal systems using APSIM. *Australian Journal of Agricultural Research* 49:317-327.

Turpin, J.E., Hayman, P.T., Marcellos, H. and Freebairn, D.F. (1998) Nitrogen fertiliser decisions for wheat on the Liverpool Plains NSW 1. Should farmers consider paddock history and soil tests? In: Michalk, D.L. and Prately, J.E. (eds.) Agronomy – Growing a greener future. Proceedings of the 9th Australian Agronomy Conference. Charles Sturt University, Wagga Wagga, pp. 761-764.

15

Nitrogen Fertilizer Equivalency Values for Different Organic Materials Based on Maize Performance at Kabete, Kenya

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Abstract

Decline in crop yields has been a major problem facing small holder farming in Kenya and the entire sub-Saharan region. This is attributed mainly to the mining of macronutrients due to cropping without external addition of adequate nutrients. Inorganic fertilizers are expensive hence unaffordable by most small holder farmers. Although organic nutrient sources are available, information about the right proportions of application is scanty.

An experiment was set up in 1999 at the National

Agricultural Research Laboratories (NARL) at Kabete, with the overall objective of determining nitrogen fertilizer equivalencies based on high quality organic inputs. The specific objectives of the study included determination of the nitrogen fertilizer equivalency values of *Tithonia diversifolia*, *Senna spectabilis* and *Calliandra calothyrsus* and the investigation of nitrogen use efficiency from combined organic and inorganic inputs.

The experiment consisted of maize plots to which freshly collected leaves of *Tithonia diversifolia* (tithonia), *Senna spectabilis* (senna) and *Calliandra calothyrsus* (calliandra) (all with % N >3) obtained from hedgerows grown *ex situ* (biomass transfer from outside) and urea (inorganic nitrogen source) were applied. Results obtained indicated that a combination of both organic and inorganic nutrient sources gave higher maize grain yield than when each is applied separately, except for tithonia whose sole application gave better grain yield than a combination of the same with mineral fertilizer. Maize grain yield production after organic and inorganic application was in the order of tithonia > tithonia+urea = calliandra+urea > urea > senna+urea > calliandra > senna > control. The percentage N recovery was highest in sole application of urea followed by a combination of both urea and tithonia while sole application of tithonia biomass had relatively lower percentage N recoveries. In both seasons, the mineral N content was high in sole application of tithonia than in senna and calliandra treatments. The three organic materials (senna, calliandra and tithonia) gave fertilizer equivalency values of 68%, 72% and 119% respectively.

Key words: N fertilizer equivalency, mineral-N, N-recovery

Introduction

Decline in soil fertility is an acute problem facing small holder farming in Kenya. Due to the high cost and uncertain availability of inorganic fertilizers, it is important to provide alternative sources of nutrients such as organic materials. In the recent past there has been increased interest in the use of leaf biomass from woody perennials as a source of nutrients to annual crops (Kang *et al.*, 1990; Palm *et al.*, 1997; Mugendi *et al.*, 1999). The big challenge to this approach is ensuring that crops efficiently utilize nutrients from the applied organic materials. Synchronizing release of nutrients from decomposing biomass with crop demand could lead to increased nutrient-use efficiency (Becker *et al.*, 1994; Mwale *et al.*, 2000b), and this in turn could minimize nutrient loss (Swift, 1987; Myers *et al.*, 1994; Mugendi *et al.*, 1999). The use of organic materials of differing quality in combination with inorganic fertilizers to optimize nutrient availability to annual crops is still a challenge to scientists currently.

Much research has been done to determine the use of organic plant materials as a source of nutrients in place of inorganic fertilizers and most of this research has revealed both advantages and disadvantages of combining nutrient sources (Palm *et al.*, 1997). However, little predictive understanding for the management of organic inputs especially in tropical agroecosystems is available (Palm *et al.*, 2001). It has been therefore difficult to give valid advice to farmers on the best organic N source for direct application and the right combinations with inorganic N source.

Although organic N sources have the potential to supply large quantities of N required by growing crops, to obtain maximum production and for more sustainability, they should be supplemented with inorganic fertilizers (Mugendi, 1997; Jama *et al.*, 2000; Vanlauwe *et al.*, 2001). The combination of inorganic N fertilizer with organic N sources is said to increase the rate of decomposition and mineralization (Mugendi *et al.*, 1999) of low quality materials. This coupled with the right time of application can improve synchrony of the N released from the decomposing biomass and nutrient requirement by annual crop, thereby, reducing N losses. This postulation is however, yet to be ascertained.

This research was therefore aimed at shedding light on the combined use of organic (tithonia, senna and calliandra) and inorganic N sources for farmers in the central region of Kenya. In addition, the study will provide information to link the fertilizer equivalency of organic materials (specific amount of an organic material that can have same effect on crop yield as a certain amount of inorganic fertilizer) with the resource quality as well as investigating the influence of N source on N uptake by maize.

Materials and Methods

Site description

The experiment was carried out at the National Agricultural Research Laboratories (NARL), Kabete, Kenya. The station is located at 36°46'E and 01°15'S and an altitude of 1650 m above sea level. The soils are mainly Humic Nitisols (FAO, 1990) that are deep and well weathered, and with the following chemical characteristics: pH =5.4; total N = 1.35g kg^{1}; extractable P = 27mg kg^{-1}; carbon = 1.6%; exchangeable Ca, Mg, and K (cmol kg^{1}) of

5.8, 1.7, and 0.7 respectively; clay = 40%; sand = 23%; and silt = 37%. The mean annual rainfall is about 950 mm received in two distinct rainy seasons; the long rains (LR) received mid March to June and the short rains (SR) received mid October to December. The rainfall amount during the study period is shown in figure 15.5. The average monthly maximum and minimum temperature is 23.8°C and 12.6°C respectively.

Experimental design and treatments

The experiment was designed and established by Tropical Soil Biology and Fertility (TSBF) Programme in 1999 with the aim of determining fertilizer equivalency values based on high quality organic materials. The experiment was a completely randomised block design (CRBD) with 10 treatments replicated 4 times. The plot size was 5.25 m by 5 m with an interplot spacing of 0.75 m. Urea and freshly collected leaves of tithonia, senna and calliandra (Table 15.1) were applied directly into the plots after which maize was planted. Collection of the organic materials was done by hand at the same location for both seasons. The leaves included the petioles, and in the case of senna and calliandra, they also included the rachis since these two have compound leaves. The calculation of the application amount of organic materials (that would give 60 kg N ha^{-1})(Table 15.2) was done on dry matter basis giving 1.3, 1.8 and 1.9 t ha^{-1} for tithonia, senna and calliandra respectively. The percentages (%) indicated in Table 15.2 refer to the specific amount of N that was applied as different treatments in kg ha^{-1}.

Table 15.1: Chemical properties of plant materials used at NARL, Kabete, Kenya

Sample	%N	%P	%K	%Ca	%Mg	%PP	%Lignin
Season 1 (1999 short rains)							
Tithonia	4.7	0.5	5.1	3.0	0.2	2.5	5.2
Senna	3.7	0.2	2.0	0.9	0.2	3.4	10.7
Calliandra	3.2	0.1	1.0	1.1	0.3	9.9	14.4
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8
Season 2 (2000 long rains)							
Tithonia	4.0	0.4	5.5	2.2	0.4	1.9	9.3
Senna	3.1	0.1	1.8	0.9	0.2	1.8	10.9
Calliandra	2.4	0.1	0.7	1.1	0.3	12.4	17.5
sed	0.2	0.03	0.3	0.3	0.1	1.0	1.8

Abbreviations: PP= Polyphenols
sed = Standard error of differences

Table 15.2: Experimental Treatments at NARL Kabete, Kenya.

Trt.	Inorganic N (kg ha^{-1})	Organic N (kg ha^{-1})
1. * (Control)	0	0
2.	30	30 (50% tithonia)
3.	0	60 (100% tithonia)
4. *	60	0
5.	30	30 (50% senna)
6.	0	60 (100% senna)
7.	30	30 (50% calliandra)
8.	0	60 (100% calliandra)
9. *	35	0
10. *	100	0

* These are the treatments that were used in plotting of the response curve, which was used in the calculation of the nitrogen fertilizer equivalency values of the three organic inputs.

Selection of tithonia, senna and calliandra as the organic N sources was based on their contrasting qualities with respect to polyphenols and rates of decomposition (Gachengo *et al.*, 1999; Mutuo *et al.*, 1999). The chemical characteristics of these three organic inputs used for the two cropping seasons are shown in Table 15.1.

Sampling and analyses

Plant samples were oven-dried at 35°C for 48 hours then ground to pass through a 1.0 mm sieve and analyzed for total N, P, K, Ca, and Mg by Kjeldahl digestion with concentrated sulfuric acid (Anderson and Ingram, 1993; ICRAF, 1995). Nitrogen and phosphorus were determined colorimetrically (Parkinson and Allen, 1975) while potassium was by flame photometry (Anderson and Ingram, 1993). Magnesium and calcium was by atomic absorption spectrophotometer at wavelength of 2852 and 4227 respectively. Determination of lignin was done using the acid detergent fiber (ADF) method as described by Van Soest (1963). Total soluble polyphenols were analyzed by extraction using 50% aqueous methanol (Anderson and Ingram, 1993). The plant material to extractant ratio was 0.1 g / 50 ml and phenols were analyzed colorimetrically using the Folin-Ciocalteu reagent as described by Constantinides and Fownes (1994).

Data Analysis

Fertilizer equivalency value

Fertilizer equivalencies (FE) of organic materials were obtained by comparing the yield from the organic material treatments to that of the nitrogen (N) response curve from inorganic N fertilizer (Mutuo *et al.*, 1999). Calculation for the corresponding N fertilizer equivalent for an organic material was obtained from the quadratic equation ($Y = aFE^2 + bFE + c$) exhibited by the N response curves. The following formula for solving quadratic equations was used:

$$FE = \frac{-b \pm \sqrt{b^2 - 4ac)}}{2a}$$

Where a, b, and c are constants, with values -0.0001, 0.0252, and 1.8297 respectively for 1999 short rains (Figure 15.1) and -0.0001, 0.0284, and 2.0827 respectively for 2000 long rains (Figure 15.2).

Figure 15.1: Season 1 biomass yield response to levels of N at NARL – Kabete, Kenya, 1999

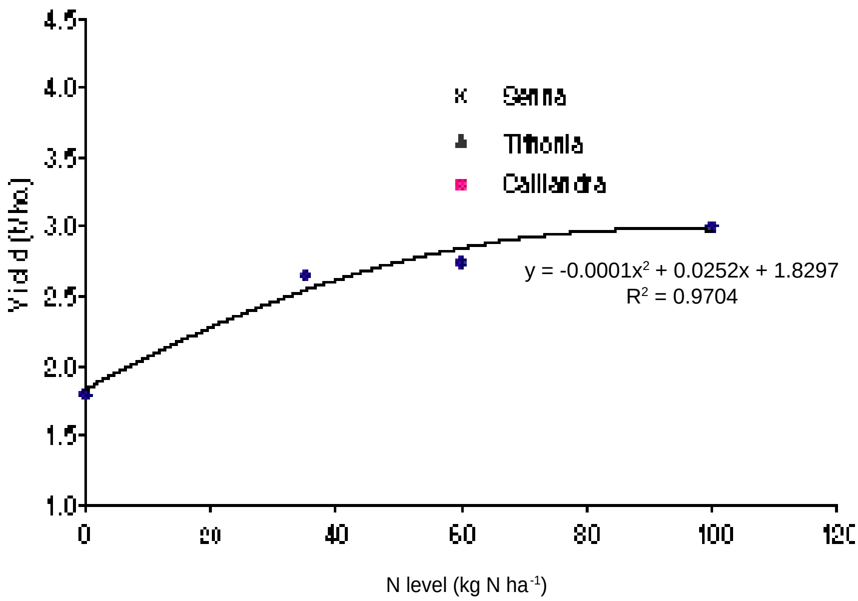
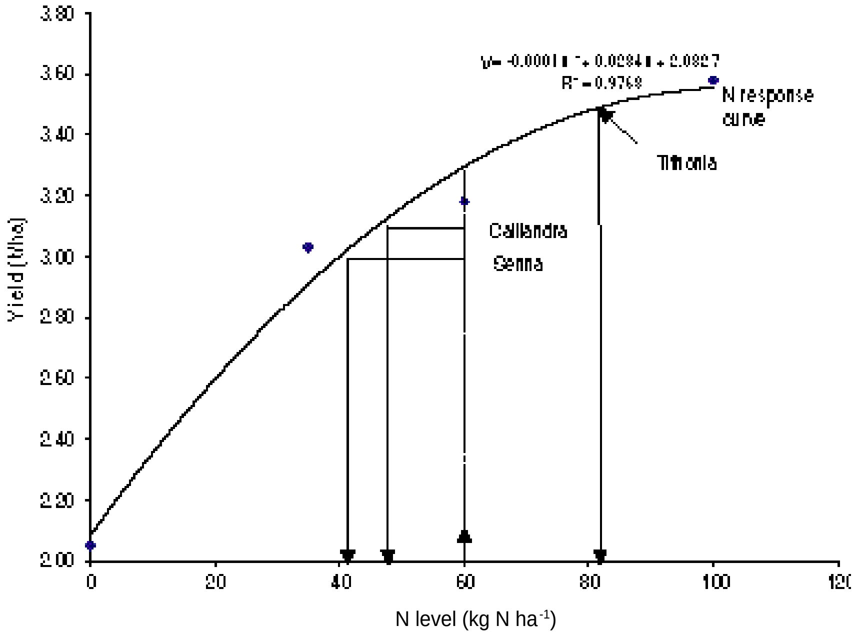


Figure 15.2: Season 2 grain yield response to N levels at NARL – Kabete, Kenya, 2000



In order to compare the fertilizer equivalencies of organic materials, the fertilizer equivalency (FE) % values were calculated as follows:

$$\%FE = \frac{FE}{N\ applied} \times 100$$

Where: N applied = actual amount of N applied (100% organic/inorganic).

Source: Mutuo *et al.* (1999).

Maize yields

To compare treatment effects on maize grain yield, yields were converted to relative increase compared to the control:

$$\text{Yield increase (\%)} = \frac{(\text{Yield}_{\text{treatment}} - \text{Yield}_{\text{control}})}{\text{Yield}_{\text{control}}} \times 100$$

(*Source:* Gachengo *et al.*, 1999)

Nitrogen uptake

Nitrogen uptake by the maize crop was determined by multiplying the grain, stover and core yields with the nitrogen concentration in the specific components. Nitrogen recovery was determined as shown below:

$$\text{Nitrogen recovery (\%)} = \frac{(\text{N uptake}_{\text{treatment}} - \text{N uptake}_{\text{control}})}{\text{Amount of nitrogen applied}} \times 100$$

Statistical comparisons

Treatment effects on soil N availability and maize yield were analyzed using Genstat 5 for windows (Release 4.1) computer package. Treatment means found to be significantly different from each other were separated by Least Significant Differences (LSD) at $P < 0.05$.

Results and Discussions

Nitrogen fertilizer equivalencies of tithonia, calliandra and senna

The study sought to attain this by investigating the performance of maize crop supplied with green leaves from the organics as compared to maize grown with urea as N source. Due to poor rainfall distribution during the 1999 short rains, maize crop was harvested six weeks before maturity hence no grain yields were obtained. Biomass yield data was therefore used in calculating the fertilizer equivalencies for the organics. Results obtained showed that maize biomass yields were 3.3, 3.6 and 3.9 t ha^{-1} for 60 kg N ha^{-1} of calliandra, tithonia and senna treatments respectively. As shown in Figure 15.1, these yields were higher than the biomass yields from any of the inorganic N source treatments whose highest yield was only 3.0 t ha^{-1}. Thus, the values for the yields obtained from the three organic materials fell high above the response curve. Hence, the fertilizer equivalencies for the organic materials could not be estimated from the N response curve. These differences in the yields obtained from the organic and inorganic N sources could be attributed to the poor rainfall distribution during that growing season and the timing of the N application. Much of the rainfall was received late November, 1999 and early December, 1999 and scarcely any rainfall in January, 2000 which was the tussling stage for the maize. Also, the fact that all the 60 kg N from the organics was applied when there was moisture (at planting) unlike for urea which was applied in split (20 kg N at planting and 40 kg N applied after five weeks) could also be a partial explanation for the better performance of the maize crop supplied with the organics. This is mainly because the application of the second split of the urea was followed by a dry spell. Hence, the growing maize crop might not have utilized this portion of the urea, thus leading to the low maize biomass yields from urea treatment. The relatively high biomass yield from organic treatments could also be due to other positive effects of the organic materials on soil physical properties (like moisture retention) and chemical properties (other micronutrients like calcium and magnesium) (Chen and Avnimelech, 1986; Wallace, 1996; Mutuo *et al.*, 1999).

A better maize performance was observed during the 2000 long rains season. Maize grain yields from the organic treatments were 3.6, 3.1 and 3.0 t ha^{-1} for 60 kg N ha^{-1} tithonia, calliandra and senna respectively compared to the highest yields from urea treatments of about 3.6 t ha^{-1} (Figure 15.2). This gave fertilizer equivalency values of 119%, 72% and 68% for tithonia, calliandra and senna. The implication was that tithonia biomass performed better than an equivalent amount of inorganic fertilizer in improving maize grain yield while calliandra and senna performed relatively lower to an equivalent amount of inorganic N source. The high fertilizer equivalency value for tithonia compared to the other two organic materials (senna and calliandra) could be attributed to its low polyphenol content compared to senna and calliandra. Hence, decomposition rate and subsequent N release is higher in tithonia green biomass (Gachengo *et al.*, 1999) as compared to senna and calliandra (Lehmann *et al.*, 1995). The N content in the material also influence decomposition and N release as Mutuo *et al.* (1999) noted in different sites in East and Southern Africa. The conclusion was that fertilizer equivalency value of organic materials is proportional to the N content. However, from the results we obtained, the fertilizer equivalency values for senna and calliandra (68% and 72% respectively) did not differ significantly despite the 3.1 and 2.4% N content in the two organic materials. This could be an indication of more conspicuous residual effect (from season one) in the calliandra treatment than in senna treatment.

Fertilizer equivalency values for tithonia and calliandra were almost twice the values reported by Mutuo *et al*. (1999) for the same organic materials in their trial in Western Kenya. This could be attributed to the difference in the climatic conditions. Western Kenya received adequate rains, while the Central region (Kabete trial site) was characterized by poor rainfall distribution during the two seasons when this research was carried out.

As per the study findings, tithonia green biomass can be recommended for direct application while senna green biomass can be applied in combination with inorganic fertilizer. Calliandra leaf biomass on the other hand may not be recommended for direct application due to the high polyphenol content (11.1%) as compared to the suggested critical level of 4.0% (Palm *et al.*, 1997; Palm *et al.*, 2001) and also because of it's low nitrogen content (2.4% N). Therefore, as suggested in the organic matter management decision tree (Delve *et al.*, 2000; Palm *et al.*, 2001), calliandra leaf biomass may give better results when mixed with inorganic N fertilizer.

Maize performance as influenced by the N source

Maize yields were dependent on the N source (Figure 15.3 and Figure 15.4). During the 1999 short rains, biomass yield obtained from a combination of either of the three organic inputs with inorganic N source differed significantly from biomass yield obtained from sole application of inorganic N source (Figure 15.3). It was also found that maize biomass yield obtained from tithonia + urea treatment was significantly higher compared to maize biomass yield obtained from sole tithonia and sole urea treatments. Approximately twice as much maize biomass yield was obtained with combination of tithonia and urea as compared to urea applied alone. This could be an indication of better results in combining organic and inorganic N source, which could be attributed to better synchrony of nutrient availability to maize crop demand. Separate application of either tithonia or urea did not show significant differences.

Sole application of senna green biomass and a combination of the same with urea had significantly higher maize biomass yield than urea applied separately. Calliandra, calliandra + urea and sole urea treatments did not show any significant differences from each other. It was also found out that the control gave significantly lower maize biomass yield compared to all the other treatments.

Figure 15.3: The effect of combining organic-inorganic N sources on maize biomass yield during 1999 short rains at NARL – Kabete, Kenya

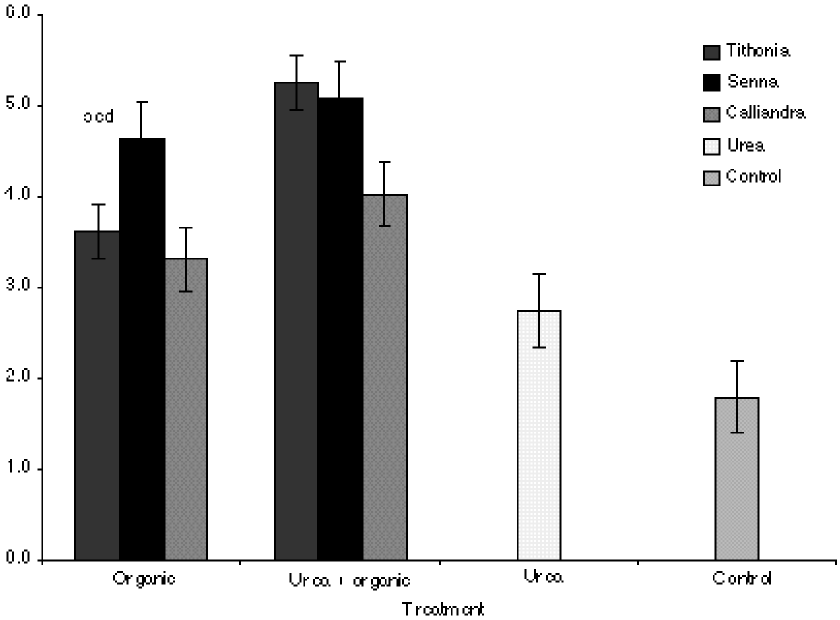


Figure 15.4: The effect of combining organic-inorganic N sources on maize grain yield during 2000 long rains at NARL – Kabete, Kenya

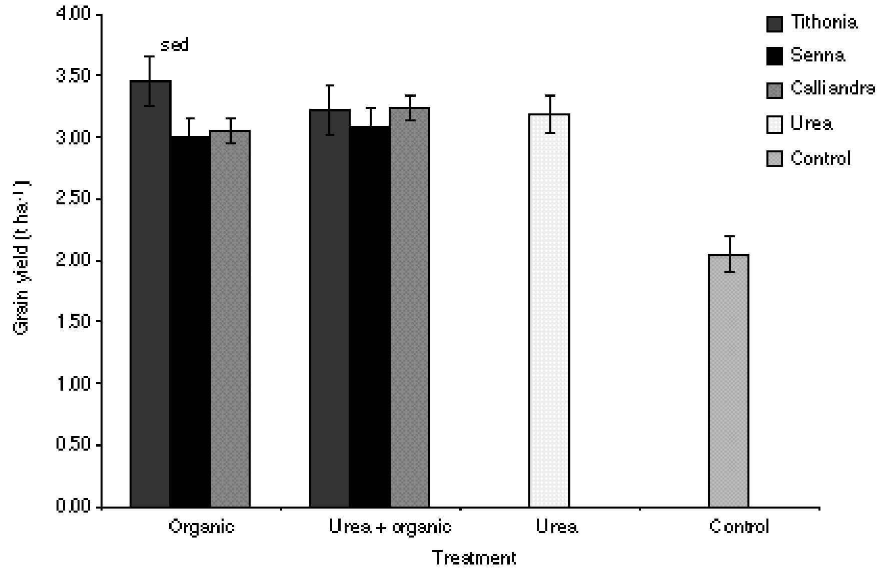
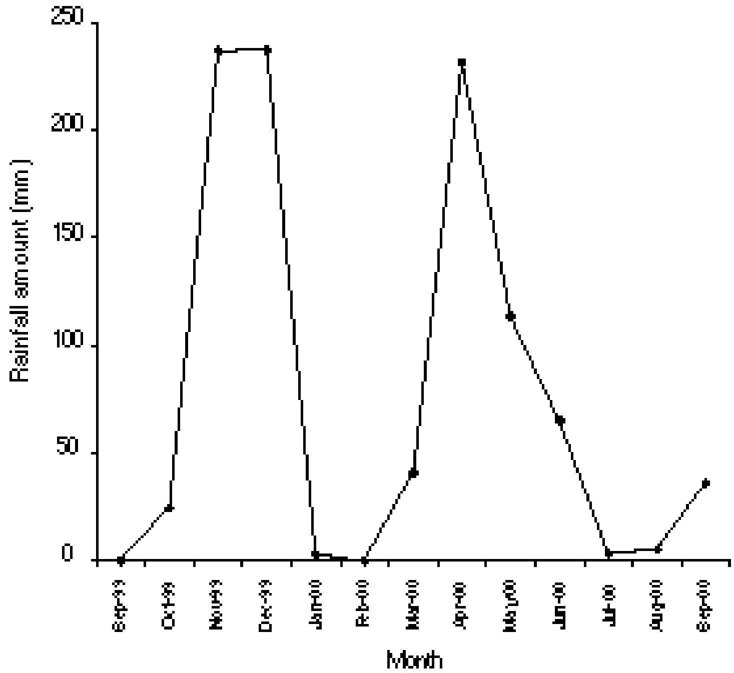


Figure 15.5: Rainfall data (1999-2000) at Kabete, Kenya



Similar results were reported by Jama *et al*. (2000) who observed higher maize yields obtained from a combination of tithonia and phosphorus fertilizer in their work in western Kenya. Other researchers have observed greater maize production through application of high-quality organic inputs like tithonia in combination with inorganic fertilizer as compared to sole application of mineral fertilizers (Gachengo, 1996; Palm *et al*., 1997).

Results obtained during the 2000 long rains season revealed that all other treatments had significant increase on maize grain yield above the control (Figure 15.4). Tithonia green manure increased maize grain yield by about 71.4% while calliandra and senna increased grain yield by 48% and 43% respectively. A percentage grain yield increase of about 52% above control was realized from sole urea treatment. Maize grain yields from combined use of organic-inorganic N sources were dependent on the organic material used. Although there was significantly higher maize grain yield from tithonia green biomass as compared to senna and calliandra, grain yield obtained from sole application of any of the organic materials and a combination with mineral fertilizer did not significantly differ from each other.

The relatively better results realized from tithonia sole application than a combination with mineral N source and sole application of urea (though not significantly different) could still be attributed to other indirect effects to the soil such as moisture retention (Wallace, 1996; Lehmann *et al*., 1999) and addition of other macro- and micronutrients. Nziguheba (2001), also reported increase in maize growth with application of tithonia green biomass which (in addition to increased N availability), was attributed to increased labile P as compared to inorganic inputs.

As noted also during 1999 short rains, time of application might have as well played a major role in maize performance. All the tithonia green biomass was applied at once at planting when there was rain while only one third of the urea was applied at planting. Two thirds of the urea was applied five weeks later, which was followed by a dry spell, hence, insufficient amounts of the urea N were available to the growing crop.

Lower maize grain yields obtained from sole application of either calliandra or senna, could be attributed to N immobilization or reduced N release as Mwale *et al*. (2000b) also noted in their study at Chalimbana, Zambia. Other researchers also observed that, large portion of N from a slowly decomposing biomass may be incorporated into soil organic matter fractions (Lehmann *et al*., 1999) or immobilized into forms not readily available to annual crops (Mugendi *et al*., 1999). Therefore tithonia green biomass can be recommended for direct incorporation for soil fertility improvement (Delve *et al*., 2000; Palm *et al*., 2001).

Nitrogen uptake and total %N recovery by maize

The results revealed that, nitrogen concentration in the grain, stover and core yields differed significantly among N sources (Table 15.3). Nitrogen uptake ranged from 93.3 to 131.9 kg ha^{-1}. From the study findings, it was noted that the inorganic fertilizer (urea) applied treatment gave the highest N uptake while control had the lowest. Tithonia + urea and urea treatments were significantly higher than the control. Above ground yield from urea sole application had about 131.9 kg ha^{-1} total N uptake while tithonia + urea gave 114.3 kg ha^{-1}. This relatively high N uptake from the two treatments could be attributed to the readily available N from the urea. The N uptake by maize that received tithonia green biomass alone as nitrogen source was about 97.6 kg ha^{-1}, which was not significantly different from the control.

Table 15.3: Nitrogen recovery by maize crop in long rains 2000 at NARL, Kabete, Kenya

Treatment	N applied (kg N ha^{-1})	Nitrogen uptake (kg N ha^{-1})	%N Grain	%N Stover	Total % N recovery
Control	0	93.3	1.7	0.63	N/A
Tithonia + Urea	60	114.3	1.9	0.9	35
Tithonia	60	97.6	1.8	0.8	7.2
Urea	60	131.9	2.0	1.1	64.3
sed	-	16.4	-	-	N/A

The apparent percentage N recovery by maize crop that received sole tithonia green biomass was found to be 7.2% while 35% was recovered in tithonia + urea treatment. Sole urea treatment had a 64.3% nitrogen recovery. However, these values might not have reflected the actual N recoveries by the maize. This is because the material used was not labelled hence it was not possible to follow up the applied nitrogen (either in organic or inorganic form). Therefore, calculated total % N recovery values obtained in the study were meant to be estimates to the actual recoveries.

Nitrogen recovery by the maize crop that received sole application of urea and the one that received a combination (inorganic-organic N source), was significantly higher compared to nitrogen recovered by maize that received sole tithonia green biomass. The high N recoveries by maize crop planted in sole urea and tithonia + urea applications were an indication that there was less N loss from soil-plant system. Therefore, the growing maize crop took up a large percentage of the N supplied by either the inorganic or inorganic-organic inputs. This justifies split application of urea.

Grain yield accounted for a greater portion of the recovered N than either stover yield or the core. This was also noted by Mugendi *et al*. (2000) in their work in the subhumid highlands of Kenya.

Other researchers working on different N sources (organic and inorganic inputs) also reported a percentage N recovery ranging from 25% to 111% (Westerman *et al.*, 1972; Kruijs *et al.*, 1988; Christianson *et al.*, 1990; Gachengo *et al.*, 1999). In this study, nitrogen recovery values from tithonia green biomass was found to be relatively lower than the values Gachengo *et al*. (1999) observed using the same organic material in a study in Western Kenya. This could be due to differences in environmental conditions especially rainfall distribution between the two sites. However, the N recovery value from inorganic fertilizer (urea) agrees with the findings of Chabrol *et al*. (1988) in a study in Bedfordshire, England as well as what Mugendi *et al.* (1999) found out in their studies in the subhumid highlands of Kenya.

Conclusions

Tithonia had a fertilizer equivalency value of 119% while calliandra and senna had 72% and 68% respectively. The extent to which an organic material will perform comparable to mineral fertilizer, is dependent on several factors especially the quality of the organic materials, climatic factors and site characteristics. Although higher biomass and grain yields were obtained from tithonia sole application compared to sole urea application, maize crop supplied with sole urea was found to recover nitrogen at a higher rate than maize crop supplied with tithonia biomass. It is evident that the effect of external inputs on crop N use efficiency is dependent on the organic material used and climatic conditions (especially rainfall amount) prevailing throughout the growing period of the annual crop.

Tithonia diversifolia can be used as a source of nitrogen in place of mineral fertilizer and smallholder farmers should be encouraged to use tithonia green biomass for annual crops especially in areas of inadequate rainfall. *Senna spectabilis* and *Calliandra calothyrsus* green biomass should be recommended for use in combination with inorganic N source for better results. A similar research should be recommended for other organic materials and at different agroecological zones as well as to establish other specific beneficial effects of organic inputs on annual crop yields.

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References

Anderson, J.M. and Ingram, J.S.L. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, U.K.

Becker, M., Ladha, J.K. and Ottow, J.C.G. (1994) Nitrogen losses and lowland rice yield as affected by residue nitrogen release. *Soil Science Society of America Journal* 58: 1660-1665.

Chabrol, M., Powlson, D.S. and Hornby, D. (1988) Uptake by maize (Zea mays L.) of nitrogen from 15N-labelled dazomet, 15N-labelled fertilizer and from the soil microbial biomass. *Soil Biology and Biochemistry* 20: 517-523.

Chen, Y., Avnimelech, Y., (Eds) (1986) The role of organic matter in modern Agriculture. Martinus Nijhoff Publishers, Dordrecht. The Netherlands.

Christianson, C.B., Bationo, A., Henao, J. and Vlek, P.L.G. (1990) Fate and efficiency of N fertilizers applied to millet in Niger. *Plant and Soil* 125: 221-231.

Constantinides, M. and Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and polyphenol concentrations. *Soil Biology and Biochemistry* 26: 49-55.

Delve, R., Gachengo, C., Adams, E., Palm, C., Cadisch, G. and Giller, K.E. (2000) The Organic Resource Database. In: The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998. PP 20-22.

FAO (Food and Agriculture Organization) (1990) New Environmental Threat: Declining Soil Fertility. Land and Water Technical Newsletter.

Gachengo, C.N. (1996) Phosphorus release and availability on addition of organic materials to phosphorus fixing soils. M.Phil. thesis. Moi University, Eldoret, Kenya.

Gachengo, C.N., Palm, C.A., Jama, B. and Otieno, C. (1999) Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. Agroforestry Systems 44**,** 21-36.

ICRAF (1995) Laboratory Methods for Soil and Plant Analysis: Version 1.1. Nairobi.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A., Gachengo, C., Nziguheba, G. and Amadalo, B. (2000) Tithonia diversifolia as a green manure for soil fertility improvement in western Kenya: A review. *Agroforestry systems* 49: 201-221.

Kang, B.T., Reynolds, L. and Atta-Krah, A.N. (1990) Alley farming. *Advances in Agronomy* 43: 315-359.

Kruijs, A. C. B. M. van., Wong, M. T. F., Juo, A.S.R. and Wild, A., (1988) Recovery of 15N-labelled fertilizer in crops, drainage water and soil using monolith lysimeters in south-east Nigeria. *Journal of Soil Science* 39: 483-492.

Lehmann, J., Schroth, G., Zech, W. (1995) Decomposition and nutrient release from leaves, twigs and roots of three alley-cropped tree legumes in Central Togo. *Agrofor Syst*. 29: 21-36.

Lehmann, J., Feilner, T., Gebauer, G., Zech, W. (1999) Nitrogen uptake of sorghum *(Sorghum bicolor L.)* from tree mulch and mineral fertilizer under high leaching conditions estimated by nitrogen-15 enrichment. *Biology and Fertility of Soils* 30: 90-95.

Mugendi, D.N. (1997) Tree Biomass decomposition, Nitrogen Dynamics and Maize growth Under Agroforestry conditions in the sub-humid highlands of Kenya. PhD Thesis, University of Florida, Gainesville, Florida, U.S.A.

Mugendi, D.N., Nair, P.K.R., Mugwe, J.N., O'Neill, M.K., Swift, M.J. and Woomer, P. (1999) Alley cropping of maize with Calliandra and Leucaena in the Sub-humid highlands of Kenya. Part 2: Biomass decomposition, N mineralization, and N uptake by Maize. *Agroforestry Syst*. 46: 51-64.

Mugendi, D.N., Nair, P.K.R., Graetz, D.A., Mugwe, J.N. and O'Neill, M.K. (2000) Nitrogen recovery by alley-cropped maize and trees from 15N-labeled tree biomass in the subhumid highlands of Kenya. *Biol. Fertil. Soils* 31: 97-101.

Mutuo, P. K., Marandu, A.E., Rabeson R. Mwale, M. Snapp, S. and Palm, C.A. (1999) Nitrogen fertilizer equivalencies based on organic input quality and optimum combinations of organic and inorganic N sources: Network trial results from East and Southern Africa. In SWNM Report on the combating Nutrient Depletion – East Africa Highlands consortium.

Mwale, M., Mapiki, A. and Phiri, L.K. (2000a) Optimal combinations of organic and inorganic N sources. In: The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998. PP 38-40.

Mwale, M., Mapiki, A. and Phiri, L.K. (2000b. To synchronize nutrient availability with plant uptake. In: The Biology and fertility of Tropical soils: A TSBF Report 1997- 1998. PP 40-41.

Myers, R.J.K., Palm, C.A., Cuevas, E., Gunatilleke, I.U.N. and Brossard, M. (1994) The synchronization of nutrient mineralization and Plant nutrient demand, In the Biological management of soil fertility, Woomer, P.L. and Swift, M.J., (eds) John Wiley & Sons, Chichester.

Nziguheba, G. (2001) Improving phosphorus availability and maize production through organic and inorganic amendments in phosphorus deficient soils in Western Kenya. PhD thesis, Katholieke University, Leuven.

Palm, C. A. Myers, R. J. K. and Nandwa, S. M. (1997) Combined use of organic and inorganic nutrient Sources for soil fertility Maintenance and replenishment. In Buresh, R. J., and Sanchez, P.A., (eds). Replenishing soil fertility in Africa SSSA spec. Publ. 51. SSSA, Madison, WI.

Palm, C.A., Gachengo, C.N., Dalve, R.J., Cadisch, G. and Giller, K.E. (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment*. 83: 27-42.

Parkinson, J.A. and Allen, S.E. (1975) A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. *Communications in Soil Science and Plant Analysis* 6: 1-11.

Shepherd, G., Buresh, R.J. and Gregory, P.J. (2000) Land use affects the distribution of soil inorganic nitrogen in smallholder production systems in Kenya. *Biol. Fertil. Soils* 31: 348-355.

Swift, M.J. (1987) Tropical Soil Biology and Fertility: Interregional research planning workshop, special issue 13, in biology international IUBS, Paris.

Thonnissen, C., Midmore, D.J., Ladha, J.K., Olk, D.C. and Schmidhalter, U. (2000) Legume decomposition and nitrogen release when applied as green manures to tropical vegetable production systems. *Agron. J.* 92: 253-260.

Vanlauwe, B., Aihou, K., Houngnandan, P., Diels, J., Sanginga, N. and Merckx, R. (2001) Nitrogen management in 'adequate' input maize-based agriculture in the derived savanna benchmark zone of Benin Republic. *Plant and Soil* 228: 61-71.

Van Soest, P.J. (1963) Use of detergents in the analysis of fibrous feeds. II: A rapid method for the determination of fibre and lignin. *Journal of the Association of Agricultural Chemists* 46: 829-835.

Wallace, J.S. (1996) The water balance of mixed tree-crop systems. In: Ong, C.K., and Huxley, P. (eds) Tree-crop interactions, a physiological approach. CAB International, Wallingford, UK, pp 73-158.

Westerman, R.L., Kurtz, L.T. and Hauck, R.D. (1972) Division s-4 – soil fertility and plant nutrition: Recovery of 15N-labeled fertilizers in field experiments. Soil Science Society of America Proc., Vol. 36: 82-86.

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Base Nutrient Dynamics and Productivity of Sandy Soils Under Maize-Pigeonpea Rotational Systems in Zimbabwe

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Abstract

A two-year study was conducted in a smallholder farming area in northeast Zimbabwe to determine the rotational effects of pigeonpea (*Cajanus cajan* L. Millsp.) of different maturity genotypes on maize (*Zea mays* L.) yields. Researcher and farmer-managed on-farm rotation experiments were established on ten sites in farmers' fields, with a long history of maize monocropping. A maize crop receiving different rates of mineral N fertilizer followed long, medium and short duration pigeonpea genotypes plus control maize. Relationships between N management factors and nutrient uptake by maize under the three pigeonpea genotypes were examined in light of the current soil fertility management practices by the farmers. Significant ($p<0.05$)

maize yield responses were obtained after pigeonpea despite low productivity of these legumes at all sites. Relative to the control, medium and long duration pigeonpea treatments resulted in maize yield increases of 46% to 37% for biomass and 20% to 28% for grain, respectively, while there was a 6-19% decrease in yield after short-duration pigeonpea. The low N contributions from pigeonpea, which ranged from 6-18 kg N ha^{-1} could not account for the observed yield responses. Yields across all treatments increased with increasing mineral N application. Maize tissue analyses at 6 and 15 weeks after emergence (WAE), showed significant increases in P, K, Ca and Mg uptake. Regression analysis showed highly significant ($P<0.001$) linear relationships between N uptake and Mg ($R^2 = 0.74$; DF = 78), Ca ($R^2 = 0.62$; DF = 78) and K ($R^2 = 0.53$; DF = 78) uptake. Based on multiple regression models, N and Mg uptake accounted for most of the maize grain yield increases observed. Because of the low N contributions from pigeonpea, increases in maize yields were largely attributed to improved availability of base nutrients, particularly Mg. Pronounced maize yield responses to mineral N observed under pigeonpea systems, were likely due to increased N use efficiency.

We concluded that the residual benefits of pigeonpea in these cropping systems are largely due to their capacity to remobilize and recycle base nutrients, and that the productivity potential of granitic sandy soils is undermined by continued depletion of these cations under current management practices.

Introduction

Positive residual effects of N_2-fixing legumes on subsequent cereals in rotations have been widely reported in both olden and modern agriculture (Giller and Wilson, 1991; Kumwenda *et al.*, 1995; Peoples *et al.*, 1995). The yield increases have been primarily attributed to an improvement in N economy of the soils. However, beneficial effects may also arise from breaks in disease and pest cycles, changes in soil microbial and faunal activity, and chemical and physical attributes (Peoples and Craswell, 1992), although these factors have seldom been quantified. In order to optimize the ecological contribution of legumes in low-input agricultural systems, it is imperative that the differential effects of these factors are clearly understood and the benefits due to their interaction quantified. This is particularly important in tropical savanna agro ecosystems in which soil nutrient stocks are inherently low.

Studies on the predominantly sandy soils of Southern Africa have shown the complexity of soil fertility problems on smallholder farms and the challenges in developing sustainable management options (Scoones *et al.*, 1996; Scoones, 1998; Snapp *et al.*, 1998; Giller, 2001). There are slim chances of building soil organic matter and hence nutrient stocks (Giller *et al.*, 1997), rendering farmers to rely heavily on external nutrient inputs on a seasonal basis. However, most of the smallholder farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets (Kumwenda *et al.*, 1995; Ahmed *et al.*, 1996). This, therefore, calls for increased efficiency in use and recycling of both exogenous and endogenous nutrient pools in the cropping systems. Although problems of multiple nutrient deficiency are often apparent under most continuously cropped soils (Grant, 1981; Mukurumbira and Nemasasi, 1998), little has been done to determine the influence of the various soil fertility technologies on availability of nutrients such as K, Mg and Ca. In this study, we examined the residual effect of pigeonpea (*Cajanus cajan* (L.) Millsp.) cropping has on maize (*Zea mays* L.) yields on a sandy soil in Zimbabwe, with particular attention on N, P, K, Mg and Ca uptake.

Pigeon pea, a relatively new crop in Zimbabwe, was chosen for its ability to grow on relatively infertile soils, and tolerance to drought and other environmental stress (Whiteman *et al.*, 1985; van der Maesen, 1990).

Study site

The study was conducted in Murewa Communal Area, 130 km north east of Harare (17°45'S and 31°31'E). The area has a unimodal rainfall pattern, receiving an average of 750-1000 mm annually, between November and March and is about 1300 m above sea level. The mean annual temperature is 22°C. Soils are predominantly Lixisols (FAO Classification), derived from granitic parent material. Because of intensive agricultural activity and population pressure, most of the natural *Julbernardia globiflora* and *Brachystegia spiciformis* (miombo) tree vegetation has disappeared.

Materials and Methods

The experiment was conducted for two seasons on 10 farm sites, with each farm site considered as a replicate. All sites had been under maize monocropping with no manure application for at least five years. Soil samples were taken from 0-20 cm depths for physical and chemical analysis, at the beginning of each growing season. Three pigeonpea maturity types, namely short (cv. ICPL 87109 – 90 days to maturity), medium (cv. ICP 9145 – 150 5ays), long duration (cv. Ex-Marondera – 180 days), were grown during season one. Maize (cv. SC 501) was included as a fourth treatment to serve as a control in season two. Each plot measured 18 m x 4.5 m in gross area. Pigeonpea was spaced at 0.9 m between rows and 0.2 m within rows while maize was spaced at 0.9 m x 0.3 m. Land preparation was done by farmers using an ox-drawn plough. The pigeonpea received 12.5 kg P ha^{-1} and 18 kg S ha^{-1} in form of single superphosphate (SSP) incorporated just before planting. The maize received a basal dressing of Compound D at 200 kg ha^{-1} (16.0 kg N ha^{-1}; 12.4 kg P ha^{-1}; 11.6 kg K ha^{-1} and 13 kg S ha^{-1}), and was top-dressed with ammonium nitrate at 63.8 kg N ha^{-1}. The short duration pigeonpea was harvested for grain at 101 days after planting (DAP) and residues retained in the field for incorporation. The medium and long duration pigeonpea were incorporated as green manure at flowering at the request of farmers who feared interference from livestock. An ox-drawn plough was used for incorporation. For each pigeonpea cultivar, a net plot of 17 m x 2.7 m was harvested to determine fresh shoot biomass before incorporation. Sub-samples of three whole plants each were taken in replicates for moisture correction and quality analysis. Maize harvesting was done at physiological maturity. The samples were oven-dried at 60°C to constant mass, for dry matter measurements. Dried samples were ground and passed through a 1 mm sieve in a Wiley Mill. Total C, N, lignin and polyphenol contents were determined using methods described by Anderson and Ingram (1993).

In the second season, all plots were planted with maize. The crop was given a basal P, K and S fertilizer dressing in form of Compound D as described above for year one. However, each of the season one plot was divided into two, with one half receiving no mineral N application and the other getting 60 kg N ha^{-1} in form of ammonium nitrate. This gave rise to a split plot design, with the different rotation treatments (pigeonpea maturity types + maize control), providing for main plots and the two N fertilizer rates as subplots. The N was split applied, with 30 percent being applied at 2 WAE, 50% at 6 WAE and other 20% at 9 WAE. Three randomly selected plants were taken for biomass estimates at 2, 6 and 15 WAE. At each sampling time, the biomass was analyzed for N, P, K, Mg and Ca uptake. Individual farmers did the weeding whenever it was necessary. Grain yield was determined from a net plot of 4 m x 2.7 m and measured at 12.5% moisture content.

Pigeonpea productivity was also determined in the second season by planting the three maturity types on areas adjacent to the season one plots. All the areas had been put under maize by farmers in the previous season and the plots measured 4.5 m x 5 m. Shoot biomass were determined at flowering and physiological maturity by destructive sampling from a 1.8 m^2 area. At maturity, cumulative litter was handpicked from the sampled area and quantified for dry matter. The plant shoot samples were analyzed for total C, N, lignin and polyphenol content as described above. An area measuring 4 m^2 was harvested for grain yield determination.

All soils were analysed using methods given by Anderson and Ingram (1993). Organic C was determined using a modified Wakley-Black method while the resin method was used to measure available P. Ammonium and nitrate N were determined using the indophenol and cadmium-reduction methods respectively, with the N measured colourimetrically. Soil exchangeable K was determined by flame photometry and Mg and Ca by atomic absorption spectrophotometry following leaching of soil with ammonium acetate.

Treatment differences were tested using ANOVA and treatment means compared by LSD at $P<0.05$. Linear and multiple regression analyses were used to determine the relationships between maize yields and nutrient uptake.

Soil properties

All the farm sites used in the study were low in major plant nutrients, especially N and P (Table 16.1).

Table 16.1: Soil characteristics for the ten farm sites used for a pigeonpea study in Murewa Communal Area, Zimbabwe

Site	Clay (%)	Sand (%)	pH ($CaCl_2$)	Avail. N (ppm)	Resin P(ppm)	Organic C (%	Total N (%)	K (cmolc-kg^{-1})	Ca (cmolc-kg^{-1})	Mg (cmolc-kg^{-1})
Mukarakate	4	89	4.2	17	8	0.26	0.02	0.07	0.39	0.15
Shangwa	4	90	4.3	30	2	0.35	0.02	0.09	0.68	0.35
Gutu	4	92	4.1	17	6	0.28	0.01	0.06	0.52	0.21
Chikurunhe	3	92	4.6	34	10	0.23	0.02	0.06	0.96	0.30
Chawanda	4	86	4.4	26	3	0.40	0.02	0.07	1.19	0.40
Marume	5	88	4.2	27	2	0.24	0.02	0.06	0.60	0.20
Chiroodza T	9	82	4.5	31	2	0.44	0.01	0.14	1.39	0.59
Chiroodza M	6	90	4.6	18	11	0.32	0.02	0.08	2.06	0.75
Chamboko	9	86	4.4	27	4	0.47	0.02	0.13	0.94	0.26
Chituwu	6	92	4.2	16	8	0.32	0.02	0.10	0.85	0.30

Clay content ranged from 3 to 9%. Available P ranged from 2 to 11 mg kg^{-1}, while N ranged from 17 to 34 mg kg^{-1} soil. The soils were strongly acidic and had a mean organic C of 0.33% (Table 16.1).

Pigeonpea productivity and quality attributes

Pigeonpea biomass yields recorded during the season one were highly variable across the different farm sites. The yields ranged from 264 kg ha^{-1} for the short duration type to 1104 kg ha^{-1} for the long duration type. High variability was partly due to excessive rainfall, as severe waterlogging was experienced in some of the farms. The yields for Short-duration pigeonpea yields are likely to have been undermined by the relatively low plant population used. Maize biomass and grain yields in control maize plots averaged 2856 and 450 kg ha^{-1} respectively. The long duration pigeonpea yielded 1.5 times more biomass than the medium duration variety (Table 16.2).

Table 16.2: Biomass yields and resource quality characteristics for pigeonpea of different maturity types (at flowering) grown on poor sandy soils in Murewa Communal Area, Zimbabwe

Parameter	Cultivar /duration		
	ICPL 87109 (short)	ICP 9145 (medium) (medium)	Ex-Marondera (long)
Season 1			
*biomass (kg ha^{-1})	264 (95)	733 (251)	1104 (302)
Shoot N (kg ha^{-1})	6 (2)	13 (5)	18 (5)
N (%)	2.35 (0.05)	1.78 (0.08)	1.65 (0.07)
C (%)	43 (0.5)	44 (0.2)	44 (0.5)
C:N	18 (0.4)	25 (1.2)	27 (1.3)
Polyphenols	2.8 (0.04)	2.8 (0.05)	3.3 (0.05)
Lignin	10.7 (0.3)	13.2 (0.6)	12.7 (0.4)
Season 2			
*biomass (kg ha^{-1})	1884 (259)	6071 (721)	7619 (900)
Shoot N (kg ha^{-1})	46 (7)	130 (16)	157 (19)
N (%)	2.48 (0.05)	2.20 (0.10)	2.16 (0.08)
C (%)	43 (0.4)	43 (0.6)	44 (0.5)
C:N	17 (0.3)	20 (0.9)	20 (0.8)
Polyphenols	2.2 (0.04)	2.4 (0.04)	3.3 (0.03)
Lignin	11.2 (0.2)	10.8 (0.4)	13.0 (0.6)

*biomass = shoot biomass determined at flowering; Numbers in parentheses indicate standard errors

Because of poor biomass yields and low shoot N concentration, the total N produced by all the pigeonpea types were low. In season two, pigeonpea yields were about 6-8 times more than those obtained in season one, partly due to a favourable rainfall pattern. The long duration genotype, Ex-Marondera, gave four times more biomass than the short duration variety at flowering stage (Table 16.2). Potential N contribution to soil, as measured at flowering stage, ranged from 46 kg ha^{-1} for the short duration to 150 kg ha^{-1} for the long duration type. There was only a small increase in biomass between flowering and maturity stages due to terminal drought (Table 16.3). There was also a rapid increase in litterfall between the two growth stages.

Table 16.3: Biomass (at physiological maturity) and grain yields for pigeonpea of different maturity types grown on a sandy soil in Murewa Communal Area, Zimbabwe

Pigeonpea Maturity Type	Biomass (kg ha^{-1})	Litterfall (kg ha^{-1})	Grain Yield (kg ha^{-1})
Short (ICPL 87109)	1939 (263)	112 (±13)	725 (±68)
Medium (ICP 9145)	6436 (701)	745 (±108)	284 (±28)
Long (Ex-Marondera)	8106 (879)	994 (±131)	391 (±67)

*Numbers in parentheses indicate standard errors.

Although most of the litterfall was observed to occur soon after maturity, this could not be quantified due to disturbances of plots by livestock. The terminal drought also contributed to poor grain yields by the medium and late pigeonpea (Table 16.3). Grain filling was apparently more affected by moisture stress than pod set.

Residual effects of pigeonpea on yields of subsequent maize

An analysis of variance on grain yield and biomass yields at 2, 6 and 15 WAE, showed significant ($P<0.05$) rotation and mineral N fertilizer effects. There was no significant interaction between rotation and mineral N fertilizer. The medium and long duration pigeonpea gave rise to significantly higher maize yields compared with the maize-maize control and short duration pigeonpea (Table 16.4).

Table 16.4: Maize biomass at 2, 6 and 15 weeks after emergence, and grain yields obtained following pigeonpea of different maturity types grown under two mineral N fertilizer rates on sandy soils in Murewa Communal Area, Zimbabwe

Pigeonpea rotation/ mineral N fertilizer	Biomass (kg ha^{-1})			Grain (kg ha^{-1})
Maturity Type	2 WAE	6 WAE	15 WAE	
Short (ICPL 87109)	49^{ab}	717^{a}	3015^{a}	733^{a}
Medium (ICP 9145)	70^{c}	1064^{bc}	4690^{b}	1156^{b}
Long (Ex-Marondera)	$59b^{c}$	1069^{b}	4442^{b}	1229^{b}
Maize control (SC 501)	45^{a}	803^{ac}	3203^{a}	962^{ab}
SED	6	129	526	173
Fertilizer Level				
0 (kg N ha^{-1})	nd	709^{a}	2499^{a}	615^{a}
60 (kg N ha^{-1})	nd	1118^{b}	5176^{b}	1425^{b}
SED	nd	57	290	125

Numbers in the same column followed by the same letter are not significantly different; WAE = weeks after maize emergence; nd = not determined

At all harvesting stages, there were no significant differences in yield between short duration pigeonpea and maize-maize control plots, although the latter gave numerically higher yields at 6 and 15 WAE.

The maize grown after medium and long duration pigeonpea treatments yielded 46% and 37% more biomass, respectively, relative to the control. Similarly, there was 20% and 28% more grain under the two treatments, respectively. Mineral N fertilizer had a highly significant effect on maize yields, with yield increase ranging from 58% for biomass at 6 WAE to 132% for grain relative to the unfertilized treatments (Table 16.4). Without mineral N fertilizer application, the maize grain yields ranged from 427 kg ha^{-1} after short duration pigeonpea to 779 kg ha^{-1} after the long duration genotype. Grain yield for the control maize was 530 kg ha^{-1}.

Effect of pigeonpea cropping on soil N availability and maize nutrient uptake

Rotation treatments had no significant (P<0.05) effect on N and P uptake at 2 WAE, while only P and K uptake were influenced by the rotation systems at 6 WAE. While P, Ca and Mg uptake were significantly increased by mineral N fertilizer application at this stage, N and K uptake were not affected (Table 16.5).

Table 16.5: Rotational effects of pigeonpea of different maturity types on maize nutrient uptake under a sandy soil in Murewa Communal Area, Zimbabwe

Rotation system /	Nutrient (kg ha^{-1}) /sampling stage (WAE)									
N level	N		P		K		Ca		Mg	
	6	15	6	15	6	15	6	15	6	15
Maturity Type										
Short	18	22^{a}	0.2^{a}	0.7	16^{ab}	14^{a}	3	5^{a}	1	2^{a}
Medium	17	38^{b}	0.3^{b}	0.9	15^{ab}	30^{b}	4	8^{b}	2	4^{b}
Long	16	37^{b}	0.3^{b}	0.9	23^{a}	24^{ab}	4	8^{b}	2	4^{b}
Maize control	13	24^{a}	0.2^{a}	0.6	9^{a}	15^{a}	4	5^{a}	1	2^{a}
SED	ns	4	0.02	ns	6	5	ns	0.5	ns	1.4
Fertilizer Level										
0 (kg N ha^{-1})	19	18^{a}	0.2^{a}	0.5^{a}	13	12^{a}	2	4^{a}	1	2^{a}
60 (kg N ha^{-1})	18	43^{b}	0.3^{b}	1.1^{b}	19	29^{b}	4	9^{b}	2	4^{b}
SED	ns	3	0.01	0.07	ns	4	0.5	1	0.2	0.3

Short duration = variety ICPL 87109; medium duration = ICP 9145; Long duration = Ex-Marondera; Maize = cv. SC 501. WAE = weeks after maize emergence. Numbers in the same column followed by the same letter are not significantly different at P<0.05.

There was a 50% increase in P uptake after medium and long duration pigeonpea, relative to the control maize. Although maize yield after short duration pigeonpea was generally lower than that of the control, this treatment resulted in a 90% increase in K uptake (Table 16.5). Unlike early in the maize growth stages, both rotation systems and mineral N had a highly significant effect on uptake of all the measured nutrients at 15 WAE.

In general, there were no significant ($P<0.05$) differences in nutrient uptake between the medium and long duration pigeonpea rotation systems and between the control and the short duration. Regression analyses showed highly significant ($P<0.001$) linear relationships between N uptake and Mg ($R^2 = 0.74$; DF = 78), Ca ($R^2 = 0.62$; DF = 78), and K ($R^2 = 0.53$; DF = 78) uptake. Uptake of these nutrients increased with increased N application rates and uptake. There were significant ($P<0.05$) relationships between maize grain yield and nutrient uptake, particularly N and Mg (Table 16.6).

Table 16.6: Linear relationships between maize grain yield and nutrient uptake rotated with pigeonpea of different maturity types on sandy soils in Zimbabwe

Regression equation	DF	R^2	P-level
Y (Grain yield) = 34 *X* (total N uptake)	78	0.76	0.001
Grain yield = 1429 (total P uptake)	78	0.57	0.001
Grain yield = 131 + 34 (total K uptake)	78	0.55	0.001
Grain yield = 256 + 117 (total Ca uptake)	78	0.44	0.001
Grain yield = 313 (total Mg uptake)	78	0.75	0.001

Discussion

Pigeonpea productivity under poor soil fertility

Low pigeonpea biomass yields during the first season was mainly attributed to waterlogging and poor soil fertility of the soils at the study sites. Waterlogging occurred during the early vegetative phase. This could have interfered with N_2-fixation resulting in poor N nutrition and hence growth of the plants (Mapfumo *et al.*, 1999). Because of their relatively long growth duration, the medium and long maturity pigeonpea were able to recover from the adverse effects of excessive soil moisture resulting in relatively high yields. Wide plant spacing could also have contributed to low biomass for short duration pigeonpea. While the high biomass yields obtained in the second season strongly indicated pigeonpea tolerance to poor soil fertility, the results also suggest that there could be significant interactions between soil moisture and crop nutrition under sandy soils. According to Grant (1981), soil acidity may contribute to soil infertility in high rainfall areas. About 50% of the farm sites used in this study had a pH of 4.3 ($CaCl_2$), a value considered critically low for most crops, particularly legumes (Grant, 1981). Liming is a possible solution in a number of communal areas including Murewa (Dhliwayo et al., 1998). However, the dynamics of soil acidity under different soil moisture regimes in sandy soils in Zimbabwe is not well understood.

Low grain yields found for the medium and long duration pigeonpea were indicative of problems likely to be encountered by farmers in regenerating seed. Although pigeonpea was able to sustain growth on residual moisture, the soil moisture reserves were apparently not sufficient to promote grain filling. Because of the poor water-holding capacity of sandy soils, there is usually a rapid soil moisture decline soon after the end of the rainy season (Mapfumo, 1995). Terminal drought has been reported as a major constraint to grain production in long duration pigeonpea (Whiteman *et al.*, 1985; ICRISAT, 1993). This may be a disincentive for farmers whose primary interest is grain production. The short duration type may be attractive to farmers in that respect. There is need to identify germplasm of appropriate maturity types to minimize terminal drought effects while ensuring optimum biomass accumulation.

Rotational effects on subsequent maize

Because of the low levels of pigeonpea biomass produced during season one, the potential N contribution to the cropping system was low despite the high quality of the incorporated biomass. Only 6-18 kg N ha^{-1} could be added to the system from pigeonpea shoots. Given that only 20% of this N was likely to be taken up in maize (Palm, 1995; Palm *et al.*, 1997), it was therefore highly likely that the observed treatment differences were due to rotational effects other than N. While there were significant treatment effects on maize biomass yield at 6 WAE, both rotation systems and mineral N did not significantly affect N uptake during the same period. This further suggests that N *per se* had no significant effect on early maize development.

During the same period (6 WAE), P, K and Ca uptake were significantly higher under medium and long duration pigeonpea rotations than under the other two treatments. The yield increases may, therefore, be partly attributable to the increased availability of these nutrients after pigeonpea.

Rotation and mineral N effects on maize N uptake only became significant at crop maturity. This could have been due to increased nutrient use efficiency (NUE) under the pigeonpea treatments between

6 and 9 WAE. In sandy soils of the Sahel region, there was a 20% NUE, under pearl millet monocropping compared with 28% after a cowpea rotation (Bationo *et al.*, 1991; Bationo and Vlek, 1997). The results in this study also showed a highly significant linear relationship between maize grain yield and Mg uptake, suggesting that Mg may be a major limiting nutrient for maize production in these sandy soils. Magnesium uptake was also linearly related to N uptake, suggesting that increased use of mineral N fertilizers in maize monocropping may accelerate Mg depletion in sandy soils. Magnesium deficiency on continuously cropped sandy soils has been historically reported from smallholder farms in Southern Africa (Grant, 1981). Application of pigeonpea residues did not only improve Mg nutrition, but also increased P, K and Ca uptake. Although it may be difficult to account for the observed yield depression under short duration pigeonpea based on our limited results, it is likely that low potential of the short duration pigeonpea to remobilize and recycle these nutrients was a factor. The genotype may therefore not be suitable for soil fertility enhancement on sandy soils.

Practical significance of rotational benefits and pigeonpea productivity on-farm

Maize grain yields of about 1000 kg ha^{-1} obtained after pigeonpea, may fall short of farmers' expectations despite their statistical significance. Currently, most successful farmers achieve high yields (about 3000 kg ha^{-1}), by applying more than the recommended rates of mineral N (Mapfumo and Mtambanengwe, 1999). Athough there is little documentation on the economics of such production systems, low N use efficiency may be eroding profits. Pigeonpea rotations, may help to improve NUE and increase the yield potential of the cropping system through remobilization and cycling of other nutrients such as Mg, Ca and K. Our limited results indicate that there is merit in directing our focus on non-N benefits of organic resources, particularly the influence on availability of base nutrients, which may be undermining the productivity of sandy soils even in cases where N becomes available. The productivity potential of the granitic sandy soils in Southern Africa might be declining due to base nutrient depletion.

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References

Ahmed, M. M., Rohrbach D. D., Gono L. T., Mazhangara E. P., Mugwira L., Masendeke D. D. and Alibaba S. (1996) Soil Fertility Management in the Communal Areas of Zimbabwe: Current Practices, Constraints and Opportunities for Changes. Results of a diagnostic survey. Southern and Eastern Africa Regional Paper number 6. ICRISAT-Southern and Eastern Africa Region. 27 pp.

Anderson, J.M. and Ingram, J.S.I. (1993) Tropical Soil Biology and Fertility: A handbook of Methods. Second Edition. C. A. B. International. Wallington, UK. 221pp.

Bationo, A., Ndunguru, B.J., Ntare, B.R., Christianson, C.B. and Mokwunye, A.U. (1991) Fertilizer management strategies for legume-based cropping systems in the West African Semi-Arid Tropics. In: Johansen, C., Lee, K.K., Sahwat K.L (eds.), *Phosphorus Nutrition of Grain Legumes in the Semi-arid Tropics*. ICRISAT, 1991. Patancheru, A.P. 502 324, India:ICRISAT.

Bationo, A. and Vlek, P.L.G. (1991) The role of mitrogen fertilizers applied to food crops in the Sudano-Sahelian zone of West Africa. In: Renard, G., Neef, A., Becker, K., and von Oppen, M. (eds.). *Soil fertility management in West African land use systems*. Wekersheim, Germany: Margraf Verlag. pp. 437–444.

Dhliwayo, D.K.C., Sithole, T. and Nemasase, H. (1998) Soil acidity - Is it a problem in Zimbabwe? In: Waddington, S.R., Murwira, H.K. Kumwenda J.D.T., Hikwa D., Tagwira F. (eds.), *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe*. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe. pp. 217-221

Giller, K.E. (2001) Targeting management of organic resources and mineral fertilizers: Can we match scientists' fantasies with farmers' realities? In: Vanlauwe, B., Sanginga, N., Diels, J., Merckx, R. (eds.), *Balanced Nutrient Management Systems for the Moist Savanna and Humid Forest Zones of Africa*. CAB International, Wallingford. pp. 155 -168.

Giller, K.E. and Wilson, K.J. (1991)*Nitrogen Fixation in Tropical Cropping Systems*. CAB International, Wallingford, UK. 313 pp.

Giller, K.E., Cadisch, G., Ehaliotis, C., Adams, E., Sakala, W.D. and Mafongoya, P.L. (1997) Building soil nitrogen capital in Africa. In: Buresh, R.J., Sanchez, P.A. (eds.), *Replenishing Soil Retility in Africa*. SSSA Special Publication 51. SSSA, Madison, WI, USA. pp. 151-192.

Grant, P. M., (1981) The fertilization of sandy soils in peasant agriculture. *Zim. Agric. J.* 78(5):169-175.

ICRISAT, (1993) *Improvement of Pigeonpea in Eastern and Southern Africa*. Biannual Progress Report submitted to African Development Bank. 20 pp.

Kumwenda, J.D.T., Waddington, S.R., Snapp, S.S., Jones, R.B. and Blackie, M.J. (1995) Soil Fertility Management for Smallholder Maize-Based Cropping

Systems of Southern Africa: A Review. Network Working Paper No. 1. *Soil Fertility Network for Maize-Based Cropping Systems in Countries of Southern Africa*. CIMMYT, Harare, Zimbabwe. 34 pp.

Mapfumo, P. (1995) Agronomic and ecological adaptation of Lupinus spp for Communal Area farming systems in Zimbabwe. M. Phil Thesis. Department of Crop Science, University of Zimbabwe.Harare, Zimbabwe. 218 pp.

Mapfumo, P. and Mtambanengwe, F., (1999) Nutrient mining in maize-based systems of rural Zimbabwe. In: CIMMYT and EARO, 1999. *Maize Production Technology for the Future: Challenges and Opportunities*. Proceedings of the Sixth Eastern and Southern Africa Regional Maize Conference, 21-25 September, 1998, Addis Ababa, Ethiopia. pp. 274-277.

Mapfumo, P. Giller, K.E. Mpepereki S. and Mafongoya, P.L. (1999) Dinitrogen fixation by pigeonpea of different maturity types on granitic sandy soils in Zimbabwe. *Symbiosis* 27:305-318.

Mtambanengwe, F. and Kirchmann, H. (1995) Litter from a tropical savanna woodland (Miombo): chemical composition and C and N mineralization. *Soil Biol. Biochem*. 27:1639-1651.

Mukurumbira, L. and Nemasasi, H. (1998) Micronutrients in the maize-based system of the communal areas of Zimbabwe. In: Waddington, S.R. Murwira, H.K. Kumwenda, J.D.T. Hikwa, D. Tagwira F. (eds.), *Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe*. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe. pp. 229-232.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agrofor. Syst*. 30:105-24.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J. Sanchez, P.A. (eds.), *Replenishing Soil Fertility in Africa*. SSSA Special Publication 51. SSSA, Madison, WI, USA. pp. 193-217.

Peoples, M. B. and Craswell, E.T. (1992) Biological nitrogen fixation: Investments, expectations and actual contributions to agriculture. *Plant and Soil* 141:13-39.

Peoples, M.B., Herridge, D.F. and Ladha, J.K. (1995) Biological nitrogen fixation: An efficient source of nitrogen for sustainable agricultural production. *Plant and Soil* 174:3-28.

Scoones, I. (1998) Investigating soil fertility in Africa: Some reflections from research in Ethiopia and Zimbabwe. In: Bergstrom, L. Kirchmann, H. (eds.), *Carbon and Nutrient Dynamics in Natural and Agricultural Tropical Ecosystems*. CAB International, Wallingford, UK. pp. 245-259.

Scoones, I., Chibudu, C., Chikura, S., Jeranyama, P., Machaka, D., Machanja, W., Mavedzenge, B., Mombeshora, B., Mudhara, M., Mudziwo, C., Murimbarimba, F., and Zirereza, B. (1996) ha*zards and opportunities. Farming livelihoods in dry land Africa: Lessons from Zimbabwe*. London, UK and New Jersey, USA: Zed Books Ltd, in association with International Institute for Environment and Development (IIED). 267 pp.

Snapp, S.S., Mafongoya, P.L. and Waddington, S. (1998) Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agric. Ecosyst. Environ.* 71:185-200.

van der Maesen, L.J.G. (1990) Pigeonpea: Origin, History, Evolution and Taxonomy. In: Nene, Y.L. hall S.D., Sheila U.K. (eds.), *The Pigeonpea*. C.A.B. International, UK. ICRISAT. pp. 15-46.

Whiteman, P.C., Byth, D.E. and Wallis, F.S. (1985) Pigeonpea (Cajanus cajan L.). In: Summerfield, R.J. and Roberts, E.H. (Eds.), *Grain legume crops*. Collins, London. pp. 658-698.

17

Soil Organic Matter (SOM): The Basis for Improved Crop Production in Arid and Semi-Arid Climates of Eastern Kenya

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Abstract

Soil organic matter (SOM) plays an important role in maintaining physical, chemical and biological properties of the soil, and therefore the crop productivity. A study was conducted in arid and semi-arid lands (ASALs) of eastern Kenya to assess the influence of SOM on crop productivity after 10 years of application of high quality goat manure. The manure was acquired from a single source where same breeds and flock management were maintained throughout the experimentation period. The manure contained 0.48 % P, 2.04% N and 25.62% C, and was annually applied at 0, 5 and 10 tons ha^{-1} in soils where continuous cultivation was a common practice. The residual effects of manure were monitored after discontinuation of 4 years manure application. Also, inorganic fertilizers to supply phosphorus (P) and nitrogen (N) were applied to compare the potency of long-term SOM maintenance and inorganic fertilizers on crop performance. The observed maize yields were compared with simulated (predicted) values from modelling using the Agricultural Production Systems Simulator (APSIM) model. The results showed that both the application of manure and mineral fertilizers improved crop total dry matter, and discontinuation of annual manure application led to run-down trends in crop yields. A general conclusion made from the study was that, it is worthwhile in terms of crop productivity to maintain SOM through annual application of high quality manure at 5 tons ha^{-1} in ASALs where continuous cultivation is practiced.

Key words: Soil organic matter (SOM), crop yields, arid and semi-arid lands (ASALs), manure, inorganic fertilizers, modelling

Introduction

Enhancement and maintenance of soil productivity is one of the essential aspects for sustained agricultural production in sub-Saharan Africa (Bunting, 1992). This is an important aspects, especially when the aim is to achieve one of the most important objectives of our time, overcoming hunger and poverty amongst the smallholder farmers who are the majority among the stakeholders in agricultural production systems (Micheni, 1996). Soil organic matter (SOM) serves as an indispensable source of plant nutrients and enhances soil biological, chemical and physical properties (Mokwunye *et al.*, 1996). Almost all soil nitrogen and other important soil properties such as moisture retention, cation exchange capacity (CEC) and stabilization of soil aggregates are related to SOM. The amount of SOM in the soil is dependent on the annual inputs of organic materials and the rate of decomposition, the later being the highest in hot, humid climatic regions (De Ridder and Van Keulen, 1990; Rowell, 1994). Plant residues are the main source of soil organic matter while animal remains and their waste are secondary sources (Rowell, 1994).

According to Jaetzold and Schmidt (1983), the ASALs of eastern Kenya are characterized by frequent droughts due to erratic and unreliable rainfall, which is bimodal with first and second rains coming in April and November, respectively. The average annual rainfall is about 750 mm with poor distribution within and between seasons. The soils are generally sandy-loam, shallow and are low in organic matter (Jaetzold and Schmidt, 1983; Warren *et al.*, 1998). They are also deficient in major plant nutrients such as nitrogen and phosphorus, a situation significantly influencing crop yields and land biodiversity (Smaling *et al.*, 1997; Warren, 1998). Similarly, Ikombo (1984) noted that the soils of semi-arid eastern Kenya have low soil organic carbon compared to those of high rainfall areas. The situation is worsened by the methods of cultivation that may be described as more of nutrients mining, rather than nutrient build-up (Ikombo, 1984; Micheni, 1996). The farming practices amongst some farmers involve burning crop residues, weeds and other plant materials to make way for grazing and crop production (Gibberd, 1995; Irungu *et al.*, 1997). The problem is aggravated by tree harvesting for timber, charcoal burning, and failure by farmers to apply sufficient external soil fertility improvement inputs (Okoba and Altshul, 1995; Lal and Stewart, 1995). Wind and water erosions also causes significant decline in soil organic matter and nutrients (DAREP, 1995; Okoba and Altshul, 1995).

Use of mineral fertilizers has been recommended and popularized to farmers, but the adoption of fertilizer based technologies is constrained by the high costs, low farm returns and unavailability of the right fertilizers to the resource poor farmers in arid and semi-arid areas (Micheni, 1996). Most farmers apply insufficient or no soil fertility improvement inputs to refurnish the removed soil nutrients (DAREP, 1995). Nitrogen is also lost through volatilization during prolonged dry spells that are common phenomenon in arid and semi-arid climates (Coen *et al.*, 1992).

Indigenous shifting cultivation system characterized by long fallow periods, thereby restoring soil fertility through build-up of SOM are currently not applicable due to high pressure on land caused by the ever-increasing human population. Organic nutrient resources (crop residues, biomass transfer and livestock manure) may be an alternative to mineral fertilizers. However, the low quality and labour required for transporting, spreading and incorporating manure in the field are major limitations (Ikombo, 1984; Kihanda, 1998). Another major constraint regarding the use of organic inputs is their bulkiness. For example, large quantities (5 – 10 tons ha^{-1}) of farm-yard manure (FYM) are required to provide a fraction of what would be needed to maintain agricultural production at a desirable level (Kihanda, 1998). Farmers in Machang'a are smallholders and keep livestock and grow dryland crops for food and cash generation. Because of small family land sizes, continuous cultivation, even on sloppy and fragile fields is common.

To effectively improve the level of SOM in soils where continuous cropping is practiced, large quantities of organic inputs should be continuously applied in erosion free cultivated fields (De Ridder and Van Keulen, 1990). A long-term manure application trial was initiated in 1989 with the aim of establishing crop performance resulting from SOM improvement through manure application. With a realization that the long term trials are costly and take a lot of time, resources and manpower, a decision was made to use the long-term Machang'a data in modelling using Agricultural Production Systems Simulator (APSIM) model to predict the future agronomic systems. The model considers the soil as the central focus and allows for simulations of agricultural production scenarios using pre-prepared weather, crop type and management templates.

Materials and Methods

This study was carried out at Machang'a ($0^0 40^0$ S-$0^0 45^0$ S, $37^0 35^0$ E-$37^0 45^0$, 1050 m above sea level and 230 mean annual temperatures). The site is in ASALs of eastern Kenya and has an average annual rainfall of 750 mm, coming in two rainy (crops growing periods) seasons. The rainy seasons are identified by the month that effective rainfall occurs. They are the "April season" that runs from March to June/July and the "November season" falling from October to January. The soils are generally sandy clay loam (Chromic cambisol) with 6.45 pH (water), 0.67% organic carbon, 0.94mg kg^{-1} extractable P (Olsen method; 0.5M Na HCO_3) and 0.06% total nitrogen. The soils are shallow (about 1m deep) and lose their organic matter, including nutrient rich aggregates within 3-4 years of cultivation with inadequate internal/external organic material inputs and soil protection from water erosion. They have poor structures and are easily compacted and eroded especially during heavy storms that characterize the area.

A long-term (approximately 10 years) manure experiment was initiated in 1989 with the aim of assessing the crop yields performance following continuous cropping and improvement of SOM through manure application. The manure was obtained from a single source where the same breed and flock management were maintained throughout the experimentation period and was applied at the rate of 5 and 10 tons ha^{-1}. It (manure) was considered to be of high quality with 2% N, 26% C and 0.5% P and was applied in October, prior to November rains by evenly spreading and incorporating it within the cultivation depth (0-0.15m) of the soil.

Initially, from April 1989 to April 1993 the trial was based on a complete factorial design with three replicates and 3 manure treatments and three cropping systems. The net plots measured 5.0 m x 5.0 m and were well protected from run-off or external water erosion by having a cut-off drains on the upper side of the experimental field. Some terraces were also constructed along the contours between blocks to control the soil movement from the upper to lower blocks/plots. The treatments initially adapted for the study were, no inputs (C3M0), manure application at 10 tons ha^{-1} (C3M1) and 5 tons ha^{-1} (C3M2) continuous cropping systems. The cropping systems (C3M0, C3M1 and C3M2) were rotations of [sorghums *(Sorghum bicolor,* var. 954066) + cowpea *(Vigna unguiculata*, var. M66)] and [peal millets *(Pennisentum typhides*, var. KPM-1) + grams *(Vigna aures*, var. N26)] intercrops in November and April seasons, respectively. Maize *(Zea maize,* var. Katumani) as a test crop was introduced in 1999 November season and was grown both seasons replacing sorghum and millet as test crops. In 1993, four years after the start of the trial, annual manure application was discontinued in C3M1 (10 tons ha^{-1} manure) and C3M2 (5 tons ha^{-1} manure) to form treatments C3R1 and C3R2 to respectively assess the 10 and 5 tons ha^{-1} residual manure effects on crop dry matter yields (Table 17.1). Another treatment (C3F) of annual inorganic fertilizer at the rate of 51 and 12kg ha^{-1} of N and P yearly, but splitted in equal amounts between April and November rains was also introduced in the former C3M0 (control) to assess the benefits of crop production using organic over inorganic fertilizers. The rate of applied N and P was equivalent to nutrient contribution by 5 tons ha^{-1} manure treatment.

Table 17.1: Soil fertility management treatments for both field observations and APSIM model simulation on crop yields performance

Field Code	Treatment description
C3M0	No external input
C3M2	5 tons ha^{-1} annual manure application
C3M1	10 tons ha^{-1} annual manure application
C3F (ex- C1M0)	Inorganic fertilizer (N and P) from 1993
C3R2 (ex-C1M2)	Residual manure at 5 tons ha^{-1} (from 1993)
C3R1 (ex-C1M1)	Residual manure at 10 tons ha^{-1} (from 1993)

Planting of all crops was done at the on-set of rains to make sure that the crops benefited from the low and erratic rains experienced within the trial site. Other agronomic practices (weeding, pest control and harvesting) were carried out as per local recommendations and except for the grains, other crop residues were returned into their respective plots at the end of every season. The aboveground biomass (stovers) were cut at the ground level, chopped before being incorporated into the soil during land preparation. Data on weather, crop biophysical and soil physical and chemical parameters were collected as part of APSIM model inputs.

Results

Cumulative crop dry matter (DM) responses were improved by manure application at 5 and 10 tons ha^{-1} (Table 17.2). Over time cultivation without application of manure showed a decline in crop DM (Figure 17.1a). After a period of 20 growing seasons, the cumulative mean DM from 5 tons ha^{-1} (C3M2) was 3,435 kg ha^{-1} and 4,141kg ha^{-1} from 10 tons ha^{-1} manure year^{-1} (Figure 17.1b). Continuous cultivation without application of manure (C3M0) had the lowest average crop DM of 989 kg ha^{-1}. This was about four times less than the highest recorded DM (4,141 kg ha^{-1}) from 10 tons ha^{-1} continuous annual manure application. The problem was associated to overtime run-down of nutrients during crop removal and aggravated soil erosion. Like the cumulative (10 years) average crop yield response. There was no significant ($p=0.05$) difference in crop yields between 5 and 10 tons ha^{-1} annual manure rates. The average crop DM was significantly ($p=0.05$) different between all treatments (C3F, C3M2 and C3M1) that had received external fertility inputs, including manure residuals (C3R1 and C3R2) and absolute control treatment (C3M0). The responses to residual manure at 10 and 5 tons treatments (C3R1 and C3R2) were also not significantly different ($p=0.05$). There was a general decline trends in DM production from 1993 when manure application was stopped to November 2000 cropping season when the last observations were done (Figure 17.1d).

Table 17.2: Cumulative average crop dry matter (DM) yields under different soil fertility managements

Treatment description	Years manure applied	Cumulative DM yields	
		No. seasons observed	kg ha^{-1}
No external input (C3M0)	0	20	989
5 tons ha^{-1} annual manure application (C3M2)	10	20	3435
10 tons ha^{-1} annual manure application (C3M1)	10	20	4141
Inorganic fertilizer (C3F)	0	11	3723
Residual manure at 5 tons ha^{-1} (C3R2)	4~	11	3499
Residual manure at 10 tons ha^{-1} (C3R1)	4~	11	2677

~ Before manure residual effect study was initiated

Figure 17.1a: Comparison of field observations and APSIM simulated crop dry matter (DM) for 1989-2000 Machang'a/cultivation without application of organic or mineral fertilizers

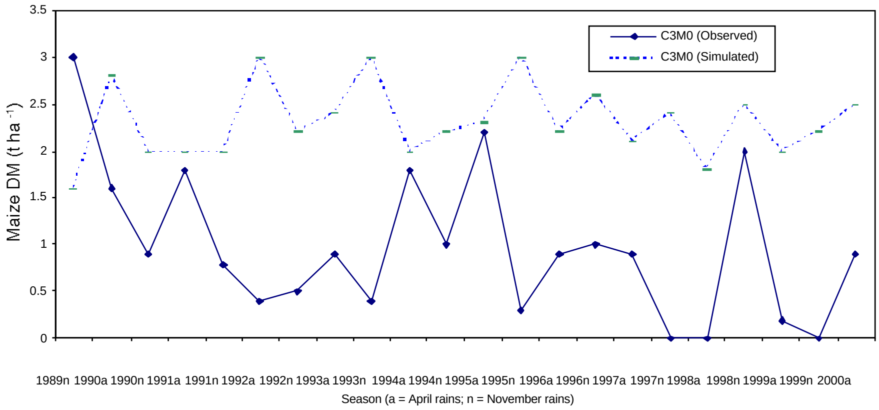


Figure 17.1b: Comparison of field observations and APSIM simulated crop dry matter (DM) for 1989-2000 10 tons/ ha long-term manure application experiment

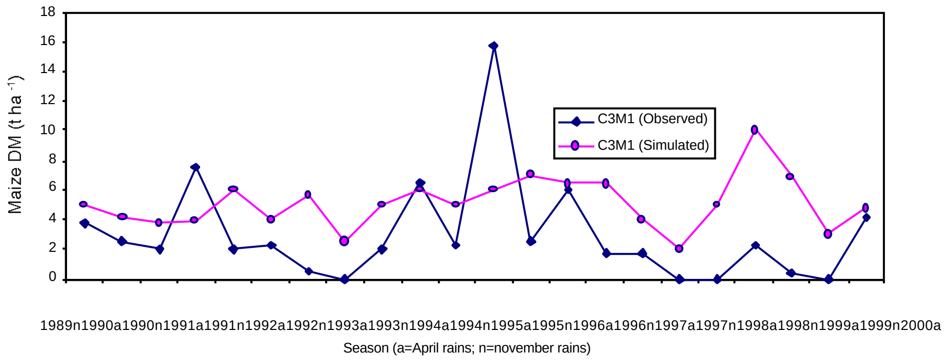


Figure 17.1c: Comparison of field observations and APSIM simulated crop dry matter (DM) for 1989-2000 cultivation without manure application followed by mineral fertilizer application (1994-2000)

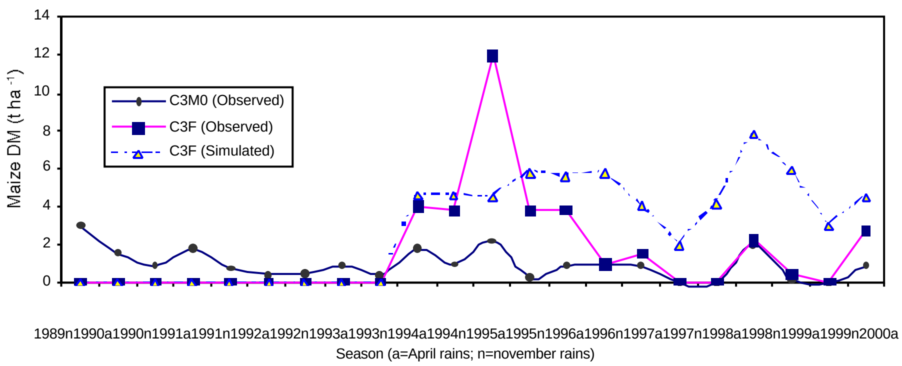
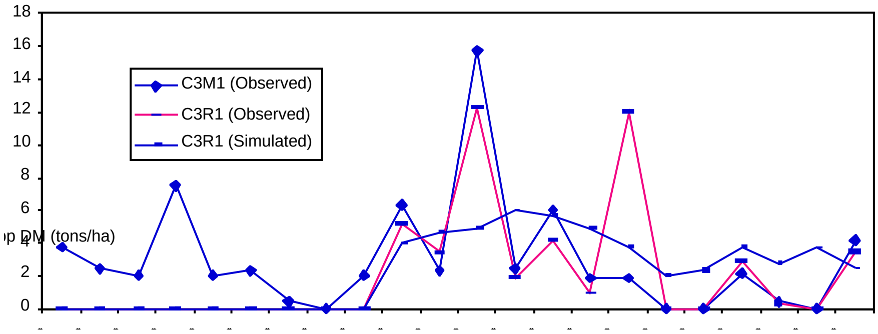


Figure 17.1d: Comparison of field observations and APSIM simulated crop dry matter (DM) for 1989-2000 cultivation with manure application at 10 ton/ha followed by assessment of manure residue effect (1994-2000) on crop performance



Yields in the residue treatments remained higher compared to the control (C3M0) treatment whose yields were the least (Figure 17.1d). Application of inorganic fertilizer (C3F) tremendously increased crop DM to almost three folds relative to the no inputs treatment (Figure 17.1c). Observed crop DM yields from all the treatments were compared with simulations from APSIM model. Crop DM yields of 15.6 tons ha^{-1} was recorded from the fields while the model predicted 7.5 tons ha^{-1} for the 10 tons ha^{-1} annual manure application in 1994. This shows that the model cannot fully be depended on in prediction of crop responses to various soil fertility management options for the smallholder farmers. However, the model may be used to provide the trends on future scientific expected output(s) and predictions for on going or to be initiated studies.

Conclusions

Enhancement of soil productivity through the improvement of SOM is essential for sustained agricultural production systems. This is particularly important in ASAL where rainfall is erratic and soils are low in most of the major nutrients needed by plants, and continuous cultivation with little or no external soil fertility inputs is a widespread practice. The study indicated that the annual manure application had positive response to crop dry matter (DM) production. Cumulative mean crop DM production after 20 seasons from 5 tons ha^{-1} and 10 tons ha^{-1} manure application did not differ significantly and therefore a recommendation was put forwards to ASALs farmers to apply 5 tons ha^{-1} manure in erosion free continuously cultivated lands. Manure residual effects were monitored for 11 seasons after four years of annual manure application and 5 tons ha^{-1} residual recorded a cumulative crop DM of 3499 kg ha^{-1} compared to 2677 kg ha^{-1} from 10 tons ha^{-1} manure residual. Discontinuation of manure application led to a decrease in crop yields. This is probably due to the effect of nutrient run-down through continuous cropping without application of manure or mineral fertilizers. Non-application of mineral fertilizer or manure had negative response to crop yields. Field crop yield observations and APSIM model simulations had some positive correlation in terms of trends but not on the actual values. This suggested that the model cannot fully be relied upon in provision of true field situations, but on general trends of scientific scenarios.

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References

Bunting, A. H. 1992 Feeding the world in the future. In: Spending, C. R. W. (eds). Farmer's Principles of Food and Agricultural (17th edition), pp. 256 – 290. Oxford: Blackkwell Scientific Publications.

Cambardella, C.A. and Elliot, E.T. 1993) Carbon and nitrogen distribution in aggregates from cultivated and native grassland soils. *Soil Science Society of America* Journal 57: 1071 – 1076.

Coen, R., Haverkort, B. and Ann, W.B. (1992) Farming for the future: An introduction to low-external input and sustainable agriculture (ILEIA), Macmillan, pp. 24-208.

DAREP, 1995. Farming in Tharaka; an informal diagnostic survey report of the semi-arid areas of Tharaka/Nithi District. KARI/KEFRI/NRI, DAREP-Embu, Kenya.

De Ridder, N. and Van Keulen, H. (1990) Some aspects of the role of organic matter in sustainable intensified arable farming systems in the West African semi-arid tropics. *Fert. Res*. 26: 299-310.

Gibberd, V. (1995) Crop Production Workbook for Arid and Semi- arid Land. Chatham, UK: Natural Resources Institute.

Irungu, J.W., Micheni, A.N., Sutherland A.J. and Warren G.P. (1997) An appraisal of soil fertility in smallholder farms in the semi-arid areas of Tharaka-Nithi

District: Farmers assessment compared to laboratory analysis. In: *Proceedings of the Conference on participatory Dryland Agricultural Research East of Mount Kenya*, January 21-24, 1997. KARI: Kitale, Kenya. Pages 243-248.

Ikombo, B.M. (1984) Effects of farmyard manure and fertilizers on maize in semi-arid areas of eastern Kenya. *East. Afr. Agric. for. J.* 44: 266-274.

Jaetzold, R. and Schemidt H. (1983) *Farm management hardbook of Kenya. Natural conditions and farm information. vol.11/ C. East Kenya.* Ministry of agriculture, Kenya.

Kihanda, F.M. (1998) Improvement of FYM quality through composing with high quality organic residues. Research proposal funded by the African Science Career Awards of the Rockefeller Foundation (1998-1999). KARI, Nairobi, Kenya.

Lal, R. and Stewart, B.A. (1995) Soil management, Experimental Basis for Sustainability and Environmental Quality. *Advances in Soil Science*, Lewis, London.

Micheni, A.N. (1996) The role of legumes in soil fertility maintenance in arid and semi-arid areas (Reference to Tharaka, Kenya); MSc. thesis, University of Reading, UK.

Mokwunye, A.U., de Jager, A and Smaling, E.M.A., (Eds.) (1996) Restoring and Maintaining the Productivity of West African Soil: Key to sustainable Development. In: *Miscellaneous Fertilizer Studies* No. 14.

Okoba, B.O. and Altshul, H.J. (1995) *A report of a PRA in Gachoka Division, Kenya*. KARI - Embu, Kenya

Rowell, D.L. (1994) *Soil science: Methods and applications*. Longman. U.K., pp. 266-276.

Smaling, E.M.A., Nandwa, S.M. and Janssen, B.H. (1997) Soil fertility in Africa is at stake. In: Buresh,R.J, Sanchez, P.A. and Calhoum, F.(eds.) , Replenishing Soil Fertility in Africa. SSSA Special Publication No.51. Wisconsin, USA. Pp. 47-61.

Warren, G.P. (1998) Effects of continuous manure application on grain yields at seven sites of trial 1, from 1993 to 1996. *In:* Maintenance of soil fertility and organic matter in dryland areas. (Eds: Kihanda, F.M. and Warren G.P.). The department of soil science, the University of Reading Occasional publication No. 3. The University of Reading, UK.

Warren, G.P. (1998) Effects of native phosphorus on biodiversity, productivity and the dynamics of soil carbon and nitrogen at Machang'a and Mutuobare sites. *In:* Maintenance of soil fertility and organic matter in dryland areas. (Eds: Kihanda, F.M. and Warren G.P.). The department of soil science, the University of Reading, Occasional publication No. 3. The University of Reading, UK.

Warren, G.P. Irungu J.W. and Muthamia J. (1998) Residual value of manure in Trial 1. *In:* Maintenance of soil fertility and organic matter in dryland areas. (Eds: Kihanda, F.M. and Warren G.P.). The department of soil science, the University of Reading,. Occasional publication No. 3. The University of Reading, UK.

18

Response of *Tephrosia vogelii* to Minjingu Phosphate Rock Application on a Ferralsol of Varying Soil pH

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Abstract

Low available P and low soil pH are among soil conditions, which could lead to poor growth of some N_2 fixing plants. The effect of these two soil conditions to *Tephrosia vogelii* (agroforestry leguminous shrub) growth parameters needs to be determined. A Glasshouse study using *T. vogelii* was conducted on a Ferralsol with soil pH 5.0 and 5.9 and low available P (2.5-2.9 mgP kg^{-1}). The objectives of this study were to assess the effects of soil pH and Minjingu Phosphate Rock (MPR) on *T. vogelii* plant height, dry matter production and shoot N and P contents. The two soils were treated with P as MPR and planted with *T. vogelii* for twelve weeks. The pots were replicated six times and arranged in a completely randomized design. The parameters assessed include plant height and dry matter yields at three and twelve weeks and shoot N and P contents at twelve weeks.

Soil pH 5.9 had significant ($P \leq 0.05$) effect on plant height, dry matter yields, shoot N and P concentration and shoot N and P uptakes. Application of P as MPR significantly ($P \leq 0.05$) increased these parameters on both soil pH values. The results suggest that in strongly acid soils with low available P, *T. vogelii* biomass will be improved by addition of MPR.

Key words: T. vogelii, soil pH, Ferralsol, Minjingu phosphate rock, plant height, dry matter yields, shoot N and P concentrations and shoot N and P uptakes

Introduction

Low soil pH and inadequate levels of N and P are common features in highly weathered tropical soils (Fox *et al.*, 1985; National Soil Service, 1989), and are among major factors limiting crop production in sub-Saharan Africa (Eswaran *et al.*, 1997). Soil pH *per se* is not the growth limiting factor but rather one or more secondary factors, which are pH dependent (Mengel and Kirkby, 1982). Some of the pH dependent secondary factors, which limit plant growth at low soil pH include Al and Mn toxicity, fixation and hence unavailability of P and deficiency of Ca and Mo. Others are depression of the activity of microorganisms involved in nitrification and N fixation and inhibition of the activity of symbiotic microorganisms, which lead to poor nodulation of some legumes (Brady, 1984). The situation is even worse when such soils are continuously cultivated without addition of any fertilizers. The overall consequences are low crop yields, persistent food insecurity, malnutrition and wide spread rural poverty.

In order to remain productive, such soils need to be carefully managed. Use of fallows (particularly improved fallows) - a common feature of small scale farming throughout the tropics can achieve this goal. Improved fallows consists of deliberately planted species-usually legumes with the primary purpose of fixing N_2 as part of a crop-fallow rotation (Sanchez, 1999). Improved fallows have the advantage of *in-situ* accumulation of biomass, optimisation of nutrient cycling, enhancing soil biological activities and maximising the use efficiency of minimal external inputs (Sanchez, 1994). *T. vogelii* Hook. F. is one of the indigenous leguminous shrubs with high potential of improving soil fertility when used in improved fallow situations (Balasubramanian and Sekayange, 1992). This species is a valuable leguminous cover crop in grass areas, relatively resistant to periodic fires, unpalatable to animals and hence a suitable fallow species in places where livestock are traditionally allowed to graze crop residues in the fields after harvest

(ICRAF, 1993). As a fallow species, *T. vogelii* has been reported to increase significantly yields of maize in Tanzania (Mgangamundo, 2000), maize in Malawi and Zambia (Kwesiga *et al*., 1999) and maize, sorghum and beans in Rwanda (Balasubramanian and Sekayange, 1992; Hagedorn *et al*., 1997).

The soil fertility improvement potential of *T. vogelii* fallow has been noted in Nyabisindu, Rwanda (Prinz, 1986) and in Gairo, Tanzania (Mgangamundo, 2000). The chemical constituents of *T. vogelii* foliar biomass as analysed in different laboratories are 2.85-4.0 % N, 0.38 % P, 1.03 % K, 1.89 % Ca, 0.16 % Mg, 8.0-8.3 % lignin, 2.37 % polyphenols, 21.1 % cellulose and 0.97 % retonones (Hagedorn *et al*., 1997; Mutuo *et al*., 1998; TSBF, 1999). However, poor growth of *T. vogelii* at Morogoro in Tanzania has been reported (Mugasha, 1999 Personal Communication). Also, Ngazi and Kapinga (1998) reported low cotton and cassava yields following a one year of *T. vogelii* fallow at Ukiriguru, Tanzania. Low cotton and cassava yields were attributed to low biomass produced by yield *T. vogelii*. Inadequate levels of available P at low soil pH could be the causal factors. Donald and Williams (1955) noted that generally legume growth and *Rhizobium* symbiosis are sensitive to available P. Phosphorus deficiency reduces nodulation, N_2 fixation and plant growth. Research elsewhere reported that low available P limits N_2 fixation and growth of *Leucaena lucocephala* and *Sesbania goetzei* (Luyindula and Haque, 1992). Hence in order to optimise the benefits from *T. vogelii* fallows, it is important to identify soil factors that may limit its performance. Based on this background, a glasshouse experiment was conducted using two soils with Bray-I low available P (2.5-2.9-mgP kg^{-1}) and low soil pH (pH 5.0 and 5.9), applied with and without P as MPR and *T. vogelii* as a test agroforestry species. The objectives of the experiment were as follows:

- To assess the effect of low soil pH on *T. vogelii* growth and shoot N and P contents.
- To evaluate the effect of MPR applications on such soils on *T. vogelii* growth and shoot N and P contents.

Materials and Methods

General description of the study area

The soils for the glasshouse trial were obtained from experimental site located in the Sokoine University of Agriculture (SUA) Farm, in Tanzania at longitude 37°39'12.4"E and latitude 06°50'24.5"S, and an elevation of 540 m above sea level. The experimental site has a slope of about 1.5 - 2%. Prior to field experimentation, the soils of the site were classified by using both World Reference Base for Soil Resources (1998) as Hyperdystri-

Umbric Ferralsol and by Soil Taxonomy system (Soil Survey Staff, 1998) as Typic Haplustox (Table 18.1). The soil pH of the site is variable and thus two soil samples, one with pH 5.0 and another with pH 5.9 were collected from different areas of the field and used for the glasshouse study. The two soils were analysed for selected chemical and physical properties using standard analytical methods as described by Okalebo *et al.* (1993) and the results are presented on Table 18.2. The glasshouse study was conducted between December and March 2001.

Table 18.1: Initial soil physical and chemical properties of trial site

Parameter	Magnitude
Sand (%)	36
Silt (%)	10
Clay (%)	54
Textural class	Clay
Soil pH (water)	5.06
Soil pH ($CaCl_2$)	4.60
Organic Carbon (%)	1.3
Total N (%)	0.07
C:N ratio	18.6
P (Bray-1 method) (mg kg^{-1})	2.1
Exchangeable Bases (me $100g^{-1}$)	
Ca	4.4
Mg	2.3
K	0.68
Na	0.18
Cu (mg kg^{-1})	1.13
Zn (mg kg^{-1})	0.63
B (mg kg^{-1})	Nd
Exch. Al^{3+} ($me100g^{-1}$)	0.005
Exch. H^{+} ($me100g^{-1}$)	0.11
Total Acidity ($me100g^{-1}$)	0.115

Glasshouse study

Five-litre plastic pots were filled with 5kg soil (air-dry weight) that was sieved through 8mm sieve. Two levels of P *viz*. 0 and 400mg P kg^{-1} soil were tested as MPR in a completely randomized design replicated six times. Basal applications of potassium (K), magnesium (Mg), and zinc (Zn) were made at the rate of 50 mg kg^{-1} soil K as K_2SO_4, 25 mg Mg kg^{-1} soil as $MgSO_4$ and 5 mg Zn kg^{-1} soil as $ZnSO_4$ kg^{-1} soil. Also, a starter N dose as NH_4SO_4 at 20 mg N kg^{-1} soil was applied because the N and O.C levels were < 0.12 and < 1.5 %, respectively. The fertilizers were thoroughly mixed with soil by hand and five *T. vogelii* seeds planted in each pot and then watered with deionized water to 80 % of the field capacity by weight as described by Klute (1986). The seedlings were thinned to two plants per pot one week after germination (WAG). *T. vogelii* plant height and dry matter yield data were collected at 3 and 12 WAG and N and P contents analysed in the plant samples collected at 12 WAG. Dry matter yield was obtained by cutting the plants at 2.0 cm above the soil, then washed to remove the adhering soil particles, weighed and then dried in an oven at 70°C to constant weight. The dried plant materials were weighed, cut into small pieces of about 1.0 x 0.5 cm and ground by Sample Mill to pass through 0.5mm sieve.

Table 18.2: Initial properties of two soils used in the Glasshouse study

Soil property	Soil 1	Soil 2
Sand (%)	36	34
Silt (%)	10	10
Clay (%)	54	56
Textural class	clay	clay
Soil pH (water)	3.0	3.9
Soil pH ($CaCl_2$)	1.63	1.60
Organic carbon (%)	1.3	1.2
Total N (%)	0.07	0.07
C:N ratio	18.6	17.1
P ($mgkg^{-1}$)	2.5	2.9
Exchangeable bases ($me100g^{-1}$)		
Ca ($me100g^{-1}$)	3.0	3.9
Mg ($me100g^{-1}$)	1.63	1.60
Na ($me100g^{-1}$)	0.23	0.19
K ($me100g^{-1}$)	0.9	0.68
Cu ($mgkg^{-1}$)	1.3	1.2
Zn ($mgkg^{-1}$)	0.64	0.63

Laboratory Analyses

Laboratory methods as described by Okalebo *et al.* (1993) were used for both soil and plant analysis. Soil pH was measured using 1:2.5 soil-water and 1*M*-potassium chloride mixture using a pH meter. Available P was extracted using the Bray-1 reagent and was determined colourimetrically after developing colour with ascorbic acid. Organic carbon was determined by the wet digestion method of Walkley-Black method. Total N was determined by the macro-Kjeldahl digestion-distillation method. Cation exchange capacity (CEC) was determined by the ammonium saturated method. Available Cu and Zn were extracted by the DTPA and their concentrations determined by AAS. Particle size analysis was done by the hydrometer method.

Phosphorus in plant samples was analysed using dry ashing method and determined colourimetrically while calcium was determined by AAS.

Statistical analyses

The data were analysed by MSTAT-C using completely randomized design. Significant means were separated using Duncan's New Multiple Range Test.

Results and Discussion

Plant height

Plant height of *T. vogelii* at three and twelve weeks as affected by soil pH and P application is given on Table 18.3. At three weeks, plant height on the soils without P applications was lower (11.62 cm plant^{-1}), on soil with pH 5.0 compared to soil with pH 5.9 (17.97 cm plant^{-1}), and at twelve weeks plant heights were 81.33 and 99.76 cm plant^{-1}for soil pH 5.0 and 5.9, respectively. The plant height for the soil with pH 5.9 without P application at 3WAG was higher (17.97 cm plant^{-1}) than that obtained on soil with pH 5.0 (15.6 cm plant^{-1}) with P application. The plant heights observed on soil that had pH 5.0 without P application were significantly ($P \leq 0.05$) different both at 3WAG and at 12WAG. Also, the plant heights for the soil pH 5.9 without P application and pH 5.0 with P application at 3WAG were statistically ($P \leq 0.05$) different. Low plant heights at soil pH 5.0 with P application at 3WAG is probably due to inadequate levels of some nutrients especially Ca (3.0 me100g-1) as compared to soil with pH 5.9 (3.9 me100g^{-1}) (Table 18.2). Application of P on soil with slightly higher levels of Ca and a lower level of Al^{3+} at 3WAG led to higher plant height (23.2 cm plant^{-1}) which was significantly ($P \leq 0.05$) different from the other treatments.

Table 18.3: Effect of soil pH and MPR applications on plant height (cm plant^{-1}) of *T. vogelii*

Treatment	3WAG	12WAG
Soil pH 5.0 -MPR	11.62 ^{c}	81.33 ^{b}
Soil pH 5.0 +MPR	15.60 ^{c}	93.00 ^{a}
Soil pH 5.9 -MPR	17.97 ^{b}	99.77 ^{a}
Soil pH 5.9 +MPR	23.20 ^{a}	104.37^{a}
LSD (0.05)	1.53	11.56
Std error	0.44	3.341
C.V. (%)	5.81	6.12

The *T. vogelii* plant heights at three weeks on soil with pH 5.0 were 15.6 and 11.62 cm plant^{-1} for with and without P application, respectively. The plant heights for twelve weeks on soil with pH 5.0 were 93.03 cm plant^{-1} with P and 81.3 cm plant^{-1} without P application. P applications did not significantly increase plant heights at three weeks but significantly ($P \leq 0.05$) increased it at twelve weeks possibly due to increased Ca uptake and P dissolution from MPR (Rajan *et al.*, 1996) at 12 weeks.

At twelve weeks, application of P on soil with pH 5.9 increased plant height from 99.7 to 104.3 cm plant^{-1}. The increase in plant height for soil with pH 5.0 due to P application was statistically comparable to plant height obtained on soil with pH 5.9 without P application. The small increase in plant height on soil pH 5.0 that received P was caused by strong soil acidity, which depressed the activity of microorganisms involved in various activities (including nitrification) in the rhizosphere (Brady, 1984; Mengel and Kirkby, 1982).

Dry matter yield

The dry matter yield (DYM) of *T. vogelii* accumulated at three and twelve weeks as affected by soil pH and P application is shown on Table 18.4. At three weeks, P application on soils with pH 5.0 increased DYM from 0.75 to 1.2 gpot^{-1} and for the soil with pH 5.9 DYM increased from 1.2 and 1.8 gpot^{-1}. Soil at pH 5.0 without P application had significantly ($P \leq 0.05$) lower dry matter production than the other treatments. The dry matter production from the soil with pH 5.9 applied with P was significantly ($P \leq 0.05$) higher than the other treatments.

Table 18.4: Effect of soil pH and MPR applications on dry matter production (gpot^{-1}) of *T. vogelii*

Treatment	3WAG	12WAG
Soil pH 5.0 -MPR	0.75^{c}	17.90^{c}
Soil pH 5.0 +MPR	1.20^{b}	34.80^{b}
Soil pH 5.9 -MPR	1.20^{b}	37.63^{b}
Soil pH 5.9 +MPR	1.80^{a}	51.33^{a}
LSD (0.05)	0.21	7.98
Std error	0.061	2.306
C.V. (%)	8.40	11.28

At twelve weeks, the DMY was doubled by the application of P on the soil with pH 5.0. The dry matter production were 17.9 and 34.8g pot^{1} with and without P application, respectively. The DMY at soil pH 5.9 was also increased from 37.63 without P treatment to 51.3 gpot^{-1} in pots that were applied with P. The difference was significant ($P \leq 0.05$).

The observations made by Fox *et al*. (1985), Aggarwal, (1994) and Giller *et al.* (1998) using different N_2 fixing species are similar to the results obtained in this study with *T. vogelii.* Fox *et al.* (1985) in Hawaii assessed the growth response of *L. lucocephala* to varying soil pH that ranged from < 5 to > 7 and found that relative yield increased with increasing soil pH until above pH 7. The increased relative yield was attributed to improved Ca nutrition that was associated with increasing soil pH in the range of 6 to 7. Aggarwal (1994), assessed 15 bean varieties on limed soils with soil pH 4.6-5.0 and low available P 0.35-1.40 in Malawi and reported a linear increase in the nodule number and grain yield with increased lime application up-to 75 % level of Al neutralisation. Giller *et al.* (1998) observed that addition of P fertilizer (26 $kgPha^{-1}$) on soils with pH ranging from 5.8-7.0 and available P 0.2-6.6 mg Pkg^{-1} dramatically increased the number of root nodules, N and seed yields of *Phaseolus vulgaris* in farmers fields in the West Usambara Mountains in northern Tanzania.

Balasubramanian and Sekayange (1992) in Rwanda obtained contradicting results with other N_2 fixing species. These workers compared the responses of *Crotalaria ochroleuca, Mucuna pruriens, Cajanus cajan* and *Sesbania sesban* to P applications (9-40 $kgPha^{-1}$) on a soil with pH 5.1 and 7 mg kg^{-1} of Bray II P and reported that P applications had no effect on the biomass production.

Shoot N and P concentration and uptake at twelve weeks

Table 18.5 gives the shoot N and P contents (%) and their uptakes (g pot^{-1}) as influenced by soil pH and P application of twelve weeks old *T. vogelii.* MPR application increased shoots N content both at pH 5.0 and pH 5.9. At pH 5.0, N concentration increased from 2.3% in the pots that were not applied with P to 3.5 % in the pots that were applied with P while at pH 5.9 the corresponding increase was from 2.5 to 3.2 %. The N concentration for the soil of pH 5.9 treated with MPR was lower than the comparable treatment of pH 5.0. However, the N uptakes (g pot^{-1}) for the soil of pH 5.9 treated with MPR was higher than the comparable treatment of pH 5.0 confirming that there was more available P after MPR application. The N uptakes (g pot^{-1}) for the soil of pH 5.9 treated with MPR was higher because at this soil pH level the activities of micro-organisms involved in various processes like nitrification are increased (Brady, 1984; Mengel and Kirkby, 1982).

On both soil pH levels, the shoot N concentrations were significantly ($P \leq 0.05$) increased due to P application. Similar observation was made on *P. vulgaris*. Addition of P fertilizer (26$kgPha^{-1}$) on soils with pH ranging from 5.8-7.0 and available P (0.2-6.6 mg Pkg^{-1}) dramatically increased N content of *P. vulgaris* (Giller *et al.*, 1998). The shoot N content for both soils when P was not applied was statistically the same, which suggests that N_2 fixation was depressed due to possibly one or more secondary factors which are pH dependent (Mengel and Kirkby, 1982). Contrary to the observation made in this study Balasubramanian and Sekayange (1992), reported that P applications to *C. ochroleuca*, *M. pruriens*, *C. cajan* and *S. sesban* (9-40 $kgPha^{-1}$) on a soil with pH 5.1 and 7 mg kg^{-1} of Bray II P had no effect on N content of these fallow species.

Table 18.5: Effect of soil pH and MPR applications on shoot N and P concentration (%) and uptake (g pot^{-1}) of *T. vogelii* after twelve weeks

Treatment	Shoot concentrations (%)		N and P uptake (g pot^{-1})	
	N	P	N	P
Soil pH 5.0 -MPR	2.32^{c}	0.22^{d}	0.43^{c}	0.04^{c}
Soil pH 5.0 +MPR	3.53^{a}	0.32^{b}	1.26^{a}	0.12^{ab}
Soil pH 5.9 -MPR	2.53^{c}	0.25^{c}	0.95^{b}	0.09^{bc}
Soil pH 5.9 +MPR	3.21^{b}	0.35^{a}	1.28^{a}	0.18^{a}
LSD (0.05)	0.32	0.02	0.039	0.006
Std error	0.091	0.006	0.018	0.018
C.V. (%)	5.47	7.30	2.01	2.62

The shoot P concentrations and P uptakes as influenced by soil pH and P application at twelfth week are presented on Table 18.5. MPR application increased shoot P concentration at soil pH 5.0 from 0.22 % to 0.32 % for pots that were not treated with P and for pots that were treated with P, respectively. At soil pH 5.9, MPR application increased shoot P concentration from 0.25 % for pots that were not treated with P to 0.35 % for pots that were treated with P. These shoot P concentrations were significantly ($P \leq 0.05$) different, with the highest shoot P concentration on soil with 5.9. *T. vogelii* P uptake at twelfth week was also increased with MPR application on both soil pH levels tested. However, the P uptakes at both soil pH levels when MPR was applied were not significantly ($P \leq 0.05$) different suggesting that P is necessary for *T. vogelii* in soils with low pH. The P uptakes for the soil of pH 5.0 in pots that were treated with P were statistically similar to pots that were not treated with P at soil pH 5.9. Similar observations were made on *Tritcum aestivum* and *Lupinus albus*. Kamh *et al.* (1999) reported significant ($P \leq 0.05$) N and P uptakes and shoot dry weight of *T. aestivum* and *L. albus* after P application as $Ca(H_2PHO_4)_2$.

Conclusion

From this pot experiment, the following conclusions can be made:

- On soils low in pH (strongly acid soil) and low available P, *T. vogelii* performance is appreciably reduced.
- On soils with low soil pH and low levels of available P, improved *T. vogelii* performance is observed when P levels are increased.
- Applications of P as MPR significantly increase *T. vogelii* plant height, dry matter yield, shoot N and P concentrations and shoot N and P uptakes. However, the increase of these parameters on a more strongly acid soil (pH 5.0) applied with MPR was lower than that obtained on soil pH 5.9, suggesting that P was not the only nutrient element limiting *T. vogelii* performance on soil with pH 5.0.

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References

Aggarwal, V.D. (1994) An overview of SADC/CIAT bean activities in Malawi. *Bean Research* 8, 15 - 31.

Balasubramanian, V. and Sekayange, L. (1992) Five years research on improved fallow in the semi-arid highlands of Rwanda. In: (eds Mulongoy, K., Gueye, M. and Spencer, D.S.C.) *Biological Nitrogen Fixation and Sustainability of Tropical Agriculture*. International Institute of Tropical Agriculture. A Wiley-Sayce Co-Publication, pp 405-422.

Brady, N.C. (1984) *The Nature and properties of soils*. 9th Edition, MacMillan Publishing Company, New York. pp 206-209.

Donald, C.M. and Williams, C.H. (1955) Fertility and productivity of a podsolic soil, as influenced by subterranean clover (*Trifolium subterraneum* L.) and superphosphate. *Soil Biology and Biochemistry* 5: 83-89.

Eswaran, H., Almaraz, R., van den Berg, E. and Reich, P. (1997) An assessment of the soil resources of Africa in relation to productivity. *Geoderma* 77, 1 - 18.

Fox, R.L., Yost, R.S., Saidy, N.A. and Kang, B.T. (1985) Nutritional complexities associated with pH variables in humid tropical soils. *Soil Science Society of America Journal* 49:1475-1480.

Kamh, M., Horst, W.J., Amer, F., Mostafa, H. and Maier, P. (1999) Mobilization of soil and fertilizer phosphate by cover crops. *Plant and Soil* 211: 19-27.

Giller, K.E., Amijee, F., Brodrick, S.J. and Edje, O.T. (1998) Environmental constraints to nodulation and nitrogen fixation of *Phaseolus vulgaris* L. in

Tanzania. II Response to N and P fertilizers and inoculation with *Rhizobium*. *African Crop Science Journal* 6: 171-178.

Hagedorn, F., Steiner, K.G., Sekayange, L. and Zech, W. (1997) Effect of rainfall pattern on N mineralization and leaching in a greenhouse experiment in Rwanda. *Plant and Soil* 195: 365-375.

Annual report 1992. ICRAF, (1993) International Centre for Research in Agroforestry, Nairobi, Kenya. pp 208.

Klute, A. (1986) Water Retention: Laboratory Methods. In: (ed) *Methods of soil Analysis*. Part 1. Physical and Mineralogical Methods. 2nd edition (Klute, A.) Number 9 (1) in Series of Agronomy. pp 635 - 660.

Kwesiga, F.R., Franzel, S., Place, F., Phiri, D. and Simwanza, C.P. (1999)*Sesbania sesban* improved fallows in Eastern Zambia: Their inception, development and farmer enthusiasm. *Agroforestry Systems* 47: 49-66.

Luyindula, N. and Haque, I. (1992) Effect of Rhizobium innoculation and P on growth and N fixation in tree legumes grown on highland Vertisols. In: eds Mulongoy, K., Gueye, M. and Spencer, D.S.C.) *Biological N Fixation and Sustainability of Tropical Agriculture*. IITA, Nigeria. pp 109-112.

Mengel, K. and Kirkby, E.A. (1982) *Principles of plant nutrition*. 3rd Edition, International Potash Institute – Bern, Switzerland. pp 54-61.

Mgangamundo, M.A.(2000) Effect of fallow periods of *Cajanus cajan*, *Sesbania sesban* and *Tephrosia vogelii* on soil fertility improvement and maize and fuelwood production at Gairo in Morogoro, Tanzania. MSc Thesis, Sokoine University of Agriculture, Morogoro, Tanzania. pp 51-67.

Mutuo, P., Marandu, A.E., Rabeson, R. and Mwale, M. (1998) N fertilizer equivalency values of organic materials of differing quality: Network trial results from East and southern Africa, season 1. In: *Proceedings of the 24th East Africa Soil Science Society Annual General Meeting.* 13 - 19 December, Tanga, Tanzania. pp 88 -101.

National Soil Service, (1989) *Effect of continuous cultivation and fertilizer applications on yields of maize and soil characteristics of a Ferralsol-Luvisol catena on Gneiss in North eastern Tanzania.* Mlingano Agricultural Research Institute, Tanga Tanzania. Soil Fertility Report F 5. pp 1-10.

Ngazi, H. and Kapinga, R. (1998) Effects of fallow species and length of fallow on soil fertility and cotton yield improvements on sandy loam soils. Annual Progress Report 1998, Ukiriguru, Mwanza, Tanzania. pp 8-9.

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (1993) *Laboratory Methods of soil and Plant analysis. A* working manual. KARI, SSEA, TSBF, UNESCO-ROSTA, Nairobi. pp 88.

Prinz, D. (1986) Increasing productivity of smallholder farming system by introduction of planted fallows. *Plant Research Division* 24: 31-56.

Rajan, S.S.S., Watkinson, J.H. and Sinclair, A.G. (1996) Phosphate rocks for direct application to soils. *Advances in Agronomy* 57: 77-159.

Sanchez, P.A. (1994) Tropical Soil Fertility research: Toward the second paradigm. In: *Proceedings of the 15th Transactions of the World Congress of Soil Science.* 10 - 16 July 1994, Acapulo, Mexico. pp 65 - 88.

Sanchez, P.A. (1999) Improved fallows come of age in the tropics. *Agroforestry Systems* 47: 3-12.

Soil Survey Staff (1998) *Keys to Soil Taxonomy*. United States Department of Agriculture, Natural Resources Conservation Unit (8th Edition). pp 328.

Tropical Soil Biology and Fertility (1999) *Organic Resource Database: A Guide for Selecting Organic Inputs for Soil Fertility Management.* Tropical Soil Biology and Fertility, Nairobi. pp 5.

World Reference Base for Soil Resources (1998) Food and Agriculture Organization of the United Nations. World Soil Resources Reports No. 84, International Society of Soil Science, International Soil Reference and Information Centre, Rome. pp 88.

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Decomposition of Organic Matter in Soil as Influenced by Texture and Pore Size Distribution

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Abstract

The carbon mineralization of fresh organic matter in soils of different texture was determined using ^{14}C-labelled tobacco (*Nicotiana tobacum*) starch solution and ^{14}C-labelled barley (*Hordeum vulgare)* straw particles. A heavy clay soil (56% illite clay) was mixed with acid washed sand to come up with a range of different soil textures, with clay contents varying between 5.6 and 56%. For each resultant texture, three treatments were imposed, namely, barley straw amendment, tobacco starch solution amendment and an unamended control. Total porosity ranged from 60.3% in soils with 56% clay content to 43.7% in soils with a clay content of 5.6%. Total clay content, porosity, bulk density and pore-volume (0.75 to 6 m in diameters) were all positively correlated to $^{14}CO_2$-C evolution (a measure of decomposition) of the amended soils. In both amended and unamended soils, the C mineralization decreased with increasing clay content, with ranges of 42-121 mg C g^{-1} soil with 5.6% clay and 34-107 mg C g^{-1} soil with 56% clay. Regression analysis showed that pores <75 m in diameter had the greatest influence on the amounts of CO_2-C released (R^2 =0.91 for starch and 0.94 for straw). Our findings provide empirical evidence to support the theory that decomposition of fresh organic matter is governed by its physical accessibility by microbes as determined by soil texture and pore size distribution. We concluded that pores of <75 µm are responsible for the protection of organic substrates against microbial decomposition in soils. The study provides insights on the role of clays in organic matter stabilization and hence the vulnerability of the limited amounts of organic inputs often available to smallholder farmers in tropical environments where soils are predominantly low in clay.

Key words: organic substrate, carbon mineralization, soil texture, pore size distribution, organic matter decomposition

Introduction

The influence of soil texture on organic matter decomposition has been widely studied and results indicate that the rate of decomposition and net mineralization depend on the accessibility of organic substrates to soil organisms (Oades, 1984; Christensen, 1987; Amato and Ladd, 1992, Hassink, 1996). Although organic matter decomposition studies are numerous, few have addressed the relative importance of direct and indirect mechanisms of soil texture control on organic matter stabilization (Srensen, 1981; van Veen *et al.*, 1985). In general, the quantity and nature of the soil clay affect the amount of C stabilized in soil. Fine textured soils (clays) often contain higher amounts of organic matter than sandy soils. Two mechanisms have beet put forward to explain the effect of soil texture on organic matter decomposition:

- the protective action by clays against organic matter degradation through the formation of complexes between metal ions associated with large clay surfaces and high CEC (Giller *et al.*, 1997); and
- accessibility by soil microbes (van Veen and Kuikman, 1990).

Clay particles are believed to protect some of the more easily decomposable organic compounds from rapid microbial breakdown through encrustation and entrapment (Paul and van Veen, 1978; Anderson, 1979; Tisdall and Oades, 1982).

The soil pore size distribution is one factor determining the microbial habitat since it is assumed that microorganisms mainly live in pores of a certain size. Considering the size of bacterial cells, pores of a neck diameter of 2-6 μm are favourable microhabitats for soil bacteria (Hattori and Hattori, 1976). Hassink (1992) also found a good correlation between the habitable pore size fraction and N mineralization. Killham *et al.* (1993) showed that substrate utilization by microbes in soil was strongly affected by its location, both in terms of pore size and the matric water potential under which turnover takes place. It should, however, be noted that only a very small fraction of organic material in soil is likely to be at close proximity to soil organisms at any one time (Adu and Oades, 1978).

Organic matter may be physically protected in soil such that large amounts of decomposable compounds can be found in the vicinity of starving microbial populations (van Veen and Kuikman, 1990). Elliott *et al.* (1980) used a combination of bacteria, amoebae and nematodes to demonstrate the importance of microbial trophic structure in relation to soil texture and habitable pore space. Ladd *et al.* (1985) found a significant linear relationship between residual labelled C in topsoil and clay contents ranging from 5 to 42%. The higher the clay content in the different soils, the higher the residual C content after 8 years of experimentation. On the assumption that bacterial cells were found in pores with a diameter of between 0.8 and 6 μm (Kilbertus, 1980; Hattori and Hattori, 1976), the aim of the experiment was to test how soil texture and habitable pore space affect decomposition of fresh organic matter applied to soil.

Materials and Methods

Soil-sand mixtures

The topsoil of a heavy clay from a site in Uppsala, Kungsängen soil, classified as a fine, illitic, frigid *Gleyic Cambisol* in the FAO-system (Kirchmann, 1991) was used. The same amount of air-dried soil comprising of 56% clay (<0.002 mm), 39.9% silt (0.002-0.06 mm) and 4.1 % sand (0.06-2 mm) and with a pH of 6.9, 2.14% C and 0.26% N, was mixed with different quantities of acid-washed quartz sand (0.3-0.5 mm) to create a range of textures resulting in different soil pore-size distribution. As the same amount of soil was mixed with increasing proportions of sand, it was assumed that the soil mixtures under investigation were uniform with respect to:

a) the number of exchange sites which was the same in all the mixtures,
b) the initial amount of organic matter, and
c) the initial number of microbes present.

The only physical aspect that was changed was the pore size in the soil-sand mixtures. Bulk densities and volumetric water contents of the mixtures were determined at -500 KPa, -1 500 KPa wilting point) and -4 000 KPa water pressures (Table 19.1). The pore size distribution of each soil mixture was obtained from the moisture characteristic curves relating volumetric water content to soil metric potential. The porosity of the soil-sand mixtures was determined assuming a particle density of the sand of 2.65 g cm^{-3} and for the Kungsängen soil, of 2.62 g cm^{-3} (Kirchmann, 1991).

Table 19.1: Particle size distribution, bulk density and soil pore space of the different soil treatments

10g Kungssangen soil+ *x*g sand	Soil texture(%)			Bulk density Mgm^{-3}			Total Porosity		
mixtures	Sand	Silt	Clay	Control soil only	soil+ starch	soil+ straw	Control soil only	soil+ starch	soil+ straw
0.0	4.1	39.9	56.0	1.1	1.1	1.0	60.4	60.4	62.6
2.5	23.3	31.9	44.8	1.2	1.2	1.1	56.0	56.0	58.5
6.7	42.5	23.9	33.6	1.3	1.3	1.2	51.3	51.3	54.7
10.0	52.0	20.0	28.0	1.3	1.3	1.2	50.2	50.2	53.6
15.0	61.6	16.0	22.4	1.4	1.4	1.3	48.8	48.8	49.8
23.3	71.2	12.0	16.8	1.4	1.4	1.4	46.9	46.9	47.7
40.0	80.8	8.0	11.2	1.4	1.4	1.4	45.1	45.1	45.5
90.0	90.4	4.0	5.6	1.5	1.5	1.5	43.3	43.3	43.3

Soil amendments

Triplicate samples of each clay content (10 g of Kungsängen soil plus sand as described in Table 19.1), were moistened to 45% of their respective water-holding capacities. The samples were then amended with either 2 ml of a tobacco (*Nicotiana tobacum*) starch solution containing 44.4 mg starch C, 45.5 μCig^{-1} starch ^{14}C or 2 ml distilled water plus 100 mg ground (<2 mm) barley straw (*Hordeum vulgare)* containing 100 $\mu Cig^{-1}C$ plant ^{14}C and 2.1 mg plant N. The moistened soil treatments were incubated at 25°C for 45 days. Incubation vials of corresponding moistened soil-sand mixtures without organic amendments were used as controls. Determination of CO_2 evolution was done using 10 ml traps with 0.1 M NaOH (Stotzky, 1965), that were titrated with 0.1 M HCl after 1, 3, 7, 11, 17, 24, 31, 38 and 45 days. Radioactivity of absorbed $^{14}CO_2$ was determined by scintillation counting (Beckman liquid scintillation systems LS 1801) and residual organic ^{14}C was determined by wet combustion of the oven dried soil subsamples.

Statistical Analyses

Data were subjected to a two-factor (time and treatment) analysis of variance (ANOVA) to determine if the materials mineralized differently with time. Possible mean differences of the cumulative mineralization data were tested using independent Student t-tests and residual ^{14}C was correlated to the different soil properties using linear regression analysis with the statistical package of MINITAB (Ryan *et al.*, 1985).

Results

Changes in soil pore size distribution upon amendments

Changing the texture through sand amendments increased the bulk densities of the soil but lowered the total soil porosity (Table 19.1). The addition of tobacco starch solution to the soils did not alter the physical structure of the soils resulting in these soils having the properties similar to the control soils. Bulk densities ranged from 1.05 Mg m^{-3} (soil 56% clay) to 1.50 Mg m^{-3} (soil 5.6% clay) in control and starch-amended soils. However, adding straw particles (*Hordeum vulgare*) to the same soils lowered the bulk densities in high clay soils but not in more sandier soils which had almost equal bulk densities to control soils. Total porosity increased with increasing clay content from 43.3 to 60.4% in the soil-sand mixtures and from 43.3 to 62.6% in the straw-amended soil-sand mixtures.

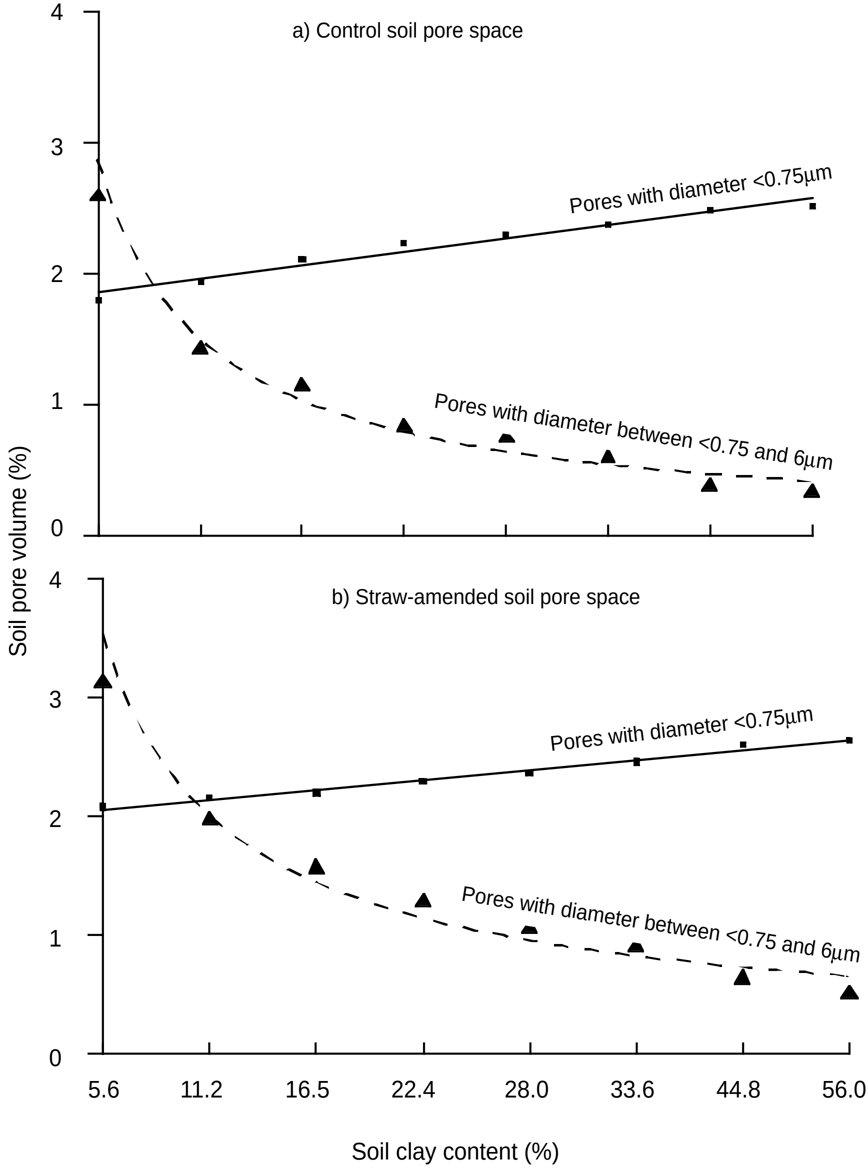
The absolute pore volume in the soil-sand mixtures was affected when sand was added with increasing quantities to the Kungsängen soil (Table 19.2). The volume of pores with diameters of <6 m was higher in straw amended soils than in starch amendments and the control soil-sand mixtures. Differences were statistically significant only in soil-sand mixtures of between 5.6 and 28% clay content ($P<0.05$) while in all the high clay soils (>28% clay), the volume of pores <6 μm occupied between 44 to 50% of total porosity (Table 19.2). Soil pore volumes of diameters between 0.75 and 6 μm in both straw and starch amended soils decreased exponentially with increasing clay content. In the same soils, the pore volume of the smaller, supposedly inaccessible pores of <0.75 m in diameter increased linearly and showed significant relationships (R^2 = 0.91 for starch amended and 0.94 for straw amended soils.

Table 19.2: Soil pore space, pore volume and CO_2-C evolution in amended and unamended soils

Soil treatment and pore size	56.0% clay	44.8% clay	33.6% clay	28.0% clay	22.4% clay	16.8% clay	11.2% clay	5.6% clay
Control soil								
Pores >6 µm (%)*	50	52	55	60	66	71	78	85
Pores >6 µm (mL)	3	3	4	5	6	8	12	24
Pores <0.75 µm (%)*	44	41	36	30	25	19	12	6
Pores <0.75 µm (mL)	3	2	2	2	2	2	2	2
Pores (0.75-6) µm (%)*	6	6	9	10	9	10	9	9
Pores (0.75-6) µm (mL)	0.4	0.4	0.6	0.8	0.8	1	1	3
CO2-C evolution (mg C g^{-1} soil)	29	31	35	35	36	37	38	40
Tobacco starch- amended soil								
Pores >6 µm (%)*	50	52	55	60	66	71	78	85
Pores >6 µm (mL)	3	3	4	5	6	8	12	24
Pores <0.75 µm (%)*	44	41	36	30	25	19	12	6
Pores <0.75 µm (mL)	3	2	2	2	2	2	2	2
Pores (0.75-6) µm (%)*	6	6	9	10	9	10	9	9
Pores (0.75-6) µm (mL)	0.4	0.4	0.6	0.8	0.8	1	1	3
CO2-C evolution (mg C g^{-1} soil)	10.3	114	120	121	118	120	127	141
Barley straw-amended soil								
Pores >6 µm (%)*	51	52	56	61	62	67	74	82
Pores >6 µm (mL)	3	3	4	5	6	8	12	24
Pores <0.75 µm (%)*	41	39	32	27	24	19	14	7
Pores <0.75 µm (mL)	3	3	2	3	2	2	2	2
Pores (0.75-6) µm (%)*	8	10	12	12	14	14	13	11
Pores (0.75-6) µm (mL)	0.5	0.6	0.9	1	1	2	2	3
14CO2-C evolution (mg C g^{-1} soil)	97	103	108	100	101	103	110	118

*expressed as a percentage of total porosity

Figure 19.1: The relationship between soil-pore volume and clay content of (a) unamended control soil and (b) the same soils following addition of barley straw



Carbon Dioxide Evolution

In the control soil-sand mixtures, there was very little difference in the amount of native soil organic matter evolved as CO_2 after 45 days of incubation. Significant differences were apparent at high clay contents ($P<0.05$). Total cumulative values ranged from 29.3 mg C g^{-1} soil (56% clay) to 40.1 mg C g^{-1} soil (5.6% clay). The same trend of C mineralization was observed when soils were amended with fresh organic matter (Table 19.2). Both barley straw and starch were decomposed to a higher extent in soils with low clay contents of 5.6 to 16.8%. The CO_2 evolution from starch amended treatments was greater than from straw amended ones. At the end of the incubation period, more than quarter of the added C had been mineralized in all the treatments. Cumulative CO_2-C evolution data from starch-amended soils showed differences between high and low clay content within one week and these differences became statistically significant from the third week onwards ($P<0.05$) (Figure 19.2a).

In the straw-amended soils, there was very little difference in the evolution of $^{14}CO_2$-C in six of the eight mixtures ($P>0.05$) (Figure 19.2b). The pattern of C mineralization observed was very similar to that of the control soil-sand mixtures. Cumulative $^{14}CO_2$-C evolution data showed that C mineralization was initially rapid and after about 3 weeks, decreased rates of $^{14}CO_2$-C production following a first-order function were observed. At the end of the incubation period, the highest percentage of labelled C evolved (39.1% of added straw ^{14} C) was noted in soil with 5.6% clay, the other 7 soil mixtures released between 29.2 and 36.5% of the C added.

Relationships between C mineralization and soil physical properties

There were good correlations between labelled substrate C mineralization and clay content, bulk density and soil pore spaces. Bulk density was positively related to C mineralization whereas total porosity was negatively related (Table 19.3). Differentiating soil pore diameters into three possible groups (<0.75 m, 0.75-6 m and >6 m), the highest correlation with C evolution was obtained with the volume of pores of diameters <0.75 m ($R^2 = 0.914$ for starch and 0.935 for straw; $p < 0.001$) (Figure 19.3). The results showed that the higher the concentration of these small pores, the less the $^{14}CO_2$-C evolved. Linear regression analysis showed that translating percentage porosity into absolute pore volume per given soil did not improve correlations between the different pore groups and $^{14}CO_2$-C evolution.

Figure 19.2: Net cumulative $^{14}CO_2$-C evolution of soil-sand mixtures amended with a) tobacco starch solution and b) <2mm granulated barley straw. Means are based on n = 3

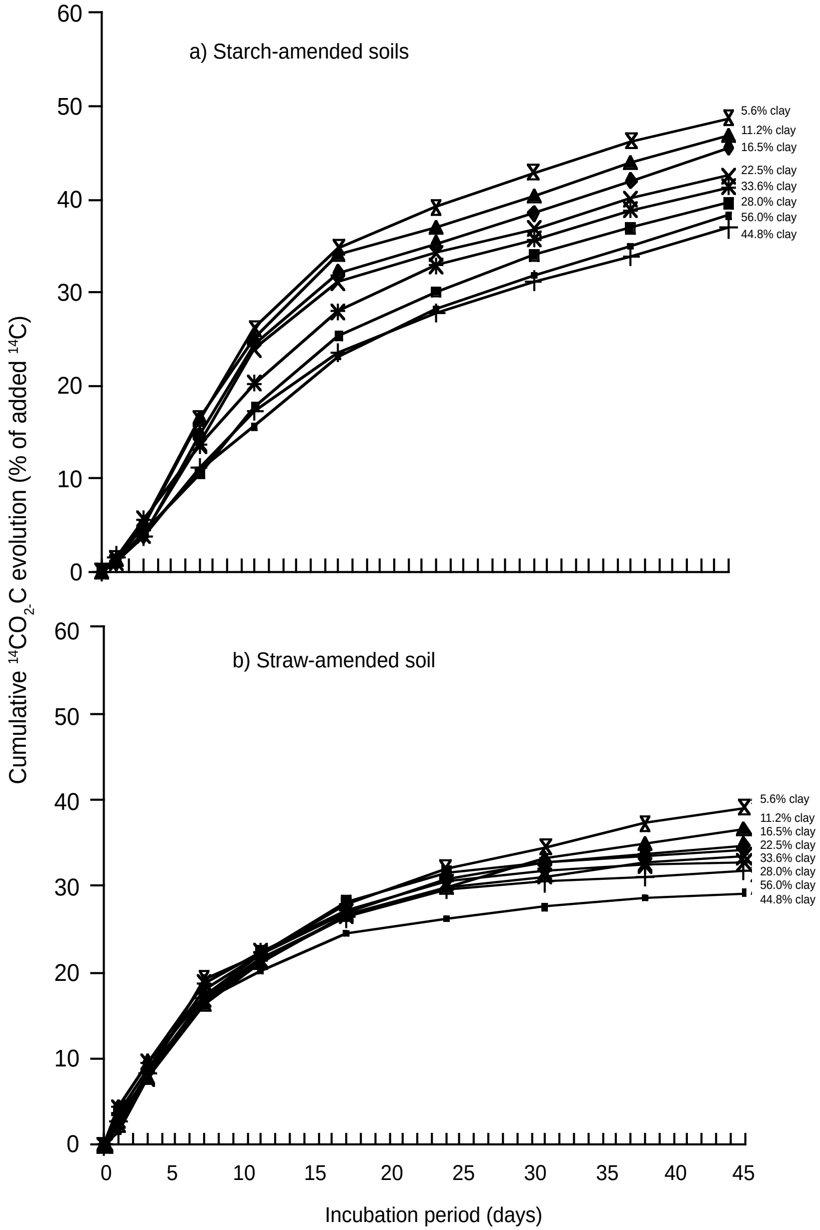
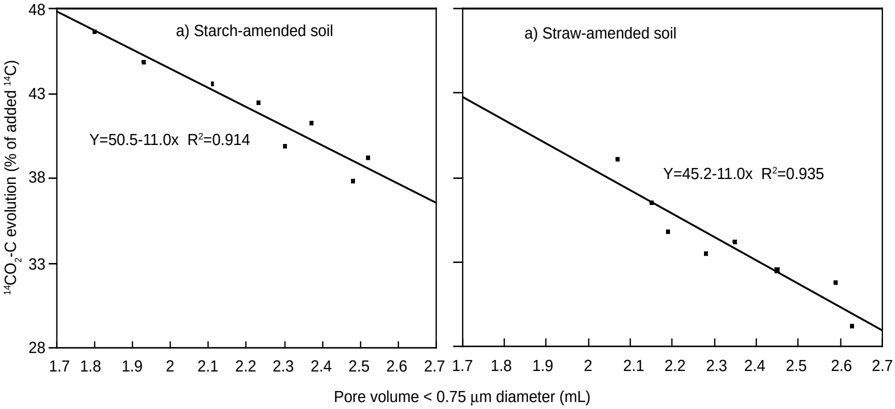


Table 19.3: Linear regressions for $^{14}CO_2$-C mineralization between (a) tobacco (*Nicotiana tobacum*) starch and (b) barley (*Hordeum vulgare*) straw and soil properties after 45 days of soil incubation

Quality variable (x)	Dependent variable (y)	Intercept	Slope	R^2
Clay (%)		46.3	-0.2	0.81
Bulk density		18.1	18.1	0.76**
Total porosity (%)		65.7	-0.5	0.78**
Total pore volume (mL)		38.2	0.3	0.75**
Porosity (<0.75 m) (%)	a	47.6	-0.2	0.91***
Pore volume (<0.75 m) (mL)		50.5	-0.1	0.91***
Porosity (>6 m) (%)		27.1	0.2	0.91***
Pore volume (>6 m) (mL)		39.1	0.4	0.75**
Clay (%)		38.5	0.2	0.91***
Bulk density		13.4	16.2	0.90***
Total porosity (%)		56.2	-0.4	0.90***
Total pore volume (mL)	b	29.8	0.4	0.79**
Porosity (<0.75 m) (%)		40.2	-0.2	0.92***
Pore volume (<0.75 m) (mL)		45.2	-1.1	0.94***
Porosity (>6 m) (%)		17.1	0.6	0.93***
Pore volume (>6 m) (mL)		30.8	0.4	0.79***

*** - significant at $p < 0.001$, ** - significant at $p < 0.01$, * - significant at $p < 0.05$

Figure 19.3: Relationship between cumulative $^{14}CO_2$-C evolution and soil pore volume of diameters of <0.75m for starch-amended soils (a) and straw-amended soils (b)



Discussion

The addition of a readily decomposable organic C sources stimulated the mineralization of native soil organic C in the soil-sand mixtures. The extent to which the two different substrates ^{14}C was decomposed was consistent in both amendments being higher in low clay than in high clay soils. Given that the *Kungsangen* soils used in treatments already had high initial C and N, sampling possibly opened up some labile C that would have been otherwise protected in soil aggregates resulting in increased C evolution. However, the nature of the decomposer population and available pore space have been found to influence the rate of mineralization of organic substrates added to soil (Srensen, 1975; Elliott *et al.*, 1980; Hassink *et al.*, 1993). Pores with diameters of less than 0.75 µm were presumed to be responsible for the protection of microbial decomposition of the fresh organic substrates added to soil-sand mixtures. These pores were found in higher proportions in high clay soils and thus may explain why high clay soils are better able to protect organic matter from decomposition. The concept of microbial accessibility in soil seem to be most meaningful if it is used in relation to the size of the microbial inaccessible pores. The structure of the decomposer community available in the Kungsängen soil was not investigated in this study. In our study, we sampled soils that had been under intensive cereal production for over 25 years (Kirchmann, 1991) thus the amount and quality of native organic matter in the soil was assumed to be similar and was not disturbed during sample preparation. The number of exchange sites of the clay were kept constant and the effect of pore size could be investigated without interaction of other media. Although soil texture has been shown to correlate with long-term C dynamics (Jenkinson, 1971; Ladd *et al.*, 1985), our results show that differences in soil texture in the control soils had no significant effect on CO_2-C mineralization of native soil organic matter. We therefore suggest the key factor controlling organic matter decomposition in different textured soils is the soil pore size and distribution. Since soil texture controls the pore size distribution and it is in this way that conclusions on texture affecting organic matter decomposition have been made (Hassink, 1992; Hassink *et al*, 1993). Our results have shown that as the soils became more sandy, the degree of soil porosity decreased. Carbon dioxide evolution from the two added organic substrates appeared to be strongly affected by the soil pore-size distribution and pore continuity.

There is no general agreement on the critical factors influencing movement of organisms in soil, but larger organisms are probably more restricted than smaller ones. Pore-size distribution and continuity are known to influence soil water availability, gas diffusion and the movement of soil organisms (Coleman *et al.*, 1984; Scott *et al.*, 1996). Pore-neck size determines whether an organism can enter a given pore, thus whether a substrate located within the soil pore is available to microorganisms. We found that the best correlation was the negative relationship between soil pores of less than 0.75 µm and the amount of $^{14}CO_2$-C evolved for both starch- and straw-amended treatments. These results indicate the importance of those pores that are inaccessible for microbes in the stabilization of organic matter. The theory of physical accessibility and its linkage between soil texture as described by soil pore size distribution to decomposition of fresh organic matter was affirmed. Hassink *et al.* (1993) found good relationships between pore volumes of between 0.2 and 1.2 µm diameter and bacterial biomass. The difference between $^{14}CO_2$ released from the high clay soils and the low clay soils in both starch and straw amendments may be considered to be a measure of the proportion of starch or straw in micropores potentially protected from microbial degradation. Adu and Oades (1978) attributed physical protection from microbial decomposition when a portion of soluble starch in micropores was left unmineralized.

The concept of substrate quality has also been identified as an important factor in soil organic matter stabilization (McClaugherty *et al.*, 1985; Duxbury *et al.*, 1989; Melillo *et al.*, 1989). Although the contribution of native soil organic matter to total carbon mineralization was significant as was shown by the control soils, several studies have shown what Jenkinson (1971) described as the 'priming action' following the addition of fresh organic matter to soil. Carbon dioxide evolution from the control (unamended) soils was significantly lower than that of amended soil signifying the stimulation of ‘microbial priming action’ following soil amendments. Higher mineralization and decomposition rates are known to be stimulated by increased N availability (Palm and Sanchez, 1991; Tian *et al.*, 1995). Our study showed that incubation of starch-amended soils showed greater utilization than high N-containing, thus higher quality barley straw (Cadisch and Giller, 1997). This was probably due to an abundance of readily available C for maximum utilization for microbial growth relative to N. The delayed differences in C mineralization of straw amended soils observed towards the end of the study imply a gradual narrowing of the C:N ratio when at some point, N becomes no longer limiting to microbial growth. In addition, accessible pore space also played a major role during the mineralization of a presumably distributed (soluble starch) organic substrate and more strongly of unevenly distributed one (granulated straw).

Conclusion

Our findings provide a challenge to soil fertility research focussing on soil organic matter build-up and maintenance using organic amendments. Given that most of the smallholder farming areas in tropical environments are dominated by sandy soils, the vulnerability of the limited amounts of organic inputs available in most of these farming systems is implied. The study provides empirical evidence to support the theory that decomposition of fresh organic matter is governed by its physical accessibility by microbes as determined by soil texture and pore size distribution. We therefore concluded that pores of diameters of <75 μm were responsible for the protection of organic substrates against microbial decomposition in soils. To be able to understand fully the importance of clay in organic matter stabilization, there is a need for more research in the soil pore system and the mechanisms that take place within and develop organic matter management options for soils of different textures.

Acknowledgements

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References

Adu, J.K., and Oades, J.M. (1978) Physical factors influencing decomposition of organic materials in soil aggregates. *Soil Biol. Biochem.* 10: 109-115.

Amato, M., and Ladd, J.N. (1992) Decomposition of 14C-labelled glucose and legume material in soils. Properties influencing the accumulation of organic residue C and microbial biomass. *Soil Biol. Biochem.* 24: 455-464.

Anderson, D.W., (1979) Processes of humus formation and transformation in the soils of the Canadian Great Plains. *J. Soil Sci.* 30, 77-84.

Cadisch, G., Giller, K. (1997) *Driven by Nature: Plant Litter Quality and Decomposition.* CAB International, Wallingford.

Christensen, B.T. (1987) Decomposability of organic matter in particle size fractions from field soils with straw incorporation. *Soil Biol. Biochem.* 19, 429-435.

Coleman, D.C., Anderson, R.V., Cole, C.V., McClellan, J.F., Woods, L.E., Trofymow, J.A., and Elliott, E.T. (1984) Roles of protozoa and nematodes in nutrient cycling. In: Giddens, J.E. and Todd, R.L. (Eds.), *Microbial-Plant Interactions*. ASA Special Publication 47. SSSA, Madison, pp. 17-28.

Duxbury, J.M., Smith, M.S. and Doran, J.W. (1989) Soil organic matter as a source and sink of plant nutrients. In: Coleman, D.C., Oades, J.M. and Uehara, G. (Eds.), *Dynamics of Soil Organic Matter in Tropical Ecosystems.* NifTAL Project, University of Hawaii, Honolulu, pp. 33-67.

Elliott, T.E., Anderson, R.V., Coleman, D.C., and Cole, C.V. (1980) Habitable pore space and microbial trophic interactions. *Oikos* 35: 327-335.

Giller, K.E., Cadish, G., Ehaliotis, C., Adams, E., Sakala, W. and Mafongoya, P. (1997) Building soil nitrogen capital in Africa. In: Buresh, R.J., Sanchez, P.A., Calhoun, F. (Eds.), *Replenishing Soil Fertility in Africa.* SSSA Special Publication No. 51, Madison, pp. 151-192.

Hassink, J. (1992) Effects of soil texture and structure on carbon and nitrogen mineralization in grassland soil. *Biol. Fert. Soils* 14: 126-134.

Hassink, J. (1996) Presevation of plant residues in soils differing in unsaturated protective capacity. *Soil Sci. Soc. Am. J.* 60: 487-91.

Hassink, J., Bouman L.A., K.B. Zwart, K.B. and Brussard, L., (1993). Relationship between habitable pore space, soil biota and mineralization rates in grassland soils. *Soil Biol. Biochem.* 25: 47-55.

Hattori, T. and Hattori, R. (1976) The physical environment in soil microbiology: An attempt to extend principles of microbiology to soil microorganisms. *CRC Crit. Rev. Microbiol.* pp. 423-461.

Jenkinson, D.S. (1971) Studies on the decomposition of 14C labelled organic matter. *Soil Sci.* 111: 64-72.

Kilbertus, G., (1980) Etude des microhabitats contenus dans les agregats du sol. Leur relation avec la biomasse becterienne et la taille des procaryotes presents. *Rev. d'Ecol. Biol. Sol* 17: 543-557.

Killham, K., Amato, M. and Ladd, J.N. (1993) Effect of substrate location in soil and soil pore-water regime on carbon turnover. *Soil Biol. Biochem.* 25: 57-62.

Kirchmann, H. (1991) Properties and classification of soils of the Swedish long-term fertility experiments. 1. Sites at Fors and Kungsängen. *Acta Agric. Scand.* 41: 227-242.

Ladd, J.N., Amato, M. and Oades, J.M. (1985) Decomposition of plant material in Australian soils. III. Residual organic and microbial biomass C and N from isotope labelled plant material and organic matter decomposition under field conditions. *Aust. J. Soil Res.* 23: 603-611.

McClaugherty, C., Pastor, J. and. Muratore, J.F. (1985) Forest litter decomposition in relation to soil nitrogen dynamics and quality. *Ecol.* 66: 266-275.

Melillo, J.M., Aber, J.D., Linkins, A.E., Ricca, A., Fry, B. and K.J. Nadelhoffer., K.J. (1989) Carbon and nitrogen dynamics along a decay continuum: Plant litter to soil organic matter. In: Clarholm, M., Bergstrm, L. (eds.), *Ecology of Arable Land.* Kluwer, Dordrecht, pp. 53-62.

Oades, J.M. (1984) Soil organic matter and structural stability: mechanisms and implications for management. *Plant and Soil* 76: 319-337.

Oades, J.M. (1988). The retention of organic matter in soils. *Biogeochem*. 5: 35-70.

Palm, C. and Sanchez, P. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem*. 23: 83-88.

Paul, E.A., van Veen, J.A. (1978) *The use of tracers to determine the dynamic nature of organic matter*. International Congress of Soil Science, Transactions of the 11th Symposia Papers. 3: 61-102, Edmonton.

Ryan, F.R., Joiner, B.L. and Ryan, T.A. (1985) *MINITAB handbook*. Prindle, Weber and Schimdt Publishers, Boston.

Scott, N.A., Cole,V.C., Elliott, E.T. and Huffman, S.A. (1996) Soil textural control on decompostion and soil organic matter dynamics. *Soil Sci. Soc. Am. J.* 60: 1102-1109.

Srensen, L.H. (1975) The influence of clay on the rate of decay of amino acid metabolites synthesized in soils during decomposition of cellulose. *Soil Biol. Biochem*. 7: 171-177.

Srensen , L.H. (1981) Carbon-nitrogen relationships during the humification of cellulose in soils containing different amounts of clay. *Soil Biol. Biochem*. 13: 313-321.

Stotzky, G. (1965) Microbial respiration. In: Black, C.A. (ed.), *Methods of Soil Analyses Part 2*, 2nd Edition, Agronomy Monograph 9, ASA, SSSA, Madison, pp. 1550-1572

Tian, G., Kang, B.T. and Brussard, L. (1995) Mulching effect of plant residues with chemically contrasting composition on maize growth and nutrient accumulation. *Plant and Soil* 153: 179-187.

Tisdall , J.M. and Oades, J.M. (1982) Organic matter and water-stable aggregates in soils. *J. Soil Sci.* 33: 141-163.

van Veen, J.A. and Kuikman, P.J. (1990) Soil structural aspects of decomposition of organic matter by micro-organisms. *Biogeochem*. 11: 213-233.

van Veen, J.A. and J.N. Ladd, J.N. and Amato, M. (1985) Turnover of carbon and nitrogen through the microbial biomass in sandy loam and a clay soil incubated with [14C(U)] glucose ([15N](NH4)2)SO4 under different moisture regimes. *Soil Biol. Biochem*. 17: 747-756.

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Soil Conservation and Fertility Improvement Using Leguminous Shrubs in Central Highlands of Kenya: NARFP Case Study*

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Abstract

Declining land productivity with reduced crop yields has been a major problem facing smallholder farmers in the central highlands of Kenya. The major factors contributing to the reduced land productivity is soil impoverishment caused by continuos cropping without addition of adequate fertilizer and manure, and soil erosion on steep slopes. The National Agroforestry Research Project (NAFRP) initiated research work in 1992 to try and address these problems. The research work investigated the potential of using two leguminous shrubs (*Leucaena leucocephala* and *Calliandra calothyrsus*) for improving soil fertility and soil conservation on steep slopes. The studies were carried out both at on-station and on-farm.

Treatments where leafy prunings of calliandra and leucaena were incorporated yielded higher than the control treatments without prunings incorporation. Leucaena alley cropping system was beneficial and maintained crop yields at 4 t ha^{-1} in most seasons. Calliandra hedgerow intercropping system on the other hand depressed crop yields. However calliandra was effective in controlling soil erosion when planted as a contour-hedgerow system. The contour hedgerows in addition to conserving soil produced additional benefits in terms of high quality animal fodder.

This study concluded that in the central highlands of Kenya where land is slopy, and similar areas, it is advisable for the smallholder farmers to plant leguminous fodder trees on terraces as contour hedgerows for both soil conservation and biomass production. The resulting biomass could be incorporated into the soil to improve soil fertility for farmers without livestock, or fed to livestock for farmers who own livestock. If the biomass is fed to livestock, possibilities of recycling nutrient through animal manure should be explored to ensure soil nutrient replenishment.

Key words: Alley-cropping, *Calliandra calothyrsus*, *Leucaena leucocephala*, Contour hedgerows, Leafy prunings (prunings), Fodder

Introduction

The central highlands of Kenya are densely populated with more than 500 persons Km^{-2} (Government of Kenya, 1994) and declining land productivity with reduced crop yields has been a major problem facing smallholder farmers in the region (Kipkiyai *et al*., 1998). The major factors contributing to the reduced land productivity is soil impoverishment caused by continuous cropping with inadequate addition of fertilizer and/or manure, and soil erosion on steep slopes (Minae and Nyamai, 1988).

Land sizes are small, averaging 1.2 ha per household, and this promotes continuous cropping with limited scope for crop rotation and inadequate soil fertility replenishment. Nitrogen and phosphorus are the most limiting nutrients to crop production and high costs of inorganic fertilizers limit their sufficient use by majority of the smallholder farmers. Indeed a substantial number of farmers do not use fertilizers and the ones who use fertilizers apply below the recommended rates (Kihanda, 1996). Muriithi *et al* (1994) reported use of fertilizers by farmer to be less than 20 kg N and 10 kg P ha^{-1} against recommended rate of 60 kg N and Pha^{-1}.

The topography of the central highlands of Kenya is gently to steeply rolling with a medium to high erosion hazard as determined by FAO (Kassam *et al.*, 1992). The sloping topography and high rainfall has resulted to soils in the region being highly prone to water erosion (O'Neill, 1997; Ongwenyi *et al* 1993). Water erosion carries away soil nutrients and, soil nutrient depletion has been reported to be taking place at an alarming rate in all the agroecological zones (Pieri *et al.*, 1995).

Leguminous trees species have shown some potential for soil fertility improvement and soil conservation. Soil fertility improvement can be achieved through biomass transfer, short term fallows, nitrogen fixation, re-activation of the 'N bulge' and phosphorus scavenging (Rosecrance *et al.*, 1992; Amadalo *et al.*, 1995; Jama *et al.*, 1998; Hartemink *et al.*, 2000). The leguminous trees have similarly shown potential of reducing soil erosion through five processes; interception of rainfall impact by tree canopy, surface runoff impediment by tree stems, soil surface cover by litter mulch, promotion of water infiltration and formation of erosion-resistant blocky soil structure (Nair, 1987; Young, 1989; Young and Sinclair, 1997). Researchers at other sites within East Africa AFRENA (ICRAF, 1991) have had success of varying degrees by incorporating fodder grasses and trees along the contours to both reduce soil erosion and provide products which would help convince the farmers that soil conservation can be profitable.

Despite the potentials for the use of tree shrubs for soil conservation and soil fertility improvement, their use in the region is limited (ICRAF, 1992). A survey carried out in Meru District (Murithi *et al.*, 1994) found that 83 percent of the farmers surveyed had soil fertility problems while 91 percent had soil erosion problems. In the survey majority of farmers (93 percent) used manure for improving soil fertility with limited use of tree prunings while none of the farmers used trees for soil erosion control.

To address the aforementioned problems of soil fertility decline and soil erosion on steep slopes, the National Agroforestry Research Project (NAFRP), based at the Kenya Agricultural Research Institute (KARI), Regional Research Centre-Embu, Kenya, conducted some research activities to investigate feasibility of using leguminous trees for soil fertility improvement and soil conservation. The research work was initiated in 1992 and this manuscript review consolidates the research work, highlighting the major findings and also discusses the dissemination potential. The leguminous shrubs used are Le*ucaena leucocephala* (Lam.) de Wit and *Calliandra calothyrsus* Meissn. The two species have been shown to be the most appropriate species for soil improvement and crop sustainability through agroforestry research at Maseno, Kenya (Heinemann *et al*., 1990).

Methodology

The study area

The highlands of Central Kenya are characterized by a bimodal rainfall distribution, which ranges from 600 mm to 2000 mm annually in the mandate region of the National Agroforestry Research Project based in Embu. Agriculture is characterized by smallholder mixed farming activities, which include cash crops (coffee, tea and horticultural crops), food crops (Maize, beans, bananas and Irish potatoes) trees and livestock (dairy and beef cattle, goats, sheep, poultry and pigs). Nearly all farmers in the region practice dairy farming under zero and/or semi-zero grazing and the need for fodder is a main constraint (Minae and Nyamai, 1988). Napier grass *(Pennisetum purpureum*) is the major fodder and is generally produced in fodder plots or along the bunds of terraces where it is also used as stabilizer for the erosion control structures.

High population pressure (> 500 persons Km^{-2}) has led to the sub-division of family farms into small units (app. 1.2 ha) which require intensive agricultural practices to produce enough food for home consumption and outside sales. This has led to the exploitation of lands of decreasing productivity and increasing soil erosion potential.

The soils are locally known as “Kikuyu Red Clay Loams”. They are deep (>2m), well drained, dusky red to dark reddish brown in colour with moderate structure (Mwangi, 1997). They are derived from rich, basic volcanic rocks and have been classified as Typic Palehumult (Humic Nitisols according to FAO-UNESCO, 1975).

Research Activities

Within the period 1992 and 1998 two on-station experiments and one on-farm experiment were carried out to address the problems of declining soil fertility and soil erosion on steep slopes. These experiments are described in the following sections.

Alley-cropping experiment

An alley-cropping was installed during 1992 at the Embu Regional Research Centre. The aim was to evaluate feasibility of using leafy prunings of calliandra and leucaena in a maize production system for soil productivity enhancement in both alley-cropping and monocropping systems. The experimental design was a Randomized Complete Block with four replicates. The plot dimensions were 9 x 10 m while the sample plot was 6 x 4.5 m. Maize (*Zea mays* L.) variety Hybrid 511 was the test crop. The experiment consisted of ten treatments. Six of these had fresh leaf prunings of tree species (leucaena and calliandra) applied. The prunings were obtained from hedgerows grown *in situ* (alley-cropped) or *ex-situ* (cut and carry) from other sources. The treatments were as follows:

Alley-cropping; no fertilizer

1. Calliandra; prunings incorporated
2. Leucaena; prunings incorporated
3. Calliandra; prunings removed to treatment 5
4. Leucaena; prunings removed to treatment 6

Maize only; no alley cropping; prunings from outside incorporated

5. Calliandra prunings from 3; no fertilizer
6. Leucaena prunings from 4; no fertilizer
7. Calliandra prunings + fertilizer (25 kg N ha^{-1})
8. Leucaena prunings + fertilizer (25 kg N ha^{-1})

Maize only; no alley cropping; no prunings

9. With fertilizer (50 kg N ha^{-1})
10. Without fertilizer

The prunings were always lopped and soil-incorporated using hand hoes immediately before maize was planted. The weight of prunings applied to treatments 5 and 7, and 6 and 8 was equal to the weight of prunings obtained from Treatments 3 and 4.

Harvesting of maize was done by cutting maize plants at soil level. Maize cobs were manually separated from the stover, sun-dried and packed in paper-bags before threshing. After threshing, moisture content of the grains was determined using a moisture meter and grain weights adjusted to 12% moisture content.

Contour hedgerow experiments (on-station and on-farm)

An on-station contour hedgerow experiment was set up in 1993 with two objectives. First to determine the degree to which contour hedges of grasses and trees, in combination and alone, can reduce soil erosion and; secondly to determine the amount and quality of fodder the various combinations could provide over time. Due to the limited size of available land, the maximum number of sufficiently large plots were eight. Hence there were two replications of four treatments: the control (with no hedge), grass hedge (consisting of two rows of Napier grass) (Penni*setum purpureum*)), tree hedge (consisting of two rows of calliandra), and combination hedge (consisting of one row of calliandra and one row of Napier grass). The runoff plots measured 5 x 30 m on an 18% slope and runoff was measured by a tipping bucket system (Khan and Ong, 1997). Maize was grown on all the plots at the recommended density and the crop's agronomic practices of the area followed as recommended.

Following promising results from the on-station experiment (O'Neill *et al*., 1995), an on-farm experiment was initiated in 1996, with an objective of assessing the impact of contour hedges on soil and water conservation under direct farmer management practices. Treatments consisted (1) tree hedge consisting of two rows of calliandra (2) A grass hedge consisting of two rows of napier grass and (3) control with no hedges. They were replicated thrice on two different slopes (20% slope and 40% slope) within Kianjuki Catchment of Embu District, Kenya. Runoff was collected in drums/barrels at the lower part of runoff plots.

Results and Discussions

Alley-cropping experiment

In the alley cropping experiment highest mean yields were obtained from treatment 2 (leucaena alley crop + prunings) and treatments 5 and 6, (maize monocrop + prunings) and 7 and 8 (maize monocrop with prunings + 25 Kg N ha^{-1}) in most seasons over the 11 seasons under study (1993 – 1998) (Table 20.1). These treatments had significantly higher mean maize yields at 5 % probability level than all the other treatments. This is an indication that the soil-incorporated leafy prunings of calliandra and leucaena improved maize growth resulting to increased maize grain yields. The results agree with findings of Guevara (1976), Kang (1981) Evensen (1984) and Attah-Krah (1990) who reported significant maize yield increases following application of green manure. In the present study the leafy prunings incorporated into the soil (as green manure) at the beginning of the season decomposed and released nutrients especially nitrogen which enhanced crop performance (Mugendi *et al*., 1999a).

Table 20.1: Mean maize grain yield (t ha^{-1}) for 1993-1998 seasons from various treatments in an on-station study at Embu, Kenya

TRT	LR 93	SR 93	LR 94	SR 94	LR 95	SR 95	LR 96	LR 97	SR 97	LR 98	SR 98	Mean
1	2.4 ^{a}	0.1 ^{b}	0.2 ^{cd}	3.2 ^{ab}	3.4 ^{b}	2.4 ^{e}	2.0 ^{c}	2.3 ^{b}	4.3 ^{d}	2.7 ^{b}	0.7 ^{ab}	2.6 ^{bc}
2	2.2 ^{a}	0.2 ^{ab}	0.2 ^{d}	3.8 ^{a}	4.4 ^{a}	3.9 ^{bc}	3.6 ^{b}	3.1 ^{a}	5.0 ^{c}	3.8 ^{a}	0.6 ^{b}	3.5 ^{a}
3	1.7 ^{a}	0.01 ^{b}	0.3 ^{cd}	1.6 ^{c}	1.1 ^{e}	1.0 ^{g}	1.3 ^{d}	1.9 ^{b}	3.6 ^{e}	1.3 ^{d}	0.5 ^{b}	1.6 ^{d}
4	1.5 ^{a}	0.2 ^{ab}	0.5 ^{cd}	2.7 ^{b}	1.8 ^{de}	1.7 ^{f}	1.5 ^{cd}	1.7 ^{c}	4.6 ^{cd}	2.2 ^{c}	0.7 ^{ab}	2.1 ^{c}
5	1.9 ^{a}	0.6 ^{a}	0.3 ^{cd}	3.6 ^{ab}	4.0 ^{ab}	4.9 ^{a}	3.8 ^{b}	3.0 ^{a}	4.0 ^{d}	2.8 ^{b}	1.0 ^{a}	3.4 ^{a}
6	1.6 ^{a}	0.3 ^{ab}	0.9 ^{b}	3.3 ^{ab}	4.2 ^{a}	4.7 ^{ab}	3.9 ^{ab}	2.5 ^{b}	7.1 ^{b}	2.7 ^{b}	1.2 ^{a}	3.7 ^{a}
7	2.1 ^{a}	0.6 ^{a}	2.1 ^{b}	3.6 ^{ab}	2.2 ^{cd}	5.6 ^{a}	4.2 ^{a}	2.2 ^{b}	7.9 ^{a}	3.4 ^{a}	0.9 ^{a}	3.8 ^{a}
8	1.8 ^{a}	0.3 ^{ab}	2.5 ^{ab}	3.2 ^{ab}	3.1 ^{bc}	5.0 ^{a}	4.0 ^{ab}	1.8 ^{bc}	7.5 ^{ab}	2.6 ^{bc}	1.1 ^{a}	3.5 ^{a}
9	1.6 ^{a}	0.3 ^{ab}	3.0 ^{a}	3.1 ^{ab}	3.1 ^{bc}	3.5 ^{c}	3.6 ^{b}	2.0 ^{bc}	4.1 ^{de}	2.9 ^{b}	0.7 ^{ab}	2.9 ^{b}
10	1.4 ^{a}	0.2 ^{ab}	1.1 ^{c}	3.0 ^{ab}	2.8 ^{c}	1.8 ^{cd}	1.8 ^{c}	1.9 ^{bc}	3.2 ^{e}	2.3 ^{c}	0.6 ^{b}	1.9 ^{c}

Means followed by the same letter within a column are not significantly different at $P < 0.05$

Abbreviations: SR = short rains; LR = long rains

Source: (Mugwe and Mugendi, 1999)

During the first phase of this experiment, from 1993 long rains (LR) to 1994 LR, nutrient deficiencies especially nitrogen and phosphorus (P) occurred and resulted in low crop yields (Mugwe *et al.*, 1997). During 1994 LR, Mwangi (1997) reported phosphorus deficiencies in all plots except where fertilization was done. This was attributed to low native phosphorus as a result of high P-fixing capacity of these soils and that the biomass harvested from the hedgerows was low and contained little amount of P (about 0.2 %) which could not supply adequate amounts of P into the soil to meet the crop demand (Mugwe *et al.*, 1999). This agrees with findings of Palm (1995) and Salazar *et al.*(1993) who found insufficient amount of P in prunings of most tree species. As such, supplementation of P through the use of inorganic fertilizers was recommended.

Biomass production over the study period was generally low in the range of 1.1 to 3.5 Mg ha^{-1} season^{-1} (Table 20.2). Highest biomass production was obtained during 1997 SR and 1998 LR which was attributed to higher rainfall during the seasons due to El-*nino* phenomenon (Mugwe *et al.*, 2000). The low biomass incorporated resulted in low nutrient contribution (containing approximately 60 kg N ha^{-1} season^{-1} or 120 kg N ha^{-1} yr^{-1}). This could not contribute sufficient amounts of nutrients to compensate fully for those lost in crop harvests (Mugendi *et al.*, 1999a; Mugwe and Mugendi, 1999) as nitrogen removal by crop harvests in the plots that received prunings ranged from 150 kg to 269 kg ha^{-1} year^{-1} (Mugendi *et al.*, 1999b). The results agree with those reported by Kang (1993), Nair (1993) and Scroth *et al.* (1995) where a small decline in soil fertility was observed in plots that had prunings applied. The findings, however did not agree with reports from the humid tropics where application of prunings to the soil resulted in increased soil organic matter and higher N, P, K, Ca, and Mg (Kang *et al.*, 1985; Kang *et al.*, 1990; Tian *et al.*, 1993). The difference between the current study and studies in the humid tropics is that, whereas hedgerow species in the humid tropics produced 8 to 10 Mg ha^{-1} yr^{-1} of biomass (Young 1989) the trial at Embu produced less than half this amount (Table 20.3). The low biomass production of hedgerow species in alley cropping systems in most areas is one major drawback that limits the potential of prunings to improve fertility and productivity of soils (Mathews *et al.*, 1992; Yadvinder *et al.*, 1992; Young 1989; Nair, 1993).

Consistently higher yields were obtained in leucaena alley crop with prunings incorporated treatment (treatment 2) than the fertilizer alone and control treatments (Treatments 9 and 10) (Table 20.1). This is an indication that leucaena can be used effectively in alley cropping arrangements to improve crop yields (Mugendi *et al.*, 1999a; Mugwe *et al.*, 1999). This corroborates with findings of other studies (Kang, 1993; Xu, 1993) where biomass incorporation in alley cropping system increased crop yields. Calliandra alley crop on the other hand gave significantly lower yields than leucaena alley cropping in the present study. Other researchers working with calliandra reported mixed performance. For instance, some have reported improved crop yields (Heinneman,1992; Rosecrance *et al.*, 1992), while Gutteridge (1992) reported depressed or marginal yields.

The poor performance of calliandra in alley cropping may be explained by the root morphology of the two species. Mugendi *et al.* (1999c) in this experiment showed that over 95 % of all maize roots were located in the top 90 cm while for calliandra and leucaena it was 60 % and 25 % respectively (Table 20.3). This agrees with findings of other authors, for example, NAS (1993) who reported that calliandra trees develop strong superficial root system in addition to the taproot and Jama *et al.*(1997a) who demonstrated that calliandra had the highest root density in the top 0-5 cm compared to other tree species in Western Kenya.

Results from this experiment indicated that incorporation of prunings of calliandra and leucaena in a maize monocrop system improves crop yields. Also alley cropping with leucaena for soil productivity improvement is advantageous but not with calliandra. However, in already phosphorus deficient soils, soil productivity improvement through alley cropping using *Leucaena leucocephala* or *Calliandra calothyrsus* is advantageous. This is mainly because biomass produced from the hedgerows is low and contains low amounts of P that is insufficient to meet crop demands.

Contour hedgerow experiments (On-station and on-farm)

From the on-station contour hedgerow experiment O'Neill *et al.* (1998) reported that maize grain yields from 1993 long rains to 1997/98 short rains fluctuated with rainfall with a mean ranging from 0.64 t ha^{-1} during 1996 short rains (drought period) to 7.2 t ha^{-1} during 1997/98 (El Nino period). However there were no significant differences between treatments for maize grain yield during individual seasons (O'Neill *et al.*, 1998). This is an indication that competition between the hedgerows of Napier/ calliandra was not significant. Competition was however observed in the alley cropping experiment where calliandra was found to lower maize grain yields. Other studies, for example, those by Evensen, (1989), Fernandes (1990) and Rosecrance *et al.* (1992) have shown competition between hedgerows of trees and foodcrops. In the present study, lack of significant competition can be explained by the fact that the hedges were widely spaced with an inter-row spacing of 15 m compared to alley cropping system which had an inter-row spacing of 4.5 m.

Table 20.2: Amount of prunings incorporated into the soil over the study period (1993-1998) in an on-station study at Embu, Kenya

Trt	SR 93	LR 94	SR 94	LR 95	SR 95	LR 96	LR 97	SR 97	LR 98	SR 98	Average N supplied per season	average P supplied per season
					……………...Biomass t ha^{-1}……………..				…...…..Kg ha^{-1}………..			
1	2.2	1.4	2.6	1.1	2.3	1.5	2.3	3.3	3.1	2.0	62	4
2	1.7	1.2	2.5	2.2	1.3	1.3	1.6	1.2	1.0	1.2	42	3
5	2.3	1.3	2.3	1.5	3.1	2.3	2.5	3.5	3.4	2.4	70	5
6	2.3	1.2	2.6	2.4	1.9	2.1	1.9	1.5	1.5	1.4	53	4
7	2.2	1.3	2.3	1.5	3.1	2.3	2.5	3.5	3.1	2.0	70	5
8	2.3	1.2	2.6	2.4	1.9	2.1	1.9	1.5	1.5	1.4	53	4

Abbreviations:Trt = treatment (refer to page 5 for treatments description)

Nutrient concentration of prunings incorporated: N = 2.8 %P = 0.2 % (Source: Mwangi, 1997)

Nutrient contribution = quantity of prunings * nutrient in the prunings

Table 20.3: Total root length for maize, leucaena and calliandra at various soil depths at maize grain-filling stage in the first season 1998 at Embu, Kenya

Depth (cm)	Maize	Calliandra	Leucaena	SED
	---------- Total root length (m cm^{-2}) --------			
0-30	65.5	25.7	9.4	5.4
30-60	53.4	30.3	11.3	7.2
60-90	14.3	13.7	14.7	2.1
90-120	3.4	11.8	31.2	3.6
120-150	1.8	9.9	18.6	2.7
150-180	0.4	6.3	12.8	3.3
180-210	0.1	5.1	11.6	1.3
210-240	0.1	3.4	8.2	2.6
240-270	0.1	4.2	7.4	3.2
270-300	0.1	3.8	6.6	1.2

Source: Murithi *et al.* (1999)

The results of runoff, soil loss and fodder production presented in Table 20.4 indicate that contour hedges were effective in reducing soil loss. Soil loss in the control was substantially greater than in any of the control hedge treatments. This agrees with findings of other authors, for example, contour hedges of Ing*a edulis* planted in a 16% slope at Yurimaguas, Peru with 2200 mm annual rainfall reduced soil loss on an Ultisol from 53 to 1 t ha^{-1} yr^{-1} and runoff form 12 % of the annual rainfall to only 2% (ICRAF, 1994). In Philippines, it was shown that contour-hedgerow intercropping technology was capable of achieving a 50 to 58% reduction in soil erosion on a 17-18% (Comia *et al.*, 1994; Watson *et al.*, 1995). Kieppe (1995) demonstrated that, hedgerows reduced soil erosion by 94% and runoff by 78% and that a combination of hedgerows and mulch conserved 98% of the soil and 88% of water at Machakos, Kenya. In addition to conserving soil and promoting terrace formation, the contour hedges produced biomass that could be used as fodder source (O'Neill *et al.*, 1998). Indeed, Table 20.4 shows that the combination hedge (napier plus calliandra) produced the highest biomass in all seasons and consequently the highest crude protein.

Cumulative runoff and soil loss for three years in the on-farm trial (Table 20.5) was higher on the 20% slope than on the 40% slope. Angima (2000) attributed these difference to individuals farmers practices that dated back 30 years. The farmer on the 40% slope practiced better crop husbandry and crop rotation and periodically adds manure to his farm while the farmer on 20% slope did not. Manure has been found to contribute greatly to stability of soil aggregates making them less susceptible to erosion.

Table 20.4: Runoff, soil loss and fodder production in an on-station study at Embu, Kenya for the 1997 long rains and the 1997/98 short rains

	Control	Napier	Calliandra	Combination
Runoff (mm)				
1997 long rains	108.0	49.0	48.0	40.0
1997/98 short rains	33.0	9.0	15.0	14.0
Soil loss (t/ha)				
1996 long rains	51.0	10.0	38.0	20.0
1997/98 short rains	21.1	7.5	6.4	8.3
Fodder - leafy dry matter (t/ha)				Grass + Shrub
1997 long rains	-	1.5	1.0	3.6 + 0.7 = 4.3
1997/98 short rains	-	4.0	1.9	8.2 + 1.4 = 9.6
Fodder - crude protein* (kg/ha)				Grass + Shrub
1997 long rains	-	103.0	255.0	252 + 170 = 422
1997/98 short rains	-	280.0	466.0	574 + 343 = 917

Assume 7 % CP for Napier and 25 % CP for calliandra.
Source*:* O'Neill, *et al*. (1999)

Table 20.5: Cumulative runoff and soil loss for 3 years and total N and P losses in eroded sediments in an on-farm study at the Kianjuki catchment Embu, Kenya

Treatment	20% slope	40 % Slope
	…….Runoff (mm)…….	
Control	356 [a]	122 [a]
Hedge	298 [b]	186 [b]
	…….Soil loss (Mg ha^{-1})……	
Hedge	578 [a]	539 [a]
Control	410 [b]	393 [b]
	……P loss (Mg ha^{-1} yr^{-1})……	
Hedge	1.6 [a]	2.0 [a]
Control	0.9 [b]	1.4 [b]
	……N (Mg ha^{-1} yr^{-1})……	
Hedge	1.5 [a]	1.8 [a]
Control	1.0 [b]	1.4 [b]

Source: Adapted from Angima (2000) and Murithi *et al*. (1998)

The hedges were found to be effective in reducing both runoff, soil loss and nutrient loss (Table 20.5). The hedges reduced both runoff and soil loss by 30% over the control treatment which had no hedges (Angima, 2000). This agrees with studies carried out in Ibadan, Nigeria, where contour hedgerows of *Leucaena leucocephala* and *Gliricidia sepium* on a 7 % slope showed 85 % reduction in both soil and nutrient loss compared to conventional plowing (Young, 1989). Also, in Columbia, hedgerows of *Gliricidia sepium* reduced soil losses from 23-35 t^{-1} ha^{-1} yr^{-1} under maize to 13 Mg^{-1} ha^{-1} yr^{-1} on both 45% and 75% slope, resulting in a 48% soil loss reduction (Young, 1989).

In this study, there were more nutrients lost on the 40% slope than the 20% slope with the control plots loosing more than the hedge plots. Murithi *et al.* (1999) estimated an equivalent of over 200 kg ha^{-1} of TSP and 300 Kg ha^{-1} TSP lost by the control plots over the hedge plots for the 20% slope and 40% slope respectively. This also supports the farmer practices of applying farmyard manure on 40% slope than on gentle slopes of 20%. This underlines the need to control runoff and soil loss in these zones to retain nutrients for crop production and reduce pollution of rivers and reservoirs from eutrofication. Young (1997) has recently documented further experimental evidence on the effectiveness of contour hedgerows in controlling soil erosion. The evidence that covers diverse countries, varying slopes, different climates and soils indicate the contour-hedgerow systems reduced soil erosion by factors ranging from 2 to 58.

Results of this contour hedgerow experiments showed that calliandra planted along contour hedgerows is effective in controlling soil erosion. In addition, it produces biomass that contains high crude protein and can therefore be used effectively as animal protein supplement.

Dissemination Potential

These studies demonstrated beneficial effects on crop yields of incorporating prunings of calliandra and leucaena especially when biomass is brought from outside (ex-situ). It is also evident that alley-cropping with leucaena have great potential as a method of improving sustainable yields at about 4 t ha^{-1} in the region. However, it has been pointed out that the advantages of alley cropping seems to rest in the complementarity of resource capture (Ong and Black, 1995); while it has disadvantages in establishment costs and labour requirements. Therefore, despite this promising results shown by alley cropping with leucaena, the question of labour availability needs to be addressed properly before a wide adoption by farmers can be envisaged. This technology is labour-intensive with much of the demand for labour occurring during the start of the rainy season which is the busiest time of the year.

Calliandra alley-cropping system adversely affected crop yields and should not be recommended as an alley-crop species. Reasons advanced for this was that calliandra developed a strong superficial system that competed with associated foodcrops for growth resources. However, calliandra was found to be effective in controlling soil erosion when used as a contour hedge possibly because of the strong root system that holds the soil together. In addition to conserving the soil, calliandra provides up to 24 % crude protein and the large tonnage of biomass yield from using hedges as a soil conservation resource can supplement and in some cases substitute input protein rations in animals. Results from western Kenya (Jama *et al*., 1997) indicate that fodder trees like calliandra are most profitable when utilized as a protein supplement for livestock.

Further research by NAFRP have have shown potential for calliandra adoption by smallholder farmers for use in dairy production (Tuwei *et al*., 1999). On-farm feeding trials have confirmed the effectiveness of calliandra both as supplement to the basal diet and as a substitute for dairy meal. The trials found that one kilogram of dry calliandra had about the same amount of digestible protein as one kilogram of dairy meal; both increased milk production by roughly 0.75 kg under farm conditions (O'Neill *et al*., 1995,(Paterson *et al*., 1996a). Following these findings a dissemination programme for calliandra was initiated in 1997 where the main focus was the use of participatory methods and involvement of partners (Tuwei and Mugwe, 1998).

The dissemination procedure involved working with farmer group nurseries. The group nurseries were provided with calliandra seeds to raise and transplant following the onset of the rains. An evaluation of planting niches adopted by farmers in Meru and Embu District showed that terraces were the most preferred niche by farmers for planting calliandra (Table 20.6). Majority (46%) indicated that they preferred planting calliandra along terraces for soil conservation on the steep areas. The calliandra planted on the contours for soil conservation could help retain and cycle N in the soil for sustainable agriculture. Studies by Jama *et al*. (1998) showed that calliandra roots develop and grow rapidly into the subsoil and capture NO_3^- that accumulate in the subsoil even at low available phosphorus.

Table 20.6: Niches where farmers planted calliandra during 1999 in Embu and Meru Districts, Kenya

Niche	Frequency	Percentage (%)
Terrace	83	46
External border	63	35
Homestead	38	21
Cropland	19	11
Coffee	1	0.5

N=178

Source: Tuwei and Mugwe (1999)

They also found that calliandra and sesbania reduced soil NO_3^- in the top 2m by about 150 to 200 Kg kg N ha^{-1} within 11 months after establishment and effectively captured subsoil NO_3^- in western Kenya. At Embu (Experiment in this study), monocropped treatments (Maize only) accumulated higher amounts of mineral N (averaging 15-30 Mg NO_3^- N kg^{-1}) in the 200-300 cm depth layer than treatments with calliandra and leucaena which had an average of 1-3 mg NO-N kg^{-1} in the same depth (Mugwe, 1999).

In this region, where dairy production is predominant, farmers have the option of using prunings for direct incorporation into the soil to improve their soils or may be better off using the calliandra for fodder. If they use the prunings as fodder, they are then likely to benefit from increased milk production and possibly increased incomes (O'Neill *et al* 1997; Franzel *et al.*, 1999). The calliandra could be pruned for fodder 9 to 12 months after planting, and pruning continues at the rate of four or five times per year (Roothaert *et al.*, 1998). However, harvesting of the biomass and removal from the site mines soil nutrients and a means of replenishing the soil nutrients is necessary. This could be achieved through recycling manure. This practice is feasible and economical and is likely to have high adoption rates. If adopted, soil conservation and fertility improvement could be enhanced.

Conclusions

These studies showed great potential for using *Calliandra calothyrsus* and *Leucaena leucocephala* for soil fertility improvement and soil conservation. Soil conservation improvement can be achieved through application of leafy prunings from the leguminous shrubs into the soil. In this study application of Calliandra and leucaena prunings into the soil significantly increased maize grain yields over the control treatment. The use of leguminous shrubs in an alley-cropping system however presented mixed results. Leucaena can be used successfully as an alley species and maintained maize grain yields at about 4 t ha^{-1} in the region. Calliandra on the other hand was more competitive and depressed maize grain yields. However calliandra contour hedges were found to be effective in reducing soil loss, runoff and loss of soil nitrogen and phosphorus in eroded sediments. In addition, calliandra on contour hedges produced a large tonnage of biomass with high crude protein that could be used as animal fodder.

Considering that smallholdings in the central highlands of Kenya occur on sloping lands, and the importance of dairy production in the region, there is great potential for using calliandra contour hedges for soil conservation. The harvested prunings could either be used for soil fertility improvement through direct soil-incorporation or could be used for fodder. Farmers in the region and similar areas should therefore be encouraged to adopt this practice. If used for fodder, feasibility of replenishing soil nutrients through recycling manure from the animals needs to be explored.

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References

Amadalo, B., Gathumbi. S., Niang, A. and Otieno, H. (1995) The effect of six shrub species on grain yield of maize at Maseno. Biomass transfer. AFRENA, Maseno Progress report. ICRAF, Nairobi, Kenya.

Agus, F., Cassel, D.K. and Garrity, D.P. (1998) Bromide transport under contour hedgerow systems in sloping Oxisols. *Soil Sci. Soc. Am. J.* 62 (4): 1042-1048.

Akyeampong, E. and Muringa, K. (1994) Cutting management of *Calliandra calothyrsus* in the wet season to maximise dry season fodder production in the central highlands of Burundi. *Agroforestry Systems* 27: 101-105.

Angima, S.D. (2000) Soil erosion prediction using RUSLE in central Kenya. PhD thesis. Faculty of Purdue University graduate School. USA.

Attah Krah, A.N. (1990) Alley farming with leucaena. Effect of short grazed fallows on soil fertility and crop yields. *Experimental Agriculture* 26: 1-10

Comia, R.A., Paningbatan, E.P. and Hakansson, I. (1994) Erosion and crop yield response to soil conditions under alley cropping systems in the Philippines. *Soil and Tillage Research* 31: 249-261.

Evensen, C.L. (1984) Seasonal yield variation, green leaf manuring and eradication of *Leucaena leucocephala* (L) de Wit. MSc. Thesis, Department of Agronomy. University of Hawaii, USA.

Evensen, C.L. (1989) Alley cropping and green manuring for upland crop production in West Sumatra. Ph.D Dissertation, Department of Agronomy, University of Hawaii, USA.

FAO-UNESCO (1988) Food and Agriculture Organization of the United Nations/ UNESCO, Soil Map of the World. Revised Legend. World Soil Resources. Report 60. FAO. Rome.

Fernandes, E.C.M. 1990. Alley cropping on acid soils. Ph.D. Dissertation. North Carolina State University. Raleigh, North Carolina.

Franzel, S., Arimi, H., Murithi, F.M. and Karanja, J. (1999) *Calliandra calothyrsus*: Assessing the early stages of a fodder tree in the highlands of central Kenya. AFRENA Report No. 127. International Centre for Research in Agroforestry (ICRAF) Nairobi, Kenya.

Government of Kenya (1994) The 1989 Kenya National census Census resultsResults. Ministry of home Home Affairs. Nairobi, Kenya.

Guevara, A.B. (1976) Management of Leucaena leucocephala (Lam) de wit for maximum yield and N-contribution to intercropped corn. Ph.D. Dissertation, University of Hawaii, Department of agronomy. Honolulu, Hawaii.

Gutteridge, R.C. (1992) Evaluation of a range of tree legumes as a source of nitrogen for crop growth. *Experimental Agriculture* 28: 195-202.

Hartemink, A.E., Buresh, R.J., Jama, B. and Janssen, B.H. (1996) Soil nitrate and water dynamics in sesbania fallow, weed fallows, and maize. *Soil Sci. Soc,. Am. J.* 60: 568-574.

Heinnemann, M. Mengich, E.K., Olang, A.D. and Otieno, H.J.O. (1990) Agroforestry Research Network for Africa Report No. 21. Maseno progress report for the period January 1988 to January 1990. ICRAF, Nairobi, Kenya.

Heinnemann, A.M. (1997) Growth and yield of eight agroforestry tree species in line plantings in Western Kenya and their effects on maize yields and soil properties. *Forest Ecology and Management* 91: 103-135.

ICRAF (1992) Annual Report. International Centre for Research in Agroforestry, Nairobi, Kenya.

ICRAF (1994) International Centre for Research in Agroforestry. Annual Report 1993. ICRAF, Nairobi, Kenya.

Jaetzold, R. and Schmidt H. (1983) Farm management handbook of Kenya. Vol II/C, East Kenya. Natural condition and farm management information, Ministry of agricultureAgriculture, Nairobi.

Jama., B., Buresh, R.J., Ndufa, J.K. and Shepherd, K.D. (1998) Vertical distribution of roots and soil nitrate; tree species and phosphorus effects. *Soil Sci. Soc. Am. J.* 62(1): 280-286.

Jama, B., Swinkles, R.A. and Buresh, R.J. (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus in western Kenya. *Agronomy Journal* 89: 597-604.

Kang, B.T. (1993) Alley cropping. Past achievements and future directions. *Agroforestry systems* 23: 141 – 155.

Kang, B.T, Wilson. G.F. and Sipkens, L. (1981) Alley cropping maize (*Zea mays*) and *Leucaena leucocephala* (Lam) in Southern Nigeria. *Plant and soil* 63: 165 –179.

Kang, B.T., Grime, H. and Lawson T.L. (1985) Alley-cropping sequentially cropped maize with *Leucaena leucocephala* on a sandy soil in southern Nigeria. *Plant and Soil* 85: 267-277.

Kang, B.T., Reynolds, L. and Atta-Krah, A.N. (1990) Alley farming. *Advances in Agronomy* 43: 315 - 359.

Khan, A.H.A. and Ong, C.K. (1997 Design and calibration of tipping bucket system for field runoff and sediment quantification. *Journal of soil Soil and water Water conservation Conservation* 52 (6) 437-443.

Kapkiyai, J.J., Karanja, N.K., Woomer, P. and Quereish, J.N. (1998) Soil organic carbon fractions in a long-term experiment and the potential for their use as a diagnostic assay in highland farming systems of central Kenya. *African crop Crop science Science journal Journal* 6: 9-28.

Kieppe, P. (1995) Effects of Cassia siamea hedgerow barriers on soil physical properties. Geoderma 66: 113-120.

Kihanda, F.M. (1996) The role of farmyard manure in improving maize production in the sub-humid highlands of central Kenya. Ph. D Thesis. University of Reading, UK.

Mathews, R.B., Holden, S.T., Volk, J. and Lengu, S. (1992) The potential of alley-cropping in improvement of cultivation systems in the high rainfall areas of Zambia I. Chitemene and Fundikila. *Agroforestry Systems* 17: 219-240.

Minae, S. and Nyamai, D. (1988) Agroforestry research proposal for the Coffee based land use system in the bimodal highlands, Central and Eastern provinces, Kenya. *AFRENA Report No*. 16. International Centre for Research in Agroforestry, Nairobi, Kenya. pp 58.

Mugendi, D.N., Mugwe, J.N. O'Neill, M.K. (1999) Nitrogen movement in an Ultisol in the central highlands of Kenya. Paper presented at the International Soil Conservation Organization conference at Purdue University, USA, May 1999.

Mugendi, D.N., Nair, P.K.R., Mugwe, J.N., O'Neil,l M.K., Swift, M.J. and Woomer, P.L. (1999b) Calliandra and leucaena alley cropped with maize. Part 2; Biomass decomposition, N Minerilization, and N uptake by maize. *Agroforestry Systems* 46:51-64.

Mugendi, D.N., Nair P.K.R., Mugwe, J.N., O'Neill, M.K. and Woomer, P.L. (1999a) Calliandra and leucaena alley cropped with maize. Part 1; Soil fertility changes and maize production in the subhumid highlands of Kenya. *Agroforestry Systems* 46:39-50.

Mugwe, J.N. and Mugendi, D.N. (1999) Use of leguminous shrubs for soil fertility improvement in sub-humid highlands of Kenya. Soil Science Society of East Africa Proceedings of the 17th conference, Pg 194-198 (Eds) Tenywa JS, Zake JYK, Ebayat P, Semalulu O, Nkalubo ST. 6-10 September 1999, Kampala, Uganda.

Mugwe, J.N., O'Neill, M.K. and Mugendi, D.N. (1997) *Leucaena leucocephala* and *Calliandra calothyrsus* for Soil Productivity Improvement in Sub-Humid Highlands of Kenya. Pgs 181-184 ACIAR Proceedings No. 86. Leucaena adaptation, Quality and Farming systems. Australian Centre for International Research, Canberra, Australia.

Mugwe, J.N., Mugendi, D.N. and Gachanja, S.P. (2000) Soil productivity Improvement through use of leguminous shrubs in subhumid highlands of Kenya. Paper presented at the International Soil Conservation Organisation (ISCO) conference. Held in Buenos Aires, Argentina. 22-27 October, 2000.

Muriithi, F.M., Thijssen, H.J.C., Mugendi, D.N., Mwangi, JN., O'Neill, M.K. and Nyaata, O.Z. (1993) Report of a survey on Agroforestry technologies used for fodder production and soil fertility improvement in Meru District, Kenya. National Agroforestry Research Project, Regional Research Centre, Embu, Kenya.

Murithi, F.M., O'Neill, M,.K., Gachanja, S., Karanja, G., Kariuki, I., Mugwe, J.N., Tuwei, P. and Roothaert, R. (1999) National Agroforestry Research Project. KARI-Regional Research Centre – Embu, Annual Report: March 1998 – March 1999.

Mwangi, J.N., O'Neill, M.K. and Mugendi D.N. (1996) Effect of Leaf leaf Prunings prunings incorporation on Crop crop Yields yields in Alley alley cropping and sole Cropping cropping ssystems. *East African Agricultural and Forestry Journal.* 62: 209-218.

Mwangi, J,N. (1997) Effect of soil incorporated leaf prunings on soil productivity in alley and sole cropping systems using *Leucaena leucocephala* (Lam) de Wit and *Calliandra calothyrsus* Meissn. M. Phil. thesisThesis,. Moi University.,, Eldoret, Kenya.

Nair, P.K.R. (1993) An introduction to Agroforestry. Kluwer publishers, Dordrecht, the Netherlands.

Nair,P.K.R. (1987) Soil productivity under agroforestry. In: Gholz, HL (ed), Agroforestry, Realities, Possibilities and Potentials., pp 21-30. Martinus Nijholf. Dordrecht. The Netherlands.

NAS, National Academy of Sciences. (1993) Innovations in tropical reforestation. Calliandra: A versatile tree for the humid tropics. National Academy Press. Washington DC, USA.

O'Neill, M., Gachanja, S., Karanja, G., Kariuki, I., Kanampiu, F., Kiruiro, E., Murithi, F.,Okoba, B., Nyaata, Z., Mwangi, J., Tuwei, P., Roothaert, R. and Paterson, R. (1996) National Agroforestry Research Project. KARI-Regional Research Centre – Embu, Annual Report: March 1995 – March 1996. AFRENA Report No. 108. ICRAF, Nairobi, Kenya.

O'Neill, M., Gachanja, S., Karanja, G., Kariuki, I., Murithi, F., Nyaata, Z., Mwangi, J., Tuwei, P. and Roothaert, R. (1997) National Agroforestry Research Project. KARI-Regional Research Centre – Embu, Annual Report: March 1997 – March 1998. AFRENA Report No. 120. ICRAF, Nairobi, Kenya.

O'Neill, M., Gachanja, S., Karanja, G., Kariuki, I., Kanampiu, F., Kiruiro, E., Murithi, F.,Okoba, B., Nyaata, Z., Mwangi, J., Tuwei, P., Roothaert, R. and Paterson, R. (1997) National Agroforestry Research Project. KARI-Regional Research Centre – Embu, Annual Report: March 1995 – March 1996. AFRENA Report No. 108. ICRAF, Nairobi, Kenya.

O'NiellO'Neill, M.K., Gachanja, S.P., Karanja, G.M., Kariuki, I.W., Murithi, F.M., Mugwe, J.N. Tuwei, P.K and Roothaert, R.L. (1998) National Agroforestry Research Project. KARI – Regional Research Centre – Embu. Annual Report: March 1997 – March 1998.Agrforestry Research Networks for Africa, AFRENA Report 120. International Centre for Research in Agroforestry, ICRAF, Nairobi, Kenya.

O'Neill, M., Murithi, F., Mwangi, J., Nyaata, Z., Paterson, R., Roothaert, R. and Kihanda, F. (1995) National Agroforestry Research Project. KARI Regional Research Centre- Embu, Annual Report: March 1994-March 1995, AFRENA Report No. 92, ICRAF, Nairobi, Kenya.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. Agroforestry systems.

Paterson, R.T., Kiruiro, E.M. and Arimi, H.K. (1996) Input and Output data monitoring at the zero-grazing model farm unit at RRC-Embu; the case for Dairy Cattle Performance on Agroforestry based Feeding System. Proceedings of Livestock Feeding Systems Project, End of Phase 1 Workshop. Izaak Walton Inn, 30th July, 1996.

Rosecrance, R.C., Brewbaker, J.L. and Fownes, J.H. (1992a) Alley cropping of maize with nine leguminous trees. *Agroforestry systems* 17: 159 –168.

Salazar, A., Scott, L.T. and Palm, C.A. (1993) Crop-tree interactions in alley cropping systems on alluvial soils of the upper Amazon Basin. *Agroforestry systems* 22: 67-82.

Ogwenyi, G.S., Kithara, S.M., and Denga, F.O. (1993) An overview of the soil erosion and sedimentation problems in Kenya; Strategies for monitoring, predicting and control. Proceedings of the Yokohama Symposium, July 1993. IAHS Publication No. 21: 217-223.

O'Neill, M., Murithi, F., Mwangi, J., Nyaata, Z., Paterson, R., Roothaert, R. and Kihanda, F. (1995) National Agroforestry Research Project. KARI Regional Research Centre-Embu, Annual Report: March 1994-March 1995, AFRENA Report No. 92, ICRAF, Nairobi, Kenya.

Roothaert, R., Karanja, G.M., and Kariuki, I.W., Paterson, P., Tuwei, P., Kiruiro, E., Mugwe, J. and Franzel, S. (1998) Calliandra for livestock, Technical Bulletin No. 1, National Agroforestry Research Project, KARI-regional Research Centre, Embu, Kenya.

Schroth, G. (1995) Tree root characteristics as criteria for species selection and systems design in agroforestry. *Agroforestry Systems* 19: 67-78.

Tuwei, P.K. and Mugwe, J.N. (1999) Adaptive on-farm technology Development; Experience of the National Agroforestry Research Project, Embu. A case study of *Calliandra calothyrsus* as an animal fodder. Paper presented in the social forestry extension seminar for the promotion of tree planting in arid and semi-arid areas of Kenya at KEFRI, Muguga 27-30 September 1999.

Watson, H.R., Laquihon, W.A. and Palmer, J.J. (1995) SALT vs SALT alley farms in the Southern Philippines. In Kang *et al* (1995), q.v pp 366-371.

Tuwei, P.K., Wambugu, C., Karanja, G.M., and Mugwe, J. (1999) Adaptive on-farm technology development experiences of regional research centre, Embu; A case study of *Calliandra calothyrsus* as an animal fodder. Paper presented during AFRENA conference. "Is Agroforestry making a difference?". ICRAF, Nairobi, Kenya.

Xu, Z.H., Saffigna, R.J.K., Myers, R.J., and Chapman, A,L. (1992) Nitrogen fertilizer in leucaena alley cropping and maize response to nitrogen fertilizer and fate of fertilizer-15N. Fertilizer Research. Dordrecht; Kluwer academic Academic Publishers 33 (3); 219-227.

Yadvider, S., Bijay, S. and Khind, C.S. (1992) Nutrient transformations in soils amended with green manures. *Advances in Soil Science* 20:38-298.

Young, A. (1997) Agroforestry for soil management (2nd Edition). CAB International, Wallingford, UK.

Young, A. (1989) Agroforestry for soil conservation. International Ccentre for Research in Agroforestry, ICRAF. Nairobi, Kenya.

Young, A. and Sinclair, F.L. (1997) The effectiveness of contour hedgerows for soil and water conservation. *Agroforestry systems* 8:2-4.

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The Relationship Between Nitrogen Mineralization Patterns and Quality Indices of Cattle Manures from Different Smallholder Farms in Zimbabwe

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Abstract

The use of cattle manure as a source of nutrients is widespread among the smallholder-farmers of Zimbabwe. Benefits of cattle manure on crop yields depend on the amount, quality, nutrient release patterns and uptake by the crops. Characterization of a large range of manure samples from Chivi, Mangwende, Shurugwi and Tsholotsho, showed that the quality was variable with N content ranging from 0.1% to 2.76%. Most manures had C:N ratios ranging between 10 and 20. A laboratory study was conducted using a selection of cattle manures with N contents ranging from 0.45 to 1.5% to determine their N release patterns, indices of quality that correlated to N mineralization and the effect of rate of manure application. The leaching tube methodology was used to study the mineralization patterns of (1) ten different manures with N contents of 0.45% to 1.5% applied at 100 kg N ha^{-1} equivalent and (2) two manures with low (0.89% N) and high N content (1.5% N) applied at 0, 5, 10, 20 and 40 t ha^{-1} equivalent.

The N release patterns were similar for the ten manures, with a net immobilization phase occurring in six of the manures in the first 14 days. Net mineralization occurred in all the manures after the initial 14-day period. The %N, %C, C:N, ash and lignin contents were significantly ($P<0.05$) correlated to N mineralization after 56 days of incubation. A linear model was proposed where net mineralized N was given as 27.7N + 2.7Lignin + 2.34C:N + 1.49Ash –1.39C –86.2. The rate of application did not cause a change in the mineralization pattern in the low N manure (0.89% N) except for the 40 t ha^{-1} treatment where there was no net N immobilization throughout. With the high N manure content (1.5% N), the high rates of 20 and 40 t ha^{-1} did not exhibit the N immobilization phase during the initial stages of mineralization which were seen with the lower rates. Mineral N was positively correlated to the rate of application during immobilization and mineralization phases.

Key words: Cattle manure quality, N mineralization, N immobilization, manure decomposition indices

Introduction

The amounts of nutrients released from organic materials is a function of their physical/chemical composition, the amounts applied and environmental factors. The efficacy with which N in manure is used depends on the synchrony between rate of mineralization and the crop demand. Manure types used by farmers are variable due to different management strategies. Determining N release patterns of the cattle manures can give an estimate of the potential amount of N that a given manure can contribute to crops.

Currently, there are several recommendations on the amount of manure to use on maize crops in Zimbabwe (Mugwira and Murwira, 1997). The recommended quantities were derived from simple manure response trials in different regions of the country. Addition of cattle manure to infertile sandy soils increases nutrients for crop uptake. The minimum amount of manure, which is required to give economical crop yields, has not been determined.

Relationships between the mineralization of N from manure and indices to describe manure quality have not been examined in detail. Crop response work done in a greenhouse demonstrated that crop uptake gives a good account of the quality of manure (Mugwira, 1984). Studies done on green manures and agroforestry species show that it is possible to use the release patterns, laboratory chemical indices and textural indices to describe quality of materials and predict rates of decomposition and N release (Melilo *et al.*, 1982; Frankenberg and Albdelmagid, 1985; Palm and Sanchez, 1991; Handayanto *et al.*, 1997; Mafongoya *et al.*, 1997). The rate of net N mineralization of manures and other organics must be known to optimise use and predict supplementation rates of mineral fertilizers (Constantinides and Fownes, 1994; Hadas and Portnoy, 1994). The paucity of such information on cattle manures makes guidelines on their effective use, in the short and long term, difficult to derive.

The 'lignin' content measured in manure depends on the cattle diet and other constituents like the microbial remains. A diet containing material with large proportions of high molecular weight, recalcitrant carbon compounds will lead to high lignin contents in manures. Work done by Mafongoya *et al.* (1997) on the effect of drying on litter quality suggests that measured lignin contents also increases through the browning reactions between polyphenols, proteins and carbohydrates. Similar effects may also occur in the cattle rumen. This fibre or 'lignin' material degrades slowly in the soil. The physical protection caused by lignin on other organic constituents causes a general reduction in the rate at which the organic material is degraded (Haider, 1986). Manures collected from smallholder farms in Zimbabwe also have other contaminants like sand, twigs and wood particles, and other recalcitrant materials.

This study aimed to characterise manures from four smallholder farming areas, to determine N mineralization patterns of selected manures, and examining relationships between N release and the initial % N, %C, C:N ratio, lignin, % ash and % polyphenol (indices of quality). The effect of rate of application of different manures on N release was also studied following a laboratory characterization of manures from Chivi, Mangwende, Shurugwi and Tsholotsho districts of Zimbabwe.

Materials and Methods

A total of 329 manure samples were collected prior to the onset of rains in 1997 from Chivi, Mangwende, Shurugwi and Tsholotsho and analysed for %N, %C, lignin content, %ash and polyphenols (Anderson and Ingram, 1993). Some of the manure samples were selected for further use in the mineralization studies described below.

Nitrogen mineralization of cattle manures

N mineralization was studied using the aerobic leaching tube method (Stanford and Smith, 1972). Glass tubes of 300 mm length with a diameter of 50 mm and a thickness of 1 mm were used. A rubber stopper inserted with a glass tube for drainage at the centre was used to close the lower end of the tube.

A mass of 150 g of soil was used in each tube. This was mixed with manure quantities equivalent to 100 kg N ha^{-1} per tube. Ten different manures CM1-CM10 were used in this experiment. A set of control tubes was included in the design, where no manure was added to the 150 g of soil. The treatments were each replicated four times.

Effect of rate of application on N release

In a parallel experiment, the effect of rate of application on N release was investigated by using manure rates of 0, 5, 10, 20 and 40 t ha^{-1} equivalent as treatments. Two manures were used in this experiment with low N (0.89% N) and high N (1.5% N). The samples were mixed with sandy soil and added to leaching tubes.

A completely randomised design was used in both experiments with four replicates of each treatment. Leaching tubes were randomised on racks in the constant temperature room.

Sampling procedure

Leaching and collection of samples was done on day 0, 3, 7, 14, 28, 42 and 56 days. A leaching solution made up of 0.9 mM KCl, 1 mM $CaCl_2$, 1mM $MgSO_4$ and 0.1mM KH_2PO_4 was used. After each leaching event the tubes were subjected to mild suction to bring the water content of each tube to 70-80% WHC. The leachate collected was analysed for mineral N (NH_4-N and NO_3-N) colorimetrically. The net mineralization or immobilization was calculated using the difference between total N in the amended soils and the control.

Glasswool was placed at the base to prevent soil and manure particles from washing out of the tube. To ensure an even distribution of suction and no further loss of the materials a layer of 10 g of acid-washed sand was added on top of the glass wool before adding the soil-manure mixture. Another 10 g of sand was added at the top of the soil-manure mixture to avoid disturbance of particles from the sample on pouring in the leaching solution. Each treatment mixture was thoroughly mixed in a glass jar before transferring to the tube. To prevent separation of different soil fractions and lumping up of the manure added on transferring to the tube, about 5 ml of distilled water was added to the soil and manure during mixing. The amount of water added was enough to enable the mixing process without soil particles sticking to the walls of the glass jar. Distilled water was then added to adjust each leaching tube to 70-80 % of water holding capacity. Aluminium foil was used to loosely cover the tops of each tube to minimise moisture losses.

Carbon was analysed using the Walkley Black method while nitrogen was analysed after digestion using colorimetric methods (the cadmium reduction and the salycilate methods). Lignin and ash were done via Acid Detergent Fibre method and polyphenols were analysed using the Folin-Ciocalteau method (Anderson and Ingram, 1993). A bulk soil sample was collected from the plough layer (0-20 cm) from Chinonda site in Mangwende for use in the laboratory incubations. The soil was air dried and passed through a 2 mm sieve.

Results

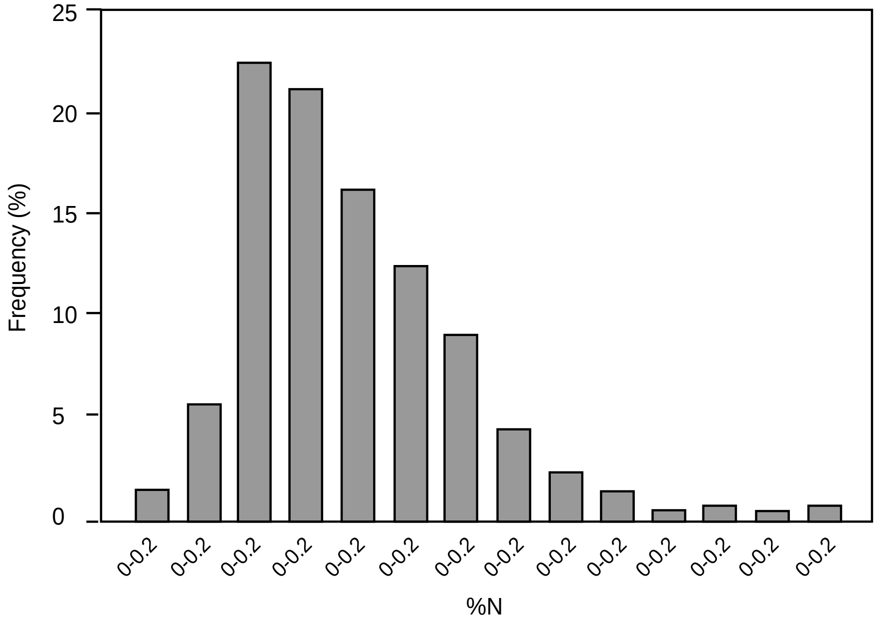
Manure characteristics

The characterisation of manure samples from four smallholder farming areas of Zimbabwe showed that the average N contents of manure at the time of application is 0.89% (Table 21.1). The frequency of distribution was strongly skewed with the majority of samples with N content ranging between 0.4% and 1.2% (Figure 21.1). A similar trend was observed with samples from each of the communal areas.

Table 21.1: Means of characteristics of manures from Chivi, Mangwende, Shurugwi and Tsholotsho

Variable	Mean	Std Dev	Minimum	Maximum	No. of samples
%N	0.89	0.43	0.10	2.76	329
%C	13.1	6.2	5.4	28.8	81
C:N	13.7	3.8	4.2	25.3	81
% Lignin	8.7	5.4	0.4	28.7	108
%Ash	70	17	27	92	92
%Polyphenols	0.13	0.12	0.04	0.45	16

Figure 21.1: Frequency distribution of the measured N content (%) of manures from Chivi, Mangwende, Shurugwi and Tsholotsho



The ash contents of the manures were high ranging from 27 % to 92% with an average of 70% (Table 21.1). Only 7% of the manure analysed had ash contents of less than 40%. About 60% had values between 60 and 80%. A plot of the frequencies of the ash contents was heavily skewed towards higher values. The high values in ash contents are an indication of the high contamination from sand, which is a common problem with manures from smallholder farmers. The C:N ratios of the manure were all less than 30. Manure with C:N ratios between 10 and 20 constituted 77% of the samples analysed. Only 6% of the manures had a ratio more than 20 (Figure 21.2). The polyphenol contents of the manures were small. A few samples analyzed for polyphenols showed that they are not present in significant amounts. The average 'lignin' content of the manures was low but some manures had significantly high amounts of up to 29% (Table 21.1). There was a significant positive correlation between the %N and the %C of the manures. However, ash content and lignin explained only a small proportion, 42% and 30% respectively, of the variability in N content of the manures (Figure 21.3).

Figure 21.2: Frequency distribution of the measured C/N ratios of manures from Chivi, Mangwende, Shurugwi and Tsholotsho

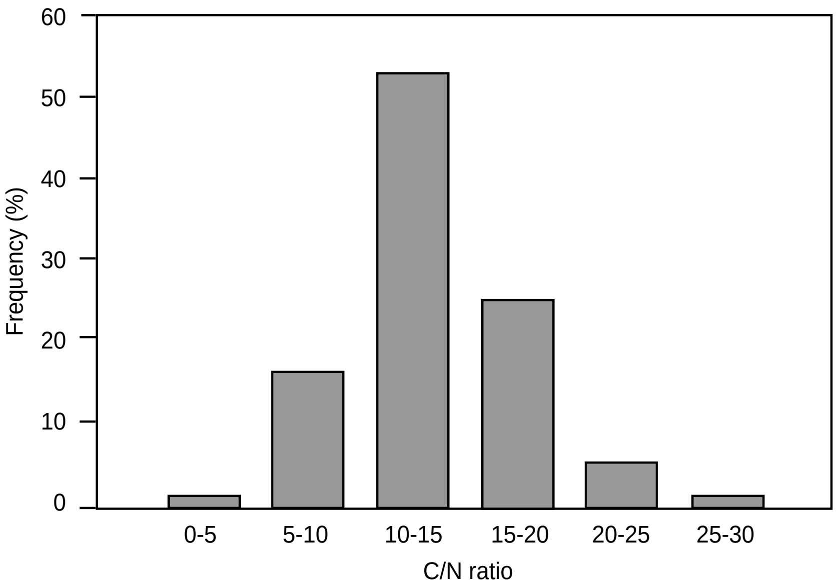
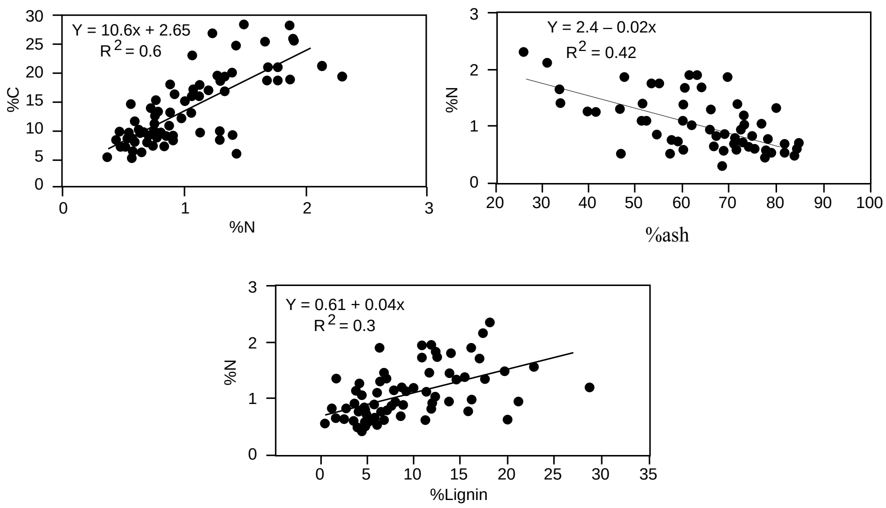


Figure 21.3: Some relationships between measured variables of manures from Chivi, Mangwende, Shurugwi and Tsholotsho



Nitrogen mineralization patterns

There was net mineral N from all the manures at the start of the incubation, the trend was however downward. This was followed by immobilization of N for all the manures except for manure CM8 (Figure 21.4 and 21.5). Of the ten manures, four had immobilization phases. Those which did not give net N immobilization had less mineralization at this point compared to previous measurements. There was a significant positive correlation between the initial %N, C:N, ash content and %C and net N mineralised after 7 days of incubation and a weak correlation with lignin (Table 21.3).

Table 21.2: Characteristics of manures used in the laboratory incubation experiments

Sample ID	% Total N	% Org. C	% Lignin	% Ca	% Mg	% K	C:N ratio	% Polyphenol	% Ash
CM1	0.45	8.10	3.8	0.22	0.07	0.53	18.0	0.04	87
CM2	0.47	9.90	6.1	0.18	0.04	0.33	21.1	0.07	83
CM3	0.56	8.10	6.1	0.23	0.06	0.78	14.5	0.05	82
CM4	0.60	6.90	6.5	0.27	0.07	0.45	11.5	0.04	84
CM5	0.89	18.00	13.8	0.30	0.10	0.70	20.2	0.07	68
CM6	0.89	12.90	21.1	0.41	0.10	0.66	14.5	0.14	56
CM7	1.10	16.80	9.2	0.70	0.15	1.10	15.3	0.33	70
CM8	1.24	26.70	6.5	0.82	0.18	1.02	21.5	0.12	78
CM9	1.29	19.20	14.5	0.86	0.20	1.31	14.9	0.16	58
CM10	1.50	28.80	22.9	1.19	0.29	1.59	19.2	0.45	31

Table 21.3: Regression equations for the two phases, the initial immobilization and the mineralization phase

Indices	Equation	R^2 value
Immobilization phase		
%N	Y = 8.13x – 7.7	0.73*
%C	Y = 0.33x – 5.2	0.60*
%Lignin	Y = 0.15x – 2.14	0.15
C/N	Y = 0.47x – 7.8	0.54*
%Ash	Y = -0.2x + 13	0.67*
Net mineralization phase		
%N	Y = 17.6x – 35	0.60*
%C	Y = 0.86x – 32	0.50*
%Lignin	Y = -0.15x + 31	0.66*
C:N	Y = -1.21x – 0.88	0.50*
%Ash	Y = -0.4x + 9.2	0.70*

*Significantly different from zero at P<0.05

Figure 21.4: Total N mineralization patterns for ten manures with initial N contents of 0.45-1.5% applied at a rate of 100 kg N ha^{-1}

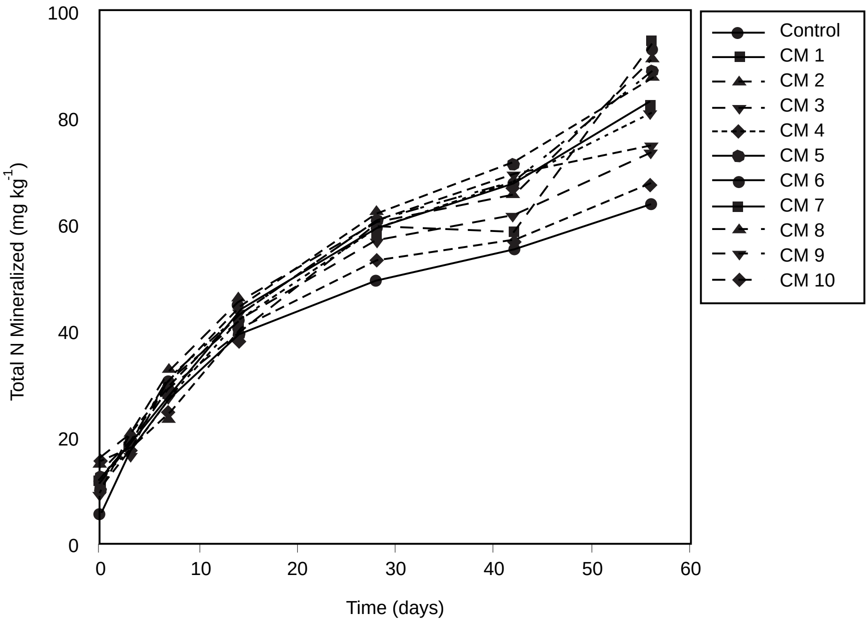
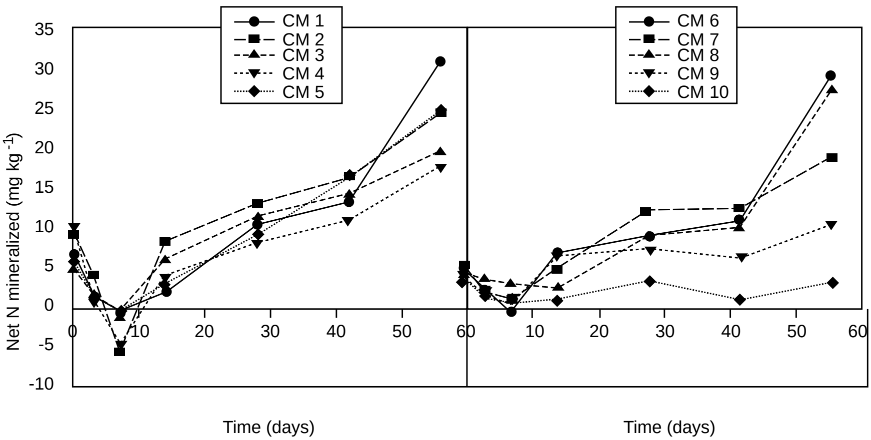


Figure 21.5: Net N mineralization patterns for ten cattle manures with initial total N contents of 0.45-1.5% applied at a rate of 100 kg N ha^{-1}



The results showed that between day 3 and 14 there was a N immobilization in six of the ten manures used in the initial phase of incubation. All the manures showed net N mineralization from the 14th day of incubation (Figure 21.5). With the exception of CM8, the manure treatments exhibited an increase in the net amount of mineralised N in the first two weeks. After four weeks of incubation the C:N ratio of the manures had significant negative correlation with the net mineralised N (Table 21.3).

A multifactor regression on the net mineral N values obtained showed that the indices influenced the manure decomposition process. However different sets of indices were important for different phases of decomposition during the period of incubation (Table 21.3). The lignin content could not explain the variance in mineralization during the early stages of decomposition but became important in the later phase. Availability of easily degradable C during the beginning of the experiment implies that more resistant C fractions would be utilized later on in the decomposition process. For the N mineralization within 56 days a model with indices and their relative weights as a measure of the overall influence on the N mineralization of manures was developed where;

Net mineralized N = 27.7N + 2.7Lignin + 2.34C:N + 1.49Ash – 1.39C – 86.2. Percent N far outweighed the other indices in terms of its weight and influence on the decomposition processes of the manures.

Effect of manure rates on N mineralization patterns

The low N (LN) manure, rates of up to 20 t ha^{-1} gave an initial net N immobilization period during the first 7 days of incubation with positive net values only measured after 14 days (Figure 21.6). The 40 t ha^{-1} treatment had positive net mineralised N for the entire incubation period. The general pattern of N release did not change with increasing quantities of manure applied. However, for the 5, 10 and 20 t ha^{-1} treatments there was no initial positive flush of mineralization with the low N manure.

Release patterns from incubating manure with high N (HN) (1.50 %) showed a similar initial immobilization period between days 3 and 14 for only the 5 and 10 t ha^{-1} treatments. Treatments with high quantities of 20 and 40 t ha^{-1} did not show any immobilization phase at the beginning (Figure 21. 6).

Figure 21.6: Net N mineralization of low (LN) and high N (HN) manure applied at different

rates equivalent to 5, 10, 20 and 40 t ha^{-1}

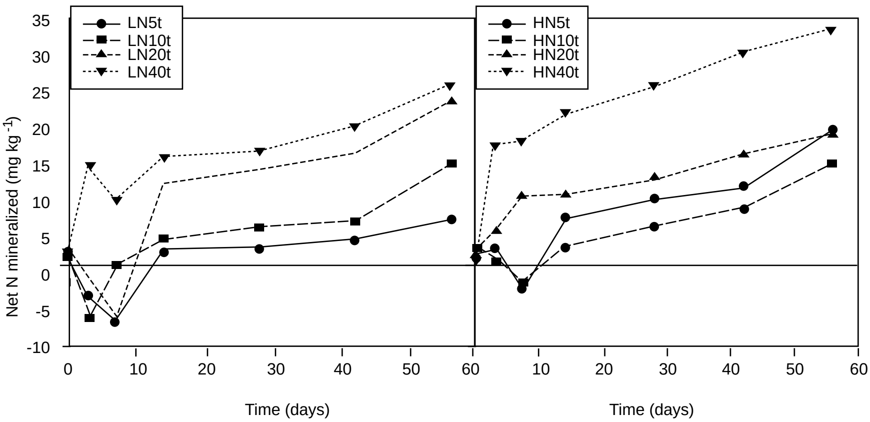
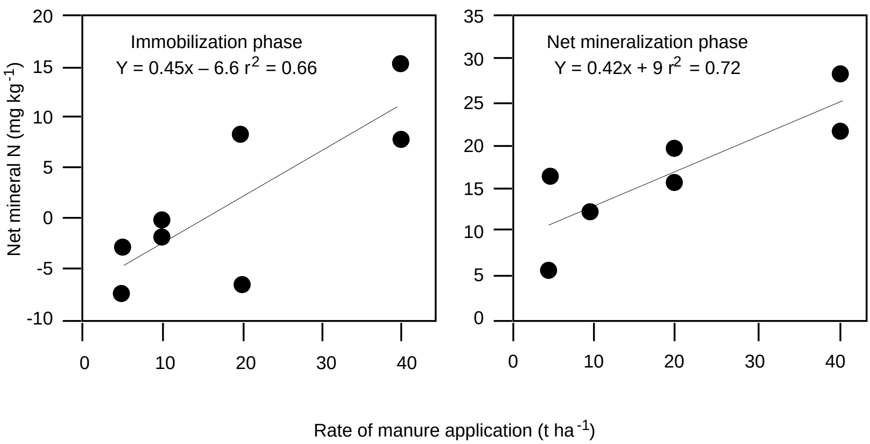


Figure 21.7: The relationship between rate of application of manure and mineralized N



Discussion

Characteristics of cattle manure from study areas

Manure is managed in different ways by farmers, hence the variation in manure quality. The frequency distribution graph shows the N content of most manures varied between 0.4 and 1.2% (Figure 21.1). The variations in the N contents of manures are mainly due to differences in losses during handling, contamination with sand in the kraal and addition of legume and other residues to dung. The fact that less than 7% of the manure had N content greater than 1.5% while 67% had N content less than 1% imply that the current management practices by most farmers do not result in manures with high N content.

The ash content values were high, averaging 70%. This indicated that sand contamination was high in all the manures from the different areas. This is mainly because new cattle kraals in which manure accumulates are built on loose sandy soils. Accumulation of manure on a loose earth base results in manures mixing with the sand. High sand content in cattle manure in Zimbabwe has also been reported by Mugwira (1984) as an indicator of the manure quality. Contamination also occurs when digging out the manure. Some farmers however have developed interventions of building kraals on anthills or putting concrete floors in order to reduce the loss in quality of the manure. There was an inverse relationship between %N and ash content, indicating that sand contamination causes part of this variability (Figure 21.3).

Net N mineralization pattern and manure indices

Manures with N contents higher than 0.89% (CM6-CM9) mineralised through out the entire incubation period with the exception of CM10 (Figures 21.4 and 21.5). N immobilization was observed with six of the manures after incubating the manured soil for two weeks. The findings are similar to green house studies by Mugwira and Mukurumbira (1984) in which they reported a depression in yields in the first two weeks followed by significant plant growth increases after two weeks of planting in manured pots. Tanner and Mugwira (1984) also observed a crop yield depression in the first 4 weeks in a greenhouse study using manures from other smallholder areas. Much longer periods of immobilization from cattle manure of up to 105 days have been observed (Fauci and Dick, 1994). These results are contrary to observation by Pathak and Sarkar (1994) who reported cattle manure with %N of 0.79, C:N of 26 and an ash content of 27.5% mineralised throughout the entire study period. The observation that manure with %N less than 0.89 (Figure 21. 5) immobilized more during the first 14 days is not in line with the general conclusion drawn by Mugwira and Mukurumbira (1986). When they classified manure into three groups they did not find any difference in the effects of manures with %N ranging from 0.62% to 1.22% that were all classified as medium and low quality groups.

The C:N ratio of the manure was an important index for indicating the occurrence of a net N immobilization period. Manures with C:N ratio less than 20 immobilized N, consistent with results of Castellanos and Pratt (1981) who reported immobilization from manures with C:N ratio of 15.9 and N contents of 2%. However this contrasts with reports from workers who used plant materials who report C:N ratio of 23 as the threshold for net mineralization (Frankenberger and Abdelmagid, 1985; Janssen, 1996; Quemada and Cabrera, 1995; Swift *et al.*, 1979). The implication is that neither %N nor C:N can on its own be used to explain the mineralization patterns in manures.

An initial flush of net mineral N was found at day 3 in all the manures studied, (Figures 21.5 and 21.6). Under field conditions this flush which occurs after the initial wetting of the soil by the rains will provide N to young plants early in the season. It is the balance between this initial mineralization and leaching losses together with crop uptake that determines the initial benefits of manures on crops.

The positive correlation between mineral N and the %N and the %C during the immobilization period shows their importance in determining the extent of mineralization in manures (Table 21.3). The organic carbon content of manures is an important determinant of the mineralization/ immobilisation processes. This is shown by positive correlation with mineralization at these initial stages of decomposition. Nitrogen and carbon are the primary needs for soil microbes for energy and biomass accumulation. These results corroborate studies on other organic materials in which N and C have been identified as important indices of mineralization (Constantinides and Fownes, 1994; Jansen, 1996). Hadas and Portnoy (1994) also report that %N, %C and efficacy with which C is assimilated are important in determining mineralization patterns of organic materials.

The low percentage of the variance that is explained suggests that indices have different overall effects on the mineralization trends with time as the substrate concentration and composition changes. After 14 and 28 days of incubation the % ash, lignin and C:N ratio become important indices of mineralization of these manures together with the %C and %N. This shows that indices change in importance as the decomposition process progresses. In studying green manures Oglesby and Fownes (1992) found correlation of indices significant at different times and phases of decomposition. The N content of the manure explains most of the variance in the N release patterns of manure throughout the incubation period thus it outweighs other indices in importance.

Whilst lignin and polyphenols are important intrinsic factors in plant materials, the relatively low values in the manures analysed (Tables 21.1 and 21.2), renders the parameter less influential in the decomposition processes. Palm and Sanchez (1991) reported threshold values of lignin as 15% and 3% for polyphenols in leaves of tropical legumes for net N mineralization to occur immediately. The average from the four areas studied of lignin is 8.74% and that of polyphenols is 0.13%. Mostly, cattle feed on the grass from the grass velds in the different areas and this, together with the rumen digestion process, explains the low concentrations for these two parameters. In the short term the lignin content did not affect the N mineralization but became important in the later stages. Cattle browsing on shrubs may have manure of higher lignin contents.

The polyphenol contents of manures were low. As manure passes through the alimentary canal, polyphenols react and form other products through condensation reactions. Measured values from samples collected from communal grazing areas are all less than 1% (Palm *et al.*, 2001). The effect of polyphenols in plant materials applied to the soil has been those of reduced N release through their protein binding capacity. They also bind enzymes which catalyse mineralization, in the nitrification process in particular. However, under aerobic conditions most polyphenols are quickly degraded (Paul *et al.*, 1994).

Rates of manure application

As expected, increasing rate of manure application led to increases in the overall amount of N mineralised from manure (Figure 21.4). There was a significant positive correlation between the rate and the amount of net mineralization during both the immobilization period and the positive net mineralization afterwards (Figure 21.7). This is in line with findings by Chang and Janzen (1996), who found a similar relationship from a long term study on rates of manure application. Schmitt *et al.* (1992) also found a linear relationship between release of NH_4-N and manure application rate.

The net mineralization pattern itself of the manures used in this study did not change. Except for the 20 t ha^{-1} and the 40 t ha^{-1} treatments of high N manure where there was no N immobilizaion phase throughout. Other treatments in the high and low N manures all showed immobilization within seven days of incubation. Lack of differences in the mineralization pattern for the low rates of application implies that the amount of substrate added to the soil did not alter mineralization in the low N manures. However, the apparent difference in pattern with the high N manure indicates that the C and N loading in the 40 t ha^{-1} treatment overrides any effects of immobilization.

Conclusions

The study on the characteristics of cattle manures from four smallholder farming areas showed that they are highly variable, with N content that ranged between 0.10 and 2.76% and that ash content was high averaging 70%. Most manures had a C:N ratio between 10 and 20. The %N, %C, %ash, lignin and the C:N ratio were the most reliable indices of manure N release. The indices however influenced the release of N from manure at different stages of the decomposition. Whilst %N, %C, C:N and ash content are important in the initial stages of mineralization, the lignin content became important at a later stage. Polyphenol contents were low in cattle manure thus the Browning reaction (reactions between polyphenols and carbohydrates or soluble carbon) did not explain the immobilization phase observed with the manures. It should be noted that the ash content as an index of quality in manure is important in that it can be estimated by hand texturing of materials in the field unlike others that require chemical analysis. This could be important for use by farmers as a quick test of quality. The regression model developed in this study containing five indices, %N, %C, C:N, lignin and ash content, needs further validation.

For all the manures used, the period of reduced mineralization was the same, in the initial stages of incubation. It is only the extent of immobilization not the duration which depended on quality. High N manures, with N content greater than 1% mineralised while low N manures immobilized N during the early stages of incubation.

The rate at which manure is added to the soil affects the amount of net mineralised N. In both high N and low N manures, increasing the quantities applied reduced the amount of immobilization and increased net mineralization. The high N manure released higher net N amounts compared with low N at the same rate of application. The rate of N release was also high with increase in quantities of manure. Cattle manure quality was important in determining N release pattern. The linear relationship between quantities and release show that quantity did not affect the mineralization pattern. The 40 t ha^{-1} treatment was an exception possibly because of the amount of carbon and nitrogen loading associated with application of large amounts of organic materials.

Acknowledgements

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References

Anderson, J..M., Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility. A Handbook of Methods.* CAB International, Wallingford.

Bremmer, J.M. (1965) Nitrogen availability indexes. In C.A. Black (Ed.) *Methods of Soil Analyses.* Agronomy 10, 1324-1345, American Society of Agronomy, Madison, Wisconsin.

Castellanos, J.Z., Pratt, P.F. (1981) Mineralization of manure nitrogen-Correlation with laboratory indexes. *Soil Science Society of America Journal* 45: 354-357.

Chang, C., Janzen, H.H. (1996) Long term fate of N from animal feedlot manure application. *Journal of Environmental Quality* 25: 785-790.

Constantinides, M., Fownes, J.H. (1994) Nitrogen mineralization from leaves and litter of tropical plants: relationship to nitrogen, lignin and soluble polyphenol concentrations. *Soil Biology and Biochemistry* 26: 49-55.

Fauci, M.F., Dick, R.P. (1994) Plant response to organic amendments and decreasing inorganic nitrgen rates in soils from a long term experiment. *Soil Science Society of America Journal* 58: 134-138.

Frankenberger, W.T., Abdelmagid, H.M. (1985) Kinetic parameters of nitrogen mineralization rates of leguminous crops incorporated into soil. *Plant and Soil* 87: 257-271.

Hadas, A., Portnoy, R. (1994) Nitrogen and Carbon mineralization rates of composted manures incubated in soil. *Journal of Environmental Quality* 23: 1184-1189.

Haider, K. (1986) Changes in substrate composition during the incubation of plant residues in soil. In: Jensen, V., Joun, M., Sprensin, L.H. (Eds.), Microbial Communities in Soil. FEMS Symposium Number 33. Elsevier.

Handayanto, E., Giller, K.E., Cadisch, G. (1997) Regulating N release from tree legume prunings by mixing residues of different quality. *Soil Bioliology and Biochemistry* 29: 1417-1426.

Jansen, B.H. (1996) Nitrogen mineralization in relation to C:N ratio and decomposibility of organic materials. *Plant and Soil* 181: 29-45.

Mafongoya, P.L., Dzowela, B.H., Nair, P.K. (1997) Effect of multipurpose trees, age of cutting and drying methods on pruning quality. In: Cadisch, G., Giller, K.E. (Eds.), *Driven by Nature: Plant Litter Quality and Decomposition.* CAB International, Wallingford, UK, pp. 167-174.

Melillo, J.M., Aber, J.D., Muratore, J.F. (1982) Nitrogen and lignin control of hard wood leaf litter decomposition dynamics. *Ecology* 63: 621-626.

Mugwira, L.M. (1984) Relative effectiveness of fertilizers and communal area manures as plant nutrient sources. *Zimbabwe Agricultural Journal* 81: 85-89.

Mugwira, L.M., Mukurumbira, L.M. (1984) Comparative effectiveness of manure from communal areas and commercial feedlots as plant nutrient sources. *Zimbabwe Agricultural Journal* 81: 241-250.

Mugwira, L.M., Mukurumbira, L.M. (1986) Nutrient supplying power of different groups of manure from the communal areas and commercial feedlots. *Zimbabwe Agricultural Journal* 83: 25-29.

Mugwira, L.M., Murwira, H.K. (1997) *Use of cattle manure to improve soil fertility in Zimbabwe: Past, Current Research and Future Needs.* Network Research Results Working Paper No.2. Department of Research and Specialist Services, Chemistry and Soil Research Institute, Harare, Zimbabwe.

Oglesby, K.A., Fownes, J.H. (1992) Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. *Plant and Soil* 143: 127-132.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G., Giller, K.E. (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment* 83: 27-42.

Palm, C.A., Sanchez, P.A. (1991) Nitrogen release from some tropical legumes as affected by lignin and polyphenol content. *Soil Biology and Biochemistry* 23: 83-88.

Pathak, H., Sarkar, M.C. (1994) Nitrogen supplying capacity of an Ustochrept amended in manure, urea and their combinations. *Journal of the Indian Society of Soil Science* 42: 261-267.

Paul, J.W., Covert, J.A., Beauchamp, E.G. (1994) Influence of soil temperature and moisture on water soluble phenolic compounds in manured soil. *Canadian Journal of Soil Science* 74: 111-114.

Quemada, M., Cabrera, M.L. (1995) Carbon and Nitrogen mineralization from leaves and stems of four cover crops. *Soil Science Society of America Journal* 59: 471-477.

Schmitt, M.A., Sawyer, J.E., Hoeft, R.G. (1992) Incubation of injected liquid beef manure: effect of time and manure rate. *Agronomy Journal* 84: 224-228.

Stanford, G., Smith, S.J. (1972) Nitrogen mineralization potentials of soils. *Soil Science Society American Proceedings* 36: 465-472.

Swift, M.J., Heal, O.W., Anderson, J.M. (1979) *Decomposition in Terrestrial Ecosystems*. Blackwell, Oxford, UK. 372pp.

Tanner, P.D., Mugwira, L. (1984) Effectiveness of communal area manures as sources of nutrients for young maize plants. *Zimbabwe Agricultural Journal* 81: 31-35.

22

Effect of Cattle Manure and N Fertiliser on Nitrate Leaching Losses in Smallholder Maize Production Systems of Zimbabwe Measured in Field Lysimeters

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Abstract

Maize (*Zea mays* L.) production in the smallholder farming areas of Zimbabwe is based on both organic and inorganic nutrient sources. A study was conducted to determine the effect of cattle manure, N fertiliser, and their combinations on nitrate concentration in leachate leaving the root zone and to establish N fertilisation levels which minimise N leaching. Maize was grown for two seasons (1996/97 and 1997/98) in field lysimeters repacked with a coarse grained sandy soil. Average leachate volumes over the two seasons were quite similar between different treatments, and ranged from 388 to 418 mm yr^{-1}. Nitrogen fertiliser, especially the high rate (120 kg N ha^{-1}), and manure plus N fertiliser combinations resulted in high nitrate leachate concentrations (up to 37 mg N L^{-1}) and nitrate losses (up to 56 kg N ha^{-1} yr^{-1}) which represent both environmental and economic concerns. Nitrate leaching from manure only treatments was relatively low (av. less than 23 kg N ha^{-1} yr^{-1}), and plant availability in these treatments tended to be higher in the second season. The partitioning between N leaching and uptake depended on the intensity and timing of the rainfall after fertiliser application. It was concluded that N leaching at high inorganic N fertiliser rates posed a serious economic and environmental risk when all the fertiliser was applied at planting. It was also concluded that the risk of N leaching from aerobically composted cattle manure was low in the short-term.

Key words: Nitrate leaching, N uptake, lysimeter, manure, N fertiliser

Introduction

The smallholder cropping systems in Zimbabwe are based on maize, the staple food crop, which accounts for about 50% of the calories consumed. Cattle manure remains the major source of nutrients for plant growth in the smallholder farming sector although some inorganic fertiliser is also used. The Alvord system, recommended for the smallholder farming sector of Zimbabwe, has widely been adopted by the farmers and is based on the application of 30-40 t ha^{-1} of manure to a four-course rotation of two maize crops, followed by a legume and finally a small grain crop (Grant, 1976). However the low efficiency of smallholder manures as sources of N (Murwira and Kirchmann, 1993; Nyamangara, *et al.*, 1999) has prompted farmers to supplement the manures with inorganic N fertiliser. There is need to improve synchrony between N release and plant uptake in order to optimise yield and minimise N leaching losses which may occur when organic and inorganic fertilisers are used in combination.

Nitrogen leaching from agricultural soil represents both an economic loss to farmers and environmental pollutant to natural water systems. The concentration of nitrate in groundwater, rivers and lakes has been increasing steadily for the past thirty years in large parts of the world, and agriculture is considered to be the major contributor (Addiscott et *al.*, 1991; Beckwith *et al.*, 1998). However, the situation is quite different to most smallholder farmers in developing countries in Africa and elsewhere, for whom inorganic fertilisers are often unaffordable (Kamukondiwa & Bergström, 1994a), and hence their efficient use is of both agronomic and socio-economic importance.

Most studies on N leaching from soils amended with manure and/ or inorganic fertilisers have focussed on humid temperate regions (Beckwith et *al.*, 1998; Thomsen *et al.*, 1993; Unwin, 1986), and overall, very few quantitative measurements of N leaching have been made in tropical and subtropical regions of Africa (Arora & Juo, 1982; Omoti *et al.*, 1983; Wong *et al.*, 1987). In Zimbabwe, N leaching losses of up to 39 kg N ha^{-1} yr^{-1} have been reported on a sandy soil (Kamukondiwa & Bergström, 1994b). However, the above study was carried out during a sequence of very dry years, which limits the representativeness of the results. Other studies, also on sandy soils in Zimbabwe (Hagmann, 1994; Vogel *et al.*, 1994), indicated that most of the fertiliser (up to 54 % of applied N) was leached out of the plough layer (0-0.5 m) when heavy rains followed N fertiliser application. However, some of the leached nitrogen can probably be recovered by roots later in the season.

In addition to being a potential environmental threat, large leaching losses of N may also cause nitrate-related health problems. The World Health Organisation (WHO) of the United Nations, the European Community (EC) and the US Environmental Protection Agency (USEPA) limit concentrations for nitrate in potable water at 22 (Killham, 1994), 11.3 (Addiscott et a*l.*, 1991) and 10 (Spalding & Exner, 1993) mg NO3-N L^{-1}, respectively. However, Addiscott and Benjamin (2000) recently reported that nitrate is important in the control of gastroenteritis in humans. Although concentrations greater than 10 mg NO3-N L^{-1} have been reported in some districts in Zimbabwe (Interconsult A/S - NORAD, 1985) their link to agricultural activities is unclear.

Although the rainfall is seasonal, highly variable and generally insufficient in most smallholder farming areas of Zimbabwe (Piha, 1993), its intensity is often very high and this may trigger N leaching in the predominantly coarse-textured soils used for agriculture (Twomlow, 1994). This led us to design a study in which the objective was to measure nitrate in water leaving the root zone in agricultural fields typical of smallholder cropping systems of Zimbabwe, and to establish fertilisation levels which minimise N leaching losses, but maintaining crop yields.

Materials and Methods

Experimental location and soil properties (Table 22.1)

The 2-year study was conducted at Domboshawa Training Centre (17035'S, 31010'E), about 35 km north of Harare, Zimbabwe, where average rainfall is 900 mm per annum (Agroecological Region IIa), mostly restricted to the summer season (November-April). The soil is a well drained, loamy sand (Typic Kandiustalf in the USDA soil classification system, or Haplic Lixisol in the FAO system) (Nyamapfene, 1991) with a low water holding capacity (AWC = 9% vol.) (Vogel *et al.*, 1994).

Table 22.1: Chemical and physical properties of the experimental soil, Domboshawa, Zimbabwe

Soil depth cm	pH ($CaCl_2$)	org-C %	N1 mg kg^{-1}	Clay %	Silt %	Fine sand %	Med. Sand	C. sand %	Bulk density Mg m^{-3}
0-20	4.7	0.4	23	6	3	23	51	17	1625
20-60	4.6	0.2	21	10	3	20	52	15	1620

1 Soil brought to field capacity using monocalcium phosphate and incubated for 14 days at 350C before KCl-extraction (Saunder *et al.,* 1957).

Lysimeter installations

A lysimeter station consisting of 27 repacked lysimeters was established in the autumn of 1995 at the field site. A trench at the centre of the lysimeter station contained twenty-seven buckets to collect leachate. The lysimeters, square-shaped (1 m^2) and 1.1 m deep, were constructed from 1.6 mm thick galvanized steel sheets. The lysimeter walls were painted to provide a rough surface that would prevent water from channelling between the soil and the tank walls. The lysimeter boxes were surrounded by field soil to prevent excessive heating of the lysimeter soil.

A 1 mm wire mesh was fixed at the lysimeter outlet and covered with a 10-cm layer of gravel before the soil was placed, reducing the effective depth of the lysimeters to 1 m. The gravel improved drainage (Stevens *et al.*, 1992) and also prevented the fine soil material from washing into the 10 mm steel outflow pipes. The pipes were laid at a slope of about 2% to ensure rapid water flow to the collecting vessels.

The topsoil was a coarse loamy sand (0-0.3 m) overlying a sandy loam subsoil (0.3-1.0 m). The layers were repacked to original density following the sequence of the soil profiles identified during site characterisation. Repacking the soil was considered appropriate because it only introduces small changes in water transport and nitrogen behaviour in course textured soils (Bergström, 1990). The lysimeters were water saturated from the bottom end and thereafter allowed to drain freely, and left to settle for 14 months before the experiment was started in the summer of 1996.

Experimental design and layout

The treatments were manure (0, 12.5, and 37.5 t ha^{-1}, which contained 0, 116 and 348 kg N ha^{-1}) and N fertiliser (0, 60 and 120 kg N ha^{-1} as NH4N03) replicated three times in a 2-factor randomised complete block design. The manure rates were based on current recommendations for maize in smallholder farming areas of Zimbabwe where about 37 t ha^{-1} is applied every fourth year, or annually at about 12 t ha^{-1} (Mugwira & Murwira, 1998). The 12.5 t ha^{-1} manure and N fertiliser treatments were applied in both years but the larger manure treatment was applied only in the first year.

The manure was aerobically composted and contained 0.93% N, 8.37% C (C:N = 9) and 73.7% soil. The low N and high soil contents of the manure is typical of manures from smallholder farming areas in Zimbabwe (Mugwira & Murwira, 1998). The manure and fertiliser, all applied before planting, were incorporated into the top 0.1 m of the soil at planting. Two maize plants were grown in each lysimeter during both summer seasons, which were seeded on 3 December 1996 and 24 November 1997, respectively. The above-ground maize parts were harvested after 12 weeks each year (milk dough stage) and the fresh weight, dry weight and N content determined.

Leachate sampling and measurement of nitrate concentrations

Leachate volume was recorded following each rain event when break-through of leachate was expected. Representative samples were taken 1-3 times each week depending on volume of leachate for nitrate-N determination by colorimetric analysis (Keeney & Nelson, 1982). It was assumed that the concentration of ammonium-N in leachate was negligible.

Statistical analysis

A two-way ANOVA model in MStat (MSTAT, 1988) was used to determine the significance of leachate volume, N leaching losses and maize N uptake between treatments, and to determine whether there were manure x N fertiliser interaction effects.

Results and Discussion

Soil, weather and drainage conditions

The 1996/97 growing season was wetter (1395 mm) than the long-term seasonal average for the area, whereas in 1997/98 seasonal rainfall was close to average (840 mm). Compared to 1997/98, most of the rainfall received in 1996/97 was in the form of high intensity storms (up to 120 mm day^{-1}), which contributed to the larger total leachate volumes recorded in 1996/97 (average 496 mm) compared to 1997/98 (average 311 mm) (Table 22.2). In both seasons leachate volumes accounted for about a third of the total seasonal rainfall. The possible effect of repacking on leachate volume was not estimated.

Above-ground N uptake

Total above-ground N uptake by maize from lysimeters which received manure or N fertiliser was significantly (P<0.001) greater than that from the control in both seasons (Table 22.3). There was a positive manure and N fertiliser interaction which was more significant in the first growing season (1996/97) (P=0.0000) than in the second growing season (1997/98) (P=0.0004).

Table 22.2: Cumulative leachate volumes for the study period, Domboshawa, Zimbabwe

	Leachate (mm)		
Treatment	1996/97	1997/98	Average
Control NO	509	325	418
60 kg N ha^{-1} N60	480	296	388
120 kg N ha^{-1} N120	495	294	395
12.5 t ha^{-1} Manure ML	493	300	398
37.5 t ha^{-1} Manure MH	494	335	415
12.5 t ha^{-1} Manure + 60 kg N ha^{-1} N60ML	496	319	408
12.5 t ha^{-1} Manure + 120 kg N ha^{-1} N120ML	489	317	412
37.5 t ha^{-1} Manure + 60 kg N ha^{-1} N60MH	508	310	409
37.5 t ha^{-1} Manure + 120 kg N ha^{-1} N120MH	501	303	402
Significance	NS	NS	NS
CV (%)	9.8	11.9	7.8
LSD (P<0.05)	86.1	64.6	53.6

1The high rate of manure in the zero fertiliser treatment was only applied in the first season.

Table 22.3: Total N uptake in above-ground plant parts during 1996/97 and 1997/98 growing seasons, Domboshawa, Zimbabwe

Treatment	N uptake (kg N ha^{-1})	
	1996/97	1997/98
N0	25.5	22.5
N60	45.4	56.3
N120	95.2	63.4
ML	48.7	78.1
MH	70.8	96.6
N60ML	77.9	105.0
N120ML	153.6	133.6
N60MH	90.2	116.0
N120MH	189.1	144.7
Significance	***	***
Interaction (MxF)	***	***
CV	17.8	17.4
LSD (P<0.05)	23.4	25.9

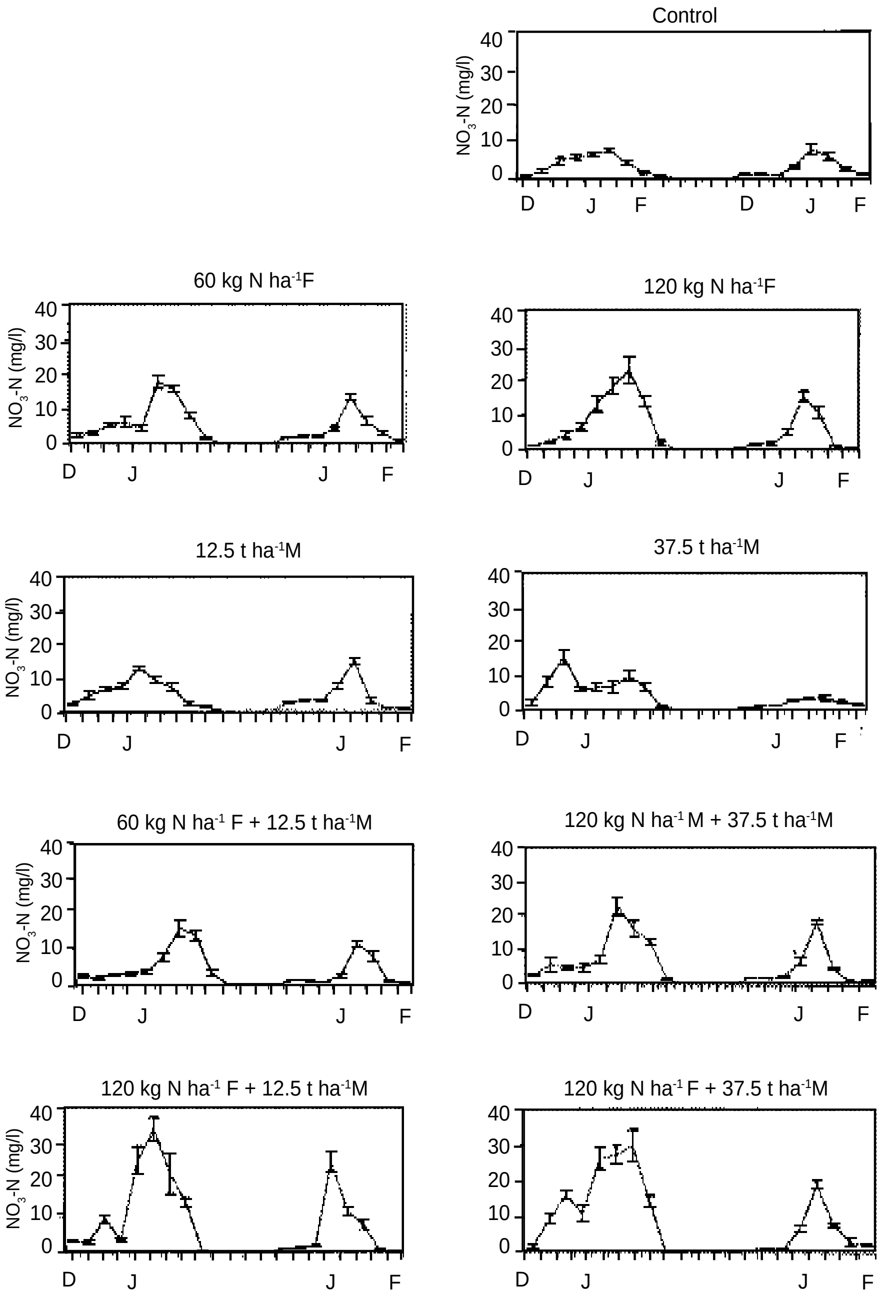
M – Manure, F – Fertiliser

Nitrogen uptake from the manure only rates (12.5 and 37.5 t ha^{-1}) was greater (60 and 36 % respectively) in the second season compared to the first season. This implied that manure N became more available (through mineralisation) for plant uptake in the second year compared to the first year.

Nitrate concentration in leachate

Nitrate concentrations in the leachate of treatments during the experimental period are shown in Figure 22.1. Concentrations from lysimeters amended with manure were comparable to the control (< 15 mg N L^{-1}) during the two growing seasons. Concentration from lysimeters amended with N fertiliser were higher than the control in both growing seasons. Kamukondiwa *et al.* (1996) also reported lower N concentration in leachates from lysimeters receiving similar manure as used in this study, compared to corresponding lysimeters receiving equal amounts of N in inorganic fertilizer. However, there are examples showing the opposite situation. For example, in a study performed under cold climate conditions, N concentrations in drainage water was higher in poultry manured soils than in soils receiving equal amounts of N with inorganic fertiliser (Bergström & Kirchmann, 1999). However, it is important to keep in mind that the manure used in that study and our study were quite different, which precludes a direct comparison of the results.

Figure 22.1: Average nitrate concentration in leachate collected from replicate lysimeters during the study period, Domboshawa, Zimbabwe. Bars represent standard errors



Manure and N fertiliser treatment combinations resulted in nitrate concentrations in leachate reaching 37 mg N L^{-1} when the high N fertiliser rate (N120) was used. The depressed nitrate concentration in the high manure plus high N fertiliser (N120MH) treatment during the second season was not expected.

High intensity rainfall recorded soon after application of the N fertiliser may have leached the soluble N resulting in high nitrate concentrations in N fertiliser treatments, although much less than one pore volume of water had leached through the profile between fertilization and this break through of water. Therefore, there is reason to believe that some of the fertilizer-N was displaced by preferential flow induced by an unstable wetting front (Steenhuis & Parlange, 1991). This flow behaviour was likely enhanced by the high rainfall intensity.

Nitrate leaching losses

The annual nitrate leaching losses ranged from 18.9 to 56.3 kg N ha^{-1} in the first year and from 11.8 kg to 24.2 kg N ha^{-1} in the second season (Table 22.4). The addition of N fertiliser only, or in combination with manure, significantly ($P<0.01$) increased nitrate leaching in the first (1996/97) growing season, while the addition of manure only had no significant effect on N leaching compared to the control. In the second season, only combinations of N fertiliser with the high (MH) manure rate significantly increased nitrate leaching compared to the control. There was a positive manure and N fertiliser interaction which was only significant in the first growing season ($P<0.001$).

Table 22.4: Nitrate leaching losses during 1996/97 and 1997/98 growing seasons, Domboshawa, Zimbabwe

Treatments	N leached (kg N ha^{-1})	
	1996/97	1997/98
NO	18.9	11.8
N60	41.9	14.3
N120	56.3	15.8
ML	24.2	14.0
MH	27.5	16.7
N60ML	48.0	16.7
N120ML	53.6	16.9
N60MH	47.5	22.1
N120MH	56.1	24.2
Significance	**	*
Interaction (MxF)	***	NS
LSD (P<0.05)	19.7	5.8
CV (%)	13.5	22.9

The higher nitrate leaching in the fertiliser treatments was attributed to the large amounts of readily available N early in the season, whereas most of the N derived from manure had to undergo mineralisation before it became available for uptake and leaching. However, smallholder farmers typically apply one third of the N fertiliser at planting and the balance at 4-6 weeks after planting, and under these conditions nitrate leaching may be lower. In this study all the N fertiliser was applied at planting.

Overall, N uptake in all treatments was weakly correlated to N losses for both growing seasons (R^2<0.20). For manure only treatments, correlation was only strong in the first season (R^2= 0.97), whereas for N fertiliser treatments the correlation was relatively strong for both seasons (1996/97, R^2 = 0.80; 1997/98, R^2 = 0.94).

Conclusions

Due to the high intensity nature of rainfall experienced at the study site and the low water holding capacity of the soil, the effects of differences in plant growth on evapotranspiration were not significant. The rainfall pattern (distribution and intensity) determined the partitioning between N plant uptake and leaching. The increased N uptake at higher N fertiliser rates means that high fertiliser addition within reasonable limits does not necessarily result in more N leaching. The application of aerobically composted manure from the smallholder farming areas of Zimbabwe to soil does not pose an economic and environmental concern due to nitrate leaching in the short-term. The application of inorganic N fertiliser to sandy soils can result in high nitrate leaching losses when all the fertiliser is applied at planting. The low manure (12.5 t ha^{-1}) plus 60 kg N ha^{-1} fertiliser treatment was the best treatment in terms of maintaining dry matter yield and minimising N leaching losses. Further studies are required to determine the effect of manure quality and split application of N fertiliser on plant uptake and leaching losses, and also the effect of soil type.

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References

Addiscott, T.M. and Benjamin, N. (2000) Are you taking your nitrate? *Food Sci. Tech. Today* 14: 59-61.

Addiscott, T.M., Whitmore, A.P. and Powlson, D.S. (1991) Farming, fertilisers and the nitrate problem. C.A.B. International, pp. 1-156.

Arora, Y., Juo, A.S.R. (1982) Leaching of fertiliser ions in a kaolinitic Utisol in the high rainfall tropics: leaching of nitrate in field plots under cropping and bare fallow. *Soil Sci. Soc. Am. J.* 46: 1212-1218.

Beckwith, C.P., Cooper, J., Smith, K.A., Shepherd, M.A. (1998) Nitrate leaching losses following application or organic manures to sandy soils in arable cropping. 1. Effects of application time, manure type, overwinter crop cover and nitrification inhibition. *Soil Use and Mgmt*. 14: 123-130.

Bergström, L.F., Kirchmann, H. (1999) Leaching of total from 15N-labelled poultry manure and inorganic N fertiliser. *J. Environ. Qual*. 28: 1283-1290.

Bergström, L. (1990) Use of lysimeters to estimate leaching of pesticides in agricultural soils. *Environ. Pollution* 67: 325-347.

Grant, P.M. (1976) Peasant farming on infertilie soils. *Rhod. Sci. News* 10: 252-254.

Hagmann, J. (1994) Lysimeter measurements of nutrient losses from from a sandy soil under conventional-till and ridge-till. In: B.E. Jensen, P. Schjonning and Mikkelsen (Eds.) Soil tillage for crop production and protection of the environment. Proceedings of the 13th International Conference, International Soil Tillage Research Organisation (ISTRO), Aalbourg, Denmark, 24 to 29 July, pp. 305-310.

Interconsult A/S-NORAD, (1985) Water quality report on nation masterplan for rural water supply and sanitation for the Republic of Zimbabwe, Harare, Zimbabwe.

Kamukondiwa, W., Bergström, L., Campbell, B.M., Frost, P.G.H., Swift, M.J. (1996) N leaching in manured and ammonium nitrate fertilised lysimeters in Zimbabwe. In: van Cleemput *et al* (Eds.) Progress in nitrogen cycling studies, Kluwer Academic Publishers, The Netherlands, pp. 675-680.

Kamukondiwa, W., Bergström, L. (1994a) Nitrate leaching in field lysimeters at an agricultural site in Zimbabwe. *Soil use and Mgmt*. 10: 118-124.

Kamukondiwa, W., Bergström, L. (1994b) Leaching and crop recovery of 15N from ammonium sulphate and labelled maize (Zea mays) material in lysimeters at a site in Zimbabwe. *Plant and Soil* 161: 193-201.

Keeney, D.R., Nelson, D.W. (1982) Nitrogen-inorganic forms. In: A.L. Page (Ed.) Methods of soil analysis Agronomy 9, Part II (2nd edn.), *Am. Soc. Agron. and Soil Sci. Soc. Am., Madison* pp. 643-698.

Killham, K. (1994) Soil ecology. Cambridge University Press.

MSTAT, (1988) A microcomputer programme for design, management, and analysis of agronomic research. Michigan State University, USA.

Murwira, H.K. and Kirchmann, H. (1993) Comparison of carbon and nitrogen mineralisation of cattle manure subjected to different treatments, in Zimbabwean and Swedish soils. In: R. Merrkx and J. Mulongoy (Eds.) The dynamics of soil organic matter in relation to the sustainability of tropical agriculture, John Wiley & Sons. Leuven, Belgium.

Mugwira, L.M., Murwira, H.K. (1998) A review of research on cattle manure as a soil fertility amendment in Zimbabwe: Some perspectives. In: S.R. Waddington *et al.* (Eds.) Soil fertility research for maize-based farming systems in Malawi and Zimbabwe, Soil Fert Net and CIMMYT-Zimbabwe, Harare, pp. 195-201.

Nyamapfene, K.W. (1991) The Soils of Zimbabwe. Nehanda Publishers (Pvt) Ltd., Harare.

Nyamangara, J., Piha, M.I. and Kirchamann, H. (1999) Interactions of aerobically decomposed cattle manure and nitrogen fertiliser applied to soil. *Nutr. Cycling in Agroecosystems* 54: 183-188.

Omoti, U., Ataga, D.O., Isenmila, A.E. (1983) Leaching of nutrients in oil palm plantations determined by tension lysimeters. *Plant and Soil* 73: 365-376.

Piha, M.I. (1993) Optimising fertiliser use and practical rainfall capture in a semi-arid environment with variable rainfall. *Exp. Agric*. 29: 405-415.

Saunder, D.H., Ellis, B.S., Hall, A. 1957. Estimation of available nitrogen for advisory purposes in Southern Africa. *J. Soil Sci*. 8: 301-312.

Spalding, R.F., Exner, M.E. (1993) Occurrence of nitrate in ground water-a review. *J. Environ. Qual.* 22: 392-402.

Steenhuis, T.S., Parlange, J.-Y. (1991) Preferential flow in structured and sandy soils. In: T.J. Gish and A. Shirmohammadi (Eds) Preferential flow, Proceedings of the national symposium, 16-17 December 1991, Chicago, pp. 12-21.

Stevens, W., Mittelstaedt, W., Stock, A., Fuhr, F. (1992) Experimental approaches to lysimeter studies: description of systems. In: Fuhr, F and R.J. Hance (Eds) Lysimeter studies of the fate of pesticides in the soil. BCPC monograph no. 53, pp. 21-34.

Thomsen, I.K., Hansen, J.K.., Kjeller, U.P.V., Christensen, B.T. (1993) Effects of cropping system and rates of nitrogen in animal slurry and mineral fertiliser on nitrate leaching from a sandy loam. *Soil Use and Mgmt*. 9: 53-58.

Unwin, R.J. (1986) Leaching of nitrate after application of organic manures: lysimeter studies. In: J.H. Williams and P.L. Hermite (Eds.) Efficient land used sludge and manure, Elsevier, London, pp. 158-167.

Vogel, H., Nyagumbo, I., Olsen, K. (1994) Effect of tied ridging and mulch ripping on water conservation in maize production on sandveld soils. *Der Tropenlandwirt* 95: 33-44.

Wong, M.T.F., Wild, A., Juo, A.S.R. (1987) Retarded leaching of nitrate measured in monolith lysimeters in south-east Nigeria. *J. Soil Sci*. 38: 511-518.

23

Combined use of *Tithonia diversifolia* and Inorganic Fertilizers for Improving Maize Production in a Phosphorus Deficient soil in Western Kenya

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Abstract

The ability of *Tithonia diversifolia*, fertilizers and their combination to improve maize production in a phosphorous (P) deficient ferralsol, was compared in western Kenya. Tithonia and fertilizers were applied separately or combined in different proportions to give equal rates of 165 kg N ha^{-1}, 15.5 kg P ha^{-1} and 155 kg K ha^{-1} in two consecutive maize growing seasons, followed by two residual maize crops. Maize grain yields and P recovered in the above-ground biomass were higher in sole Tithonia than sole fertilizer treatments. Maize yields increased with increasing rate of Tithonia in the mixed treatments. When less than 36% of the total P applied in the mixture were supplied by Tithonia, there was no added yield benefit in the combined treatments compared to the sole fertilizer treatments. However, an added value ranging from 18 to 24 % increase in yields, was observed at higher Tithonia rates. Economic returns were larger from the application of Tithonia alone than from the application of sole fertilizers, with larger profit when Tithonia was collected from existing niches than when produced on site. Collecting Tithonia from current niches resulted also in larger net returns from all combined treatments than from fertilizers. The results of this study indicate that a high quality organic residue such as Tithonia can increase maize production to a greater extent than fertilizers. The combination of Tithonia and fertilizers can be an alternative to scarce resources and an added benefit can be obtained by maximizing the proportion of Tithonia in the mixture.

Key words: economic returns, leaf biomass, maize, phosphorus recovery, relative agronomic effectiveness.

Introduction

Phosphorus has been identified as one of the major limiting nutrients for crop production in many soils of East Africa. The use of fertilizers to improve soil fertility in smallholder farming systems such as those found in the East African highlands, will continue to be constrained by the high cost of fertilizers, the low purchasing power of smallholders and the restricted access to credit.

Although organic resources such as leaf biomass of agroforestry tree (shrub) species do not provide sufficient P and have no effect in increasing the total P of the system (Palm *et al.*, 1997; Buresh, 1999), they may increase the P availability of the already present P by rendering it more accessible to crops. The contribution of organics as P sources for crop production is limited by their low P content, thus requiring large amounts to meet moderate yield increases (Palm, 1995). In densely populated areas such as western Kenya, large amounts of organic residues cannot be produced on small farms averaging 0.6 ha (David and Swinkels, 1994). The limited land therefore has to be allocated to other uses than the production of organic materials for soil fertility replenishment. Where the materials can be found, the labour required for collection, transport and incorporation becomes another handicap to the use of large amounts of organic inputs (Jama *et al.*, 2000).

A supplementation of organic inputs with P fertilizers may be envisaged as it addresses both the problem of insufficient fertilizer supply and the large amount of organic material required for P supply. The success of this strategy however will depend on many factors such as the quality of the organic material used and the proportions of nutrient applied from either source (Palm *et al.*, 1997). Most trials studying the combination of organic materials and mineral fertilizers have failed to provide conclusive guidelines of the interactive effects of nutrients supplied by the various sources in combination because nutrients were not balanced. Total nutrients in the combined treatments were often the sum of the nutrients supplied by each nutrient source applied alone, explaining the higher yields from the combination compared to either source (Gachengo *et al.*, 1999).

Substitution type of experiments in which total nutrients supplied by organic and inorganic inputs added separately or combined in different proportions are equal (Mittal *et al.*,1992) provide the appropriate design for investigating the effects of combining organic and inorganic nutrient sources. Considering the current knowledge on the role of organic residues in reducing the soil P adsorption capacity (Easterwood and Sartain, 1990), increasing the pH (Kretzschmar *et al*, 1991) and increasing soil biological activity (Smith *et al*, 1993), we hypothesize the combination of organic and inorganic nutrient sources to be more beneficial than the sole application of fertilizers.

Nziguheba *et al* (1998), reported that the combination of *Tithonia diversifolia* (Hemsley A. Gray referred to as Tithonia in the text) and TSP at 15 kg P ha^{-1} had a similar or larger effect on available P pools than the sources applied alone at equal P rates. Whether crop response to the combination of Tithonia and fertilizers reflects the observed effects on soil P needs to be confirmed.

Therefore, a field experiment was conducted to:

(i) assess the ability of leaf biomass of Tithonia to substitute for equal amounts of NPK mineral fertilizers for maize production,

(ii) test possible added benefits of the combined use of fertilizer and Tithonia as opposed to sole application of either P source,

(iii) to determine the residual effects of the various sources and their combination on maize production, and

(iv) to compare the economic returns of maize produced using Tithonia and inorganic fertilizers applied alone or in combination.

Materials and Methods

Study site

The field experiment was conducted in the highlands of western Kenya (altitude 1450 m). The area has 2 growing seasons per year (a long rainy season from March to August and a short rainy season from September to January), with a mean annual rainfall of 1800 mm. The soil was classified as a ferralsol (FAO, 1990), with the following characteristics in the top 0.15 m:

pH (soil/water suspension 1.25) = 5.4,
organic C = 15 g kg^{-1}, exchangeable Ca = 4.6 cmolc kg^{-1},
exchangeable Mg = 1.9 cmolc kg^{-1},
exchangeable K = 0.08 cmolc kg^{-1},
exchangeable acidity = 0.25 cmolc kg^{-1}.
The bicarbonate extractable P = 0.9 mg kg^{-1} (Olsen and Sommers, 1982).
The soil has a clay content of 55%, silt 25%, and sand 20%.

Experiment design and management

This nutrient substitution trial was established in the short rainy season of 1997, in a randomized complete block design with four replications and 8 treatments. The treatments consist of Tithonia fresh leaf biomass and inorganic fertilizers (urea, TSP and KCl), applied separately or combined in different proportions to supply equal N, P and K rates of 165 kg N ha^{-1}, 15.5 kg P ha^{-1} and 155 kg K ha^{-1} (Table 23.1).

Table 23.1: Description of treatments used to assess the combination of Fertilizer and Tithonia for maize production in a field trial on a Ferralsol in western Kenya

Treatments	Code	Amount of nutrient added ($kg\ ha^{-1}$)						% P from
		From Tithonia			From fertilizer			
		N	P	K	N	P	K	
Control		0	0	0	0	0	0	
NOK		0	0	0	165	0	155	
NPK		0	0	0	165	15.5	155	0
NPK + 0.45 Mg Tithonia	F1 + T1	15	1.4	14	150	14.1	141	9
NPK + 0.9 Mg Tithonia	F2 + T2	30	2.8	28	135	12.7	127	18
NPK + 1.8 Mg Tithonia	F3 + T3	60	5.6	56	105	9.9	99	36
NPK + 3.6 Mg Tithonia	F4 + T4	120	11.2	112	45	4.3	43	72
Tithonia		165	15.5	155	0	0	0	100

At these rates phosphorus would be the only limiting nutrient. Six rates of Tithoni*a* were applied, 0, 0.45, 0.9, 1.8, 3.6, 5 Mg ha^{-1} on a dry matter basis. A control treatment (no inputs) and a treatment with the full rates of N and K but without P addition (NOK), were included as references. Treatments were broadcasted and incorporated with hoes in the top 0.15 m for 2 consecutive cropping seasons (input phase).

This was followed by 2 consecutive maize growing seasons without treatment additions to study the residual effect of the different inputs (residual phase). Plot sizes were 5.25 m x 5 m. The average nutrient concentrations of Tithonia leaves during the input phase were 33 g N kg^{-1}, 3.1 g P kg^{-1} and 31g K kg^{-1}.

Maize (*Zea mays* L.) hybrids 511 and 512 were planted respectively in the short and long rainy seasons at a spacing of 0.75 m x 0.25 m. Two seeds were sown per hole and thinned to one after germination. Weeding was done whenever appropriate. At maturity, maize was harvested and the fresh weight taken. Subsamples of cobs and stover were taken from each plot and air-dried. At the end, maize grain yields were expressed on a 15% water content. The above-ground maize biomass and weeds were removed from the plots at each harvest.

Plant analyses

Phosphorus concentrations in grain and stover at the harvest of crop 2 were analyzed and used to calculate the amounts of nutrient held in the above-ground biomass for the different crops. It was shown from earlier studies in the same area that P concentrations do not change significantly during seasons within treatments (Gachengo *et al.,* 1999).

Samples from maize stover and grain collected at the harvest of the second crop were air-dried and ground to pass a 0.5 mm sieve. Phosphorus in the samples was extracted using the sulphuric acid *Kjeldahl* digestion method (Anderson and Ingram, 1993) and determined colorimetrically by the method of Parkinson and Allen (1975).

In order to compare the P source effect for different cropping seasons, maize yields were converted to relative increase compared to the NOK treatments. Yield increase was calculated using the following formula:

$$\text{Yield increase (\%)} \quad \frac{\text{Yield}_{\text{treatment}}\ \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NOK}}} \text{ x } 100 \qquad (1)$$

Relative agronomic effectiveness (RAE) values of the P sources relative to yield obtained in the sole fertilizer treatment were calculated using the formula:

$$\text{RAE (\%)} \quad \frac{\text{Yield}_{\text{treatment}}\ \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NPK}} - \text{Yield}_{\text{NOK}}} \text{ x } 100 \qquad (2)$$

The efficiency of P applied in the different treatments was estimated by calculating the P recovered in the above-ground biomass of maize (stover, core, grain) from the P applied in the treatments using the formula:

$$\text{Phosphorus recovered (\%)} \quad \frac{(\text{P uptake}_{\text{treatment}}\ \text{P uptake}_{\text{NOK}})}{\text{P added}} \times 100 \qquad (3)$$

Economic analysis

The economic returns from the application of each treatment were calculated based on the partial budgeting, which included only added costs and added benefits from the control treatment (CIMMYT, 1988). Added costs included all the expenses for buying, collecting, transporting and applying the inputs, while the added benefits referred to the gain obtained by selling the harvested maize grain at the local market (Table 23.2).

Table 23.2: Parameters used to calculate the economic returns of fertilizers and Tithonia applied alone or in combination in a maize-based system of western Kenya

Parameter	Actual values
Price of TSP	0.41 USD kg^{-1}
Price of urea	0.38 USD kg^{-1}
Price of KCl	0.44 USD kg^{-1}
Labor cost	0.16 USD h^{-1}
Labor cost for planting	17.36 USD ha^{-1}
Baseline labor for application of fertilizers	1.8 USD ha^{-1} (a)
Price of Tithonia	0.04 USD kg^{-1} DM(b)
Labor for application of Tithonia collected within the homestead	2.9 USD 100 kg^{-1} DM (c)
Price of maize	0.20 USD kg^{-1}

Key
DM= dry matter basis

Baseline labor cost for the application of fertilizers correspond to the application of 44 kg N ha^{-1} of urea, 10 kg P ha^{-1}, and 50 kg K ha^{-1}. For additional fertilizers application, an extra cost of 2% was added per kg of nutrient (Jama *et al*, 1997). The price is based on the value of maize which would be produced on the land used for Tithonia production.

Collection of *Tithonia* out of the homestead required an additional transport cost which depends on the distance of collection. In this case, the extra cost was assumed to take 20 % of the labor cost of Tithonia collected within the homestead.

Price of fertilizers and their transport cost were determined through a local market survey. Three scenarios were used in the determination of the cost of Tithonia. The first scenario was based on the current situation where Tithonia is collected from existing niches. Only the labor for collection, transport and application is counted as Tithonia cost.

If the use of Tithonia is adopted at large scale, it is unlikely that Tithonia collected from current niches will satisfy the demand of farmers. In such scenario, farmers will need to grow Tithonia. Growing Tithonia requires that farmers sacrifice part of their land normally used for crop production (e.g maize), for Tithonia production. The production cost is therefore estimated by the price of maize, which would be produced on the same plot without application of fertilizers (scenario 2). On very depleted land, a minimum of P fertilization may be required for Tithonia establishment. In this case the cost of production of Tithonia will also include the cost of fertilizers applied on Tithonia (10 kg P ha^{-1}) (Scenario 3). It was assumed that 5 Mg ha^{-1} of Tithonia on dry matter basis (2 cuttings) can be produced per year (Jama *et al.*, 2000), requiring a sacrifice of two maize crops estimated to 1 Mg ha^{-1} of grain under farmers' conditions (Shepherd and Soule, 1998).

The application of urea and TSP at 44 kg N ha^{-1} and 10 kg P ha^{-1} was estimated to take an extra 7% of the total labor cost required for planting (Jama *et al.*, 1997). The labor for collection, transport and application of Tithonia within the homestead was estimated to 2.9 USD 100 kg^{-1} on dry matter basis (Rommelse, AFRENA, pers. communication, 2000). The collection of Tithonia from existing niches (scenario 1) requires an additional transport cost, which depends on the distance of collection. For this reason, an extra 20 % of labor cost was added for Tithonia in scenario 1 compared to scenarios 2 and 3 to adjust for the added transport cost. The labor was valued at the local wage rate of 0.16 USD per hour. Harvested yields in each treatment were reduced by 10% to adjust to realistic values if the experiment was to be managed by the farmer.

Monetary values were converted to US dollars (USD) at the exchange rate of 74 Ksh=1 US$ (May, 2000).

The net benefit from each treatment was then determined as the difference between added benefits and added costs. No dominance test for checking the marginal rate of return was done because treatments with highest net benefit had the lowest added cost, thus dominating all other treatments (CIMMYT, 1988)

Data analysis

Analysis of variance was conducted using the general linear model procedure (GLM) of SAS (SAS institute, 1995), to compare treatment effects on the parameters studied. Standard errors of difference in means (SED), were used for treatment comparison. Statistical significance refers to $\alpha = 0.05$. In order to check the interaction effect from combining Tithonia and fertilizers, maize response to the integrated sources was compared to the expected response determined by the equation:

$Yi = ai\ Yf + bi\ Yt$,

where:
Y_i = the expected maize yield from treatment i,
Y_f = maize yield obtained from the application of fertilizers alone,
Y_t= maize yield obtained from the application of Tithonia alone, a_i = the proportion of P applied from the fertilizers in treatment i, and
b_i= the proportion of P applied from Tithonia in treatment i ($b_i=1-a_i$).
Single degree freedom contrasts were also run to check the significance of the benefit or reduction of yield from the interaction.

Results

Maize grain yield

Maize yields of the control treatment were significantly increased by the addition of phosphorus sources. Despite the heavy rains (El Niño) experienced during the first season, addition of P sources more than tripled the yields obtained from the control treatments (Table 23.3).

Table 23.3: Maize grain yields over 4 consecutive seasons (2 fertilized, 2 residual) as affected by application of organic and inorganic sources of nutrients to a Ferralsol in western Kenya

Treatments	Mg ha^{-1}				
	Input phase		Residual phase		Total
	Crop 1	Crop 2	Crop 3	Crop 4	
Control	0.3	0.7	0.00	1.0	2.0
NOK	0.8	0.8	0.01	1.7	3.3
NPK	1.1	3.6	0.08	2.6	7.4
F1 + T1	1.1	3.6	0.06	2.2	7.0
F2 + T2	1.1	3.6	0.12	2.8	7.6
F3 +T3	1.3	4.0	0.12	2.8	8.2
F4 +T4	1.3	4.2	0.14	2.2	7.8
Tithonia	1.4	4.3	0.17	3.0	8.9
SED	0.3	0.3	0.04	0.4	0.7

However, there was no significant difference between treatments receiving a P source, although the highest increase was observed from the sole application of Tithonia. The same trend was observed at the second season but with much more yield increases from treatments receiving P compared to the control (414% to 514 %).

The total maize grain yields during the input phase were 1.0 Mg ha^{-1} in the control treatment, and 1.6 Mg ha^{-1} in the NOK treatment, while they ranged from 4.7 Mg ha^{-1} to 5.7 Mg ha^{-1} in treatments receiving P.

Maize grain yield tended to increase with increasing amount of Tithonia in the combined treatments with the sequence:

sole fertilizer = fertilizer + (0.45 Mg) Tithonia = fertilizers + (0.9 Mg) Tithonia < fertilizers + (1.8 Mg) Tithonia < fertilizers + (3.6 Mg) Tithonia < sole Tithonia.

All treatments having more than 36 % of the total P supplied by Tithonia more than tripled the yields of the NOK treatment. The total yield from sole fertilizers (4.7 Mg ha^{-1}), was significantly lower than that from sole Tithonia (5.7 Mg ha^{-1}).

The integration of resources with less than 36% of the total P supplied by Tithonia resulted in similar grain yields as the fertilizers applied alone, but lower than the sole application of Tithonia. However, when the P supplied by Tithonia accounted for 36% or more of the total P applied in the combination, a yield increase of at least 0.6 Mg ha^{-1} was observed compared to the addition of fertilizers alone, although this increase was not significant.

The first season of the residual phase was affected by a drought resulting in a nil grain harvest in the control treatment (Table 23.3). However, treatments followed the same trend as observed during the phase of treatment additions. For the second residual season, treatments receiving a P source still more than doubled the yield of the control. However, yields tended to be lower in the treatment receiving 9% P from Tithonia than in sole fertilizers. Two reps of the combination of fertilizers with 3.6 Mg ha^{-1} of Tithonia gave very low yields in the second residual crops. As a result, the average yield in this treatment was very low. The reason for such low yields could not be identified and was most probably not due to treatment effect. For this reason, the treatment will not be considered when discussing the residual effect of treatments.

Total maize yields obtained in the 2 seasons of residual crops were 1.0 Mg ha^{-1} in the control and 1.7 Mg ha^{-1} in NOK. Yield increases in treatments which previously received a P source relative to the NOK treatment ranged from 38 % to 90% and were less than half the increases obtained after the 2 seasons of treatment additions. Although not significant, an extra 0.5 Mg ha^{-1} grain yield was obtained from the residual maize after sole Tithonia addition compared to residual maize from sole fertilizers. The only significant difference observed between the treatments which previously received P source was from the combination of fertilizers and Tithonia with 9% of total P supplied by Tithonia, which resulted in lower maize yield than the yield obtained from the addition of sole Tithonia.

Relative agronomic effectiveness of the different P sources

Addition of sole Tithonia resulted in an added maize yield of 32 % compared to the addition of fertilizers alone at the end of the input phase (Table 23.4).

Table 23.4: Relative Agronomic Effectiveness (RAE) of Tithonia and its combination with TSP compared to TSP in a maize-based system in the highlands of western Kenya

Treatments	P added per season (kg ha^{-1})	RAE* (%)		
		Input	Residual	Total
F1 + T1	15.5	100	60	90
F2 + T2	15.5	100	116	104
F3 + T3	15.5	118	122	119
F4 + T4	15.5	124	61	108
Tithonia	15.5	132	141	135

$$* \ \text{RAE (\%)} \quad \frac{\text{Yield}_{\text{treatment}} \quad \text{Yield}_{\text{NOK}}}{\text{Yield}_{\text{NPK}} - \text{Yield}_{\text{NOK}}} \times 100$$

The combination of fertilizers and Tithonia with 9 % or 18% of P supplied by Tithonia resulted in maize yields equivalent to those obtained by applying fertilizers only (RAE = 100 %). Addition of 15.5 kg P ha^{-1} from the combination of fertilizers and Tithonia with 36 % and 72 % of P supplied by Tithonia had REA values of 118 % and 124 % respectively (Table 23.4).

The benefit from the addition of Tithonia compared to fertilizers was still observed during the residual phase where an added yield of 41 % was harvested from Tithonia applied alone. The combination of fertilizers and Tithonia at 9 % P from Tithonia reduced the residual yield from fertilizers alone by 40%, while a benefit ranging from 16% to 22% was obtained from other combined treatments.

There was no significant interaction between the fertilizers and Tithonia. However, combining fertilizers and Tithonia with less than 36 % P supplied by Tithonia tended to reduce the yields predicted from the yields obtained by Tithonia and fertilizers applied separately (Figure 23.1).

When the proportion of P from Tithonia increased to 36% and above, maize yields tended to increase above the predicted values.

Phosphorus recovered in the above-ground biomass of maize

Differences in phosphorus recovered from P added in the different treatments were hardly significant. However, P recovered after the first application of treatments from Tithonia applied alone was the highest and twice the value obtained from the sole fertilizer additions (Figure 23.2).

Figure 23.1: Cumulative maize grain yields from the P added in Tithonia, fertilizers and their combination. Bars indicated the standard errors of differences in means. Number of replicates = 4.

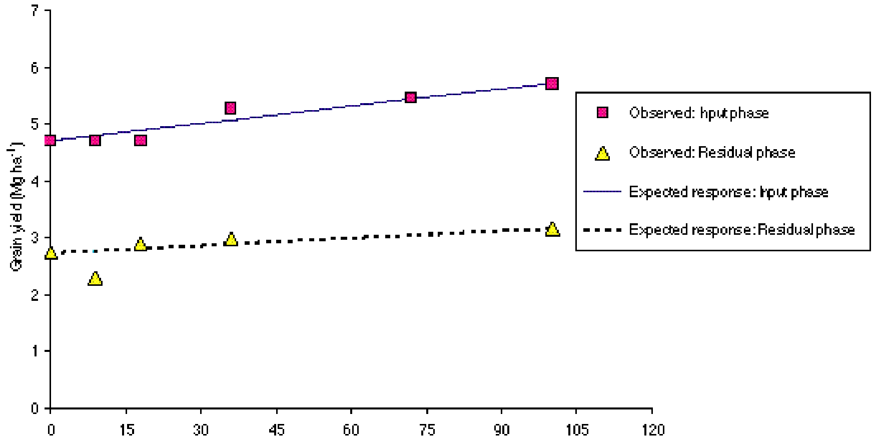
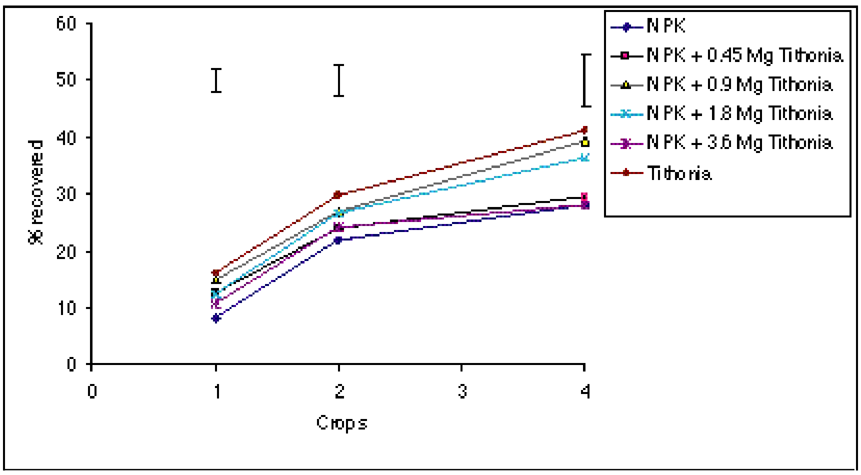


Figure 23.2: Cumulative P recoverd in the above-ground biomass of maize from the P added in Tithonia, fertilizers and their combination. Bars indicated the standard errors of differences in means. Number of replicated = 4.



The total P recovered at the end of the experiment in the 4 maize crops, was 41% of the P applied in the sole Tithonia treatments compared to 28% in the sole fertilizer treatments.

The combination of Tithonia with fertilizers resulted in larger values of P recovered compared to the pure fertilizer treatments, but were smaller compared to the sole Tithonia treatment, although the differences were not statistically significant.

Economic analysis

The net economic return from the application of N and K fertilizers without P was negative even after including the residual yields (Table 23.5).

Table 23.5: Economic returns from addition of Tithonia, fertilizers or their combination to a P deficient Ferralsol in a maize-based system

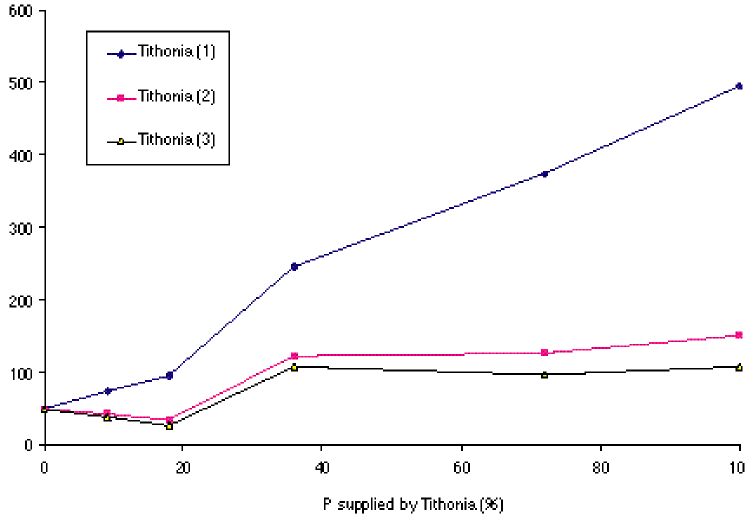
Treatments	USD ha^{-1}						
	Added Cost			Added Values		Net Benefits	
	Input 1 season	Labor 1 season	Total cost 2 seasons	2 seasons	4 seasons	2 seasons	4 seasons
NOK	273	2.6	551	102.6	219.6	-448	-331
NPK	304	2.6	614	664.2	972	50	358
Tithonia (1)		176	352	846	1233	494	881
Tithonia (2)	200	147	694	846	1233	152	539
Tithonia (3)	222	147	738	846	1233	108	495
Combine							
			Tithonia (1)				
F1 + T1	276	18	590	664	895	75	305
F2 + T2	249	34	567	662	1001	96	434
F3 + T3	194	66	519	765	1114	246	596
F4 + T4	84	128	425	799	1031	375	607
			Tithonia (2)				
F1 + T1	294	16	620	664	895	44	274
F2 + T2	285	29	628	662	1001	35	373
F3 + T3	266	55	642	765	1114	123	473
F4 + T4	228	108	671	799	1031	128	361
			Tithonia (3)				
F1 + T1	296	16	624	664	895	40	270
F2 + T2	289	29	635	662	1001	27	365
F3 + T3	274	55	657	765	1114	108	457
F4 + T4	244	108	703	799	1031	97	329

(1) no production,
(2) production of Tithonia without fertilizers,
(3) production of Tithonia with P fertilization

The application of a small dose of P fertilizers (15.5 kg P ha^{-1}) reversed the trend to a positive net benefit of 50 USD.

Net benefits from Tithonia and the combined treatments were positive, but depended on the strategy adopted for Tithonia production. For the current situation where only the labor cost for cutting, carrying and applying Tithonia are involved, higher net benefits were obtained in treatments receiving Tithonia than in the sole application of fertilizers. The benefits increased with increasing proportion of P from Tithonia, the highest being obtained from Tithonia applied alone (494 USD after 2 growing seasons) (Table 23.5, Figure 23.3).

Figure 23.3: Nets benefits from addition of Tithonia, fertilizers and their combination as affected by the proportion of P added in Tithonia and the strategy of Tithonia production. (1): Tithonia collected from existing niches, (2): Production of Tithonia without fertilizers, (3): Production of Tithonia with P fertilization



Growing Tithonia, however, reduced its benefits. Although net benefits in treatments receiving Tithonia were still positive, they were larger than those obtained from fertilizers alone only when Tithonia was applied at 1.8 Mg ha^{-1} or more.

When the residual crops were included in the economic analysis, net benefits were larger in treatments which received Tithonia than in sole fertilizer treatments for all strategies, except for the combination of fertilizers with 0.45 Mg of Tithonia (Table 23.5).

Discussion

One of the major constraints to a proper management of fertilizers in smallscale farming systems is the lack of information on limiting nutrients. The results of this study highlighted the importance of P fertilization on this site. Addition of N and K without P did not increase significantly the yield of the unfertilized plots and resulted to negative net benefit. Phosphorus either supplied by TSP, Tithonia or their combination dramatically increased the yields compared to the control treatments. However, Tithonia proved to be a more efficient P source than fertilizers by providing the largest increase in maize grain yields, the largest P recovery and an added value at least 32% higher compared to sole fertilizers. These results are consistent with the work of Nziguheba *et al.* (2000), who observed an added benefit going up to 112% from the addition of Tithonia compared to TSP on resin extractable P during one maize growing season. The results suggested that either the addition of Tithonia converted part of non-available P forms into available P forms, or the P added from fertilizers is easily transformed into non-available forms, reducing their efficiency as P sources. Nziguheba *et al.* (1998) found a decrease in P sorption from the application of Tithonia but not from TSP at equal P rates. Phan Thi Công (2000) reported a reduction of extractable aluminium and an increase of soil pH after addition of Tithonia. Aluminium plays an important role for soil phosphorus fixation (Mokwunye *et al*, 1986). In addition, an increase in microbial biomass was observed in Tithonia treatments and not in TSP treatment (Nziguheba *et al*,1998). The microbial biomass constitutes a potential source of nutrients to the crop through turnover.

The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input systems, countering the large costs of fertilizers (Janssen, 1994). This study confirmed that the integration of fertilizers with Tithonia can be an alternative to the limited use of fertilizers. However, higher proportions of P from organic materials were required to get a small benefit from the combination. From the results here, it can be deduced that the final goal is to maximize the proportion of P supplied by Tithonia in the combination. However, this strategy has many limitations. Large amounts of Tithonia are not only difficult to produce but also require much labor for cutting, carrying and incorporating (Jama *et al.*, 2000). It is also important to consider that addition of Tithonia does not constitute an added input of P in the system but rather enhances the reutilization of P already in the system. For soil P replenishment, an addition of P fertilizers remains unavoidable.

Although the rate of P added was small, its effects were still observed in the second residual crop. However combining fertilizers and Tithonia with only 9% P supplied by Tithonia resulted in a reduction of the maize yield in the pure fertilizer treatment, during the residual phase. This therefore means that not any proportion of combination is advantageous in an integrated nutrient management. No reduction of yields was observed, (at any phase), from the combination of fertilizers and Tithonia when 36% of P were supplied by Tithonia. Maize yields from this combination tended to move above the expected values during the input phase (Figure 23.1) and net benefits were higher than in sole fertilizer treatments. Therefore this combination appears to be more advantageous than the others. This combination also is in line with the quantity of Tithonia biomass available to farmers in western Kenya, estimated between one and two Mg ha^{-1} on a dry matter basis (Buresh and Niang, 1997).

The major constraint to the use of biomass transfer for P fertilization is the labor required for collection, transport and application of organic residues. This study showed that this labor accounted for almost half of the total cost of Tithonia treatments, for each season. Despite this large cost, net benefits in treatments receiving Tithonia were positive but depended on the strategy adopted for Tithonia production. Application of Tithonia from existing niches resulted in larger net benefits than the application of fertilizers. Although this strategy appeared to be economically beneficial, it can only be envisaged at a short-term, before the full adoption of the technology. In the long-term, the production of Tithonia by farmers themselves needs to be envisaged. Growing Tithonia on land normally used for maize production reduced the net benefit obtained from collecting Tithonia from existing niches, particularly if Tithonia is assumed to be produced with a minimum of fertilization. However, the net benefits at high Tithonia rates were still larger than with the sole application of fertilizers.

Due to limited land availability, the probability of growing Tithonia on land reserved for crop production is very low. In small-scale farming systems, the most likely scenario will be to grow Tithonia on marginal areas or on field boundaries. In this case, the cost of production will be limited to establishment and maintenance costs.

Conclusion

In P deficient soils, applying P in the form of soluble fertilizers, Tithonia or their combination is very crucial for maize production. Substantial maize yields and economic returns were obtained from Tithonia applied alone. This study showed that a high quality organic resource such as Tithonia can play an important role in supplying P to a growing crop. However, considering the constraints related to the availability of Tithonia biomass and the need for soil P replenishment, a combination of Tithonia and fertilizers will be a more sustainable strategy, the goal being to maximize the proportion of P derived from Tithonia in the combination.

Acknowledgement

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References

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Handbook on Methods*. CAB International, Wallingford, UK.

Buresh, J.R. (1999) Agroforestry strategies for increasing the efficiency of phosphorus use in tropical uplands. Special issue on phosphorus availability, uptake and cycling in tropical agroforestry. *Agrofor. For.* 9: 8-12.

Buresh, J.R. and Niang, I.A. (1997) *Tithonia diversifolia* as a green manure: awareness, expectations and realities. *Agrofor. For.* 8:29-30.

CIMMYT, (1988). From agronomic data to farmer recommendation: An economics training manual. *Mexico CIMMYT.*

David, S. and Swinkels, R.A. (1994) Socioeconomic characteristics of households engaged in agroforestry technology testing in Western Kenya. *AFRENA report no 78*. International Centre for Research in Agroforestry Nairobi.

Easterwood, G.W. and Sartain, J.B. (1990) Clover residue effectiveness in reducing orthophosphate sorption on ferric hydroxide coated soil. *Soil Sci. Soc. Am. J.* 54: 1345-1350.

FAO, (1990) FAO-UNESCO Soil Map of the World Revised Legend. Soils Bulletin 60, FAO, Rome.

Gachengo, C.N. Palm, C.A., Jama, B. and Othieno, C. (1999) Combined use of trees, shrubs, and inorganic fertilizers for soil fertility improvement. *Agrofor. Syst*. 44: 21-36.

Jama, B., Swinkels, A.R. and Buresh, J.R. (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus in Western Kenya. *Agron. J.* 89: 597-604.

Jama, B., Palm, C.A., Buresh, R.J., Niang, A.I., Gachengo, C., Nziguheba, G., Amadalo, B., 2000. Tithonia as a green manure for soil fertility improvement in western Kenya: a Review. *Agrofor. syst.* 49: 201-221.

Janssen, B.H. (1994) Integrated nutrient management: the use of organic and mineral fertilizers. In: *Van Reuler, H., Prins*, W.H. (Eds), The role of plant nutrients for sustainable food crop production in sub-sahara Africa. Wageningen, The Netherlands, pp 89-105.

Kretzschmar, R.M., Hafner, H., Bationo, A.. and Marschner, H. (1991) Long- and short-term effects of crop residues on aluminium toxicity, phosphorus availability and growth of pearl millet in a acid sandy soil. *Plant Soil.* 136: 215-223

Mittal, S.P., Grewal, S.S., Agnihotri, Y. and Sud, A.D. (1992) Substitution of nitrogen requirement of maize through leaf biomass of *Leucaena leucocephala*: Agronomic and economic considerations. *Agrofor. Syst.* 19: 207-216.

Mokwunye, A.U., Chien, S.H. and Rhodes, E. (1986) Phosphate reactions with tropical African soils. In: Mokwunye, A.U., Vlek, P.L.G. (Eds.), *Management of Nitrogen and Phosphorus Fertilizers in Sub-Saharan Africa.* Martinus Nijhoff Publishers, Dordrecht, The Netherlands, pp. 253-281.

Nziguheba, G., Palm, C.A., Buresh, R.J. and Smithson, P.C. (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant Soil 198, 159-168.

Nziguheba, G., Merckx, R., Palm, C.A.. and Rao, M. (2000) Organic residues affect phosphorus availability and maize yields in a Nitisol of western Kenya. *Biol. Fertil. Soils* 32: 328-339.

Olsen, S.R. and Sommers, L.E. (1982) Phosphorus. In. Page: A.L., Miller, R.H., Keeney, D.R. (Eds), *Methods of Soil Analysis Part 2.* ASA and SSSA Madison ,WI, USA, pp 403-430.

Palm, C.A. (1995) Contribution of agroforestry trees to nutrient requirements of intercropped plants. *Agrofor. Syst.* 30: 105-124.

Palm, C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: Buresh, R.J., Sanchez, P.A. and Calhoun, F. (Eds), *Replenishing Soil Fertility in Africa*. SSSA Spec. Publ. 51. ASA and SSSA, Madison, Wi, USA, pp 193-217.

Parkinson, J.A. and Allen, S.E. (1975) A wet oxidation procedure suitable for the determination of nitrogen and mineral nutrients in biological materials. *Commun. Soil Sci. Plant Anal.* 6: 1-11.

Phan Thi Công, (2000) Improving phosphorus availability in selected soils from the uplands of south Vietnam by residue management. A case study: *Tithonia diversifolia*. PhD thesis No 439. Katholieke Universtiteit Leuven, Belgium.

SAS Institute (1995) SAS/Stat User Guide 2 Version 6.1. SAS Inst Cary NC, USA.

Shepherd, D.K. and Soule, J.M. (1998) Soil fertility management in western Kenya: dynamic simulation of productivity and sustainability at different resource endowment levels. *Agric. Ecosyst. Environ*. 71:131-145.

Smith, J.L., Papendick, R.I., Bezdicek, D.F. and Lynch, J.M. (1993) Soil organic matter dynamics and crop residue management. In: Blaine, M.F. Jr. (ed.), *Soil microbial ecology: Applications in agricultural and environmental management.* Marcel Decker, New York, pp 65-94.

Effect of Combining Organic and Inorganic Phosphorus Sources on Maize Grain Yield in a *humic*-Nitisol in Western Kenya

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Abstract

The western Kenya soils are typically low in fertility due to continuous cropping with inadequate fertilizer use. A three-year experiment was conducted to investigate the effect of combining organic and inorganic Phosphorus (P) sources on maize grain yield in a P deficient (2ppm) experimental site at the Regional Research Centre, Kakamega, western Kenya. The design was a Randomized Complete Block, replicated three times. Farmyard manure (FYM) and Triple Super Phosphate (TSP) were combined at the ratios: 0:100, 25:75, 50:50, 75:25, and 100:0 to attain 30 kg P ha^{-1} and applied at planting to all plots except the control plot which received no P. To prevent Nitrogen (N) and Potassium (K) deficiencies confounding P responses, N was toped up to 100 kg N ha^{-1} and K to 120 kg K ha^{-1} in all plots. Urea N was top-dressed in equal splits at 3 and 6 weeks after maize emerged, while K (KCl) was applied at planting. Maize grain yield was determined at 13% moisture content and plotted against organic-inorganic P treatments to determine the response pattern. Non-linear regression analysis was then performed to estimate the effects of organic and inorganic P. Grain yield was significantly higher (p=0.05) with P than without and sole organic P was comparable to sole inorganic P. Grain yield responses best fitted quadratic functions and the regression coefficients estimating organic P, inorganic P and the interaction were significant (p=0.05), indicating real FYM and TSP effects and synergy between them. The results demonstrated grain yield benefits of integrating organic and inorganic P sources.

Introduction

The western Kenya region, supporting between 500 and 1200 inhabitants per km^2 (Hoekstra and Corbett, 1995) is one of the most populated rural regions of the world. However, the region is endowed with good agricultural climate and has the potential to produce sufficient food to meet the demand by the population. Despite the high agricultural potential, food production is low. Farming is mainly subsistence, with smallholder farmers growing two crops per year, with little or no fertilizer inputs. This practice has, over the years, resulted in the depletion of native soil fertility and a decline in productivity. A survey in western Kenya (Onim *et al.*, 1986) reported P deficiency in over 90% of the smallholder farms surveyed.

P inputs in smallholder fields consist primarily of inorganic fertilizers and organic sources such as biomass, animal manure, compost and crop residues. However, low quality organic materials such as maize stover, may not supply sufficient amounts of plant-available P (Palm *et al.*, 1997). While inorganic fertilizers can restore the fertility of soils and improve crop yields, their use in the East African highlands is limited (Hoekstra and Corbett, 1995) and alternative strategies for supplying P to the P-deficient smallholder systems are necessary. Studies in western Kenya indicate that the incorporation of higher quality organic manures, like *Tithonia diversifolia* and *Lantana camara,* along with TSP, increases the effectiveness of fertilizer phosphorus (Gachengo, 1996; Nziguheba *et al.*, 1998). Such integration of organic and inorganic resources would have agronomic advantage, if the organic material enhances the availability of added P (Palm *et al.*, 1997).

The processes responsible for better response from the integration of organic and inorganic P sources are not yet clearly established, mainly because of the complex nature of P dynamics in the soil. However, there are suggestions that the interactions resulting from this integration reduces P-sorption capacity of the soil (Palm *et al.*, 1997), thereby increasing P availability to plants. Other benefits include immobilization of excess nutrients that would otherwise be lost through leaching and positive physical effects associated with improved soil structure. Addition of organic residues also enhances microbial pool sizes activity (Smith *et al.*, 1993). These chemical and biological processes influence both availability and utilization of nutrients.

The objectives of this experiment were:

1) To investigate the effect of combining organic and inorganic P sources on maize grain yield
2) To determine the optimum ratio for combining organic and inorganic P, and
3) To assess the synergy resulting from integrated use of organic and inorganic P sources.

Materials and Methods

The experiment was conducted at Kakamega, western Kenya, during the long rain seasons (March to August) of 1997, 1998 and 1999. The experimental site was within the Kenya Agricultural Research Institute's Regional Research Centre, located 00° 16' N (latitude) and 34° 45' E (longitude). The altitude is 1585 m above sea level, mean annual temperature is 18-20°C, the average annual rainfall is 2012 mm and the soil is classified as d*ystro-mollic* Nitisol (Jaetzold and Schmidt, 1983). Characterization previously conducted at the experimental site (FURP, 1987) indicated the soil is well drained, extremely deep, with a thick *humic* top layer. The top soil reaction is in the strong to moderately acid range (pH 4.5) and exchangeable Al is low, while organic matter is high in the top soil (2.4%).

The experimental design was a Randomized Complete Block with three replicates. Plots were 4.5 by 5.0 m (22.5 m^2), in which 6 rows of maize were planted with a row spacing of 75 cm. Five P treatments were evaluated alongside a control that received no P. In each treated plot, P was applied at the rate of 30 kg P ha^{-1} by combining FYM and TSP in different ratios as follows:

1. 30 kg P ha^{-1} (100% inorganic P)
2. 30 kg P ha^{-1} (100% organic P)
3. 15 kg P ha^{-1} (50% inorganic P) + 15 kg P ha^{-1} (50% organic P)
4. 7.5 kg P ha^{-1} (25% inorganic P) + 22.5 kg P ha^{-1} (75% organic P)
5. 22.5 kg P ha^{-1} (75% inorganic P) + 7.5 kg P ha^{-1} (25% organic P)
6. Control (no P)

A sample of the FYM was analyzed each planting season to determine the P content, which was then used to compute the amount of the material to add to the respective plots. Since FYM also supplied up to 73 kg N ha^{-1} and 120 kg K ha^{-1} to the organic P treated plots, urea and muriate of potash (KCl) were applied to all plots, including the control, to balance N and K at 100 kg N ha^{-1} and 120 kg K ha^{-1}, respectively. Apart from correcting the N and K imbalances, the high rates were intended to prevent N and K deficiencies, which could confound P responses. Urea was applied as top-dress in two equal splits. The first split was applied at 21 days after emergence and the second one 42 days after emergence. KCl was broadcast applied at planting. Soil was sampled in all plots (0-15cm depth) for P determination prior to application of treatments. The plots were maintained throughout the trial duration.

Maize grain yield was determined at harvest. Yield was adjusted to 13% moisture content and grain yield data plotted against treatments to determine the P response pattern. To fit the curves, treatments were arranged in order of increasing proportion of inorganic P (decreasing proportion of organic P). Both linear and quadratic functions were fitted in turn, to determine the best-fit model, based on the correlation coefficient (R^2) value. The model with the highest R^2 value was selected as the best function describing grain yield response pattern. Grain yield data was then subjected to the Analysis of Variance (ANOVA). A non-linear regression model: ($Yield=a+bX_1+gX_2+dX_1*X_2$) was fitted to the data to test the effects of inorganic P, organic P and the interaction between them, on maize grain yield. The regression coefficients in the model are described below:

a = intercept
b = coefficient estimating inorganic P (X_1) effect
g = coefficient estimating organic P (X_2) effect
d = coefficient estimating inorganic P and organic P interaction (X_1*X_2) effect.

The effects of organic P, inorganic P, and the interaction between them, were evaluated by testing the null hypothesis (H_O) that the coefficient estimates were equal to zero. This was done by t-tests.

Results and Discussion

Maize grain yield response to P

Significant (p=0.05) grain yield responses to both organic and inorganic P were observed in 1997, 1998 and 1999 (Table 24.1). The highest response was recorded in 1997 when application of P increased grain yield by 3.2 t ha^{-1} compared with 2.8 and 2.3 t ha^{-1} in 1998 and 1999, respectively. Generally, yield following sole addition of FYM was equivalent to those from sole inorganic P. The FYM used was of relatively high quality (Table 24.2). The difference in grain yield between sole inorganic P and organic P was highest in 1997 (0.8 t ha^{-1}) but the difference was not significant. In 1999, grain yield from sole organic P was slightly higher than that from sole inorganic P. Grain yield responses were more variable in 1999 due to poor rainfall distribution that year (Figure 24.1). Much of the rainfall in 1999 long rain season was received during the February to April period, the beginning of the season. Rainfall sharply declined between April and June before picking up in July, which was towards the end of the growing season.

Table 24.1: Effect of organic and inorganic P on maize grain yield at Kakamega Research Station, western Kenya, in 1997, 1998 and 1999

Treatment combination		Maize grain yield (kg ha^{-1})			
% Inorganic P	% Organic P	1997	1998	1999	Mean
100	0	6.22	5.38	2.84	4.81
75	25	6.25	3.83	2.92	4.33
50	50	6.67	4.34	4.38	5.13
25	75	5.75	5.13	4.35	5.07
0	100	5.39	3.12	2.97	3.82
0	0	3.45	2.57	2.05	2.69
LSD (0.05)		1.50	0.95	1.2	1.30
CV		18.2	15.6	24.8	20.2

Table 24.2: Nutrient and lignin content of the FYM used in the trial (%) in 1997, 1998 and 1999

Year	N	P	K	Lignin
1997	1.31	0.35	2.14	10.95
1998	1.45	0.37	2.16	10.05
1999	1.25	0.39	2.11	11.05
Mean	1.33	0.37	2.13	10.68

Combination of fertilizer P with FYM in different proportions did not result in significant grain yield differences in 1997 (Table 24.1). However, in 1998, the treatment combination receiving 25% inorganic P and 75% organic P (25:75) performed similar to the 50:50 treatment but significantly better than the 75:25. In 1999, the 50:50 combination performed significantly better than the 75:25.

The grain yield results were particularly significant in 1999 given that it was the driest of the three trial years. Grain yield sharply declined compared to the two previous years. However, significant and synergistic effects of combining FYM and P fertilizer were demonstrated by the highest yields obtained with the 50:0 and 25:75 combinations (Figure 24.2). The superior performance may have been due to added benefits of the organic material (FYM). Besides the direct benefits of nutrient supply, organic materials have effect on soil physical properties that in turn influence nutrient acquisition and plant growth (Palm *et al.*, 1997). Principal among these, is the soil moisture holding capacity. By influencing moisture storage and promoting root growth, FYM may have greatly improved the efficiency with which the available P was used during the drier 1999 season. Based on analysis of combined data over the three years, no significant differences were detected between the different organic and inorganic P combinations but the 50:50 treatment combination was significantly better than sole organic P treatment (0:100).

The results indicated that the optimal organic to inorganic P combination is close to the 50:50 ratio. Combining fertilizer P with FYM at this ratio is likely to be beneficial to smallhoder farmers, who have limited access to inorganic fertilizers and are typically unable to generate sufficient quantities of high quality organic materials for fertility improvement. Suggestions for integration of fertilizer P with available organic resources have been made in the past by Janssen (1993) and Palm *et al.* (1997).

Figure 24.1: Rainfall distribution at Kakamega Research Station in 1997 , 1998 and 1999 growing seasons

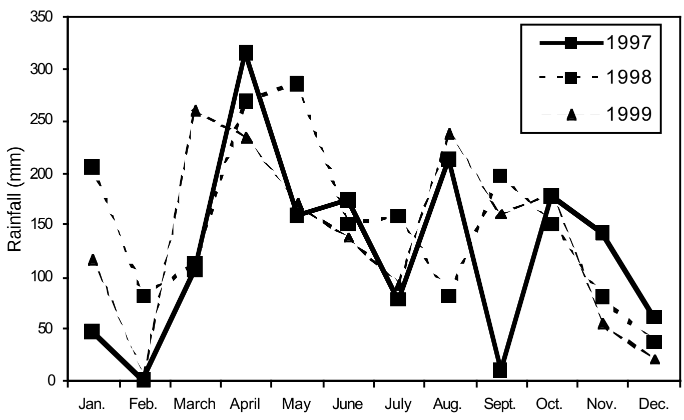
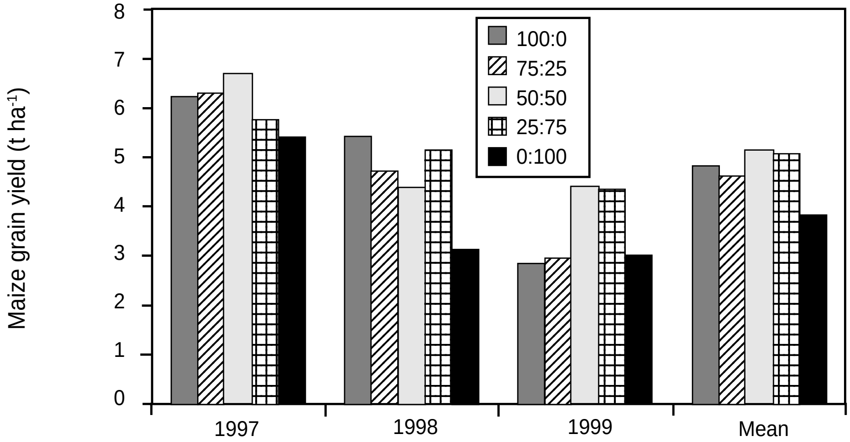


Figure 24.2: Performance of organic and inorganic P combinations across three growing seasons at Kakamega Research Center, western Kenya



Assessment of organic and inorganic P effects

The grain yield responses were best described by quadratic functions (Figures 24.3 - 24.6). The R^2 values for the functions were greater than 0.6 and were much higher than the values obtained when linear functions were fitted to the data. This indicated that the effects were largely quadratic in nature. The apparent non-linearity (curvature) in grain yield responses indicated some degree of interaction or synergistic effects between organic and inorganic P.

Figure 24.3: Mean effect of organic and inorganic P on maize grain yield (1997-1999)

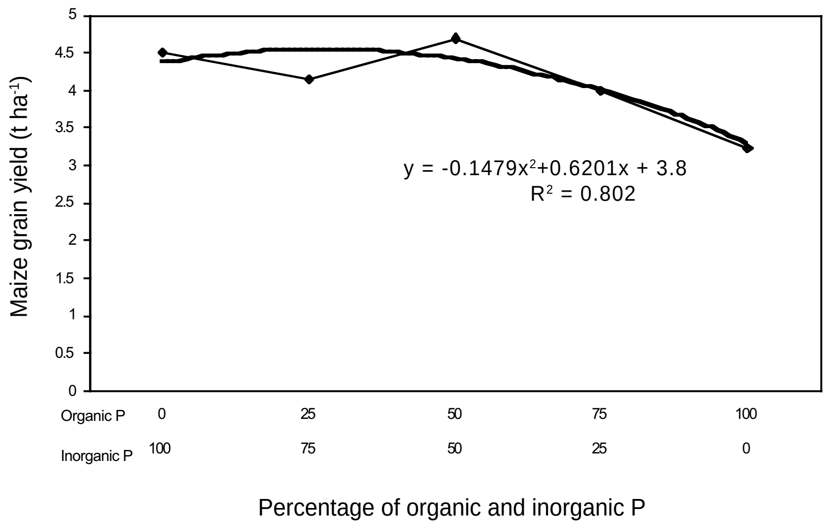


Figure 24.4: Effect of organic and inorganic P on maize grain yield in 1988

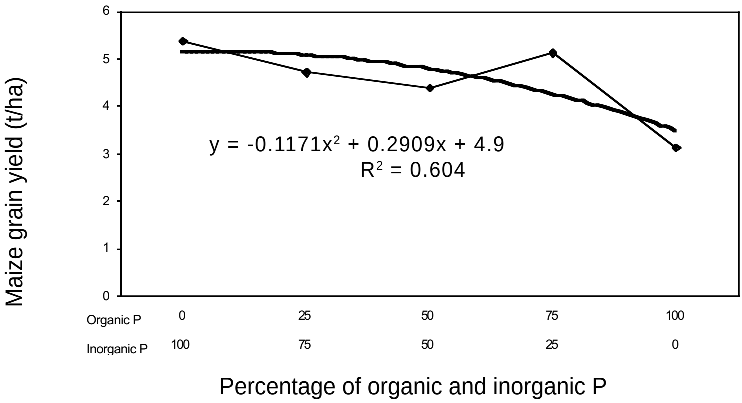


Figure 24.5: Effect of organic and inorganic P on maize grain yield in 1999

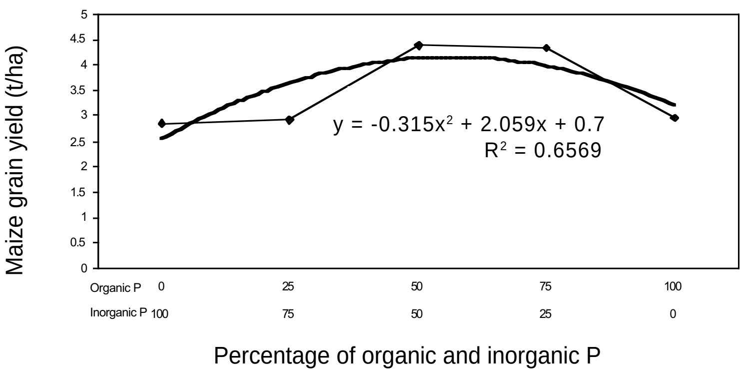
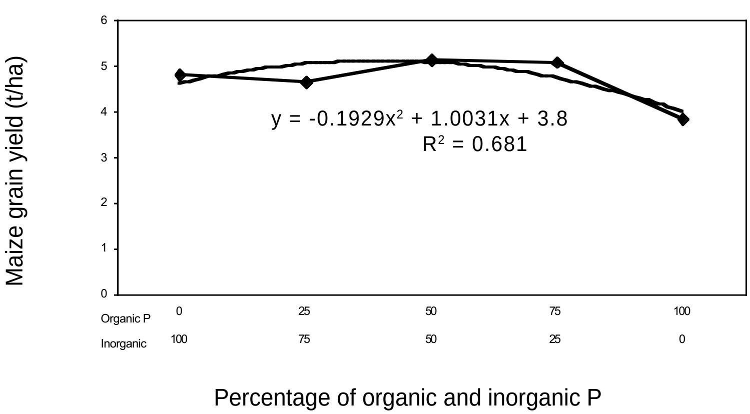


Figure 24.6: Mean effect of organic and inorganic P on maize grain yield



The curvature and the organic and inorganic P effects on maize grain yield were further tested by fitting a non-linear regression model: ($Yield=a+bX_1+gX_2+dX_1*X_2$) to the data. The regression coefficients estimating the effects of organic and inorganic P and the interaction between them are shown in Table 24.3. In 1997, both organic and inorganic P had significant effects on maize grain yield. These results were in agreement with those of the Analysis of Variance (Table 24.1). However, the inorganic P coefficient was larger than organic P, indicating that inorganic P had greater effect on grain yield. The coefficient for the interaction between organic and inorganic P was the lowest in value and the t-test was not significant. This suggested that there was no real

Table 24.3: Regression coefficients estimating the effects of organic P, inorganic P, and the interaction, on maize grain yield

		1997	
Parameter	Estimate	S.E	t value (for H_o)
a	3.444	0.586	5.878***
b	0.02742	0.00804	3.410**
g	0.01874	0.00804	2.330*
d	0.000241	0.000250	0.96 NS
		1998	
Parameter	Estimate	S.E	t value (for H_o)
a	2.565	0.497	5.160***
b	0.02353	0.00682	3.450**
g	0.01137	0.00682	1.667 NS
d	0.00061	0.000212	0.47 NS
		1999	
Parameter	Estimate	S.E	t value (for H_o)
a	2.048	0.454	4.511***
b	0.00475	0.00623	0.762 NS
g	0.01171	0.00623	1.879 NS
d	0.000499	0.000194	2.572*
		Mean	
Parameter	Estimate	S.E	t value (for H_o)
a	2.253	0.236	9.546***
b	0.01412	0.00324	4.358***
g	0.00997	0.00324	3.077**
d	0.000210	0.000101	2.079 *

*** = significant (p <0.001)
** = significant (p <0.01)
* = significant (p <0.05)
NS=Not significant (p = 0.05)
S.E = Standard Error

a= intercept
b= coefficient estimating inorganic P (X_1) effect.
g= coefficient estimating organic P (X_2) effect.
d= coefficient estimating inorganic P and organic P interaction (X_1* X_2) effect.

interaction between organic and inorganic P and the effects were probably largely additive. Similar to 1997, inorganic P had a significant effect on maize grain yield. However, the organic P and the interaction coefficients were not significant, suggesting no real effect on grain yield. In contrast to 1997 and 1998, the effects of organic and inorganic P on grain yield were small and insignificant in 1999 but the interaction coefficient was relatively large and significant. These results confirmed the conclusions drawn from the analysis of variance that addition of fertilizer P to FYM had synergistic effect on maize grain yield that year.

Based on the results of regression analysis performed on grain yield data averaged over three years (1997 to1999), the coefficients estimating the effects of organic P, inorganic P and the interaction were significant (Table 24.3). However, the coefficient of inorganic P was much larger than that of organic P, indicating greater effect of inorganic P compared to organic P. The significant interaction coefficient demonstrated synergy between FYM and fertilizer P.

Conclusions

The results of this study indicate that applying P at a modest rate of 30 kg P ha^{-1}, either in the organic or inorganic form, can substantially increase maize grain yield. Provided the FYM rate supplies equivalent amount of P, FYM appears to be nearly as effective as TSP. However, since the quality of FYM determines the quantities to be applied to attain the required P rate, low quality material could mean more labour for application, probably making the practice economically unattractive. Combining organic and inorganic P results in synergistic effects, particularly in drier, moisture-stressed growing seasons. This synergy, and other extra benefits of FYM, should be exploited by smallholder resource poor farmers. A 50/50 organic-inorganic combination ratio appears to be the optimum

Acknowledgements

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References

FURP. (1987) Fertilizer Use Recommendation Project (FURP). Final Report Annex III. Phase I. Ministry of Agriculture, Nairobi, Kenya/National Agricultural Research Laboratories, Nairobi, Kenya.

Gachengo, C. (1996) Phosphorus release and availability from organic materials amended to phosphorus deficient soils of Western Kenya. M.Sc. Thesis, Moi University, Eldoret, Kenya.

Hoekstra, D. and Corbett, J.D. (1995) Sust*ainable agricultural growth for the highlands of East and Central Africa: Prospects to 2020.* Int. Food Policy Res. Inst. Washington DC.

Jaetzold, R. and Schmidt, H. (1983) *Farm management handbook of Kenya.* Vol.iii. west Kenya. Ministry of Agriculture, Nairobi, Kenya.

Janssen, B.H. (1993) Integrated nutrient management: The use of organic and mineral fertilizers. P. 89-105. *In*: Van Reuler, H. and Pins, W.H.(eds) *The role of plant nutrients and sustainable food production in Sub-Saharan Africa.* Vereniging van Kuunstmest Producenten, Leidschendam, the Netherlands.

Nziguheba, G., Palm,C.A., Buresh, R.J. and Smithson, P.C. (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. Plant Soil 198: 1365-1373.

Onim, J.F.M., Mathuva, M., Hart, R., Fitzhugh, H. A. and Otieno. K. (1986) *Recommendation domains for dual purpose goat research in Nyanza and Western provinces of Kenya.* Proceedings of the 5th Small ruminant CRSP Kenya Workshop, Kabate, Kenya. Nov. 4-6, 1986. P 40-47.

Palm, C. A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. P. 193-217. *In* R.J. Buresh *et al*. (eds.) *Replenishing Soil Fertility in Africa.* SSSA Spec. Publ. 51. SSSA, Madison, WI.

Smith, J.L., R.I. Pependick, D.F. Bezdicek, and J.M. Lynch. 1993. Soil organic matter dynamics and crop residue management. p. 65 -94. In M.F. Blaine Jr. (ed) Soil microbial ecology: applications in agricultural and environmental management. Marcel Decker, New York.

Use of Organic and Inorganic Resources to Increase Maize Yields in some Kenyan Infertile Soils: A Five-Year Experience

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Abstract

Use of organic and inorganic resources to increase and sustain agricultural productivity of soils has been practiced worldwide over a long period. Positive effects from these materials are known to be the enhanced nutrient inputs to soils and improved soil physical and biological properties. Effects of separate or individual and combined applications of organic and inorganic materials to soils have been studied rather extensively and the results are complex. But, it appears for certain, that the quality and quantity attributes are the driving forces towards basic processes in soils such as nutrient mineralisation and release and the overall effectiveness of added materials on crop yields. However, many studies have considered mainly the immediate or one seasonal effects of organics and inorganics on crop yield. Therefore the monitoring of soil process studies in relation to crop growth and yield, as well as considerations on economic benefits arising from the use of these external resources seem to have been slighted. In this paper we present results of field studies at four on-farm, researcher managed sites that vary widely with climate and soils (acrisols, ferralsols and luvisols).

In 1994 first rains, the effectiveness of crop residues (maize stover, groundnut trash and *acacia mearnzii* prunings) on-farm manures and Minjingu phosphate rock (PR) was tested on maize yields at Ndeiya, Gatuanyaga and Malava sites. The organics above were incorporated into soils individually or in combinations giving a target or economical rate of 60 kg Nha^{-1}, while the PR was added at a uniform rate of 40 kg P ha^{-1} in various combinations of the organics. Maize yields in that season ranged from 1256 - 3761 $Kgha^{-1}$ (at Ndeiya and Malava sites only with adequate rainfall). Although maize yield increases did not attain statistical significance, the high N organics (poultry manure, *Acacia mearnzii* and groundnut trash), with PR combinations, gave overall high yield increases. The study period was too short to monitor residual effects of treatments and the solubilisation of PR. But in the Chepkoilel Campus ferralsol (Moi University), maize has been cropped over four consecutive years (1997 - 2000) in plots receiving annual maize stover, wheat straw and initial superphoshate application of 100 kg Pha^{-1} plus combined urea combinations from 20-100 kg Nha^{-1}. Maize yields over the entire study period have ranged from 751-6836 kg ha^{-1} with significant variations occurring from rainfall variations. Nevertheless, again the combined applications of organic and inorganic resources favoured maize production. There are favourable effects of the materials used to improve the soil fertility status of soils. The results suggest an economic potential, to the smallhold farmers, arising from combined use of organic and inorganic resources.

Introduction

Low input agriculture mainly explains the cause of low and declining crop yields in many countries south of the Sahara (Makken, 1993; Simpson *et al.*, 1996; World Bank, 1996). But specifically the prices of imported (inorganic) fertilizers, without subsidies, are unfavourable to most smallhold farmers in the region. Thus in Kenya, where nitrogen (N) and phosphorus (P) nutrients are widely deficient in cropped soils (Okalebo *et al.*, 1992; FURP, 1994; TSBF, 1994), attempts have been and continue to be made to find affordable technologies to correct nutrient deficiencies in soils. These include agroforestry practices especially the use of improved fallows (Jama *et al.*, 1997; Sanchez *et al.*, 1997), combinations of organic and inorganic resources (Palm *et al.*, 1997; Okalebo *et al.*,1999) and use of direct and combined applications of the reactive Minjingu (Tanzania) phosphate rock (PR) with organic materials (Okalebo *et al.*, 1991/1995; Okalebo and Woomer, 1994; Okalebo and Nandwa, 1997; Jama *et al.*, 1997; Woomer *et al.*, 1997). These PR and organics combinations have focussed on the provision of cheap N inputs from organics and the solubilisation of PR through formation of favourable acid environments that result when organics (in contact with PR) decompose in soils (Nahas et al, 1996; Mutuo *et al.*, 1999; Nyambati, 2000; Waigwa *et al.*, 2000). In this paper we present results of field studies whereby organic and inorganics were combined and tested on maize yields across the Kenyan infertile soils; mainly the acrisols (ultisols), ferralsols (oxisols) and luvisols (alfisols). The trial sites also varied with climatological characteristics, mainly the rainfall and its distribution.

Materials and Methods

Two types of field experiments were conducted:

Experiment 1

A randomised complete block design (RCBD) experiment with 4 replicates per site, was set up on smallholder farms at Ndeiya (Lat 10 14'S, Long 360 28'E), Kiambu district; Gatuanyaga (Lat 10, 22'S, 340 45'E), Thika district; and Malava-Kabras (Lat 00 18'N, Long 34° 45'E), Kakamega district. Both Ndeiya and Gatuanyaga receive annual rainfall of about 800 mm distributed within 2 seasons, March to May and October to December. Malava site is within the highlands of western Kenya, with a rainfall of 1000-1800 mm falling from March to September (Jaetzald and Schmidt, 1983). Some properties of surface (0-20cm) soils for the sites including Chepkoilel (for Experiment 2), taken before treatment applications are given in Table 25.1.

Table 25.1: Some properties of surface (0-20cm) soils from on-farm field trials in Kiambu, Thika, Kakamega and Uasin Gishu districts, Kenya

Properties	Kiambu Ndeiya	Thika Gatuanyaga	Kakamega Malava	Uasin Gishu Chepkoilel
		1994		1997
pH (H_2O, 1:2.5)	5.31	4.84	4.10	4.85
Total Carbon (%)	2.59	1.48	2.15	1.30
Total Nitrogen (%)	0.223	0.138	0.214	0.110
Olsen P (mg/kg)	11	10	7	4
Soil Order	Luvisol	Acrisol	Acrisol	Ferralsol

Soil properties for the sites indicate low pH levels (<5.5) favourable for PR dissolution (Sanchez *et al.*, 1997 and also low soil test P values close to or below 10mg P kg^{-1}, the level below which P responses are expected (Okalebo *et al.*, 1993).

In this on-farm, researcher-managed experiment, the main objective was to identify the readily available organic materials (crop residues, tree prunings, manures) at farm level that would increase the N and P levels in soils when incorporated with PR. Target N and P rates from combinations of these materials were 60 Kg N ha^{-1} and 40 Kg P ha^{-1} (applied as PR). These 2 rates appear to be economical for annual high and sustained maize production for the test sites (Okalebo, 1987).

Table 25.2: Treatment combination used in Experiment 1 in 1994 at Ndeiya, Gatuanyaga and Malava sites

Treatment	Nitrogen Combination (kg N ha^{-1})	Total (desired) N (kg N ha^{-1})	Desired P (kg P ha^{-1} PR)
Control	0	0	0
AM + MS	30N, AM + 30N, MS	60	-
MS + PM	30N, MS + 30N, PM	60	-
PM	60N, PM	60	-
UREA	60N, UREA	60	-
PR	-	-	40
UREA + PR	60N, UREA	60	40
MS +PR	60N, MS	60	40
AM + PR	60N, AM	60	40
FYM + PM	30N, FYM + 30N, PM	60	-

Notes:
AM = *Acacia mearnzii* (wattle prunings) used in Ndeiya and Gatuanyaga but groundnut trash used at Malava only.
MS = maize stover
PM = Poultry manure (broiler, from NARC Muguga/KARI)
FYM = on-farm yard manure or 'boma' manure; but compost was used at Gatuanyaga site only.
PR = Minjingu phosphate rock (0-30-0).

It is noted that the quantities of dry organic materials were calculated to give the above N combinations (Table 25.2) using their total N contents from prior laboratory analysis at NARC Muguga (Table 25.3). It was also assumed that the materials (with low P contents) had negligible P inputs. Overall, the experiment sought information from a wide range of treatment combinations.

At all three sites, all materials (above) were broadcast to fine seedbeds and incorporated into soil using a hoe. Maize (H511) was planted as a test crop with a plant density to 4.4 plants m^{-2}. Recommended husbandry practices (weeding, stalkborer control) were followed. A parallel N and P (inorganics) response trial was conducted at Gatuanyaga site only) with adequate on-farm land for experimentation.

Experiment 2

A randomised complete block design (RCBD) trial was set with 4 replicates at Chepkoilel Campus, Moi University, Eldoret, Uasin Gishu district (Lat 00 35'N, Long 350 18'E). This site receives annual rainfall of 1124 mm in one season from March to September (Jaetzold and Schmidt, 1983). At this site, treatments included incorporating N fertilizer with wheat straw and soybean. Treatments consisted of chopped (15 cm length) crop residues (above) applications at a uniform rate of 2 t ha^{-1} for each organic material. Urea (fertilizer N) was combined with these two organics at the rates of 0, 20, 40, 80 and 100 kg N ha^{-1} each. These treatments were applied at maize (H 614D hybrid) planting, first in March 1997, and were repeated in the subsequent years upto March 2000. To eliminate P and K limitations, 100 kgP ha^{-1} singlesuperphosphate and 100 kg Kha^{-1} muriate of potash were applied only at the start of the experiment.

Table 25.3: Some characteristics of organics applied in 1994 field experiments (Expt. 1): The nitrogen data were used to calculate N inputs

Material	% dry matter				Abbreviation
	ash	N	P	K	
Maize Stover-Muguga	9.5	0.79	0.085	1.94	MS
Maize Stover-Malava	5.3	0.76	0.084	0.56	MS
Acacia mearnzii-Muguga	5.0	2.21	0.092	0.85	AM
Groundnut trash - Malava	6.1	1.56	0.072	0.43	AM
Poultry Manure - Muguga	17.8	3.12	1.733	1.91	PM
FYM - Malava	53.5	1.30	0.227	1.14	FYM
Compost - Ndeiya	62.9	1.24	0.193	1.09	FYM

Source: NARC/KARI Muguga, Soil Chemistry Station, 1994

Notes:

a) Apart from *Acacia mearnzii* (AM) and poultry manure (PM) from Muguga applied to all 3 sites in 1994 Expt. 1 all other organics originated at on-farm level per site.

b) All materials vary in characteristics.

All inputs for both experiment 1 and 2 were incorporated into the seedbed by hand tillage and starter N for all nitrogen treatments was applied at 20 KgNha^{-1} at planting. At harvest, cobs and stover were separated. Sub-samples of these components were dried (40-50^{o}C) until constant weight, to obtain yield measurements.

Soil Sampling and Analysis

In all sites, surface (0-20cm) soils were sampled at random across all experimental fields before treatment applications. Samples (30 auger borings for each site) were bulked and mixed thoroughly and composite soils taken. After maize harvest at Chepkoilel, soils were sampled from each plot (9 borings per plot at random) and analysed to take measurements on changes in soil properties due to treatments. Soils were processed and analyzed for pH (H_2O), total carbon and extractable phosphorus (Olsen), following the procedures outlined in Okalebo *et al.* (1993).

Results and Discussion

Maize Yields

In 1994, maize grain was harvested only at the Ndeiya and Malava sites (Experiment 1), while due to severe drought at Gatuanyaga, only the biomass (above ground parts) data was obtained as given in Table 25.4. In that year grain yields ranged from 1256 to 3761 Kg ha^{-1} at the 2 sites where maize grew to maturity. On the average, the organics and inorganics applied individually or in combinations, tended to increase maize yields above the treatment with highest yield increases being obtained at the lowest soil test P site of Malava in Expt. 1 (Tables 25.1 and 25.4). At this site, the groundnut trash plus phosphate rock (AM + PR) treatment gave the highest grain yield, increase of 102% above control, while the poultry manure (PM) treatment resulted in an increase of 48%, followed by a PR yield increase of 43%.

Further, in this site, significant yield increases have been reported (Okalebo, 1987). In an earlier field study at this site (Okalebo and Lekasi, 1993), in which maize stover, groundnut trash and on-farmyard manure were applied at 0, 2, 4 and 6 t ha^{-1} each, in combination with 40 KgPha^{-1} PR for each organic resource rate, the groundnut trash significantly outyielded the maize stover organic material in terms of maize grain yield increases. At Ndeiya semi-arid site, the maize stover (MS) plus poultry manure (MS+PM) treatment gave the highest grain yield increase of 73% above control, followed by the PM treatment alone, with a yield increase of 42%.

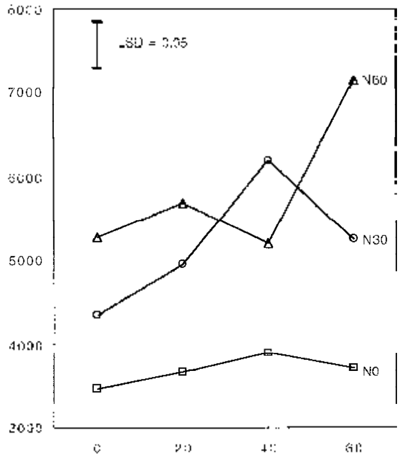
Table 25.4: Effect of crop/tree residues, manure and compost in combinations with phosphate rock on maize yield (kg ha^{-1}) in 1994

Treatment	Ndeiya (grain)	Gatuanyaga (biomass)	Malava (grain)
Control	2172	2924	1384
AM + MS	2536	3804	1256
MS + PM	3761	4034	1750
PM	3091	4030	2048
UREA	2550	4567	1543
PR	2580	3163	1974
UREA + PR	2425	4145	1567
MS + PR	2590	4241	1708
AM + PR	2549	3037	2802
FYM + PM	2646	2789	1570
Mean	(2690)	(3673)	(1760)
LSD (p = 0.05)	NS	NS	NS

AM = *Acacia mearnzii* (wattle prunings) used in Ndeiya and Gatuanyaga, but groundnut trash used at Malava only.
MS = Maize stover
PM = Poultry manure (broiler, from NARC, Muguga, KARI)
FYM = On-farm yard manure (boma manure), but compost used at Gatuanyaga.

In a study in semi-arid eastern Kenya (Probert *et al.*, 1992), addition of PM at 5 t ha^{-1} (NARC Muguga broiler quality) gave the highest maize yield increases compared to the on-farm yard manure applied at 10 t ha^{-1} and combined inorganic fertilizers: 60 kgNha^{-1} calcium ammonium nitrate plus 40 kg P ha^{-1} triplesuperphosphate. Thus on infertile soils, PM appears to boost the nutrient and organic matter levels and also to improve soil physical properties, such as infiltration and soil moisture retention. The highest maize biomass yield at Gatuanyaga site was obtained from the urea alone treatment (at 60 kg N ha^{-1}) where a yield increase of 56% was obtained, implying a nitrogen limitation in this low C and N site (Table 25.1). This observation is supported from the data in a parallel experiment (Expt. 1) at this site whereby a significant N response was found from urea applications at 0, 30 and 60 kg N ha^{-1} rates (Figure 25.1). In summary effect of treatments varied with site and Figure 25.2 shows an overall picture/overview of the performance of treatments across the 2 sites (Ndeiya and Malava) harvested for grain in 1994 (Expt. 1). The rather overall outstanding performance from MS + PM, AM + PR and PM treatments is noted. Despite these guidelines or trends, Expt. 1 in this research has illustrated the complexity in studying and adopting the use of organic resources for soil fertility restoration/ replenishment, particularly in the TSBF AfNet region, where factors such as the availability of the resource, its quality and quantity and methods of application, play significant roles.

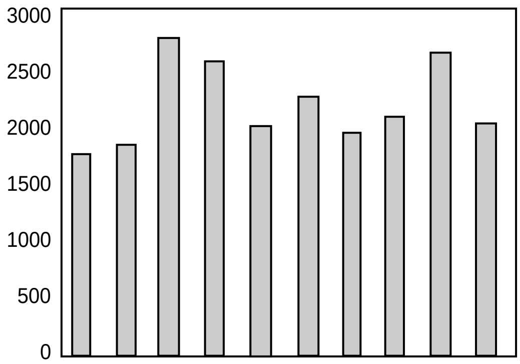
Figure 25.1: Maize biomass (kg ha^{-1}) as affected by nitrogen and phosphorus fertilizers at Gatuanyaga (on farm), Thika, long rains



N source was urea
P source was TSP

kg P ha^{-1}

Figure 25.2: An overall effect of crop residues, tree prunnings, manure with Phosphate Rock combinations on maize grain yields (kg ha^{-1}) at 2 sites in 1994



Treatments

NB:

Nitrogen as applied at 60 kg/ha for each material and urea and phosphurus was added at 40kg P/ha.

AM – Acacia mearnzii
MS – Maize stover
PM – Poultry manure
FYM – Farmyard manure
PR – Phosphate Rock (Minjingu)

In the Chepkoilel Campus experiment (Expt. 2), where the low quality wheat straw (0.67%N) and higher quality soybean trash (1.07% N) were compared from 1997 to 2000, maize grain yields varied with the treatments and years of cropping (Okalebo *et al.*, 1999). In 1997 grain yields ranged from 875 to 1876 kg ha^{-1}; from 2832 to 6836 kg ha^{-1} in 1998; and from 1363 to 2272 kg ha^{-1} in 2000 (Table 25.5).

Table 25.5. Effect of continued addition of crop residues and nitrogen fertilizers on maize grain yield (kg ha^{-1}) in Chepkoilel soils (Ferralsols)

Treatment	Year		
	1997	1998	2000
Control	875^{a}	2832^{a}	1363
80 N	1016^{a}	4883^{b}	1704
WS + 0N	960^{a}	2051^{a}	1477
WS + 20N	1321^{a}	2930^{a}	1363
WS + 40N	1304^{a}	3223^{a}	1363
WS + 80N	1666^{b}	4785^{b}	1704
WS + 100N	1677^{b}	5469^{b}	1591
SYT + 0N	751^{a}	2832^{a}	1818
SYT + 20N	1465^{b}	2500^{a}	2159
SYT + 40N	1444^{b}	3711^{a}	2272
SYT + 80N	1500^{b}	5567^{b}	2272
SYT + 100N	1876^{b}	6836^{b}	1931
Overall LSD (p=0.05)	555	1030	926 NS

Means followed by the same letters or none in a column are not significantly (p = 0.05) different (using Duncan's multiple range test).

WS = Wheat Straw applied annually at 2 t ha^{-1}
SYT = Soybean trash applied annually at 2 t ha^{-1}
N = Nitrogen applied as urea at 0, 20, 40, 80 and 100 kg N ha^{-1}

Grain yield variations are partly explained in terms of low and poor rainfall distribution (considering the 10-day periods), particularly at the maize maturity months of August and September. This is illustrated from yields obtained in 1997, 1998 and 2000 when total rainfall received in these two months was 232, 380 and 283 mm for the 3 respective years (Chepkoilel Campus Meteorological Records). This magnitude of rainfall in 1997 and 2000 did not probably favor adequate soil moisture and nutrient availability, contributing to overall low maize yield in those 2 years. Nevertheless, many treatments gave significant increases in maize yield ($P<0.05$), particularly from 2 tha^{-1} wheat straw and soybean trash combined with fertilizer N (urea) above 80 kgN ha^{-1} rate of incorporation (Table 25.5). Favourable rainfall and its distribution in 1998 most likely contributed to larger maize yields in that year. Again higher yields were found from the higher quality soybean trash and N fertilizer applied above 80 $kgNha^{-1}$. Past work in field nutrient limiting study has pinpointed a nitrogen limitation in Chepkoilel soils (Mwaura, 1998).

Changes in soil properties

Data for soil pH, C and available P parameters obtained in surface (0-20 cm) soils sampled before application of treatments in March 1997 and soils taken soon after harvesting the fourth maize crop in November, 2000 are summarised in Table 25.6. There were positive changes from organic matter inputs (and possibly continued urea addition) to increase the levels of these three parameters in soils.

Table 25.6: Changes in soil (0-20cm) properties as influenced by cumulative incorporation of crop residues and urea at Chepkoilel, Kenya, during 4 years of maize cropping

Treatment	Soil parameter		
	pH	Local C (%)	Available P (mg/kg)
After maize harvest, November, 2000			
Control (No inputs)	4.80	2.16	11.6
80 $kgNha^{-1}$ as urea	5.06	2.26	10.4
Wheat straw + N*	5.32	2.47	14.4
Soybean trash + N*	5.41	2.78	14.3
Initial contributions, March 1997	4.85	1.30	3.9

*Wheat straw and soybean trash data include all treatments receiving urea at 0, 20, 40, 80 and 100 kg N ha^{-1}

A similar trend was found from soils sampled soon after harvesting the second maize crop in October 1998 (Okalebo *et al.*, 1999). Marked increases were found in C and P levels. These are very likely due to their accumulation from consecutive organic and mineral nutrient additions made from 1997 to 2000 except P which was added only once at 100kg P ha^{-1} at the beginning of the experiment in 1997. Other additions of P probably originated from the decay and release of the organically bound P held in organic resources applied as previously described by Rusell (1973). As reported by Okalebo *et al.* (1999), there were large amounts of total N found from surface soil in all treatments (including the control) after four years of cumulative organic matter and urea incorporations into soil. Probably analytical errors contributed to these large N levels. Nevertheless, for better estimates of the N status of soils, analysis for mineral N (NH_4 and NO_3 mainly) could have been done. Mineral N gives better measurements of N released from decomposing organic resources. It also gives better estimates of N leached down the soil profile. Unfortunately the Moi University laboratory does not have facilities or equipments to analyse mineral N components in soils. Other indicators of soil fertility build-up from organic matter additions (such as an increase in particulate light fraction in soils) would also be useful.

Conclusions and Recommendations

1. In the one year (1994) of field experimentation at three on-farm researcher-managed trials (at Ndeiya, Gatuanyaga and Malava), maize yield increases were obtained from combined application of organics and inorganics. But the largest yield increases were found from incorporation of high quality poultry manure (3.1% N), groundnut trash (1.6% N) and phosphate rock (13.2% P). The effectiveness of each resource varied with site.
2. The longer-term (4 years) study of Chepkoilel site (with a major N limitation has demonstrated the positive effect of incorporating crop residues with N fertilizer into the seedbed to improve their decomposition and nutrient release characteristics. The two forms of residues tested (wheat straw and soybean trash) were each applied at a uniform rate of 2 tha^{-1}. It is quite feasible that this rate of residue be retained in croplands even while alternative requirements (for example fuel, feed are also being met)
3. Comparisons of different rates of residues are suggested to obtain responses to both residues and N fertilizer rates.
4. Organic matter fractionation needs to be done after cropping in the long-term trial, to determine the dynamics of important labile fractions (such as the proportions and contents of C, N and P in those fractions).
5. Investigations on economics of combined organic and mineral sources will provide useful information on crop/tree residue and manure management practices.
6. The study in one year (1994) was not able to pinpoint the enhanced dissolution of PR and the associated mechanisms through combined organic matter and PR incorporations into soil. This task needs pursuing.

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References

Fertilizer use Recommendation Project (FURP) (1994) *Fertilizer Use Recommendations*: Volumes 1-22, Kenya Agricultural Research Institute (KARI) Nairobi, Kenya.

Gachengo, C.N. (1996) Phosphorus release and availability on addition of organic materials to phosphorus fixing soils. M.Phil Thesis, Moi University, Eldoret, Kenya.

Jaetzold, R. and Schmidt, H. (1983) *Farm Management Handbook of Kenya. Natural Conditions and Farm Management Information.* Ministry of Agriculture, Kenya.

Jama, B, Swinkels, R.A. and Buresh, R.J. (1997) Agronomic and economic evaluation of organic and inorganic sources of phosphorus for maize. *Agron. J.* 89: 597-604.

Makken, E. (1993) Overview of the agricultural sector in sub-Saharan Africa. In Van Reuler, H. and: The role of plant nutrients for sustainable food crop production in sub-Saharan Africa Prins, W.H. (eds) pp. 25-36. Leidschendem. The Netherlands Dutch Association of Fertilizer Production.

Muasya, R.M. (1996) Wheat response to fortified wheat straw compost. *M.Phil Thesis,* Moi University, Eldoret Kenya.

Muasya, R.M., Mwakha, E., Othieno, C.O., and Okalebo, J.R. (1996)*Initial wheat response to low and high rates of phosphate fortified compost*. Proc. Of the 15th Meeting of the Soil Science Society of East Africa (SSSEA). Nanyuki, Kenya. 19-23 August, 1996, pp. 79-87.

Mutuo, P.K., Smithson, P.C., Buresh, R.J. and Okalebo, J.R. (1999) Comparison of phosphate rock and triplesuperphosphate on a phosphorus deficient Kenyan soil. *Commun. Soil Sci. Plant Anal.* 30: 1091-1103.

Mwaura, H.W. (1998) Determination of nutrients limiting crop/tree growth on a ferralsol at Chepkoilel Campus, Uasin Gishu district, Kenya. Fourth Year B.Sc. (For) Dissertation. Moi University, Eldoret, Kenya.

Nahas, E., Banzato, D.A. and Asis, L.C. (1996) Fluorapatite solubilisation by Aspergillus niger in vinasse medium. *Soil Biology and Biochemistry* 22: 1097-1101.

Nyambati, R.O. (2000) Soil phosphorus fractions as influenced by P and N sources on two sites in Western Kenya. *M.Phil Thesis*. Moi University, Eldoret, Kenya.

Okalebo, J.R. (1987) A study of the effect of phosphate fertilizers on maize and sorghum in some East African Soils. Ph.D Thesis, University of Nairobi, Kenya.

Okalebo, J.R. and Lekasi, J.K. (1993) Effect of combined groundnut trash, maize stover and farmyard manure with phosphate rock on maize yield at Malava, Kakamega. In: *NARC Muguga (KARI) Record of Research, Annual Report* 1993.

Okalebo, J.R., Lekasi, J. K. and Schnier, H.F. (1991/95) Phosphate response studies at Malava smallholder site, Kakamega, Kenya. In: NARC Muguga (KARI) Records of Research. Annual Reports. 1991-1995.

Okalebo, J.R., Simpson, J.R. and Probert, M.E. (1992) Phosphorus status of cropland soils in the semi-arid areas of Machakos and Kitui districts, Kenya. In (M.E. Probert ed.): A search for strategies for sustainable dryland cropping in Eastern Kenya. *ACIAR (Australia) Proceedings*, 41. 50-54.

Okalebo, J.R. and Woomer, P.L. (1994) Use of rock and fertilizer phosphorus in Eastern and Southern Africa: A data summary. Proc. Of the 14th Conference of the Soil Science Society of East Africa, Mbarara, Uganda, November, 1994.

Okalebo, J.R. and Nandwa, S. (1997) Effect of organic materials with and without inorganic P fertilizer on maize yield mainly in P deficient soil. Report on Activity 3.1.1. Soil Fertility and Plant Nutrition Research Programme, KARI, EU Funded pp. 10

Okalebo, J.R., Gathua, K.W. and Woomer, P.L. (1993) *Laboratory Methods of Soil and Plant Analysis: A working manual*. TSBF-UNESCO, Nairobi, EPZ Publishers, Nairobi, Kenya, 88p.

Okalebo, J.R., Palm, C.A., Gichuru, M., Owuor, J.O., Othieno, C.O., Munyampundu, A., Muasya, R.M. and Woomer, P.L. (1999) Use of wheat straw, soybean trash and nitrogen fertilizer for maize production in the Kenyan Highlands. *African Crop Science Journal*. Vol. 7 No. 4. 423-431.

Palm. C.A., Myers, R.J.K. and Nandwa, S.M. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. In: R.J. Buresh *et al.* (eds). *Replenishing Soil Fertility in Africa*. SSA Special Publ. 51. SSA. Madison. USA, p. 193-217.

Probert, M.E., Okalebo, J.R., Simpson, J.R. and Jones, R.K. (1992) The role of boma manure for improving soil fertility. In: *M.E. Probert et al* ACIAR Proc. 41, 63-70. A search for strategies for sustainable dryland cropping in Eastern Kenya. Symposium Proceedings, 1990.

Russell, E.W. (1973) *Soil Conditions and Plant Growth*. 10th ed. The English Language book Society and Longman, U.K.

Sanchez, P.A., Shepherd, K.D., Soule, M.I., Place F.M., Buresh R.J., A.M.N. Izac, Mokunye A.U., Kweriga F.B., Ndiritu C.G. and Woomer, P.L. (1997) *Soil fertility replenishment in Africa*. An investment in natural capital.

Proceedings of a Workshop 26-30 September 1996, Addis Ababa, Ethiopia. SSA Special Publication No. 51, Madison USA, p 1-46.

Simpson, J.R. Okalebo, J.R., and Lubulwa, G. (1996) *The problem of Maintaining soil Fertility in Eastern Kenya: A Review of Relevent Research.* ACIAR (Australia) Monograph No. 41 pp. 60.

Symth, T.D. and Sanchez, P.A. (1982) Phosphate rock dissolution and availability in Cerrado soils as affected by phosphorus sorption capacity. *Soil Sci. Soc. Am. J.* 46: 339-345.

Tropical Soil Biology and Fertility Programme (TSBF). (1994) Nutrient Limiting Experiment in Western Kenya by TSBF staff. 1994 - A Report.

Waigwa, M., Othieno, C.O and Okalebo, J.R. (2000) *The use of manure and crop residues to improve the solubility of Minjingu phosphate rock for phosphorus replenishment in acid soils of Western Kenya.* Presented at the 4th FORUM Meeting, Malawi, 2000.

Woomer, P.L., Okalebo, J.R. and Sanchez, P.A. (1997) *Phosphorus replenishment in Western Kenya: from field experiments to an operational strategy*: African Crop Science Conference Proceedings 3(1), 559-570.

World Bank (1996) *Natural Resource Degradation in sub-Saharan Africa*. Restoration of soil fertility, Africa Region. World Bank: Washington D.C. USA.

26

The Potential of Green Manures to Increase Soil Fertility and Maize Yields in Malawi

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Abstract

The effect of sole maize and green manures (*Mucuna pruriens*, *Crotalaria juncea* and *Lablab purpureus*) on maize for two successive cropping seasons was determined in an on-farm experiment at five locations in Malawi, from 1996 to 1999. Legume residues were incorporated in two different manners; "early" at peak biomass and "late" when the plants started to senesce.

After growing and incorporating the green manures after the end of the 1996/97 growing season, maize was planted in 1997/98 and 1998/99 to test the effect of the legumes on maize yields compared with continuous maize. Biomass production from "early" incorporated legume residues were 6.7 t ha^{-1} for Mucuna, 4.9 t ha^{-1} for Crotalaria, and 4.9 t ha^{-1} for *Lablab purpureus*; and for "late" incorporated legume residues were 5.9, 5.2 and 4.1 t ha^{-1} for the same legumes, respectively. Of the three legumes *Lablab purpureus* produced less biomass (averaged 4.2 t ha^{-1}), compared with the other two green manures and Mucuna produced the highest seed yield. Over the two seasons and across the five sites, the application of inorganic fertiliser (35 or 69 kg N ha^{-1}) to maize significantly increased maize yields in all the sites. Maize yields following green manures without inorganic fertiliser additions were much higher than yields from continuous maize with no fertiliser addition. Addition of inorganic fertiliser to legume crop residues resulted in increased maize yields at all the sites, but the highest fertilizer use efficiency was obtained from the addition of 35 kg N ha^{-1}. There were no significant maize yield differences when maize followed early or late incorporated green manures across season and sites for all the three legumes. Results indicate that all the three green manures have potential to increase maize yields when used as sole green manures or in combination with inorganic fertilizers compared to sole maize alone, following each other.

Introduction

Smallholder farmers in Malawi are confronting a difficult set of conditions that threaten not only their livelihoods, but also their abilities to feed themselves and their families. Over the past twenty-four years, Malawi has experienced a series of periodic drought that requires food relief by international agencies. Structural reforms imposed, as a condition for development aid, required the removal of subsidies for farm inputs, which in turn reduced farmers access to materials required to modernise agriculture. Continuous cropping and soil erosion has led to soil degradation. But despite these setbacks, several promising new technologies have emerged that offer promise to better manage agricultural resources. One such technology is the use of nitrogen-fixing green manure legumes (Giller and Wilson, 1991). A green manure legume is one that is grown specifically for use as organic manure and maximises the amount of N from the legume that is available for a subsequent crop.

Apart from periodic drought and effects of structural adjustments in Southern Africa, and in particular Malawi, some of the major causes of low maize yields are declining soil fertility and insufficient use of fertilisers resulting in severe nutrient depletion of soils (Buresh *et al.*, 1997). Inorganic fertilizers are unaffordable by most smallholder farmers in Malawi (Kumwenda *et al.*, 1997). Use of green manures in combination with inorganic fertilizers is a less expensive way of increasing soil fertility and consequently maize yields compared with the use of inorganic fertilizers alone. Although the use of green manures in Malawi was first initiated more than 70 years ago (Sakala, 2000), intensive research on green manures gained momentum in the 1990s.

Large increases in growth and yield of crops sown after incorporation of green manures have been reported, for example, maize yields have more than doubled by incorporation of a 3-month-old green manure of *Mucuna pruriens var. utilis* or *Crotalaria juncea* grown in alluvial soil on the island of Java, Indonesia (Hairiah and van Noordwijk, 1989). Simple decision aids based on chemical and physical characteristics of the green manures have been developed to guide scientists, as well as farmers, in choosing the legumes which are suitable for improving soil fertility (Palm *et al.*, 1997). This paper summarises the results of an experiment which was initiated to:

(i) determine biomass production of early and late incorporated legume manures
(ii) determine the effects of legume manures on the subsequent maize yields, and
(iii) test the effect of combining organic and inorganic fertilisers on maize yield.

Materials and Methods

An experiment with three legumes that were to be incorporated late (after seed was harvested) was started in the 1995/96 cropping season. The experiment was sited both on station and on-farm. During this season all the on-farm sites were not successful because animals ate all the legume crops as incorporation was scheduled after maize harvest. This led to a new experiment, which included an early incorporation treatment (before seed harvest) in 1996/1997 cropping season. This trial was initiated at Bembeke, Mathambi, Mbawa, Chitedze and Kamwendo. The site location characteristics are presented in Table 26.1.

A split plot design was used and seven treatments were arranged in randomised complete block, with 3 replications. Each plot was 18 rows, 10 m long. The treatments for the 1996/97 seasons were: Sole Mucuna (*Mucuna pruriens*), with early incorporation at maximum flowering and pod initiation incorporation, sole Mucuna, with late incorporation after harvest of Mucuna seed or grain, sole Crotalaria (*Crotalaria juncea*), with early incorporation as in I, Sole Crotalaria with late incorporation as in II, sole *Lablab purpureus* with early incorporation as in I, sole *Lablab purpureus* with late incorporation as in II and sole Maize crop (NSCM 51). In the 1997/98 and 1998/99 cropping season, maize a hybrid maize NCM51 was planted on the 7 main-plots following Mucuna, Crotalaria *or Lablab purpureus* legume crop residue, each incorporated early or late,

Table 26.1: Experimental site location characteristics where the experiment was conducted between 1996 to 1999

Trial site location	Evaluation (masl)	Lati-tude	Longi-tude	Soils	Rainfall range (mm)	Rainfall variabilty
Bembeke	1219-1585	34° 25'	14° 21'	Ferallitic Latosols	800-1,270	Low
Mathambi	1200-1810	35° 21'	16° 01'	Ferallitic Latosols	2,000-2,400	Low
Mbawa	1219-1250	33° 25'	12° 07'	Weakly Ferallitic Lotosols,	700-1,200	Medium
Chitedze	1097-1372	33° 38'	13° 59'	Ferruginous Latosols	700-1,200	Medium
Kamwendo	1067 – 1158	38' 02'	13° 50'	Weakly Ferallitic Latosols	700-1,100	Medium

and a pure continuous maize crop. Each main-plot had 3 sub-plots consisting of inorganic fertilisers which were added as packages as follows: 1) no fertiliser, 2) 35:10:0:+2S kg ha^{-1}, and 3) 69:21:0+4S kg ha^{-1} ($N:P_2O_5$:0+S). A split plot design was used and these treatments were arranged in a randomised complete block design with three replications. Each main plot had 18 rows while each sub-plot had 6 rows, each 10 m long. In plots, which had fertilizer, the basal fertiliser was applied at planting and the source was 23:21:0+4S and the top-dressing source was urea (46%N) that was applied three weeks after planting. Maize was planted at a rate of 44,000 plants per hectare. Maize yield was determined by harvesting 4 middle rows of each sub-plot, 9.1 m long each and the yield was adjusted to 12.5% moisture content. Mucuna and *Lablab purpureus* were planted at 74,407 seeds per hectare (90 cm x 15 cm x 1 plant). Crotalaria was drilled on the ridge, double row per ridge, at 45 kg of seed per hectare. Maize seed was planted at 44,000 seeds per ha^{-1} (0.9 m x 0.75 m x 3 plants). The pure crop of maize received 35:10:0+2S ($N:P_2O_5$+S) per hectare of fertiliser from 23:21:4S as a basal fertiliser and from urea as a top dressing fertiliser. The aboveground biomass was measured at each incorporation time, early or late (after seed harvest). Legume seed or grain yield of late incorporated legume manures was also determined. Seed yield of legume manures was determined by harvesting 18 rows x 10 m long each. Legume seed yields are reported for Mucuna and Crotalaria only because *Lablab purpureus* started flowering late and therefore seed was not harvested.

Maize yield was determined by harvesting 16 middle rows, 9.1 m long each, and adjusted to 12.5% moisture content. Maize and green manure yields were analysed by use of general statistical program

(GENSTAT), developed at Rothamsted experimental station (Payne, 1978). Analysis of variance was the main procedure used for testing significances of differences between means.

Results

The soils from the experimental sites were slightly acidic and pH ranged from 5.8 to 6.2 (Table 26.2). Bembeke was more acidic compared to the other sites. All sites had low organic carbon, which is a common characteristic of most soils from farmer's fields in Malawi. The exchangeable cations were also on the low side.

Table 26.2: Soil chemical characteristics for some experimental sites

Sites	pH	Total N ppm	OC %	P mg kg^{-1}	Ca mg kg^{-1}	K mg kg^{-1}	Mg mg kg^{-1}
Bembeke	5.9	45.1	1.8	5.7	1.8	0.7	0.3
Kamwendo	5.8	18.5	1.0	0.4	0.8	0.3	0.2
Mathambi	5.3	43.7	1.8	8.8	1.4	0.4	0.3
Chitedze	6.2	19.5	2.1	1.5	3.3	0.3	0.2

Crotalaria took a shorter time than the other legumes to attain maximum flowering stage, which ranged from 64 to 85 days after planting, followed by Mucuna, which ranged from 122 to 142 days after planting. Mucuna and Crotalaria were incorporated when the soil was still wet because they reached maximum flowering while the rainy season was still in progress. *Lablab purpureus* flowered very late, hence, early incorporation was thus done before flowering. At the date of early incorporation, Mucuna had accumulated the highest dry matter (5 to 11 t ha^{-1} and averaged 6.7 t ha^{-1}) followed by Crotalaria, which averaged 4.9 t ha^{-1} (Figure 26.1).

The biomass for late incorporated Mucuna ranged from 3.8 to 7.9 and averaged 5.9 t ha^{-1}, Crotalaria biomass ranged from 3.8 to 8.6 and averaged 5.2 t ha^{-1} and Lablab ranged from 0 to 8.9 and averaged 4.0 t ha^{-1}. Total nitrogen contribution to the soil ranged from 164 kg N ha^{-1} for late incorporated Lablab to 367 kg N ha^{-1} for early-incorporated Mucuna.

The highest maize grain yield 2.1 t ha^{-1} and seed yield of Crotalaria 1.7 t ha^{-1} were obtained at Chitedze in 1997/98 season (Table 26.3). The highest seed yields of Mucuna were obtained at Chitedze (1.8 t ha^{1}). Mucuna seed yield was also higher than for maize or Crotalaria at Kamwendo, Bembeke, and Mbawa. This shows that Mucuna like other legume crops can grow well even on poor soils.

Figure 26.1: Mean dry matter (t ha^{-1}) yields of early and late incorporated legume green manures at five sites in 1996/97 cropping season

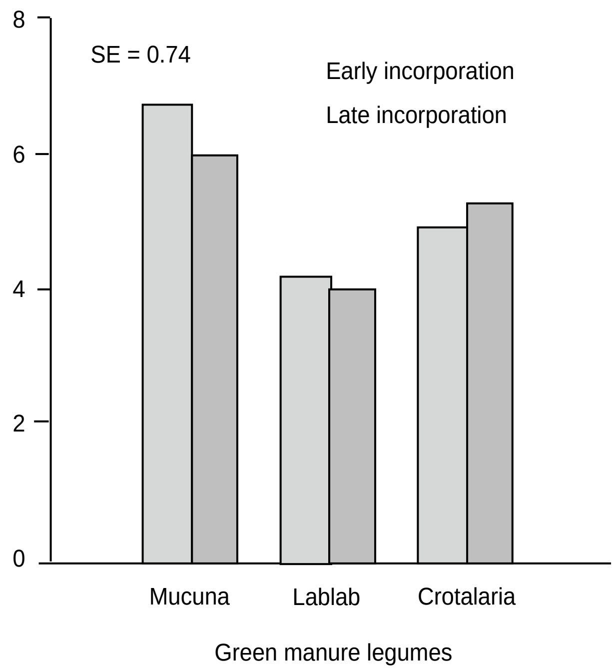

Table 26.3: Seed and grain yield (t ha^{-1}) of legume crops and maize at test sites, 1996/97 cropping season

Site	Maize	Mucuna	Crotalaria
Chitedze	2.1	1.8	1.7
Kamwendo	0.1	1.2	0.5
Bembeke	0.6	-	0.5
Mbawa	0.9	1.1	0.1
Mathambi	-	2.5	0.5
Mean	0.9*	1.7**	0.7

* Mean from 4 sites only; the farmer harvested the maize.
** Mean from 4 sites only. Mucuna did not flower at Chitala and Bembeke.

All the three green manures used in this experiment had a high N content at flowering time (4%) (Table 26.4). The N content for the three legumes were within the ranges of these green manures, which were extracted from the organic resource database compiled by the Tropical Soil Biology and fertility programme indicated in (Table 26.4).

Table 26.4: Chemical quality characteristics of Mucuna, Crotalaria and Lablab at flowering time

Legume	%N	C:N ratio	Lignin (%)	Lignin: N ratio
Mucuna	(5.5) 1.4-6.5	9.8-30.8	5.5-16.8	1.3-8.3
Crotalaria	(5.3) 1.6-5.7	8.0-32.1	3.8-9.8	1.0-6.3
Lablab	(4.1) 1.7-6.3	7.4-29.1	2.6-11.5	0.4-9.8

Source: Organic Resource Database Manual
( ) %N measured from the experiment.

When maize was planted following the three legumes and sole maize for two successive seasons at five sites, maize grain yield differed with maize following green manures having similar yields which were significantly higher (P 0.05) than maize yield from plots where maize was being grown continuously (Table 26.5). There were no significant maize yield differences for each legume due to time of green manure incorporation. Bembeke site had the least average maize yields during the two seasons and Chitedze had the largest average maize yield when grown after the green manures.

Table 26.5: Average maize grain yield following three legumes incorporated early or late at five sites in 1997/98 and 1998/1999 seasons

Legume incorporation	Bembeke	Mathambi	Mbawa ($t\ ha^{-1}$)	Chitedze	Kamwendo	Legume Mean
Mucuna early	1.3	2.4	3.1	4.4	1.7	2.7
Mucuna late	1.8	2.3	3.4	3.5	1.9	2.9
Crotaralia early	1.9	2.8	3.7	4.2	1.9	3.0
Crotaralia late	0.9	2.6	3.5	3.6	2.0	2.8
Lablab early	2.0	1.4	3.4	4.2	2.0	2.7
Lablab Late	1.3	1.8	3.1	4.0	1.9	2.7
Maize	1.1	1.9	2.6	2.5	15	2.1
Site Mean	1.5	2.2	3.3	3.8	1.8	
			Legume	Site	Interaction	
Significance			0.001	0.001	0.001	
SED			0.09	0.09	0.02	
CV (%)			6.1	36	36	

Cross season and cross sites analysis showed that at all the five sites, the application of inorganic fertilisers increased maize yield (Table 26.6). An increase in fertilizer application resulted in greater maize yield increases in plots where maize had followed a legume compared with plots where maize was grown continuously. Legume residue incorporation resulted in large maize yield increases for the two seasons that maize followed the green manure planted in the first year at all the five sites compared with continuous maize with no fertiliser additions. Again larger responses were obtained when fertilizer was combined with inorganic fertilizer. There were no significant differences in maize yields due to different types of legumes that were planted in the first season. The mean for two seasons showed no significant yield differences between maize yield following their incorporation. The effect of time of incorporating legume residue was not evident across the five sites for the two seasons.

Table 26.6: The effect of three different rates of inorganic fertilizer following legumes or sole maize on the grain yield of maize across five sites for two seasons 1997-1999

Legume time incorporation	0	35:10:0+2S	69:21:0+4S	Legume Mean
		(t ha^{-1})		
Mucuna early	2.1	2.6	3.5	2.7
Mucuna late	2.2	2.6	3.5	2.8
Crotaralia early	2.2	3.1	3.7	3.0
Crotaralia late	1.8	2.9	3.6	2.8
Lablab early	2.0	2.8	3.4	2.7
Lablab late	1.7	2.9	3.4	2.7
Maize (Control)	1.2	2.2	2.7	2.0
Fertiliser Mean	1.9	2.7	3.4	2.7
	Legume	Fertilizer	Interaction	
Significance	0.001	0.001	Ns	
SED	0.09	0.07	0.02	
CV (%)	6.1	8.7	8.7	

A combination of organic and inorganic fertilizer increased fertilizer use efficiency at both rates of inorganic fertilizer (35 and 69 kgNha^{-1}) that were applied together with the green manures that were incorporated during the first season compared to where inorganic fertilizers were applied alone. Although fertilizer use efficiency was increased by combining organic and inorganic fertilizer, the fertilizer use efficiency was much higher when lower rates of 35 kgNha^{-1} were applied for both year one (when the green manures had just been incorporated) and year two (when the fertilizer was added after one season from the time when green manures were incorporated). There were no marked differences in fertilizer use efficiency due to combination of organic and inorganic between year one and year two at each level of fertilizer added to incorporated green manure, except for early Mucuna incorporation which had a significantly reduced fertilizer use efficiency in the second year when 35 kgN ha^{-1} of inorganic fertilizer were added. On the other hand, late incorporated Mucuna had a slightly increased fertilizer use efficiency in the second season at both rates of inorganic fertilizer added to the green manures. Highest fertilizer use efficiency was realised from early-incorporated Crotalaria at both rates of fertilizer combination over the two season combined compared with the other two green manures that were used. For *Lablab purpureus* both early and late incorporation had similar fertilizer use efficiency (in the first and second season for each rate of fertilizer combined with the green manure).

Discussion

Dry matter accumulation of the green manures and their effect on maize yield

Dry matter accumulation varied among legume species because sampling for dry matter and incorporation was done when each legume had reached its maximum flowering stage. Late incorporation tended to have lower biomass because biomass was measured after seed had been harvested and during this time most leaves had senesced and started falling down This affected the final biomass yield. Again, aphids severely infested *Lablab purpureus* at Kamwendo and Mbawa and consequently resulted in reduced dry matter yield at these sites (averaged 4.2 t ha^{-1}). *Lablab purpureus* had the lowest total nitrogen contribution to the soil due to low biomass yield as well as low nitrogen content compared to the other legumes. Mucuna seed yield was also highest compared with *Lablab purpureus* and Crotalaria at Kamwendo, Bembeke, and Mbawa. This suggests that Mucuna unlike other green manure crops can grow well even on poor soils.

Significance of high N content on the three green manures

All the three green manures had N content of more than 4% N, which is an indication of better quality (Palm *et al.,* 1991). Nitrogen release from crop residues can be slow or rapid, depending on the quality of the residues. With the high N content, it is likely that these legumes will be able to release nitrogen for use by the plant when incorporated into the field. Both slow and rapid release of nutrients from organic fertilisers can have positive effects on nitrogen management in the soil (Sakala *et al.*, 2000). Rapid release enhances early nitrogen uptake by the crop but may lead to nitrogen loss through leaching if crop demand is less than the amount of nitrogen being released. Slow release would guarantee a continuous supply of nitrogen during most of the growing period of the crop, although, if the amount of nitrogen released is small its contribution to crop growth may not significantly boost crop performance

Nitrogen use efficiency

Maize yields increased with the application of green manures and inorganic fertilizers separately or in combination. However, the combination of 35 kg N ha^{-1} and any of the three green manures produced the highest efficiency in the first year of green manure application as well as in the second year, when residual effects of the green manures were being tested.

Conclusion

Results from this study have shown that early-incorporated Mucuna produced the largest biomass, which averaged 6.7 t ha^{-1}, followed by Crotalaria, which produced 4.9 t ha^{-1}. Biomass from late incorporated legume manures were lower than from early incorporated legume manures, due to the loss of leaves by harvest time. Application of organic and inorganic fertilisers separately or in combination, increased maize yields at all sites, but higher fertilizer use efficiency was obtained when the green manures were combined with 35 kg N ha^{-1}. Growing maize after legume residues resulted in increased maize yields compared with growing maize after maize. There was no difference between early and late incorporation of legume residues, when the data were pulled for two seasons. These results show that these three legume residues can be potential alternative sources of fertilisers for a following maize crop.

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References

Giller, K. E., and Wilson, K. J. (1991)*Nitrogen fixation in tropical cropping systems.* CAB ,International, Wallingford.

Hairiah, K. and van Noordwijk, M. (1989) Root distribution of leguminous cover crops in the humids tropics and effects on a subsequent maize crop. In:

van der Heide, J. (ed.) *Nutrient Management for Food Crop Production in Tropical Farming Sytems*. Institute for Soil Fertility, Haren, The Nertherlands, pp. 157-170.

Kumwenda, J.D.T, Waddington, S.R., Snapp, S.S., Jones, R.B. and Blackie, M.J. (1997) Soil fertility management in the smallholder maize-based cropping systems of Africa. In. The Emerging Maize Revolution in Africa: The Role of Technology, Institution and Policy, Michigan State University, USA, 9-12 July, 1995.

Kumwenda, J.D.T., Saka A.R., Kabambe V.H. and Ganunga R.P. (1998) Legume manure crops-maize rotation trial for the 1997/98 cropping season. *In 1997/98 Annual Report,* Chitedze Research Station, Lilongwe, Malawi.

Palm, C.A., Nandwa, S. and Myers, R.J. (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and nutrient replenishment. In: R.J. Buresh and P. A. Sanchez, (eds.) *Replenishing Soil Fertility in Africa Special Publ Vol. 51, pp. 193-217*. ASSA, CSSA, SSSA, Madison, Wisconsin.

Palm, C.A. and Sanchez, P.A. (1991) Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biology and Biochemistry* 23: 83-88.

Payne, R. W. (1978) *Genstat 5 Reference Manual*. Clarendon Press, Oxford.

Sakala, W.D. (2000) A review of potential legumes for integrated nutrient management in maize-based systems in Malawi with emphasis on pigeonpeas. Ritchie, J.M. (ed) (2000) *Integrated crop management research in Malawi.* Proceedings of final workshop on the Farming systems integrated pest management project, Club Makokola, Mangochi, Malawi, 29 November-3 December, 1999. Chatham, UK: Natural Resources Institute.

Sakala, W., Cadisch, G. and Giller, K.E. (2000) Interactions between residues of maize and pigeonpea and mineral N fertilizers during decomposition and N mineralization. *Soil Biol. Biochem*. 32 (2000): 679-68.

Effects of Ramial Chipped Wood and Litter Compost of *Casuarina equisetifolia* Tomato Growth and Soil Properties in Niayes, Senegal

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Abstract

Plantations of *Casuarina equisetifolia* in Niayes, Senegal produce litter and ramial wood as by-products. These organic materials were suspected to be potential sources of plant nutrients upon decomposition in soils. However, this potential remained to be established in the infertile sandy soils of the Niayes area, Senegal. A field experiment was therefore, conducted to study the effects of these forestry by-products on tomato growth and soil properties. The ramial wood was fragmented to produce ramial chipped wood (RCW), while the litter was composted before being applied to a sandy soil at three different levels: 10, 20, and 40 t ha^{-1} and compared to a reference control and locally recommended fertilizer mixture. Soil and plant samples were taken at 45 days of tomato growth and at harvest time for analysis. Residual effects of the materials were also evaluated through the establishment of a second tomato crop on the same plots.

Application of RCW depressed tomato growth and yield during the first cropping and this was attributed to the effect of RCW to induce intense N immobilization in the soil due to its wide C:N ratio. Improvements in growth and yield were, however, observed during the second cropping and were ascribed to improved nutrient release and especially nitrogen as a result of the mineralization of earlier immobilized nutrients, following the extended incubation of the RCW in the soil. These results indicated that in order to derive short-term benefits from RCW application, it may have to be applied in combination with experimentally determined amounts of mineral fertilizers.

Incorporation of litter compost (LC) improved tomato growth and yield during both the first and second croppings. The LC improved soil levels and tomato uptake of N, P and K and possibly other nutrients that were not measured. This was attributed to the narrower C:N ratio of LC that encouraged its faster decomposition in the soil. The observed effects were greater in the first than the second crop indicating that LC had limited residual nutrient value. Application of LC also improved soil organic matter content, dry bulk density and water holding capacity, suggesting that its regular use could result in the long-term improvement of the productivity of the experimental soil.

Key words: Casuarina equisetifolia, Litter compost, Nutrients, Ramial-chipped wood, tomato, Senegal.

Introduction

Plantations of *Casuarina equisetifolia* (Forst & Forst), were established in the Niayes region of Senegal through a re-forestation program begun in 1948 (Maheut and Dommergues, 1963). These plantations play an important role in stabilizing the coastal sand dunes and help to protect adjacent agricultural areas by acting as windbreaker. The *C. equisetifolia* trees produce large quantities of organic materials in the form of leaf litter as well as male and female spikes that accumulate on the plantation floor. Mailly and Margolis (1992) estimated that a 13-year-old plantation produces up to 3.3 kg m^{-2} $year^{-1}$ of leaf litter. The accumulated litter is so thick that it is suspected to prevent Casuarina seeds from germinating by isolating them from the mineral soil. In addition, the decomposition of the litter releases acids that further inhibit the germination of the seeds. The partial removal of the litter from the forest floor may help to solve the problem of germination of the *C. equisetifolia* seeds and thereby, facilitate the natural regeneration of the plantations. One way of encouraging its removal from the forest floor is for it to be used as a soil amendment in crop or vegetable farming. Information on the agronomic value of this amendment is, however, lacking.

Since *C. equisetifolia* plantations do not regenerate naturally, the only way by which these plantations are regenerated in Senegal is by cutting down 45-50 years old trees just before the rainy season begins. After it rains, shoots sprout from the stumps, which upon pruning grow to form new plants. This method of plantation management results in the production of large quantities of trash in the form of pruned small branches and twigs. Such branches and brushwood have been viewed for centuries as having no value. However, there is growing evidence that such brushwood and twigs, when applied to soil as ramial chipped wood (RCW), could result in the improvement of soil fertility and general soil productivity (Lemieux, 1993; Seck and Lemieux, 1993; Sylvestre and Despatie, 1995). The trash from the regeneration of *C. equisetifolia* plantation is, therefore, a by-product that should be given consideration as a soil amendment in the form of ramial chipped wood.

The Niayes area accounts for more than 80% of the vegetables produced in Senegal for local consumption and export. The vegetables are mainly produced under irrigation on sandy soils that are inherently low in fertility. Due to continuous cultivation with the same crop species, nematode infestation is reported to be a problem in the area (Netscher, 1970). Farmers maintain their production levels by using chemical fertilizers and pesticides, often in excessive amounts. This practice is thought to be an unsustainable method of land use because it reduces organic matter levels and thus enhances soil erosion, especially in drifting sand dune soils. Farmers continue to use chemical fertilizers and pesticides because of their highly visible short-term benefits, but are generally not conscious of environmental pollution, accumulation of pesticides and nitrates in the ecosystems and high levels of pesticides in their produce. These apparent limitations in the use of chemical fertilizers and their secondary effects, point to the importance of alternative soil fertility management methods such as the use of organic materials wherever these are readily available. The objective of this study was, therefore, to evaluate the effectiveness of the locally available litter compost and RCW of *C. equisetifolia* as possible alternative sources of nutrients for tomato farming in Niayes, Senegal.

Materials and Methods

Materials

The experiments were carried out on a field of the Developing Center for Horticulture (CDH) farm. The farm covers an area of 40 ha, divided into many fields in the Niayes area, Dakar, Senegal (12°30'E, 17°30'W). This region consists of a coastal band, 15 to 20 km wide along the Atlantic Ocean to the North of Dakar. The soil is classified as a dystric regosol according to the FAO system of soil classification (FAO-Unesco-ISRIC, 1990). The site was previously cropped with onions from March to June 1999, after which it was left uncultivated until the planting time for this experiment on October 28th 1999.

Fresh ligneous twigs less than 3 cm in diameter, were harvested from a *C. equisetifolia* plantation and transported to the experimental field where they were fragmented manually using a bush knife, into small pieces of around 15 to 20 mm long. The resulting product is what was used as ramial-chipped wood in this study.

The *C. equisetifolia* litter was collected from the plantation floor and composted for three months (July to October). The heap method, utilizing natural aeration (passive aeration), was used. The dimensions of each of the three heaps used were 3 m long, 1.5 m wide and 1 m high. The humidity was kept between 30% and 50% and the heaps were watered whenever humidity was less than 30%.

A germination bioassay trial was conducted to monitor litter compost maturity as the composting process progressed. In this trial, the decomposing compost was sampled at the end of every week and put in containers. Twenty-five lettuce seeds were then sown and their germination percentage determined after 3 days. The results obtained showed that seed germination was almost completely inhibited during the first five weeks. However, the germination percentage increased steadily thereafter and reached 100% during the 10th week indicating that compost maturity had been achieved. The process was allowed to continue for a further two weeks at which time the compost was used for the field trials.

Methods

A randomized complete block experimental design (RCBD), with four replications was used for the field study. Treatments included a control; recommended fertilizer (RF) rate for N, P and K; RF rate for N, P and K plus mocap powder (nematicide); LC and RCW at three levels each (10 t ha^{-1}, 20 t ha^{-1} and 40 t ha^{-1}) for a total of 9 treatments. The recommended fertilizer included 20t ha^{-1} of horse manure (on air-dry basis). The nematicide used was Ethoprophos (O-ethyl-S,S-dipropyl-phosphorodithioate) at a rate of 2 g m^{-2}. The materials were applied to plots measuring 5 m long by 3.5 m wide. The RCW was applied fresh and mixed using a spade in the top 5 cm to 7 cm of soil while litter compost was applied and mixed with the top 15 cm of soil.

Tomato (*Lycospersicum esculenta*) (CDH tomato variety XINA) seeds were sown and raised in a nursery until the three-leaf stage (around 10-15 cm tall) at which time seedlings were transplanted to the pre-irrigated plots. The seedlings were transplanted at a spacing of 50 cm within rows and 50 cm between rows. The tomato plants were regularly monitored and treated against insect pests as well as fungus and bacteria infections. Maneb ($C_4H_6N_2S_4$.Mn) was the fungicide used at a rate of 2 g m^{-2} while Copac (ammoniacal copper sulphate) at a concentration of 10 ml l^{-1} was used for bacterial control. Maneb was applied once a week and after rain events while Copac was applied every two weeks during the growing period.

Treatment effects on plant growth were evaluated by measuring plant height at 45 days of growth and tomato fruit yield at harvest time. Harvesting began 80 to 90 days after planting and was done three times a week. The harvest area was 4.5 m long and 3 m wide for each plot, 0.5m from each side of the plot were left as guard rows. The number of fruits was counted and weights determined.

Leaf, soil and root samples were taken at specific times to assess treatment effects on soil and plant nutrient contents. Leaf sampling was done at 45 days of growth and at harvest time. This was done by taking the third tomato leaf from the growing tip of each of 20 tomato plants selected randomly from every plot. Soil sampling for purposes of assessing treatment effects on soil properties was done after the second harvest.

In order to evaluate the residual effects of the organic amendments, a second tomato crop was grown on the same treatment plots after clearing, but without further organic amendment applications. The RF and RF+N treatments were, however, reapplied. The planting and the management procedures were done exactly as for the first crop.

The pre-cropping soil and soil samples taken from treatment plots after harvest were characterized for pH (McLean, 1982), organic carbon

(Nelson and Sommers, 1982), Total-N (Bremner and Mulvaney, 1982), extractable P (Olsen and Sommers, 1982) and exchangeable K (Knudsen, Peterson and Pratt, 1982), dry bulk density (Blake and Hartge, 1986), particle size analysis (Gee and Bauder, 1986), water holding capacity (Cassel and Nielsen, 1986), and cation exchange capacity (Rhoades and Miyamoto 1990).

Litter compost and RCW samples were analyzed for pH and for carbon by the wet oxidation method utilizing acidified dichromate as described by Nelson and Sommers (1982). In addition, RCW and LC along with tomato leaf samples were analyzed for N by the Kjeldahl method (Bremmer and Mulvaney, 1982) as well as for P by the vanado-molybdo-phosphorus method (Okalebo *et al.*, 1993), K by flame photometer and Ca and Mg by EDTA titration (Lanyon and Heald, 1982). The results for the organic amendments together with those of the pre-cropping soil are summarized in Table 27.1.

Table 27.1: Selected properties of the experimental soil, ramial chipped wood (RCW) and litter compost (LC)

Chemical or physical property	Soil	LC	RCW
C (%)	1.2	40	58.8
N (%)	0.08	1.3	1.15
C:N ratio	15	31	51
P (%)	0.02	2.3	0.11
C:P ratio	60	17	535
K (%)	0.08	2.8	0.53
Ca (%)	-	2.6	1.39
Mg (%)	-	0.4	0.12
EC(dS/m)	1.52	-	-
OM (%)	2.10	64	78
CEC (cmol(+)kg^{-1})	7	-	-
pH (H_20)	5.4	6.8	5.2
DBD (Mg/m^3)	1.8	-	-
Particle size analysis (%)			
-Sand	95		
-Silt	4.5		
-Clay	0.5		
WHC (mm/m)	80	-	-

Data Analysis

The raw data obtained were statistically analyzed following procedures described by Gomez and Gomez (1984). Analysis of variance (ANOVA) was performed to evaluate treatment effects on the different parameters that were measured. The least significant difference (LSD) test was used to separate treatment means and means were declared as significantly different at $P < 0.05$.

The relative effects of the amendments on plant height (RH) and fruit yield (RY) were calculated using a formula described by Engelstad *et al.* (1974), viz:

$$RH = \frac{HA - HC}{HF - HC} \times 100$$

$$RY = \frac{YA - YC}{YF - YC} \times 100$$

Where:

HF and YF = plant height and fruit yield observed in the reference fertilizer treatment plots, respectively.

HA and YA = plant height and fruit yield observed in a given amendment treatment plots, respectively

HC and YC = plant height and fruit yield observed in the control treatment plots, respectively

Results and Discussion

Effect of amendments on tomato growth and yield

Effects of ramial chipped wood

The relative effects of treatments on height (RH) at low, medium and high rates of RCW application were – 37%, 10% and –78%, respectively (Table 27.2).

The RY values were 9.75 %, -3.43 % and –25% for low, medium and high rates of RCW application, respectively. These results showed that RCW had a negative effect on plant growth and yield during the first cropping. This depression in tomato growth and yield was most likely the result of N immobilization by soil microorganisms.

According to Bartholomew (1965), addition of organic materials with a total N content of 1.5 % can trigger N immobilization in soil. The RCW that was applied in this study had a total N content of only 1.15 % (Table 27.1), which was below the critical level suggested by Bartholomew (1965). The suspected nutrient immobilization could also be explained by the C:N and C:P ratios of the applied materials. The optimum C:N ratio for a rapid decomposition and N mineralization was found to be equal or less than 30 (Brady and Weil, 1999) or about 30 to 35 (Mustin,1981). With respect to C:P ratios, Rustad and Cronan (1988), cited by Tremblay and Beauchamp (1998), reported that the critical C:P ratio of organic residues above which net immobilization occurs is between 350 to 480. The C:N and C:P ratios of the RCW used in the present study were 51 and 535, respectively. Both values were above the critical values suggesting that RCW could have induced N and P immobilization thus reducing the levels of these nutrients in the soil and their subsequent uptake by plants. The N immobilization is confirmed by leaf N concentrations data observed at 45 days of growth for the first crop (Table 27.3) which show that leaf N values in RCW treatments were less than those observed in control treatments.

Table 27.2: The effect of RCW and LC on the growth and yield of two successive tomato crops

Treatments	First crop				Second crop			
	Height (cm)	RH (%)	Yield (t ha^{-1})	RY (%)	Height (cm)	RH (%)	Yield (t ha^{-1})	RY (%)
Control	50.1^{e**}		19.8^{e}		34.9^{h}		16.5^{g}	
RF	62.3^{b}		26.6^{b}		65.2^{b}		28.6^{b}	
RF+N	61.1^{c}		28.5^{b}		64.8^{a}		28.7^{b}	
RCW10 t ha^{-1}	45.6^{g}	-37	19.0^{f}	9.7	51.7^{e}	56	24.1^{e}	62
RCW20 t ha^{-1}	48.8^{f}	-10	19.5^{ef}	-3.4	55.2^{d}	67	25.9^{d}	78
RCW40 t ha^{-1}	40.6^{h}	-78	17.7^{g}	-25	50.3^{f}	51	22.9^{f}	52
LC10 t ha^{-1}	55.8^{d}	46	23.8^{d}	47	49.5^{g}	48	26.9^{c}	87
LC20 t ha^{-1}	61.1^{c}	90	27.7^{c}	82	60.7^{c}	85	28.6^{b}	100
LC40 t ha^{-1}	65.3^{a}	100	29.2^{a}	115	64.2^{a}	97	29.1^{a}	132
LSD (0.05)	0.5		1.0		0.2		0.3	

*The recommended fertilizer included 20 t ha^{-1} horse manure.
**Means in each column followed by the same letter are not significantly different at p 0.05 according to the LSD test.

The application of RCW, however, had no effect on the leaf concentrations of P in the first crop (Table 27.3), possibly because the P immobilization was not intense enough to bring significant changes in spite of the wide C:P ratio of 535. Similarly, RCW incorporation had no effect on the leaf concentrations of K for the first crop (Table 27.3), indicating that the observed reductions on tomato growth were largely a result of the effects of added RCW on soil N.

The incorporated RCW had positive effects on the growth and yield of the second tomato crop. The relative effects on height (RH) at low, medium and high rates of RCW application were 56%, 67% and 51%, respectively (Table 27.2). The corresponding RY values for fruit yield were 62%, 78%, and 53% for low, medium and high rates of RCW application, respectively. Based on these results, it is evident that

20 t ha^{-1} of RCW application resulted in the highest tomato yields. The observed improvement in plant growth appears to be related to improved nutrient supply and availability. In contrast to the first crop, the incorporated RCW resulted in increased leaf N, P and K concentrations (Table 27.3). The most remarkable increases were observed with leaf N which changed from a depressed situation in the first crop to a situation where significant increases in leaf N were observed at each level of RCW application (Table 27.3). This suggests that by the time the second crop was planted the C:N ratio of the incorporated RCW had narrowed sufficiently to result in net N mineralization instead of immobilization.

Table 27.3: The effect of RCW and L C on tomato leaf contents of N, P and K after 45 days of growth for the first and second crops

Treatment	First crop			Second crop		
	N(%)	P(%)	K(%)	N(%)	P(%)	K(%)
Control	0.95[d**]	0.23[d]	1.11[c]	0.21[d]	0.01[d]	0.01[d]
RF	3.90[c]	0.49[b]	3.31[b]	1.37[c]	0.49[a]	3.34[a]
RF+N	4.10[c]	0.48[b]	2.61[b]	1.41[c]	0.44[a]	3.12[a]
RCW10 t ha^{-1}	0.22[e]	0.31[cd]	1.12[c]	1.51[c]	0.42[a]	1.25[c]
RCW20 t ha^{-1}	0.22[e]	0.34[c]	1.25[c]	2.80[b]	0.45[a]	2.35[b]
RCW40 t ha^{-1}	0.14[e]	0.21[c]	1.19[c]	3.88[a]	0.47[a]	2.29[b]
LC10 t ha^{-1}	3.46[c]	0.51[b]	1.58[c]	1.42[c]	0.21[c]	0.97[c]
LC20 t ha^{-1}	4.72[b]	0.71[a]	2.66[b]	1.20[c]	0.25[bc]	1.03[c]
LC40 t ha^{-1}	7.27[a]	0.75[a]	4.33[a]	2.71[b]	0.31[b]	2.28[b]
LSD (0.05)	0.66	0.10	0.71	0.65	0.08	0.35
CV (%)	15	14	19.3	17.6	16	11.4

*The recommended fertilizer contained also horse manure (20 t ha^{-1})
**Means in each column followed by the same letter are not significantly different at p 0.05 according to the LSD test.

These results imply that, in order to derive maximum short-term crop benefits from the RCW of *C. equisetifolia*, it ought to be allowed to undergo some decomposition in the soil first before a crop is planted. Studies are therefore required to determine how long, before planting, should the RCW be incorporated. If the incubation period of RCW before planting is too long, other studies can be conducted to find ways of shortening the period, possibly through co-application with limited quantities of inorganic fertilizers to overcome the deleterious effects of low quality organics. However, for longer-term crops, the RCW can be used without co-application with other materials.

The results of this study indicate that RCW is potentially a good organic amendment that should be seriously considered for use in the Niayes area. If this idea is adopted, it will be necessary to work out a sustainable ramial wood harvesting regime. At the moment, the ramial wood becomes available only after the trees have been coppiced. However, it is also practically possible to provide a regular supply of the ramial wood through regular pruning of small branches in between coppicing periods.

Effects of litter compost

Application of LC to soil stimulated plant growth. The relative effects on height for LC at low, medium and high levels were 46%, 90% and 100 %, respectively (Table 27.2). The corresponding relative effects on yield during the first crop were 47% at low level, 81% at medium level and 115% at high LC levels of application. The effects were greater during the second crop where RY values of 86% for the LC at low level, 100% for the medium level and 132% for the high level, were observed.

Table 27.4: The effect of RCW and LC on leaf contents of N, P and K at harvest time of the first and second tomato crops

Treatment	First crop			Second crop		
	N(%)	P(%)	K(%)	N(%)	P(%)	K(%)
Control	0.65^{d**}	0.09^{g}	0.08^{f}	0.10^{f}	0.01^{i}	0.01^{e}
RF	1.32^{c}	0.10^{f}	1.53^{d}	0.36^{d}	0.12^{d}	0.17^{d}
RF+N	1.27^{c}	0.10^{f}	1.59^{d}	0.35^{d}	0.12^{d}	0.16^{d}
RCW10 t ha^{-1}	0.55^{e}	0.16^{d}	1.94^{c}	1.76^{b}	0.41^{c}	1.27^{c}
RCW20 t ha^{-1}	0.72^{d}	0.16^{e}	2.18^{ab}	2.12^{a}	0.53^{b}	2.29^{a}
RCW40 t ha^{-1}	0.31^{f}	0.18^{c}	1.39^{de}	1.45^{c}	0.54^{a}	2.13^{b}
LC10 t ha^{-1}	1.28^{c}	0.10^{f}	2.04^{bc}	0.13^{e}	0.03^{g}	0.17^{d}
LC20 t ha^{-1}	2.15^{b}	0.21^{b}	1.29^{e}	0.14^{e}	0.05^{f}	0.16^{d}
LC40 t ha^{-1}	3.67^{a}	0.31^{a}	2.37^{a}	0.24^{de}	0.09^{e}	0.13^{d}
LSD (0.05)	0.09	0.27	0.18	0.16	0.02	0.07

*The recommended fertilizer contained also some horse manure (20 t ha^{-1})
** Means in each column followed by the same letter are not significantly different at p 0.05 according to the LSD test.

During the first crop, tomato growth and yield were increased with each increment in LC application, especially when the rate of applied LC was increased from 20 to 40 t ha^{-1}. This indicated that maximum tomato growth and yield was not achieved with the rates of LC application used in the present study.

The positive effects of LC on the growth of the first tomato crop were associated with its effect to increase soil levels of N, P and K relative to the control and RCW treatments (Table 27.5).

Table 27.5: The effect of RCW and LC on soil N, P and K contents after harvesting the first and second tomato crops

Treatment	First crop			Second crop		
	N(%)	P(mg kg^{-1})	K(%)	N(%)	P(mg kg^{-1})	K(%)
Control	0.15[d]	8.8[c]	0.08[e]	0.03[c]	9.37[c]	0.01[e]
RF	0.29[c]	11.68[ab]	0.18[e]	0.27[a]	12.68[b]	0.17[c]
RF+N	0.27[c]	11.32[b]	0.17[e]	0.29[a]	13.32[b]	0.17[c]
RCW10 t ha^{-1}	0.12[d]	6.21[d]	1.10[e]	0.33[a]	7.22[de]	1.93[a]
RCW20 t ha^{-1}	0.15[d]	5.95[d]	1.18[d]	0.33[a]	6.45[e]	1.96[a]
RCW40 t ha^{-1}	0.13[d]	6.25[d]	1.17[d]	0.39[a]	6.94[de]	1.35[b]
LC10 t ha^{-1}	0.36[b]	7.8[c]	1.943[c]	0.16[b]	8.75[cd]	0.15[cd]
LC20 t ha^{-1}	0.40[b]	10.40[b]	2.78[b]	0.16[b]	11.82[b]	0.17[c]
LC40 t ha^{-1}	0.51[a]	13[a]	3.51[a]	0.17[b]	17.05[a]	0.11[d]
LSD (0.05)	0.05	1.34	0.040	0.06	2	0.05
CV (%)	13	9	2	19	12	5

* The recommended fertilizer contained also horse manure (20 t ha^{-1})
** Means in each column followed by the same letter are not significantly different at p 0.05 according to the LSD test.

This was in turn reflected in corresponding increases in the plant uptake of the nutrients (Tables 27.3 and 27.4). According to Foth and Ellis (1988), young mature leaves of tomato are considered to have adequate levels of N, P and K when they contain at least 1.2% N, 0.3% P and 0.3% K. The concentration of nutrients in tomato leaves after 45 days growth in plots treated with LC (Table 27.3) was higher than the critical levels reported by Foth and Ellis (1988).

The greater effect of LC compared to RCW to increase soil nutrients and tomato growth could be explained by the differences in the C:N and C:P ratios of the two materials. The LC amendment had a C:N ratio of 31 and a C:P ratio of 17, which is within the ranges that allow organic materials to decompose easily and mineralize. By contrast, the C:N and C:P ratios of RCW were 51 and 535, respectively. These values were much higher than those considered as optimum for easy decomposition of organic materials.

The effect of LC on nutrient supply in the soil was much less during the second cropping compared to the first (Table 27.5). However, soil levels of N, P and K associated with the LC treatments were still greater than those observed for the control. The leaf concentration of these nutrients was even lower (Tables 27.3 and 27.4). Interestingly, tomato growth was not affected by this negative nutrient trend. This is possibly because, despite the negative nutrient trend, the leaf N concentration did not drop below the critical level of 1.2%. These results conclusively indicate that the litter compost of *C. equisetifolia*, unlike its ramial chipped wood, releases most of its nutrients soon after incorporation into soil, and that at least for the first two crops, it can be used as the sole source of nutrients for tomatoes. More work is needed to establish the residual effects of this amendment as well as the additional amounts that may have to be applied regularly in order to maintain yields at reasonable levels. Nevertheless, it is clear from the results of the present study that the litter compost of *C. equisetifolia* can be effectively used as a source of nutrients for tomato and possibly other vegetables in the Niayes area. If this amendment is adopted for regular use in the area, it will be necessary to determine sustainable levels of the litter harvesting taking into account its local contribution to nutrient cycling in the plantation ecosystem.

Effect on soil physical and chemical properties

At the final harvest for the second crop, soil was sampled and analyzed for organic matter content, cation exchange capacity, water holding capacity and bulk density. The results obtained are shown in Table 27.6.

Table 27.6: Effect of RCW and litter compost on selected soil properties after the second harvest

Treatment	OM(%)	CEC (cmol(+) kg^{-1})	WHC (mm m^{-1})	DBD (Mg m^{-3})
Control	1.93^{e}	5.2^{h}	99.5^{c}	1.60^{a}
RF	4.38^{b}	7.5^{d}	103.7^{c}	1.39^{bc}
RF+N	4.39^{b}	7.2^{e}	102.5^{c}	1.39^{bc}
RCW10 t ha^{-1}	2.80^{e}	5.8^{g}	125.0^{b}	1.40^{bc}
RCW20 t ha^{-1}	2.68^{e}	6.1^{f}	127.5^{b}	1.39^{bc}
RCW40 t ha^{-1}	2.75^{e}	5.8^{d}	125.5^{b}	1.47^{b}
LC10 t ha^{-1}	3.94^{d}	10.1^{c}	131.5^{b}	1.34^{cd}
LC20 t ha^{-1}	4.16^{c}	15.1^{b}	148.7^{a}	1.30^{cd}
LC40 t ha^{-1}	4.85^{a}	20.4^{a}	143.2^{a}	1.31^{cd}
LSD (0.05)	1.3	0.19	10.1	0.08

*The recommended fertilizer contained also horse manure (20 t ha^{-1})
** Means in each column followed by the same letter are not significantly differen at p 0.05 according to the LSD test

The incorporation of RCW did not increase the amount of organic matter in soil after the second harvest. However, LC application increased the amount of organic matter in soil significantly relative to the control and RF treatments. The organic matter increases observed in plots treated with composted litter could be attributed to its advanced state of decomposition due to composting, which increased the proportion of oxidizable organic matter in the soil. Ramial chipped wood was not substantially decomposed in the soil and consequently did not increase soil organic matter levels.

The cation exchange and water holding capacities of the soil were increased by the application of RCW and LC (Table 27.6). However, the effects of RCW on these parameters were much smaller compared to LC. This was consistent with the observed greater effect of LC to increase organic matter levels in the experimental soil.

All amendments reduced soil bulk density significantly relative to the control but litter compost treatments resulted in the lowest bulk density values (Table 27.6). The significantly lower soil bulk density values in plots treated with LC could be linked to the higher proportion of decomposed organic residues introduced by this amendment. In a non-aggregated soil such as the one used in the present study, it is likely that any change in bulk density was due to the effect of soil amendments. In this respect it was primarily due to polysaccharides present in the decomposing amendments and the resulting humus, which are able to cement soil particles together (Mustin, 1981), resulting in improved aggregation and subsequent reduction in soil bulk density.

Conclusions

The application of RCW depressed tomato growth and yield during the first cropping. This was attributed to the effect of RCW to induce intense N immobilization in the soil due its wide C:N ratio, which resulted in reduced N uptake by tomato plants. Improvements in tomato growth and yield were observed during the second cropping and this was ascribed to improved nutrient release, especially nitrogen, from RCW following its extended incubation in the soil resulting in the mineralization of earlier immobilized nutrients. These results suggested that in order to derive short-term benefits from RCW application it may have to be applied in combination with experimentally determined amounts of mineral fertilizers. A longer-term investigation is, however, necessary to establish the long-term effects of this amendment on the productivity of the experimental soil.

Incorporation of LC resulted in improved tomato growth and production as reflected by increased tomato height and yield relative to the absolute control and recommended fertilizer (RF) treatments during the two croppings. The positive effect of LC to improve soil and tomato uptake of N, P and K, and possibly other nutrients that were not measured by tomato, was associated with the narrower C:N ratio of the composted litter. The observed effects were greater in the first than the second crop indicating that LC had limited residual nutrient value.

Application of LC also improved soil organic matter content and water holding capacity; and reduced the soil dry bulk density suggesting that its regular use could result in the long-term improvement of the productivity of the experimental site.

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References

Bartholomew, W.V. (1965) Mineralization and immobilization of nitrogen in the decomposition of plant and animal residues. *Soil Nitrogen. Agronomy* 10: 285-290.

Blake, G.R. and Hartge, K.H. (1986) Particle Density. *In* A. Klute. *Methods of Soil Analysis. Physical and mineralogical Methods.* Agronomy no. 9 Part 1 2nd Edition. 377-382. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Brady, N.C. and Weil, R.R. (1999) The nature and properties of soils. 12th Edition. 466-489.

Bremner, J.M. and Mulvey, C.S. (1982) Nitrogen-Total. *In* Pages A. L. Methods of Soil Analysis. *Chemical and Microbiological Properties.* Agronomy no. 9 Part 2. 2nd Edition. 595-624. Soil Science Society of America, Madison, Wisconsin, U.S.A..

Cassel, D.K. and Nielsen, D.R. (1986) Field capacity and available water capacity. In methods of Soil Analysis. Physical and mineralogical Methods. Agronomy no. 9. Part 1. 2nd Edition. 901-926. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Engelstad, O.P, Jugsujinda and De Datta, S. (1974) Response by floded rice at phosphate rocks varying in citrate solubility. *Soil Sci. Soc. Am. Proc*. 38: 524-529.

FAO-UNESCO-ISRIC (1990) *Soil map of the world.* Revised legend. Reprinted with corrections. World Soil Resources Report no. 60. Food and Agriculture Organization of the United Nations, Rome Italy.

Foth, H.D. and Ellis, B. (1988) *Soil fertility*. Edt Wiley & Son. New York. pp 212.

Gee, G.W. and Bauder, J.W. (1986) Particle size analysis. In *Methods of soil Analysis. Chemical and Microbiological Properties.* Agronomy no. 9. 2nd Edition. 383-411. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Gomez, K.A. and Gomez, R.A. (1984) *Statistical Procedures for Agricultural Research.* Second Edition. 657 pp.

Knudsen, D., Peterson, G.A. and Pratt, P.F. (1982) Lithium, sodium and Potassium. *In* Pages A..L. *Methods of Soil Analysis. Chemical and Microbiological Properties.* Agronomy no. 9 Part 2 2nd Edition. 225-246. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Lanyon, L.E. and Heald, W.R. (1982) Magnesium, Calcium, Strontium and Barium. *In Methods of Soil Analysis. Chemical and Microbiological Properties.* Agronomy no. 9 Part 2, 2nd Edition. 247-262. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Lemieux, G. (1993) Le bois raméal fragmenté et la méthode expérimentale: une voie vers un institut international de pédogénese» *In les actes du quatrieme collogue international sur les bois raméaux fragmentés.* Edité par le groupe de coordination sur les bois raméaux. Departement des Sciences Forestières. Université Laval. Quebec. 124-138.

Maheut, J. and Dommergues, Y. (1963) Evaluation du taux de fixation d'azote dans un sol dunaire reboise en filoa. *Agrochimica* 7: 335-340.

Mailly, D. and Margolis, H. A. (1992) Forest floor and mineral soil development in *Casuarina equisetifolia* plantation on the coastal sand dune of Senegal. *For. Ecol. and Manage.* 55: 259-278.

Mclean, E.O. (1982) Soil and pH and lime requirements. *In* Pages A. L. Methods of Soil Analysis. *Chemical and Microbiological Properties.* Agronomy no. 9. Part 2. 2nd Edition. 199-224. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Mustin, M. (1981) *Le compost.* Editor Francois Dubusc. Paris, France.

N'dayegamiye, A. and Dube, A. (1986) L'effet de l'incorpporation de matières ligneuses sur l'évolution des propriétés chimique du sol et sur la croissance des plantes. *Can. J. Soil Sci.* 66: 623-631.

Nelson, D.W. and Sommers, L.E. (1982) Total carbon, organic carbon and organic matter. *In Methods of Soil Analysis. Chemical and Microbiological Properties.* Agronomy no. 9. Part 2. 2nd Edition. 539-579. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Netscher, P. (1970)Les nématodes parasites des cultures maraichères au Sénégal. *Cah. ORSTOM Ser. Biol.* 11: 209-283.

Okalebo, J. R., Guathua, K. W. and Woomer, P. L. (1993) *Laboratory methods and Plant Analysis. Working manual.* Karhsobf, Nairobi Kenya. pp 55.

Olsen, S.R. and Sommers, L.E. (1982) Phosphorus. *In Soil Testing and Plant Analysis.* Book series no.3. Third edition. SSSA, Madison, Winconsin, USA. pp: 403-430. Soil Science Society of America, Madison, Wisconsin, U.S.A.

Rhoades, J.D. and Miyamoto, S. (1990) Testing Soil for salinity. *In Soil Testing and Plant Analysis,* 3rd Edition. SSSA Book series no 3:299-336.

Rustad, L.E. and Cronan, C. (1988) Element loss and retention during litter decay in a red spruce stand in Maine. *Can. J. For. Res.* 18: 947-953.

Seck, A.. et Lemieux, G. (1993) Essai de fertilisation avec le boi raméal fragmenté dans les cuvette de Niayes: *In les actes du quatrieme collogue international sur les bois raméaux fragmentés.* Edite par le groupe de coordination sur les bois raméaux. Departement des Sciences Forestieres. Universite Laval. 36-41.

Sylvestre, A. and Despatie, S. (1995) *Effet des bois raméaux fragmenté sur la croissance et les rendements du mais en zone de transition foret-savane de la Cote d'Ivoire*, 5pp.

Tremblay, J. and Beauchamp, C.J. (1998) Fractionnement de la fertilisation azotée d'appoint a la suite de l'incorporation au sol de bois raméaux fragmentés : modifications de certaines propriétes biologiques et chimiques d'un sol cultivé en pomme de terre. *Can. J. Soil Sci.* 78: 275-282.

The Use of Pigeon Pea *(Cajanus cajan)* for Amelioration of Ultisols in Ghana

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Abstract

Pigeon pea, a multi-purpose species, is extensively used as food grain and green manure crop for soil fertility amelioration in local cropping systems. Recently, pigeon pea root exudates have been found to contain phenolic compounds (e.g. piscidic acid), which chelate Fe to free P in Fe bound P in soils for crop uptake. It is also reported that pigeon pea root exudates dissolve phosphate-containing rocks (e.g. phosphate rocks) to make P available for crop use. There are however, a few instances in West Africa where the use of pigeon pea has become unpopular among farmers due to its low and variable yield as well as its inability to redress soil fertility sufficiently in the long-term. In this study, the nutrient cycling, moisture storage of pigeon pea collections is reported.

Key words: pigeon pea, nutrient cycling, moisture storage

Introduction

Crop production in peasant cropping systems in the semi-arid areas of West Africa is generally constrained by low and uncertain rainfall, poor soil fertility (low nutrients content and structural degradation), lack of credit facilities to purchase inputs such as fertilizers and improved varieties (Weber *et al.*, 1996; Bationo *et al.*, 1993). Of these, phosphorus and nitrogen usually limit crop yields on farm fields. Under favourable soil and weather conditions, yields of improved maize ranged from 4.0 to 7.0 t ha^{-1} (Elemo *et al.*, 1990). However, yields of improved varieties in nutrient and moisture-stressed conditions, typical of farmers' circumstances ranged from 0.30 to 4.0 t ha^{-1} (Carsky *et al.*, 1998). Crop yields will continue to decline in so far as appropriate remedial measures are not put in place to conserve moisture and restore soil fertility (Mermut and Eswaran, 1987).

Scientists in West Africa and elsewhere in the tropics, have developed biological management practices which have the potential to address the problem of low soil productivity in the region (Peoples and Craswell, 1992; Sanchez and Salinas, 1981).

Corrective measures that have been developed by local and international research groups to address soil fertility related problems include:

1) the use of organic and inorganic mineral fertilizers (Smyth *et al.*, 1993; Manu *et al.*, 1988),
2) intercropping of cereals and legumes (Sanginga *et al.*, 1996),
3) legume based cropping systems e.g. herbaceous green manuring, agroforestry, improved fallow (Mafongoya *et al.*, 1997; Barnes, 1995)
4) crop residue mulch management (Tian *et al.*, 1993; Adeoye, 1984; De Vleeschauwer *et al.*, 1980);
5) the use of local rock phosphate (Ankomah *et al.*, 1995; Zapata and Axmann, 1991; Hammond *et al.*, 1986 and
6) integrated soil husbandry comprising a combination of the above (Mugwira and Mukurumbira, 1984).

These options were designed to increase nutrient use efficiency, make the environment less harmful as well as to reduce costs of production.

Pigeon pea, a multipurpose species, is extensively used as food grain and green manure crop for soil fertility amelioration in cropping systems (Adu-Gyamfi *et al.*, 1996; Tobita *et al.*, 1994). Pigeon pea root exudates have been found to contain phenolic compounds (e.g. piscidic acid), which chelate Fe to free P in Fe bound P in soils for crop uptake (ICRISAT, 1999). It has also been reported that pigeon pea root exudates dissolve phosphate-containing rocks (e.g. phosphate rocks) to make P available for crop use (Ae *et al.*, 1990). There are however, a few instances in West Africa where the use of pigeon pea has become unpopular among farmers due to its low and variable yield as well as its inability to redress soil fertility sufficiently in the long-term (Juo *et al.*, 1996).

The objective of the study is to validate the hypothesis that cultivation of pigeon pea results in nutrient contribution to the soil.

Methodology

Site characterisation

The field study was carried at the Soil Research Institute experimental field at Kwadaso, Kumasi (6°40'N, 1°4W; 255 m above sea level) (Soil Survey Staff, 1990) in the semi deciduous forest zone of Ghana. The mean annual rainfall in the area is 1473 mm per annum; the rainfall pattern is bimodal, the rainy season starts in March and ends in October, with a short dry spell in August with peaks in June and September. The soil is classified as Ferric Acrisol (FAO-UNESCO, 1990).

Soil sampling

Composite samples from the 0-20 cm depth were taken from the experimental sites following the method of Anderson and Ingram, (1993) The samples were transported to the laboratory at the Soil Research Institute, Kumasi and air-dried. Un-decomposed plant materials were sorted out and the samples crushed to pass a 2-mm sieve. The sieved soil samples were stored in thick polythene bags for laboratory analyses.

Soil analyses

Soil Particle size distribution was determined by the modified Bouyoucos hydrometer method as described by Day (1965). Soil pH was determined in distilled water using a Glass electrode-calomel electrode (McLean, 1982), MV Pracitronic pH meter at a soil solution ratio of 1:1. Organic carbon was determined by the method of Bremner (1965) and soil available phosphorus was by Bray 1. Exchangeable Ca and Mg in the extract were determined by an atomic absorption spectrophotometer. The K and Na were determined by flame photometry. The effective cation exchange capacity (ECEC) was calculated as the sum of the exchangeable potassium, calcium, magnesium and sodium. All analyses were carried out in duplicate.

Pot experiment

Three seeds of each collection of pigeon pea were sown into pots containing 5.0 kg soil. The treatments were replicated four times and pots were arranged in a completely randomized design. Seedlings were thinned to two per pot one week after germination. The moisture contents in the pots were kept at filled capacity throughout the experimental period with demineralized water. Plants were harvested 36 days after planting and the above-ground plant material as well as the below-ground material washed in distilled water. Harvested plant materials were oven-dried and weighed.

Establishment of pigeon pea for field study

The study site was a three- year fallow field with *Chromolaena odorata* as the dominant weed. The site was hand cleared with cutlass and the thick biomass was burnt thereafter.

Nine (9) pigeon pea cultivars of 90 % germination were planted on 13th June 2000 at two seeds per hill. The collections were:

1) 82/492;
2) 82/472;
3) GJ 93/207;
4) 82/137;
5) 82/021;
6) 82/433;
7) 82/491;
8) 82/486 and
9) 82/481.

These collections represent local pigeon pea germplasm from Ghana collected by the Plant Genetic and Research centre (PGRC, Bunso of the Council for Scientific and Industrial Research, (CSIR). The collections belong to the family Papilionaceae and the scientific name is *Cajanus cajan* and the common name is pigeon pea. The locations where collections were made are shown in Table 28.1.

Table 28.1: Some basic information of the pigeon pea cultivars

Collection number	Locality	Vernacular name	Source of sample
82/492	Gomoa Akropong	*Adua*	Field
82/472	Ejura	*Asedua*	Field
GJ 93/207	Tanoboase	*Akye*	Farm store
82/137	Kwahu Tafo	*Adua*	Farm store
82/021	Norre	*Adua*	Farm store
82/433	Bonuntong	*Adua*	Farm store
82/491	Aboabo	*Ase*	Farm store
82/486	Ayere	*Ase*	Farm store
82/481	Kontonso	*Ase*	Farm store

Experimental design for the field study.

The experimental design was a randomised complete block with four replications. Plot size was 4 m x 4 m and the distance between plants were 1 m apart.

Trial maintenance

Efforts were made to ensure 100 % seed establishment by refilling withered seedlings. Weeding was done mechanically with a hoe as often as was necessary.

N and P were applied at the rate of 50 kg N ha^{-1} and 20 kg P ha^{-1} respectively, to each treatment four weeks after planting.

Results and Discussion

Table 28.1 shows locations in Ghana where pigeon pea commonly grown were collected. The locations indicate the adaptability of the crop across the major agro-ecological zones of the country. The collections vary in seed colour and have benefited very little from morphological characterisation.

Table 28.2: Shoot and root dry matter yield of pigeon pea collections.

Collection	Shoot Dry matter yield g pot^{-1}	Root dry matter yield g pot^{-1}
82/492	4.49	1.14
82/472	3.96	0.73
GJ 93/207	2.96	0.55
82/137	2.49	0.46
82/021	3.28	0.54
82/433	5.07	0.77
82/491	4.41	0.58
82/486	4.98	0.73
82/481	2.65	0.43
LSD (0.05)	NS	NS
S.E	1.16	0.22

The production of above-ground as well as below-ground biomass from the pot study did not differ significantly among the collections (Table 28.2). Again all the collections showed few tiny ineffective nodules at harvest.

Table 28.3: The effect of pigeon pea cultivation on some soil properties after one year of cultivation.

Soil properties	Uncultivated soil	Pigeon pea cultivated soil	Standard Error
pH 1:1 H_20	4.96	4.73	0.11
Organic carbon (%)	1.98	1.93	0.06
% Nitrogen	0.23	0.23	-
C/N ratio	8.5	8.5	0.16
Exchangeable calcium (ppm)	5.92	5.2	0.39
Exchangeable magnesium (ppm)	1.0	2.08	0.42
Exchangeable potassium (ppm)	0.16	0.17	0.01
Exchangeable sodium (ppm)	0.02	0.03	-
Total exchangeable bases	7.10	7.47	0.43
ECEC (C.mol/kg)	7.2	7.58	0.43
Available P (ppm)	2.99	2.21	0.28
Available K (ppm)	57.88	77.88	5.68
Bulk density (g/cm^3)	1.28	1.40	0.03
Moisture content(g/g)	16.1	20.43	1.44
% sand	38.37	41.13	1.44
% silt	38.88	46.25	1.57
% clay	20.00	15.38	1.15

Table 28.3 shows the properties of the 0-20 cm layer of soils under pigeon pea and in the uncultivated sites after one year of cultivation. The data indicated a decline in soil pH with cultivation. The mean organic carbon content of the pigeon pea sites is about 2.5 % lower than the mean of the uncultivated sites. There are no differences between the uncultivated soil and the cultivated soil with respect to the levels of total nitrogen and C/N ratio.

In general with the exception of exchangeable calcium which was almost 12 % more in the uncultivated site compared to the pigeon pea cultivated sites, exchangeable cations were higher in the pigeon pea cultivated sites than in the uncultivated sites. Exchangeable magnesium was more than 100 % higher in the pigeon pea cultivated sites compared to the uncultivated sites. Similarly, total exchangeable bases were about 5 % higher in the cultivated sites compared to the uncultivated sites. The cation exchange capacity of the pigeon pea cultivated sites increased by 5 % with respect to the uncultivated site within one (1) year. Also, available potassium increased by 25 % in the cultivated site. Available phosphorus, however, declined by almost 26 % in the cultivated sites with respect to the uncultivated site. The texture of the soil is loam in both the uncultivated and the cultivated sites. With the exception of percentage clay , pigeon pea cultivated site indicated a higher % particle size than the uncultivated sites. More moisture was stored under pigeon pea cultivated site which also showed a higher bulk density (1.40 g cm^{-3}), than the uncultivated site (1.28 g cm^{-3}).

The decrease in soil pH with cultivation could be attributed to erosion of the exposed sites prior to canopy closure of pigeon pea. It is possible that the amount of N derived from biological nitrogen fixation was utilised by the cultivated crop rather than soil N. Pigeon pea like all legumes, has a high phosphorus need and its performance can be affected by low soil P as is the case in most tropical soils. Under the present management of low fertilizer inputs, P shows a decline with cultivation. Soils under fallow however, had high levels of P. This is a reflection of the biological biochemical mineralization processes during which organic matter is mineralized. It is also a reflection of biocycling of P through deeper plant roots causing a relative enrichment in the topsoil (Barber, 1979).

Considering the fact that moisture storage improved under pigeon pea cultivated sites, the crop could be considered as a possible candidate in a moisture-stressed agro-ecological environment.

Conclusion

The one year study clearly demonstrated that there is a high potential for pigeon pea as a good vehicle for magnesium, potassium and sodium cycling in soils. The most valuable information for management decisions is the phosphorus mining under pigeon pea cultivation, where seed grain is harvested. Given the high cost of chemical fertilizers and the fact that most peasant farmers cannot afford their purchase, the need to test the efficiency of other sources such as phosphate rocks with pigeon pea based farming systems is great.

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References

Adu-Gyamfi, J.J., Katayama, K., Gayatri, D., Rao, T. P. and Oto, O. (1996) Improvement of fertilizer and nitrogen use efficiency in intercropping. In Ito, O.

Johansen, C., Adu-Gyamfi, J.J., Katayama, K., Rao, J.V.D.K and Rego, T.J (eds.)

Dynamics of roots and nitrogen in cropping systems of the semi-arid tropics. pp 493-506. Japan International Center for Agricultural Sciences (JIRCAS), JIRCAS *International Agriculture Series No. 3.* Tsukuba

Adeoye, K.B. (1984) Influence of grass mulch on soil temperature, soil moisture and yield of maize and gero millet in a savanna zone soil. *Samaru Journal of Agriculrural Research* 2: 87-97.

Ae, N, Arihara, J., Okada, K., Yoshihara, T. and Johansen, V. (1990) Phosphorus uptake by Pigeonpea and its role in cropping systems of the Indian subcontinent. *Science* 284: 477-480.

Anderson, J.M and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A handbook of Methods.* CAB International, Wallington, U.K

Ankomah, A..B, .Zapata, F., Danso, S.K.A. and Axmann. H. (1995) Cowpea varietal

differences in uptake of phosphorus from Gafsa rock in a low-P Ultisol. *Fertilizer Res.* 41: 219-225.

Barnes, P. (1995) Dry matter of herbage productivity and aspects of chemical composition in four forage shrub species at a semihumid site in Ghana. *Agroforestry Systems* 31: 223-227.

Bationo, A., Christianson, C.B. and Klaij, M.C. (1993) The effect of crop residues and fertilizer on use of pearl millet yields in Niger. *Fertilizer Research* 34: 251-258.

Bremner, J.M. (1965) Total nitrogen. In: *Methods of soil Analysis Part 2.* Chemical and Microbiological properties. (eds) Black, C.A. *Agronomy Monograph 9.* Pp 1149-1178.

Carsky, R.J., Oyelwole, B. and Tian, G. (1998) Integrated soil management for the savanna zone of West Africa: legume rotation and fertilizer N. *Nutrient Cycling in agroecosytems* 55: 95-105

Day, P.R. (1965) Particle fractionation and particle size analysis. In C.A. Black ed., *Methods of Soil analysis,* 545-67. Madison, WI: American Society of Agronomy.

De Vleeschauwer, D., Lal, R. and Malafa, R. (1980) Effects of amount of surface mulch on physical and chemical prpperties of an Alfisol from Nigeria. *Journal of Science food and agriculture* 31: 730-738.

Elemo, K.A, Kumar, V., olukosi, J.O. and Ogunbile, A.O. (1990) Review of research work on mixed cropping in the Nigeria savanna. Samaru Miscellaneous Paper No. 127. IAR, Samaru, Nigeria.

FAO-UNESCO. 1990. Soil map of the world. *Revised Legend.* F.A.O, Rome. 119 pp.

Hammond, L.L., Chien, S.H. and Mokwunye, A.U. (1986) Agronomic value of unacidulated and partially acidulated phosphate rocks indigenous to the tropics. *Adv. Agro.* 40: 89-140.

ICRISAT, (1999) 15 *Years of Progress: Government of Japan Project at ICRISAT 1984-99* (Adu-gyamfi, J.J., ed.). 1-2 Ohwashi, Tsukuba, Ibaraki 305-9851, Japan and Patancheru 502 324, Andhra Pradesh, JIRCAS and ICRISAT. 32pp.

Mafongoya, P.L, Nair, P.K., Dzowela, B.H. (1997) Mutipurpose tree prunings as a source of nitrogen to maize under semiarid conditions in Zimbabwe.1. Nitrogen recovery rates in relation to pruning quality and the method of application. *Agrofor. Syst.* 35: 31-46.

Manu, A, Geiger, S.C. and Bationo, A. (1988) The interactive effect of P fertilizers and millet residue on P dynamics of a sandy Nigerian soil. Agronomy Abstracts p 59 Amerrican Society of Agronomy.

McLean, E.O. (1982) *Soil pH and lime requirement.* Pp 199-224. In Page, A.L., R.H. Miller and D.R. Keeney (eds) 1982. *Methods of soil analysis.* Part 2 (2nd edition). Chemical and Microbiological Properties- *Agronomy Monograph no. 9*

Mermut, A.R., and Eswaran, H. (1997) Opportunity for soil science in a milieu of reduced funds. *Can. J. Soil Sc.* 77: 1-7.

Mugwira, L.M and Mukurumbira, I.M. (1984) Comparative effectiveness of manures from the communal areas and commercial feedlots as plant nutrient sources. *Zimbabwe Agriculture Journal* 81: 241-250.

Peoples, M.B and Craswell, E.T. (1992) Biological nitrogen fixation: investments, expectation and actual contribution to agriculture. *Plant and Soil* 141:13-40.

Sanchez, P.A. and Salinas, J.G. (1981) Low input technology for managing Oxisols and Ultisols in Tropical America. *Advances in Agronomy* 34: 279-406.

Sanginga, N., Okogun, J.A., Akonbundu, I.O.and Kang, B.T. (1996) Phosphorus requirement and nodulation of herbaceous and shrub legumes in low P soils of a Guinea Savanna in Nigeria. *Applied Soil Ecol.* 3: 247-255.

Smith, A.J., Dumanski, J., Spendjian, G., Swift, M.J. and Thorton, P.K (1993) FESLM: An international framework for evaluating sustainable land management. A discussion paper. FAO, Rome.

Soil survey Staff. (1990) Keys to Soil Taxonomy USDA. *SMSS Tech. Mon.* No. 19 (4edn) Blacksburns, Virginia, USA: SMSS.

Tian, G, Kang, B.T. and Brussaard, L. (1993) Mulchiong effect of plant residues with chemically contrasting compositions on maize growth and nutrients accumulation. *Pl.Soil.* 153: 179-187.

Tobita, S, Ito, O., Matsunaga, R., Rao, T. P , Rego, T. J., Johansen,C. and Yoneyama, T. (1994) Field evaluation of nitrogen fixation and use of nitrogen fertilizer by sorghum/pigeon pea intercropping on an Alfisol in Indian semi-arid tropics. *Biol.Fert. Soils* 17: 241-248.

Weber,G., Smith, J. and Manyong, V.M. (1996) System dynamics and the definition of research domains for the northern Guinea Savanna of West Africa. *Agriculture, Ecosystems and Environment.* 57: 133-148.

Assessment of Biomass Transfer from Green Manure to Soil Macrofauna in Agroecosystem-*Soil Macrofauna Biomass*

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Abstract

During 1997 short rains (Oct 1997-Feb 1998), a study was undertaken to assess how biomass transfer within agroecosystem influence soil biodiversity (soil macrofauna biomass).

This was part of a larger experiment conducted to test the hypothesis that diversity, abundance and function of soil invertebrate fauna are related to the quality of organic residues used. Leaf biomass of tithonia (*Tithonia diversifolia* [Hemseley) A. Grey) biomass and senna (*Senna spectabilis* D.C. & H.S. Irwin) biomass at 5 t ha^{-1} dry weight were incorporated into the soil and these were compared with the control without any input and fertilizer at 120 kg N, 150 kg P and 100 kg K ha^{-1} from urea and triple super phosphate (TSP). Macrofauna biomass (fresh weight), was monitored in soil monoliths (25cm x 25cm x 30cm) at the beginning of the season, six weeks after sowing maize and at maize harvest.

Addition of organic residues increased faunal biomass substantially over the fertilized and unfertilized controls. Whereas senna increased total biomass by 45% and tithonia by 49%, the two organic residues did not differ significantly between them. Addition of either senna or tithonia significantly increased earthworm biomass by 390% over no input control. Even though termite biomass increased by 160% in senna and 120% in tithonia over no input control, F test was not significant because of high variability between replications of the same treatment. Fertilizer use did not change biomass of termites and earthworms.

This study shows that:

(1) addition of organic residues significantly increase faunal biomass indicating a likelihood that soil invertebrate functions can be manipulated by external inputs of organic residues

(2) under arable land use system characterized by low amount, range and diversity of food resources, quality of organic residues do not play a significant role in influencing foraging behaviour of soil invertebrates. It therefore remains to be demonstrated whether mixing litter of organic residues of different quality may change this foraging behaviour and consequently the invertebrate functions in agroecosystem.

Key words: Biomass transfer, macrofauna, biomass, earthworms, termites

Introduction

Soil fauna comprises a large variety of organisms with contrasted sizes and adaptive strategies. Their abundance, and composition, hence impact on soil processes vary greatly depending on vegetation and land use practices (Lavelle *et al.*, 1994a). Management practices such as continuous tillage can cause alterations in the population structure, elimination or reduction of key species and in some cases extremely low abundance or biomass (Dangerfield, 1993; Beare *et al.*, 1997). These negative effects created by management practices may last for years.

House and Parmelee (1985), found that soil arthropods and earthworm densities were higher under no tillage than in conventional tillage practices, an expanded and beneficial involvement for this fauna in crop residue decomposition processes. Studies conducted by Brown *et al.* (1996) showed that under agro-ecosystem, earthworms were the most dominant organism in terms of biomass, while in terms of numbers, ants and termites predominated. The faunal biomass was however low, compared with other tropical sites. In terms of diversity of faunal groups, they found that natural sites were richer than cultivated sites. Dangerfield (1993) found similar results and asserted that change of natural forest, for instance, to arable agriculture resulted in a dramatic decrease in faunal biomass, and diversity and a shift in dominance from millipedes to beetle larvae and earthworms. The change in habitat structure (removal of vegetation), the reduced range and abundance of food resources and the more extreme climatic conditions at the soil surface, combine to create an environment beyond the tolerance limits of most soil animals (Dangerfield, 1993). Only those species that are buffered from climatic extremes by building nests (e.g. termites) or living in deeper soil layers (e.g. beetle larvae), are not immediately affected, but may eventually suffer from the reduction in food resources (House and Parmelee, 1985; Dangerfield, 1993; Tian *et al.*, 1997). This explains why a severe depletion of soil fauna has been observed in highly degraded soils (Lavelle *et al.*, 1994b).

Mafongoya *et al.* (1996), found that changes in microbial community could be manipulated by applying prunings of different quality such that processes of litter decomposition and nutrient dynamics are enhanced. The major aim of the study was therefore to find out whether through inputs of locally available organic residues of different quality one could manipulate diversity, populations and 'biomass' of soil invertebrate fauna in order to enhance nutrient cycling, improve soil physical properties and also regulate decomposition processes.

Materials and Methods

Study site description

The study was conducted at Maseno (0°6' N, 34°35' E, and 1560 m above sea level), in Vihiga District of western Kenya (Jaetzold and Smith, 1982). The area receives an average annual rainfall of 1800 mm in two rainy seasons; 'long rains' (March to July) and 'short rains' (September to January). However during 1997 a total rainfall of 2037 mm was received, with 1200 mm in the short rains because of *El nino* phenomenon. Mean monthly temperature ranges between 14.6°C and 30.7°C. The soil at the experimental site was classified as Kandiudalfic Eutrodox (USDA, 1992). At the start of the study, the field had the following soil physical and chemical characteristics at 0-15cm and 15-30 cm depths respectively: pH (1:2.5 soil water) 5.5, 5.5; organic carbon (g kg^{-1} soil) 15.5, 14.5; extractable soil inorganic P (mg kg^{-1}) 1.3, 0.9; exchangeable calcium (cmolc kg^{-1}) 4.03, 3.85; exchangeable potassium (cmolc kg^{-1}) 0.15, 0.13; clay (%) 41, 42; sand (%) 33, 33; silt (%) 26, 25; porosity ranged between 50% and 60%. The soil is considered to be moderately P fixing with a soil P concentration corresponding to 310 mg P kg^{-1} adsorbed by the soil (Nziguheba *et al.*, 1998).

Experimental set up and management

The present study was superimposed on an on-going larger experiment that was initiated in 1995 during the short rains season to evaluate six organic tree and shrub residues (*Tithonia diversifolia*, *Lantana camara*, *Calliandra calothyrsus*, *Senna spectabilis*, *Sesbania sesban* and *Croton megalocarpus*), as sources of nutrients in comparison with inorganic nutrients at six different N and P levels. The treatments were replicated four times in a randomized complete block design in plots of 7.5 m wide and 7 m long.

The study was conducted during the 1997 short rains in the following treatments using maize as the test crop:

(1) Control: maize with no external inputs (Farmers' practice),
(2) Maize + fertilizer input at: 120 kg N, 150 kg P and 100 kg K ha^{-1},
(3) Maize + fresh biomass of *Tithonia diversifolia* at 5 tonnes (dry weight) ha^{-1} and
(4) Maize + fresh biomass of *Senna spectabilis* at 5 tonnes (dry weight) ha^{-1}.

The trial initially did not include "absolute control" (no N and P), so a farmers' no input control was randomly assigned to one of the unutilized blank plots in each replication. The site was relatively flat and there was no particular problem of runoff from plot to plot.

The amount of N and P added by the organic residues depends on the chemical composition. Chemical composition was determined every season at the time of application. All the selected material contained fairly high N and P, but differed with respect to tannin, lignin, polyphenol levels (Table 29.1). In the fertilized plots, 120 kg N ha^{-1} rate was chosen as it is close to the total N applied for the different materials ranging between 136 Kg N ha^{-1} to 183 Kg N ha^{-1}. The rate is also sufficient to overcome N limitation to maize growth in these soils. The choice of the two residues (tithonia and senna) was based on:

1) the nutrient (N and P) concentration,
2) plant residue quality index (PRQI) (Tian *et al.*, 1995) and
3) availability in the region for potential use by farmers.

The difference between the two test materials as measured by PRQI has turned out to be much smaller than initially thought. However, the experience of many researchers indicates that tithonia decomposes faster than senna and represents high quality residues (Gachengo, 1999; Palm *et al.*, 2001). In western Kenya, particularly around Maseno area, farmers grow tithonia as part of live fence around their farms to mark boundaries or as hedges on contour. *Senna spectabilis* trees are also common. The two residues were therefore readily available.

Table 29.1: Chemical composition and plant residue quality index (PRQI) of tithonia and senna foliage

Plant residue	%N	%P	%Lignin	% Poly-phenols	C/N ratio	PRQI(%)
Senna spectabilis	3.3	0.21	9.0	1.03	10.89	10.26
Tithonia diversifolia	3.5	0.28	9.0	3.20	10.10	10.59

Crop management

The entire field was tilled manually at the beginning of the season. Tithonia and senna biomass were incorporated into the topsoil during land preparation. The materials were collected a day before land preparation. The required quantity of the fresh materials at 5 t ha^{-1}, was weighed (based on predetermined fresh weight to dry weight ratio; 16:1), and distributed uniformly on the ground before working into the soil. Maize (hybrid 511), was sown on October 9, 1997 (a day after incorporating treatments), at a spacing of 0.75m between rows and 0.25m between plants. Two seeds were placed into each hole, but the crop was thinned to one plant per hole 14 days after emergence, during first weeding. In the fertilizer treatment, the entire quantity of P as triple super phosphate and K as muriate of potash and half quantity of N as urea required for the plot were weighed and incorporated into the soil during land preparation. The balance of N was top dressed one and half months (42 days), after crop emergence during second weeding. In the field, no plant protection for both pests and diseases was applied as the study involved faunal observations.

Macrofauna biomass assessment

Using a monolith unit of size 25 cm x 25 cm x 30 cm, samples were taken at three periods during the season (Anderson and Ingram, 1993):
1) at the start of the experiment before the treatments were applied (October 6, 1997),
2). six weeks after treatments were applied (November 19, 1997) and
3) at the end of the season (February 18, 1998).

At each observation, two samples were taken randomly from each plot. The monolith was placed over a randomly selected spot and using a metallic mallet, it was driven into the soil until it was level with the ground. The soil from the monolith was removed by hand depthwise (0-10, 10-20 and 20-30 cm) into plastic buckets. The soil from each depth was placed in different plastic trays (20 cm by 30 cm) and gently sorted out to locate the animals. The animals were separated into major taxonomic groups, recorded and then collected in glass and plastic bottles using a pooter. In the laboratory, counting and weighing (for biomass), were done. The fresh weight (in grams) determination took place within 12 hours from the time of sampling. Biomass of different category of animals was expressed per metre square (Anderson and Ingram, 1993).

Data analyses

The data collected were subjected to analyses of variance (ANOVA), to compare treatment effects on diversity, populations and biomass of soil invertebrate fauna ANOVA was conducted using the GENSTAT 5 Committee (1993) statistical package. Where sampling was conducted at different periods, the data were analyzed in a split-plot design with the applied treatments as the main plot factor and sampling period as the sub-plot factor. Treatment differences were evaluated using the least significance difference (LSD) at $P<0.05$. Standard error of difference of means (SED) was given.

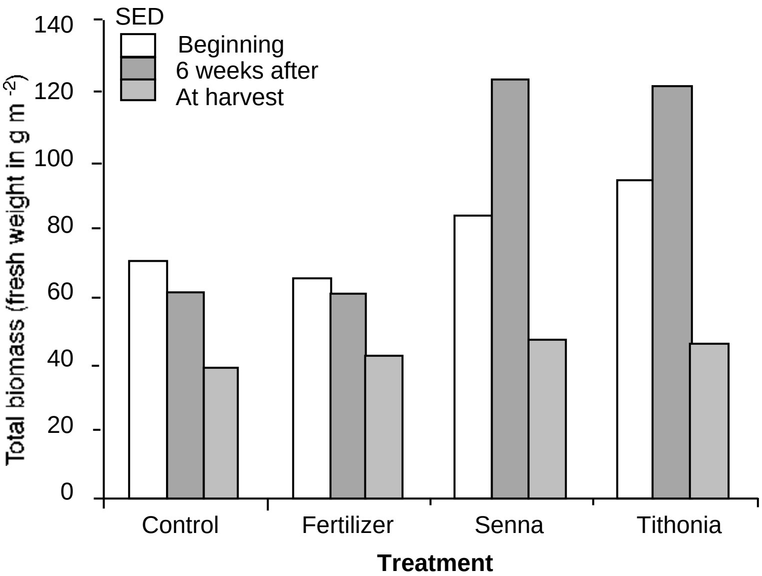
Results

Total faunal biomass

Addition of organic residues increased faunal biomass substantially over the fertilized and no input controls. Whereas senna treatment increased total biomass by 45% and tithonia by 49%, the two organic residues did not differ significantly.

Faunal biomass varied significantly over time between green manure, fertilizer and no input control. At the beginning of the season, senna and tithonia green manure treatments recorded 17% and 32% higher faunal biomass than the no input control and 28% and 43% than fertilized control, respectively. At six weeks after applying the materials, senna treatment recorded 100% higher biomass than the fertilizer and no input control treatments. Tithonia treatment recorded 96% higher biomass than both fertilizer and no input control treatments (Figure 29.1). While the biomass in the fertilized and no input treatments decreased continuously as the season progressed, it increased in the green manure treatments by 48% for senna and 29% for tithonia at six weeks stage and then declined to about 50% of the initial values at crop harvest in both treatments (Figure 29.1).

Figure 29.1: Total biomass (fresh weight) of soil fauna in maize green manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, Western Kenya



Earthworm biomass

ANOVA of earthworm biomass indicated significant differences due to treatments, sampling period and interaction between them.

The average earthworm biomass across treatments was low at 2.1 g m^{-2} for both fertilizer and no input control, but addition of both senna and tithonia green manures, significantly increased the biomass by five times. The two organic materials did not differ in their effect on earthworm biomass. For no input control and fertilizer treatments, the earthworm biomass was highest at the beginning of the season and it decreased considerably in course of the season. Green manuring with senna and tithonia increased the earthworm biomass by 100% and 72% respectively, at six weeks after applying the material, but the biomass at final crop harvest was low similar to that in other treatments (Table 29.2).

Table 29.2: Fresh weight of earthworms in maize green-manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, western Kenya

Treatment	Sampling time			Mean
	Before sowing	6 weeks after sowing	At harvest	
	(weight g m^{-2})			
Control	9.8 (3.6)	0.5 (1.2)	0.3 (1.0)	2.1 (1.9)[b]
Fertilizer	8.5 (3.4)	0.4 (1.1)	0.7 (1.3)	2.1 (2.0)[b]
Senna spectabilis	21.6 (5.2)	10.7 (3.8)	3.0 (2.2)	10.3 (3.7)[a]
Tithonia diversifolia	8.0 (3.3)	13.8 (4.2)	1.7 (1.8)	10.3 (3.7)[a]
Mean	11.4 (3.9)	4.3 (2.6)	1.2 (1.6)	
SED (treatment)		(0.4)		
SED (sampling time)		(0.3)		
SED $(\text{interaction})_1$		(0.6)		
SED $(\text{interaction})_2$		(0.6)		

F test: Treatment = $p<0.001$; Sampling time = $p<0.001$; Treatment sampling time = $p<0.001$.

Means followed by the same letter within a column are not significantly different at 5% level of probability. Values in parentheses are square-root $\{\sqrt{(x+0.5)}\}$ transformed.

SED $(\text{interaction})_1$ = Standard error of difference of means for sampling time in any treatment.

SED $(\text{interaction})_2$ = Standard error of difference of treatment means at a given sampling time.

Termite biomass

Addition of either fertilizer or organic materials, increased the biomass of termites significantly compared with the no input control.

Table 29.3: Fresh weight of termites in maize green-manured with organic residues compared with fertilized and unfertilized control at different periods during 1997 short rains at Maseno, western Kenya.

Treatment	Sampling time			Mean
	Before sowing	6 weeks after sowing	At harvest	
		(weight g m^{-2})		
Control	2.1 (1.9)	0.1 (0.8)	0.1 (0.8)	0.5 (1.2)
Fertilizer	2.0 (1.9)	0.1 (0.8)	0.2 (0.9)	0.5 (1.2)
Senna spectabilis	1.4 (1.7)	2.5 (2.1)	0.3 (1.1)	1.3 (1.6)
Tithonia diversifolia	0.7 (1.3)	2.8 (2.2)	0.5 (1.2)	1.1 (1.6)
Mean	1.5 (1.7)	0.9 (1.5)	0.2 (1.0)	
SED (treatment)		(0.3)		
SED (sampling time)		(0.3)		
SED $(\text{interaction})_1$		(0.6)		
SED $(\text{interaction})_2$		(0.6)		

F test: Treatment = NS; Sampling time = NS; Treatment sampling time = NS.

Values in parentheses are square-root $\{\sqrt{(x+0.5)}\}$ transformed.

SED $(\text{interaction})_1$ = Standard error of difference of means for sampling time in any treatment.

SED $(\text{interaction})_2$ = Standard error of difference of treatment means at a given sampling time.

NS = Not significant at 5% level of probability.

Termite biomass in fertilizer and no input control was highest at the beginning of the season, which decreased to very low levels in course of the season. In contrast to this, there was a 2-4 increase in termite biomass six weeks after applying senna and tithonia green manures, respectively. However, the biomass declined thereafter to similar levels to the other treatments. Treatment differences were not significant because of high variability among replicates.

Discussion

Microclimate, food resources and land use practices (e.g. pesticide application, burning and clearing of land), are major factors affecting the diversity, abundance and biomass of soil fauna communities (Warren *et al.*, 1987). Management practices such as continous tillage can cause alterations in the population structure, elimination/reduction of key groups and species of soil fauna and in some cases, low abundance or biomass (Dangerfield, 1993; Beare *et al.*, 1997). Studies have shown that cultivated sites are usually poorer than natural sites in terms of faunal diversity and biomass (Brown *et al.*, 1996).

Biomass of the soil fauna was low within the agroecosystem. This is similar to results observed elsewhere in arable fields (Dangerfield, 1993; Brown *et al.*, 1996). In arable land use systems, the change in habitat structure where vegetation are removed, reduced range and abundance of food resources and the extreme climatic conditions at the soil surface combine to create an environment beyond tolerance limits of most soil fauna groups. The low diversity, abundance and biomass of the soil invertebrate fauna observed, particularly in the no input control, typically represent the status of soil fauna in the fields of resource poor farmers. Most small-scale farmers clear and burn the land and rarely add external inorganic inputs to the soil for nutrient replenishment. The implication is that a change to continuous cropping decreases plant richness, thereby reducing the diversity of food resources and residue quality. Studies have shown that such changes in the land use systems lead to reduced abundance, biomass and diversity of soil fauna communities (Warren *et al.*, 1987; Dangerfield, 1993).

Application of senna and tithonia residues increased the biomass of the soil fauna groups for example earthworms. Studies have also shown that addition of organic residues such as senna and tithonia increase the faunal population by 100% over no input control (Ayuke, 2000). Organic inputs such as crop residues, tree prunings and manures, provide food to soil organisms. Greater faunal biomass in residue applied treatments may be the result of a greater accumulation of organic matter. Accumulation of organic matter from these residues (senna and tithonia), may provide resource base for the invertebrates. Coleman *et al.* (2000) states that soil organisms are strongly limited by available energy sources and are in a state of starvation much of the time. The increased supply of organic matter may possibly eliminate this state, in turn allowing their consumers, i.e. earthworms and termites, to subsequently increase in numbers hence increase in biomass. Surface applied residues preserve soil water from evaporation, reduce soil temperature and provide conducive niches for certain faunal groups. However, the insignificant differences observed in faunal biomass between senna and tithonia, could be due to reduced structural complexity and low diversity in food brought about by changes in the arable land use system.

Conclusions

In intensively cropped and nutrient depleted soils such as the Kandiudalfic-Eutrodox soil of this experiment, addition of organic residues increase the faunal biomass, for example earthworms within the cropping seasons. However under arable land use system characterized by low amount, range and diversity of food resources and the type and quality of organic residues do not play a significant role in influencing foraging behaviour, hence biomass of soil invertebrates. Even though faunal biomass was high in senna and tithonia treatments than under fertilizer and no input controls, they did not significantly differ in their effect of biomass. It therefore remains to be demonstrated whether mixing litter of organic residues of different quality may change this foraging behaviour resulting in increased biomass and consequently the invertebrate functions in agroecosystem.

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References

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Handbook on Methods*, CAB International, Wallingford UK.

Ayuke, F.O. (2000). Diversity, abundance and function of soil invertebrate fauna in relation to quality of organic residues. M. Phil. thesis, Moi University, Eldoret, Kenya.

Beare, M.H., Reddy, M.V., Tian, G. and Scrivasta, S.C. (1997) Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: the role of decomposer biota. *Applied soil biology*, 6: 87-108.

Brown, G.G., Moreno, A.G. and Lavelle, P. (1996) Soil macrofauna under different Agricultural Systems and native vegetation in four countries of East Africa. *Biological Management of Soil Fertility in Small-Scale Farming Systems in Tropical Africa, 2nd Annual report.*

Coleman, D.C., Hendrix, P.F., Beare, M.H., Cheng, W.X. and Crossley, D.A. (2000) Microbial and faunal interations a sthey affect soil organic matter dynamics in subtropical agroecosystems. *In:* Paoletti, M.G., Foissner, W., Coleman, D. (eds), *Soil Biota, Nutrient Cycling, and Farming Systems*. CRC Press, Boca Raton, FL, pp. 1-14.

Dangerfield, J.M. (1993) Characterization of soil fauna communities. *In:* Rao, M.R. and Scholes, R.J. (eds), *Report on Characterization of an Experimental Field in KARI Farm, Muguga, Kenya*. ICRAF, Nairobi, Kenya, pp. 51-67.

Gachengo, C.N., Palm, C.A., Jama, B. and Othieno, C. (1999) Tithonia and senna green manures and inorganic fertilizers as phosphorus sources for maize in western Kenya. *Agroforestry Systems* 44: 21-36.

Genstat 5 Committee (1993) *Genstat release reference manual*, Oxford University Press, Oxford UK.

House, G.J. and Parmele, R.W. (1985) Comparison of soil arthropods and earthworms from conventional, and no-tillage agroecosystems. *Soil and Tillage Research* 5: 351-360.

Jaetzold, R. and Schmidt, H. (1982) *Farm handbook of Kenya: National conditions and farm management information of west Kenya (Nyanza and western provinces*, Volume IIA: 179-222. Typo-druck, Russedorf, West Germany.

Lavelle, P., Dangerfield, M., Fragoso, C., Eschnebrenner, V., Hernadez, D.L., Pashanasi, B. and Brussard, L. (1994a) The relationship between soil macrofauna and tropical soil fertility. *In*: Woomer, P.L. and Swift, M.J. (eds). *The Biological Management of Tropical Soil Fertility*. A Wiley- Sayce publication, pp. 136-169.

Lavelle, P., Gilot, C., Fragoso, C. and Pashanasi, B. (1994b) Soil fauna and sustainable land use in the humid tropics. In: Greenland, G.A. and Szalbolcs, I. (eds), *Soil Resilience and Sustainable Land use*. CAB International, Wallingford 18: 291-307.

Mafongoya, P.L., Mpepereki, S., Dzowela, B.H., Mangwayana, E. and Makonese, F. (1996) Soil biota: Effects of pruning quality on soil microbial composition. *In:* Swift, M.J. (ed). *Report of the Tropical Soil Biology and Fertility Programme* (TSBF), Nairobi, Kenya.

Nziguheba, G., Palm, C.A., Buresh, R.J. and Smithson, P.C. (1998) Soil phosphorus fractions and adsorption as affected by organic and inorganic sources. *Plant and Soil* 198: 159-168.

Palm, C.A., Gachengo, C.N., Delve, R.J., Cadisch, G and Giller, K. (2001) Organic inputs for soil fertility management in tropical agroecosystems: application of an organic resource database. *Agriculture, Ecosystems and Environment* 83: 27-42.

Tian, G., Kang, B.T., Brussard, L. and Swift, M.J. (1997) Soil fauna mediated decomposition of plant residues under constrained environmental and residue quality and conditions. *In:* Cadisch, G. and Giller, K.E. (eds), *Driven by nature: Plant litter quality and decomposition*. CAB International Wallingford, U.K, pp 125-134,.

Tian, G., Kang, B.T and Brussard, L. (1995) An index for assessing the quality of plant residues and evaluating their effects on soil and crop in the semi-humid tropics. *Applied Soil Ecology* 2:25-32.

USDA. (1992) Soil taxonomy. *Agricultural Handbook no. 294*, Washington D.C.

Warren, S.D., Scifres, C.J. and Teel, P.D. (1987) Response of grassland arthropods to burning: A review. *Agricultural Ecosystem Environment* 19: 105-130.

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Dual Inoculation of Woody Legumes and Phosphorus Uptake from Insoluble Phosphate Rock

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Abstract

Phosphorus deficiency limits crop production in western Kenya, and there is need for more affordable sources of P for resource-limited smallholder farmers in the region. Indigenous phosphate rocks (PRs) from Uganda are abundant but unreactive, so some means of increasing their effectiveness is needed. We tested two agroforestry fallow species for their ability to grow in sand culture with P supplied as Ugandan Busumbu phosphate rock (BPR) or triple superphosphate (TSP), and with or without rhizobial and/or mycorrhizal inoculation. The test species were *Crotalaria grahamiana* and *Tephrosia vogelii*, two promising improved fallow species in western Kenya. The experiment was conducted in a greenhouse for three months. After the three months the plants were harvested and shoot, root and nodule dry biomass were determined. Addition of BPR had no effect on biomass production of the test species compared to no-P control, regardless of inoculation treatment. With P supplied as TSP, *Crotalaria* total biomass production and nodule dry weight was on average higher than that of *Tephrosia* in TSP treatments. No growth parameters were affected by inoculation with rhizobia, though uninoculated plants also nodulated strongly in the presence of TSP. Mycorrhizae had a small positive effect on root and shoot dry weight (p = 0.033 to 0.057), but had no major effect on BPR performance.

Introduction

Many soils in the tropical and subtropical regions are low in both total and available P (Chien and Menon, 1995; Rao *et al.*, 1999). As a result, P is normally the most limiting nutrient for growth of leguminous crops in tropical and subtropical regions. Continuous cropping in cultivated areas with little or no use of fertilizers can lead to depletion of soil P fertility. In many tropical regions and particularly sub-Saharan Africa, soil P is declining as a result of greater export of P through removal of harvested plant products and erosion, than inputs of P from fertilizers and manures (Smaling *et al.*, 1997). Soil P deficiency may be due to either inherent low levels of P or depletion of soils (Buresh *et al.*, 1997). This is particularly so for highly weathered acidic Oxisols and Ultisols in the humid tropics which contain high levels of iron (Fe) or aluminium (Al) oxides where P is strongly bound and thus less available for uptake by crops. Therefore, P is critically needed to improve soil fertility for sustainable crop production in acid soils (Chien and Menon, 1995).

Soil P can be replenished by addition of inorganic fertilizers or organic matter in the form of plant and animal residues. However, the application of soluble P fertilizers alone in acid soils is uneconomical due to high production costs and low utilization efficiencies, which arise from the high P-fixing abilities of the acid soils (Juo and Fox, 1977). Phosphorus fixation limits crop production in high rainfall acid soils. In addition, inorganic P fertilizers are expensive especially to smallholder farmers who usually have low-income resource base.

In recent years, phosphate rock (PR) for direct application has been tested in tropical acid soils as a potential alternative source of P to conventional water-soluble P fertilizers. Direct application of PR may be an economically attractive alternative to the use of more expensive imported soluble P fertilizers in these soils for certain crops. Soil properties of agronomic importance in the effectiveness of PR are soil pH, soil texture, P-sorption capacity and organic matter content. However, the effectiveness of PR greatly depends on soil pH (Chien and Menon, 1995). It is also documented that P release from PR may be increased by inoculation with certain bacterial types, fungi as well as root exudates from certain plant species (Tian and Kolawole 1999; Jones and Farrar, 1999; Toro *et al.,* 1996).

Plant species differ in their ability to take up nutrients from the soil. As a result, higher plants have developed various mechanisms to enhance nutrient acquisition from soils low in available nutrients. For example, in response to P deficiency, certain plant species have developed several complex mechanisms to take up P from the rhizosphere. These mechanisms are both physiological and morphological and vary from species to species (Zoysa *et al*., 1998; Dinkelaker *et al*., 1988). Some of these changes include: increased root hair length/density, enhanced symbioses with vesicular-arbuscular mycorrhizae (VAM), formation of proteoid roots, release of phosphatases to solubilize organically bound soil P and release of organic acids and H^+ to solubilize inorganic P (Jones and Farrar 1999; Rao *et al*., 1999; Dinkelaker *et al*., 1988).

Organisms that cause increases in plant-available P in the soil belong to a diverse group including bacteria, actinomycetes and several groups of fungi (Kucey *et al*., 1989). For example, roots of most crop and pasture species can be colonized by naturally occurring symbiotic fungi to form vesicular-arbuscular mycorrhizae (VAM). The fungus obligatorily depends on living plant roots for essential organic compounds and in return increase the inflow of organic P from the soil to the plant roots. Different crop species depend on varying degrees of adequate colonization of their roots with VAM fungi. Consequently, the inoculum density of VAM fungi in the soil when a crop is sown can be an important factor in determining the P nutritional status of that crop (Thompson, 1991).

Mycorrhizal plants have been shown to produce more dry matter and remove more P from the soil than non-mycorrhizal plants (Raj *et al*., 1980). For example, in 1989 Kucey and Leggett found that the inoculation of canola (*Brassica napus* L.) with VAM under greenhouse conditions increased straw and pod P concentration over uninoculated control, while VAM inoculation in the field increased canola yields. In the same study, it was found that combination of rock phosphate at 20 mg P kg^{-1} soil with VAM increased P uptake by canola to a level comparable to that obtained by the addition of monoammonium phosphate (MAP) at 20 mg P kg^{-1} soil. Mycorrhizal plants have also been shown to increase depletion of aluminium phosphate (Al-P), iron phosphate (Fe-P) and calcium phosphate (Ca-P). In another study, Asea *et al*. (1987) found that VAM fungi, *Penicillium bilaji* and *Penicillium cf fuscum* could solubilize different amounts of rock phosphate in liquid culture.

In an earlier study, Kimiti and Smithson (2001) grew 5 leguminous agroforestry fallow species and 2 legume grain crops in unsterilised, uninoculated sand culture, with P added as TSP, BPR or pure water-insoluble Al-P, Fe-P and Ca-P compounds. Growth and P uptake of species treated with BPR was poorer than that with all other P sources, and was not different from no-P control. In the current study, we hypothesised that inoculation with rhizobia and/or mycorrhizae could improve growth and P uptake of leguminous fallow species from unreactive PRs, through rhizosphere acidification or increased absorptive surface area. Our main objective was to test the effect of separate or dual inoculation with rhizobia and mycorrhizae on growth and P acquisition by the short-fallow legumes *Crotalaria grahamiana* and *Tephrosia vogelii.*

Materials and Methods

We grew *Crotalaria grahamiana* and *Tephrosia vogelii* in sand in pots at the International Centre for Research in Agroforestry (ICRAF) nursery in Nairobi. The study was a completely randomised design, with 24 treatments in four replications (Table 30.1). Seeds of *C. grahamiana* and *T. vogelii* were obtained from ICRAF, while mycorrhizae and rhizobial inocula were obtained from Kenya Forestry Research Institute (KEFRI). Rhizobial inoculum was supplied in form of broth culture and mycorrhizae as *Glomus monosporum* spores contained in chopped roots of sorghum, which had been inoculated with *Glomus* and raised in sterile potting mix in order to multiply the spores. River sand, sieved to 1-2 mm diameter, was thoroughly washed with tap water and after it was confirmed to be P-free, was sterilized in an autoclave and packed into one litre plastic pots. Phosphorus as BPR or TSP (plus no-P control) was applied at a rate of 50 kg P ha^{-1}. Seeds of *C. grahamiana* and *T. vogelii* were surface-sterilized with 70% ethanol and soaked in deionized water for 24 hours. The seeds were sown directly in the pots. Rhizobial and mycorrhizal inocula were placed over the seeds and then covered with sand. All pots were placed on raised greenhouse benches and kept moist with deionized water, and a P-free nutrient solution (Ae *at al.*, 1996) was added once per week. After three months, the plants were harvested and shoot, root and nodule dry biomass was determined. Data were analysed by analysis of variance and single degree of freedom contrasts, using the Genstat 6^{th} edition statistical package.

Table 30.1: Treatment descriptions for a sand culture experiment testing effects of P source and microbial inoculation on woody legume growth and nodulation

Trt	Crotalaria			Trt	Tephrosia		
No.	Phosphorus	Rhizobia	Mycorrhizae	No.	Phosphorus	Rhizobia	Mycorrhizae
1	No P	0	0	13	No P	0	0
2	No P	1	0	14	No P	1	0
3	No P	0	1	15	No P	0	1
4	No P	1	1	16	No P	1	1
5	TSP	0	0	17	TSP	0	0
6	TSP	1	0	18	TSP	1	0
7	TSP	0	1	19	TSP	0	1
8	TSP	1	1	20	TSP	1	1
9	BPR	0	0	21	BPR	0	0
10	BPR	1	0	22	BPR	1	0
11	BPR	0	1	23	BPR	0	1
12	BPR	1	1	24	BPR	1	1

Results and Discussion

This experiment was conducted after an earlier study where the two test species and others had been tested for their ability to access P from BPR, TSP, aluminium phosphate, calcium phosphate and iron phosphate (Kimiti and Smithson, 2001). In this earlier study, we observed that BPR, which has 13% total P, had a poor solubility in water (0.7% of total P) and neutral ammonium citrate (2.5% of total P). All 7-legume species grew poorly in BPR compared to other P sources.

In this study rhizobia and/or mycorrhizae were included to test whether BPR with microbial inclusion could improve plant growth relative to BPR alone. With TSP, growth of both *C. grahamiana* and *T. vogelli* was improved. Root and shoot biomass, nodule number and nodule dry weight were all increased with TSP relative to BPR or No P ($p < 0.0001$, Table 30.2, Figures 30.1 and 30.2) Growth with BPR was not significantly different from No P control ($p = 0.5$ to 0.9). In addition, *Crotalaria* outperformed *Tephrosia* in terms of all the growth parameters (Table 30.2). Statistical analysis revealed a significant difference ($p < 0.0001$) in root and shoot biomass, nodule number and nodule dry weight between *C. grahamiana* and *T. vogeli*i (Table 30.2, Figure 30.1).

Table 30.2: Nodulation, root and shoot biomass per pot with different P sources and inoculation treatments. SED = standard error of the difference in means

Species	P source	Rhizobia	Mycorrhizae	No.of nodules per pot	Shoot Dry wt (g per pot)	Root Dry wt (g per pot)
Crotalaria	BPR	0	0	28	0.9	0.4
		0	1	35	0.8	0.4
		1	0	35	0.8	0.4
		1	1	43	0.9	0.4
	No P	0	0	37	0.7	0.4
		0	1	17	0.7	0.4
		1	0	40	0.7	0.4
		1	1	40	0.9	0.5
	TSP	0	0	276	6.0	2.1
		0	1	267	6.5	3.1
		1	0	292	6.2	2.3
		1	1	312	5.7	2.1
Tephrosia	BPR	0	0	6	0.8	0.5
		0	1	6	1.1	0.6
		1	0	9	1.0	0.6
		1	1	9	0.9	0.6
	No P	0	0	5	0.6	0.4
		0	1	10	0.9	0.5
		1	0	11	0.8	0.5
		1	1	6	1.2	0.6
	TSP	0	0	21	2.8	0.9
		0	1	21	3.5	1.2
		1	0	30	3.4	1.0
		1	1	51	3.8	1.1
SED				31	0.33	0.21
Contrasts (Prob.)						
TSP vs other				< 0.0001	< 0.0001	< 0.0001
BPR vs No P				0.940	0.512	0.579
Rhizobia vs none				0.168	0.512	0.572
Mycorrhizae vs none				0.778	0.057	0.033

While P source strongly affected nodulation, rhizobial inoculation had almost no effect and in addition uninoculated plants nodulated almost as profusely as those inoculated with rhizobia (Table 30.2, Figure 30.2). This study was conducted in a relatively open area, and pots were exposed to airborne dust and microbes, as we did not take special precautions to avoid exposure to atmospheric dust.

Mycorrhizal inoculation had a slight positive effect on root and shoot dry weight (p = 0.033 for roots, 0.057 for shoots). In practical terms, however, the differences were extremely small, and the hypothesized improvement in BPR effectiveness was not realized.

Figure 30.1: Total dry weight production (root plus shoot, g per pot) in *Crotalaria grahamiana* (Cro.) and *Tephrosia vogelii* (Teph.), with or without inoculation with rhizobia (R1 and R0) and/or mycorrhizae (M1 and M0), and with P absent (No P), or supplied at 50 kg ha^{-1} as triple superphosphate (TSP) or Ugandan Busumbu phosphate rock (BPR). (Error bars are standard errors).

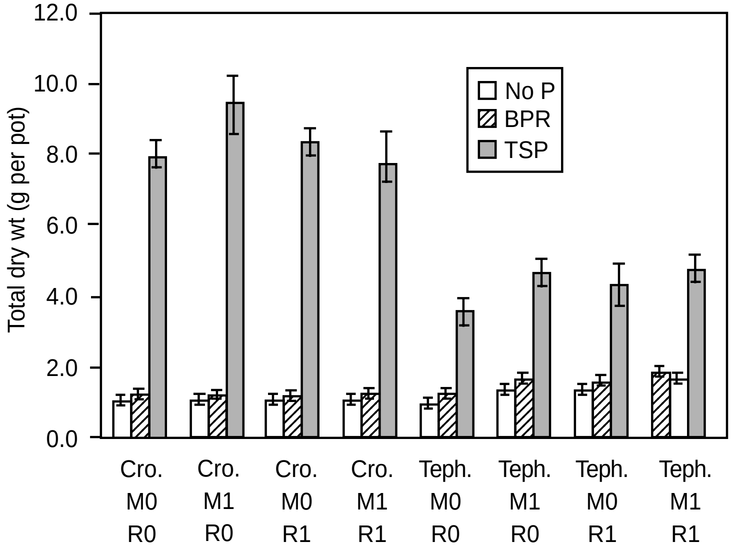
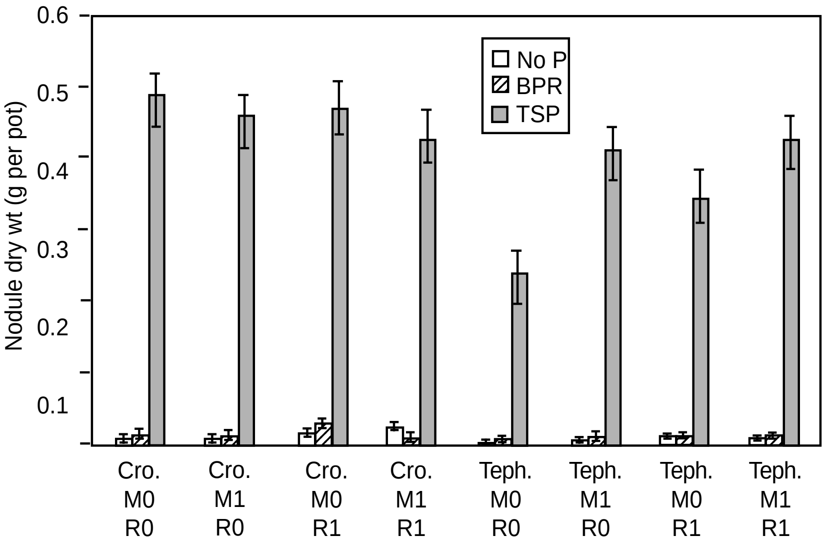


Figure 30.2: Nodule dry weight production (g per pot) in *Crotalaria grahamiana* (Cro.) and *Tephrosia vogelii* (Teph.), with or without inoculation with rhizobia (R1 and R0) and/ or mycorrhizae (M1 and M0) , and with P absent (No P), or supplied at 50 kg ha^{-1} as triple superphosphate (TSP) or Ugandan Busumbu phosphate rock (BPR). (Error bars are standard errors).



It should be emphasized that this experiment was carried out in pots in sand culture. Given these experimental conditions, the results obtained may not translate into what might happen under actual field conditions where the plants are not restricted in root growth and there is interaction between the plants, soil, other soil micro-organisms and other environmental factors. Recent field results from western Kenya (Smithson and Kimiti, unpublished data) with BPR and TSP treatments, using *C. grahamiana* and *T. vogelii* as fallows, show better maize performance with BPR when used in combination with fallow legumes than BPR alone, with N and K at equal rates throughout. This confirms that sand culture may not be a good standard to predict the results obtained from the field and that data from such studies should be interpreted with caution.

Conclusion

We found little evidence in this study of increased growth of two agroforestry legumes under P-limited conditions as a result of inoculation with rhizobia and/or mycorrhizae. Growth and nodulation were increased mainly by soluble P fertilizer and under P sufficient conditions, *Crotalaria grahamiana* grew better and nodulated more profusely than *Tephrosia vogelii*. These results, based on a pot study in sand culture, should be extrapolated cautiously, however. Ongoing field studies with BPR in combination with these same species show improved performance of BPR when combined with legumes.

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References

Ae, N., Otani, T., Makino, T. and Tazawa, J. (1996) Role of cell wall of groundnut roots in solubilizing sparingly soluble phosphorus in soil. *Plant and Soil* 186:197-204.

Asea, P.E.A., Kucey, R.M.N. and Stewart, J.W.B. (1987) Inorganic phosphate solubilization by two *Penicillium* species in solution culture and soil. *Soil Biology and Biochemistry* 20:459-464.

Buresh, R.J., Smithson, P.C. and Hellums, D.T. (1997) Building soil phosphorus capital in Africa. *In*: Buresh, R.J., P.A. Sanchez and F. Calhoun (eds). Replenishing Soil Fertility in Africa. SSSA Special Publication 51. Soil Science Society of America, Madison, Wisconsin, USA. pp. 111-149.

Chien, S.H. and Menon, R.G. (1995) Factors affecting the agronomic effectiveness of phosphate rock for direct application. *Fertilizer Research* 41:227-234.

Dinkelaker, D., Römheld, V. and Marschner, H. (1988) Citric acid excretion and precipitation of calcium citrate in the rhizosphere of white lupin (*Lupinus albus* L.). *Plant Cell and Environment* 12:285-292.

Jones, D. and Farrar, J. (1999) Phosphorus mobilization by root exudates in rhizosphere: fact or fiction. *Agroforestry Forum* 9(4):20-24.

Juo, A.R.S. and Fox, R.S. (1977) Phosphate sorption characteristics of some benchmark soils of West Africa. *Soil Science* 124:370-376.

Kimiti, J.M. and Smithson, P.C. (2001) Phosphorus uptake by fallow and grain legumes from sparingly soluble P sources. 5th Intl. Symposium on Plant-Soil Interactions at Low pH, 11-16 March 2001, Alpine Heath, KwaZulu Natal, South Africa

Kucey, R.M.N (1983) Phosphate-solubilizing bacteria and fungi in various cultivated and virgin Alberta soils. *Canadian Journal of Soil Science* 63:671-678.

Kucey, R.M.N. and Leggett, M.E. (1989) Increased yields and phosphorus uptake by Westar canola (*Brasssica napus* L.) inoculated with a phosphate-solubilizing isolate of *Penicillium bilaji*. *Canadian Journal of Soil Science* 69:425-432.

Raj, J., Bagyaraj, D.J. and Manjunath, A. (1980) Influence of soil inoculation with vesicular-arbuscular mycorrhiza and a phosphate-dissolving bacterium on plant growth and 32P uptake. *Soil Biology and Biochemistry* 13:105-108.

Rao, I.M., Friesen, D.K. and Horst, W.J. (1999) Opportunities for germplasm selection to influence phosphorus acquisition from low-phosphorus soils. Agroforestry Forum. 9(4):13-17.

Smaling, E.M.A, Nandwa, S.M. and Janssen, B.M. (1997) Soil fertility in Africa is at stake. In: Replenishing soil fertility in Africa. Buresh, R.J. Sanchez P.A and Calhoun, F. (eds.). Soil Science Society of America Special Publication 51., Soil Science Society of America, Madison, Wisconsin, pp. 47-61.

Tian, G. and Kolawole, G.O. (1999) Phosphorus availability of phosphate rock incubated with plant residues with various chemical composition. *Agroforestry Forum* 9(4):40-42.

Toro, M., Azcon, R. and Herrera, R. (1996) Effects on yield and nutrition of mycorrhizal and nodulated *Pueraria phaseoloides* exerted by P-solubilizing rhizobacteria. *Biology and Fertility of Soils* 21:23-29.

Thompson, J.P. (1991) Improving the mycorrhizal condition of the soil through cultural practices and effects of growth and phosphorus uptake by plants. *In*: Johansen, C., Lee K.K. and Sahrawat, K.L. (eds). Phosphorus Nutrition of Grain Legumes in the Semi-Arid Tropics. International Crops Research Institute for the Semi-Arid Tropics. Patancheru, India. pp. 117-137.

Zoysa, A.K.N., Janzen H.H. and Leggett, M.E. (1998) Microbially mediated increases in plant available phosphorus. *Advances in Agronomy* 42:199-227.

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Effect of Vesicular-arbuscular Mycorrhiza (vam) Inoculation on Growth Performance of *Senna spectabilis*

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Abstract

The influence of vesicular-arbuscular mycorrhiza (VAM) fungi inoculation on growth performance of *Senna spectabilis* was studied in a screen house experiment. The results obtained indicated the dependence of *Senna spectabilis* on mycorhizal symbiosis. Inoculation with vesicular-arbuscular mycorrhiza significantly improved the growth performance of *Senna spectabilis*. The height growth increased significantly by 85% after only three months while the root collar diameter increased by 71%. Shoot production increased by 213% while root biomass increased by 241%. Inoculation with vesicular-arbuscular mycorrhiza increased plant tissue phosphorus, nitrogen and potassium content. The better growth response of mycorrhizal plants were attributed to improvement in nutrient uptake, especially phosphorous, nitrogen and potassium. Vesicular-arbuscular mycorrhiza inoculation has a high potential in agroforestry as a bio-fertilizer.

Introduction

The intense exploitation of tropical forests has led to degradation of once stable ecosystems. There has been changes in abiotic and biotic soil properties, which hampers the re-establishment of proper vegetation cover (Miller, 1987). Soils in these areas are very infertile and are acidic in nature. The soils are characterized by low effective cation exchange capacity, low available water and nutrient reserve, low soil pH, low organic matter and phosphorus content and are highly susceptible to soil erosion. The deforested and degraded areas no longer regenerate into woody perennials due to lack of mycorrhiza propagules for recolonization but rather into the so-called "derived savannas" which now occupy million of hectares in Africa in form of *Imperata cylindrica* and *Themeda triandra* grasslands (Janos, 1980a). This is because grasses are the most independent of mycotrophic plants and they can tolerate low soil fertility inspite of their low ineffectiveness (Baylis, 1975).

Agroforestry, a land-use system and technology in which trees are deliberately planted on the same units of land with agricultural crop and /or animals, has been recognized as one of the most promising strategy for rehabilitating the already degraded areas. The benefits of agroforestry includes the amelioration of soil chemical and physical properties, the reduction of soil erosion, improved weed control and increased availability of fuel wood and /or fodder (Young, 1997; Chin and Huxley, 1996). The degree to which an agroforestry system can provide the above benefits partially depends on the quantity of biomass an agroforestry tree species can produce.

Acid soils are known particularly to be unfavorable for legumes due to iron, aluminum and /or manganese toxicities, as well as molybdenum, calcium, and/or magnesium deficiencies. Molybdenum is an essential nutrient in nitrogen fixation, while calcium requirements in legumes are high and therefore deficiencies of either of these elements can cause low biomass yields in an agroforestry leguminous tree species.

Mycorrhizal fungi are known to affect growth of most plant species through various ways. They increase phosphorus uptake, enhance uptake of other plant nutrients by root system and are beneficial in the biological nitrogen fixation of *Rhizobium*, biological control of root pathogens and drought resistance (Harley and Smith, 1983; Sieverding, 1991; Dela Cruz, 1987; Janos, 1980b). The potential benefit of mycorrhizal fungi in rehabilitation of degraded areas by use of agroforestry system is more apparent than ever before. The need to increase food, fibre, and fuel wood production to keep pace with the fast growing population in Africa is crucial. The low biomass production of agroforestry tree species in degraded areas can, therefore, be circumvented by the use of mycorrhizal fungi. Unfortunately, there seems to be very little research in using mycorrhizal fungi in an agroforestry setting. This paper reports a green house experiment that tested the effect of vesicular-arbuscular mycorrhiza inoculation on growth performance of *Senna spectabilis*. The plant is an important agroforestry tree species, which has passed the tests of practicability and acceptability in the eyes of researchers and farmers. The tree is widely recommended as an agroforestry tree species for degraded areas in many parts of the tropics but its main problem lies in slow growth rate in acidic soils.

Materials and Methods

The experiment was conducted in a screen house in the University of the Philippines Los Baños. The experiment was laid out in a randomized complete block (RCB) design, with four replicates and four treatments. Each treatment consisted of five 20cm clay pots. A total of eighty clay pots were used and a total of 240 plants were planted. Top soil (0-15cm) was collected from a degraded grassland area that was dominated by *Imperata cylindrica*. The soil was air dried, pulverized and passed through a 2mm sieve. The soil was then sterilized with hot air at 100 °C for 48 hours. The soil had an initial pH of 5.14 (Potentiometric Method), organic matter content of 1.67% (Walkley-Black Method), total nitrogen 0.18% (Modified Kjedahl Method), potassium 4.11me/100g (Flame Photometer Method) and available phosphorus 70.18 ppm (Bray No.2 Method).

The soil was then put into the 20cm top diameter clay pots. The VA-mycorrhizal fungi inoculants consisting of spores, mycorrhizal root fragments and infected soil was collected from pot cultures of trap plants (*Pensacola bahia*) grass which had been grown for five months after being inoculated with mycorrhiza fungus species of *Glomus tunicatum* and *Glomus macrocarpum*. The inoculants were added to some pots, at the rate of one table spoon per pot which consisted of 23 spores per gram of soil added. The rate of spores per gram of soil was determined by wet sieving and decanting, surface sterilized in 2% sodium hypochlorite and then washed. The non vesicular arbuscular control pots were left uninoculated. Seeds of *Senna spectabilis* were pre-treated with hot water for three minutes. The seeds were then germinated in sterilized river sand. After the seedlings had developed two leaves each, three seedlings were transplanted to each clay pot containing the sterilized soil, plus or minus the vesicular arbuscular mycorrhiza inoculum. Seedlings were then watered twice a day for the first week and then once a day in the following weeks.

To determine the effect of vesicular arbuscular mycorrhiza inoculation on growth performance of *Senna spectabilis*, inoculated and non-inoculated plants were raised in a screen house for three months. Height growth was measured after every 15 days, except during the first months. Root collar diameter was measured at the end of three months. After four months, 50% of the plants per block were harvested using destructive sampling and vesicular arbuscular mycorrhiza colonization above and below ground biomass production, root number and root length were determined. At the end of fifth month, some plants were harvested randomly per treatment and vesicular arbuscular mycorrhiza infection level was assessed by clearing the roots for 2 hours at 90°C in 10% KOH, neutralizing them in lactoglycerol for 20 minutes. Infection was determined by the grid-line intersect method (Giovanetti and Mosse, 1980). Biomass increment due to mycorrhiza inoculation was computed as dry weight of inoculated plants minus dry weight of non-inoculated plants divided by dry weight of non-inoculated plants multiplied by 100%.

For the plant tissue nutrient content, above ground biomass was harvested and was oven dried at 70 °C. The plant tissue were then analyzed for total nitrogen (Micro-kjedahl method), Total phosphorus (Vanadomolybdate method) and Potassium (Flame photometer method). The numbers and length of primary roots per plants were assessed and determined. The measured plants parameters were analysed using IRRISTAT version 92-1 computer software. Analysis of variance was used to describe the data.

Results and discussion

Plant Height

The results obtained indicated the dependence of *Senn*a *spectabilis* on mycorrhiza symbiosis. The effect of vesicular-arbuscular mycorrhiza inoculation on the height increment was obvious on visual comparison at the end of 90 days. As Table 31.1 shows, a significant height increment in inoculated *Senna spectabilis* was recorded after only 60 days. The enhanced height increment in *Senna spectabilis* could be attributed to the vesicular arbuscular mycorrhiza colonization. Mycorrhiza infection is known to enhance plant growth by increasing nutrients uptake (Marschner *et al.*, 1994). Nye *et al.* (1977) reported that the uptake of nitrogen, phosphorus and potassium is limited by the rate of diffusion of each nutrient through the soil. It seems likely that vesicular arbuscular mycorrhiza in this study increased nutrient uptake by shortening the distance nutrients diffused through the soil to the roots. During the first 45 days, there was no significant difference in height increment between inoculated and non inoculated plants, although the height increment in inoculated plants was higher. This could be due to the "lag phase" effect of mycorrhiza inoculation. Many studies have shown that there is a lag phase between mycorrhiza inoculation and the time period when its effect is manifested in the plant (Brandon and Shelton, 1993).

Table 31.1: Effects of VA mycorrhizal fungi inoculation on shoot height (cm) of *Senna spectabilis* after 90 days in the screen house.

Days after planting	*Senna spectabilis* Treatment with vesicular arbuscular mycorrhiza	*Senna spectabilis* Treatment without vesicular arbuscular mycorrhiza	Difference
30	7.06[e]	6.51[c]	0.55[ns]
45	9.90[d]	8.20[bc]	1.70[ns]
60	14.21[c]	8.29[bc]	6.08**
75	17.16[b]	9.03[ab]	8.13**
90	19.80[a]	10.72[a]	9.08**

Means in columns followed by the same letter are not significantly different at 5% level based on DMRT test.

** = significant at 1% level
ns = not significant

At the end of ninety days, height growth of inoculated *Senna. spectabilis* was highly significant as compared to the non inoculated plants. The higher height increment registered with inoculated plants could be as a result of enhanced inorganic nutrient absorption (Cooper, 1984) and greater rates of photosynthesis (Allen *et al*., 1981). Vesicular-arbuscular mycorrhiza are known to affect both the uptake and accumulation of nutrients and therefore, act as an important biological factor that contribute to efficiency of both nutrient uptake and use. Researchers have demonstrated that vesicular-arbuscular mycorrhiza fungi, not only increases phosphorus uptake, but also plays an important role in the uptake of other plant nutrients and water (Huang *et al.*, 1985; Ellis *et al.*, 1985). Sander *et al*. (1983), reported that the inflows of phosphorus to mycorrhiza roots can be greater than inflows to comparable non-mycorrhiza roots by up to 2-5 times.

Shoot Biomass

Inoculating *Senna spectabilis* with vesicular-arbuscular mycorrhizal fungi, increased significantly the shoot biomass yield. As shown in Table 31.2, the shoot biomass production increased by 213% and was highly significant. The highly significant shoot biomass production by the inoculated plants, could be attributed to enhanced inorganic nutrition absorption and greater rates of photosynthesis in inoculated plants (Allen *et al.*, 1981; Cooper, 1984). Vesicular-arbuscular mycorrhiza have been said to affect both the uptake and accumulation of nutrients. Chulan and Martin (1992), reported a significant shoot dry weight increment when *Theobroma cacao* was inoculated with VA-mycorrhiza. Aggangan and Dela Cruz (1991), reported a dry matter yield increment of up to 631% when *L. leucocephala* was inoculated with vesicular-arbuscular mycorrhiza. Zajicek *et al*. (1987) reported a significant increment in dry matter yield when two forbs were inoculated with vesicular-arbuscular mycorrhizal fungi. Vesicular-arbuscular mycorrhizal fungi are reported to enhance plant growth rate through an increase in nutrient uptake, especially phosphorus which is relatively immobile in soils (Kormanik *et al.*, 1981, 1982; Dela Cruz, 1987; Janos, 1980a). Vesicular-arbuscular mycorrhiza inoculation could have enhanced *Senna spectabilis* to absorb more nutrients via an increase in the absorbing surface area. Similar observation has been reported by Marschner and Dell (1994).

The movement of nutrients to plant roots and the rate of absorption of nutrients by roots, especially nitrogen, phosphorus and potassium, is known to be limited by the rate of diffusion of each nutrient through the soil and not by the ability of the root to absorb the nutrient from low concentration in the soil solutions (Abbott and Robson, 1982). In the present study, since the soil used was not very fertile, inoculation with vesicular-arbuscular mycorrhiza could have resulted in an increase in nutrient uptake by merely shortening the distance that the nutrients had to diffuse from the soil to the roots. This in turn, could have enhanced a higher shoot biomass production in the inoculated *Senna spectabilis* .

Root Biomass

As Table 31.2 shows, inoculating *Senna spectabilis* with vesicular-arbuscular mycorrhiza significantly increased the root biomass production. Vesicular abuscular mycorrhiza infection has been reported to increase both the uptake of nutrients by the roots and the concentration of nutrients in the plant tissues (Smith *et al.*, 1979). An increase in nutrient uptake, especially phosphorus in the infertile soil used, could have resulted in relief of nutrients stress and an increase in photosynthetic rate, which obviously could have given rise to an increase in plant growth. Research has shown that when root exploration is restricted, up to 80% of the plant phosphorus can be delivered by the external vesicular-arbuscular mycorrhizal hyphae to the host plant over a distance of more than 10 cm from the root surface (Li *et al.*, 1991) .

Hattingh *et al.* (1973) found that vesicular arbuscular mycorrhizal hyphae, could intercept labelled phosphorus, placed 27mm from a mycorrhizal root, whereas it remained unavailable to non-mycorrhizal roots. This confirms that vesicular-arbuscular mycorrhizal hyphae could have increased the volume of soil available to the *Senna specabilis* for nutrient uptake.

Table 31.2: Effect of vesicular-arbuscular mycorrhiza inoculation on growth performance of *Senna spectabilis* after 90 days in a screen house.

Growth Parameter	Treatment		
	VAM Inoculation	Measurement	Increment percentage
Shoot dry weight	Non inoculated	2.82	213
	Inoculated	8.83**	
Root dry weight (g pot^{-1})	Non inoculated	1.66	241
	Inoculated	5.66**	
Total shoot length (cm)	Non inoculated	10.72	85
	Inoculated	19.80**	
Root collar diameter (cm)	Non inoculated	0.21	71
	Inoculated	0.36**	
Leaf number	Non inoculated	4.30	105
	Inoculated	8.80**	
Root/shoot ratio (R/S)	Non inoculated	0.60	8
	Inoculated	0.65^{ns}	
Root length (cm)	Not inoculated	24.33	25
	Inoculated	30.41**	
Root Number/plant	Non inoculated	10.0	7.5
	Inoculated	10.75^{ns}	
Roots colonized (%age)	Non inoculated	0	67.8
	Inoculated	67.75**	

** = significant at 1% level,
ns = not significant

Mycorrhizal roots have been known to absorb phosphorus faster per gram of root than non-mycorrhizal plants (Jakobsen *et al.*, 1992). This may relate to the greater surface area per gram of mycorrhiza roots. It therefore follows that mycorrhiza were able to enhance the absorption of nutrients from the soil, which could have moved to the roots principally by mass flow, in addition to those which could have diffused through the soil slowly. This could have resulted in a higher root biomass in inoculated plants.

Root collar diameter

Vesicular-arbuscular mycorrhiza inoculation increased the root collar diameter of S*enna spectabilis* by 74%. As shown in Table 31.2, the increment of the root collar diameter of the vesicular-arbuscular mycorrhiza inoculated, plants was highly significant. The higher diameter increment of the inoculated plants could be attributed to enhanced inorganic nutrition absorption and greater rates of photosynthesis of inoculated plants (Allen *et al.*, 1981; Cooper, 1984). Vesicular- arbuscular mycorrhiza have been said to affect both the uptake and accumulation of nutrients. Researchers have demonstrated that vesicular-arbuscular mycorrhiza fungi not only increases phosphorus uptake, but also plays an important role in the uptake of other plant nutrients (Huang *et al.*, 1985; Sieverding, 1991).

Many authors have reported a significant increment in root collar diameter, after inoculating the plants with vesicular-arbuscular mycorrhiza. Reid *et al.* (1988), reported an increment in root collar diameter when sugar maple seedlings were inoculated with vesicular-arbuscular mycorrhiza. Osonubi *et al.* (1989), while working with inoculated *Gmelina* seedlings, reported a significant biomass increment. Huang *et al.* (1985) while working with inoculated *Leucaena leucocephala*, reported a significant increment in plant growth parameters. Aggangan and Dela Cruz (1991), while working with *Acacia auriculiformis* and *Leucaena leucocephala*, reported a diameter increment of between 18% to 123% when the two plants were inoculated with different types of vesicular-arbuscular mycorrhizal fungi. Castillo (1993), while working with *Pterocarpus indicus*, reported a significant diameter increment when the plants were inoculated with vesicular-arbuscular mycorrhizal fungi. Kormanik *et al.* (1981) reported a significant increment in root collar diameter when sweetgum seedlings were inoculated with vesicular-arbuscular mycorrhizal fungi. He reported that inoculation with vesicular-arbuscular mycorrhiza increased the root collar diameter by 268%.

Root to Shoot Ratio

As shown in Table 31.2, the difference between the root to shoot ratio of inoculated and non-inoculated *Senna spectabilis,* was not statistically significant at 5% level though the inoculated *Senna spectabilis* had a higher root to shoot ratio as compared to non inoculated plants. The higher root to shoot ratio of the inoculated plants could be attributed to the effect of mycorrhiza infection, which could have increased nutrients absorption, giving rise to a higher root and shoot biomass increment with a uniform growth. Clapperton and Reid (1992) while researching on the relationship between plant growth and increasing vesicular-arbuscular mycorrhizal inoculum density, reported that as the colonization by vesicular-arbuscular mycorrhizal fungi increased, so did root to shoot ratios. They concluded that this was due to the vesicular-arbuscular mycorrhizal plants being able to translocate more carbon to the roots than non-mycorrhiza plants. The same has been reported by Kucey and Paul (1982); Douds et al. (1988) and Wang *et al.* (1989). Tree seedlings with higher root to shoot ratios are able to have a higher survival percentage when planted in the field.

Root number and length

As Table 31.2 shows, inoculating *Senna spectabilis* with vesicular-arbuscular mycorhiza fungi, significantly increased the root length. The inoculation with VAM increased the root length by 25%. Huang *et al.* (1985) reported a root length increment of up to 80% when *Leucaena leucocephala* was inoculated with vesicular-arbuscular mycorrhiza. Levy and Syvertsen (1983) while working on the effect of drought stress on citrus, reported that, although plant to plant variations obscured significant differences, vesicular-arbuscular mycorrhiza plants did tend to have greater total feeder root length per plant than control plants. In addition to the mycorrhiza inoculation enhancing the plants absorption of more nutrients, especially phosphorus, via an increase in the absorbing surface area (Marschner and Dell, 1994), mycorrhiza colonization could have protected roots from soil pathogen (Perrin, 1990), and therefore increased root growth and nutrients acquisition of *Senna spectabilis*. Inoculated plants had higher number of roots than non inoculated ones, though the increment was not significant at 5% level. Mycorrhiza inoculation is known to enhance the plants absorption of more nutrients especially phosphorus via an increase in the absorbing surface area (Marschner and Dell, 1994). This in turn could have enhanced a higher plant growth rate resulting to more roots per plant. Mycorrhiza colonization also protect the roots from the soil pathogens (Perrin, 1990) and, therefore could have lead to an increase in not only the root growth and nutrient acquisition of the host roots, but also the number of surviving roots.

Root Colonization Percentage

As shown in Table 31.2, inoculating *Senna spectabilis* with vesicular-arbuscular mycorrhiza fungi resulted into a 67.8% colonization. There was no vesicular-arbuscular mycorrhiza contamination as evident in the non inoculated plants (control) which showed a 0% colonization.

Mycorrhiza colonization is normally attributed to the tree species and environmental factors. Smith *et al.* (1979) reported that the extent to which typical vesicular-arbuscular mycorrhiza fungi colonize root systems varies with species of plant. It has also been noted that there are differences in the extent of infection between genotypes of the same species. The extent of mycorrhiza infection in root systems is also known to be influenced by environmental conditions; the most important being the age of the plants, the level of phosphate (P) in the soil relative to the requirements of the plant and the capacity of the population of mycorrhiza propagules in the soil to form mycorrhiza. *Senna spectabilis* is a non nodulating legume (Ladha *et al.*, 1993) and rhizobium bacteria could not have posed any threat in competing with mycorrhiza fungi for carbohydrates. The time period of the seedlings (five months) could have been too short to record a higher colonization percentage since the root system infected normally increases with time sigmoidally. Seasonal patterns in the formation of mycorrhiza have also been said to vary considerably from year to year (Allen *et al.*, 1989).

Plant Tissue Nutrients Concentration

Inoculating *Senna spectabilis* with vesicular-arbuscular mycorrhiza, increased plant tissue nutrients concentration. As Table 31.3 shows, plant tissue phosphorus, nitrogen and potassium concentration was much higher in the inoculated plants than non inoculated ones. The higher phosphorus concentration in the inoculated plants could be attributed to a higher nutrients absorption rate by mycorrhiza plants.

Table 31.3: Effect of vesicular-arbuscular mycorrhiza inoculation on nutrient concentration (NPK) in shoot of *Senna spectabilis* after 90 days in a screen house

	Plant Concentration	Tissue	Nutrient
VAM Inoculation	Phosphorus (%)	Nitrogen (%)	Potassium (%)
Inoculated	0.46**	3.05^{ns}	1.64^{ns}
non-inoculated	0.19	2.99	1.53

** = significant at 1% level,
ns = not significant

Several authors have reported that mycorrhizal roots are able to absorb several times more phosphate than non inoculated roots from soils and from solutions (Pearson and Gianinazzi, 1983; Michelsen and

Rosendahl, 1990; Fitter, 1988; Dela Cruz *et al.*, 1988; Nielsen, 1983). Increased efficiency of phosphorus uptake by mycorrhizal plants could have led to higher concentrations of P in the plant tissues. The greater phosphate absorption by vesicular-arbuscular mycorrhizae has been suggested to have arisen due to superior efficiency of uptake from labile forms of soil phosphate, which is not attributable to a capacity to mobilize phosphate sources unavailable to non mycorrhizal roots (Pearson and Gianinaazzi, 1983). Under certain conditions, mycorrhiza is known to absorb fixed phosphate and even to stimulate root phytase activities (Pearson and Gianinazzi, 1983). Mycorrhizal roots are known to have not only a considerably greater phosphate inflow rates, but also to possess a pathway of phosphate uptake with a much higher affinity for phosphate than non mycorrhizal roots.

The higher plant tissue nitrogen content in inoculated plants could be attributed to hyphae uptake. It has been reported that the existence of extra-radical hyphal bridges between individual plants permits transfer of nutrients such as nitrogen (Marschner and Dell, 1994). The two have reported that about 24% of the total nitrogen uptake in mycorrhizal plants could be atributed to uptake and delivery by the external hyphae. There is also evidence that nitrogen is taken up by vesicular-arbuscular mycorrhiza hyphae from inorganic sources of ammonium (Ames *et al.*, 1983) and therefore, the higher nitrogen concentration in mycorrhizal plants could be attributed to the hyphae uptake. The same could be said of the higher potassium concentration in inoculated plants. In a compartment pots experiment, Li *et al.* (1991), demonstrated that about 10% of the total potassium uptake in mycorrhizal coach grass was due to hyphal uptake and transport.

Conclusion

The current study had shown that inoculating *Senna spectabilis* with vesicular-arbuscular mycorrhyza enhances growth performance. The inoculation resulted in an increment in height growth by 85% and root collar diameter by 71% within three months. Shoot biomass increased significantly by 213% while root biomass increased by 241%. Inoculated plants subequently produced more leaves per plant, which could have increased the rate of photosynthesis. Inoculated plants produced also more roots per plant which were longer than in the non inoculated plants. This improvement in plant growth could be attributed to the enhancement of the plant to absorb more nutrients, via an increase in the absorbing surface area. Vesicular-arbuscular mycorrhiza colonization also protects roots from soil pathogens and thereby increase root growth and nutrients acquisition of the host plants.

References

Abbott, L. K. and Robson, A. D. (1982) The role of Vesicular- Arbuscular Mycorrhizal fungi in agriculture and the selection of fungi for inoculation. *Aust. J. Res.* 33: 389-408.

Aggangan, N. S. and Dela, R. E. Cruz. (1991) Growth improvement of two forest tree legumes by VA mycorrhizal inoculations. *The Phillipines journal of Biotechnology* 2(1): 72-80).

Allen, M. F., Smith, W.K., Moore jr, T.S. and Christensen, M. (1981) Comparative water relations and photosynthesis of mycorrhizal *Bouteloua gracilis* H.B.K. lag ex Steud. *New Phytologist* 88: 683-693.

Allen, M. F., Allen, E. B. and Friese, C.F. (1989) Responses of the non-mycotrophic plant Salsola kali to invasion by vesicular-arbuscular mycorrhizal fungi. *New Phytol.* 111: 45-49.

Ames, R.N., Reid, C.P.P., Porter, L.K. and Cambaedella, C. (1983) Hyphal uptake and transport of nitrogen from two 15N-labelled sources by Glomus mosseae, a vesicular-arbuscular mycorrhizal fungus. *New Phytology* 95: 381-396.

Baylis, G.T.S. (1975) The magnoliod mycorrhiza and mycotrophy in root systems derived from it. In, Sanders, F.E., Mosse, B. and Tinker, P.B. (Eds). Endomycorrhizas. Pp 373-389. Academic press, London.

Brandon, N.J. and Shelton, H.M. (1993) Role of vesicular-arbuscular mycorrhizae in Leucaena establishment. *Proceedings of the XVII International Grassland congress* 2064-2065.

Castillo, E.T. (1993). Physiological responses of Narra (*Pterocarpus indicus* wild.) inoculated with VA Mycorrhiza and rhizobium in macolod soils. Ph.D. Thesis. UP Los Banos.

Chin K. Ong and Huxley, P. (editors). (1996) *Tree-crop interactions. A physiological approach.* CAB International.386 pp.

Chulan, H.A. and martin, K. (1992) *The vesicular-arbuscular (VA) mycorrhiza and its effects on growth of vegetatively propagated Theobroma cacao L. Plant and Soil* 144. 227-233.

Clapperton, M.J. and Reid, D.M. (1992) A relationship between plant growth and increasing VA mycorrhizal inoculum density. *New phytologist* 120. 227-234.

Cooper, K.M. (1984) Physiology of VA mycorrhizal associations. In: *VA Mycorrhiza* (Ed. By C. L. Powell and D. J. Bagyaraj), pp. 155-186. CRC Press, Inc., Boca Raton, Florida.

Dela Cruz, R.E. (1987) Status of Mycorrhizal Research in the Philippines and Its implication to national development, SEARCA Professional Chair Lecture given at SEARCA Auditorium March 11, 1987.

Dela Cruz, R.E., Manalo, M.Q., Agangan, N.S. and Tambalo, J.D. (1988) Growth of three legume trees inoculated with VA mycorrhizal fungi and Rhizobium. *Plant and Soil* 108: 111-115.

Dela Cruz, R.E. (1991) *Status of Bio-reforestation in the Philippines.* Paper presented during the pre-Workshop on Bio-Reforestation sponsored by

IUFRO Japan, Bogor, Indonesia March 25-29.

Douds, J.R., Johnson, C.R. and koch, K.E. (1988) Carbon cost of the fungal symbiont relative to net leaf P accumulation in split-root Va mycorrhizal symbiosis. *Plant Physiology* 86: 491-496.

Ellis, J.R., larsen, H. J. and Boosalis, M.G. (1985) Drought resistance of wheat plants inoculated with vesicular mycorrhizae. Plant and Soil 86: 369-378.

Fitter, A.H. (1988) Water relations of red clover *Trifolium pratence* L. as affected by VA mycorrhizal colonization of phosphorus supply before and during drought. *J. Exp. Bot.* 39: 595-603.

Giovannetti, M. and Mosse, B. (1980) An evaluation of techniques for measuring vesicular-arbuscular mycorrhizal infection in roots. *New Phytol.* 84: 489-500.

Harley, J.L. and Smith, S.E. (1983) *Mycorrhizal Symbiosis*. Academic Press, London 483 pp.

Hattingh, M.J., Gray, L. E. and Gerdenmann, J. W. (1973) Uptake and translocation of 32P-labelled phosphate to onion roots by endomycorrhizal fungi. *Soil Sci.* 116, 383-387.

Huang, R.S., Smith, W. K. and Yost, R.E. (1985) Influence of vesicular-arbuscular mycorrhizae on growth, water relation and leaf orientation in Leucaena leucocephala (Lam.) De wit. *New Phytol.* 99: 229-243.

Jakobsen, I., Abbott, L.K. and Robson, A.D. (1992) External hyphae of arbuscular mycorrhizal fungi associated *with Trifolium subterraneum* L. I. Spread of hyphae and phosphorus inflow into roots. *New Phytol.* 120: 372-380.

Janos, D.P. (1980a). Mycorrhizae influence tropical succession. *Biotropica*. Special edition. (1980) 56-64.

Janos, D.P. 1980b. Vesicular-arbuscular mycorrhizae affect lowland tropical rain forest plant growth. *Ecology* 61(1):151-162.

Kormanik, P.P., Bryan, W.C. and Schultz, R. C. (1981) Effects of three vesicular-arbuscular mycorrhizal fungi on sweetgum seedlings from nine mother trees. *Forest Sci, 27* No. 2. 327-335.

Kormanik, P.P. and Mcgraw, A..C. (1982) Quantification of vesicular-arbuscular mycorrhizae in plant roots. In *Methods and principles of mycorrhizal research,* by N.C. Schenck (Ed), University of Florida. pp 37-45.

Kucy, R.M.N. and Paul, E.A. (1982) Carbon flow, photosynthesis and nitrogen fixation in mycorrhizal and nodulated faba beans (*Vicia faba* L.) *Soil biology Biochemistry* 14: 407-410.

Ladha, J.K., Peoples, M. B., Garrity, D. P., Capuno, V. T. and Dart, P. J. (1993) Estimating dinitrogen fixation of hedgerow vegetation using the nitrogen-15 natural abundance method. *Soil Sci. Soc. Am. J.* 57: 732-737.

Levy, Y. and Syvertsen, J. P. (1983) Effect of drought stress and vesicular-arbuscular mycorrhiza on citrus transpiration and hydraulic conductivity of roots, *New Phytologist* 93: 61-66.

Li X-L, George, E. and Marschner, H. (1991) Extension of the phosphorus depletion zone in VA-mycorrhizal white clover in calcareous soil. Plant and Soil. 136: 41-48.

Marschner, H. and Dell, B. (1994) Nutrient uptake in mycorrhizal symbiosis. *Plant and Soil* 159:89-102.

Michelsen, A. and Rosendahl, S. (1990) The effect of VA mycorrhizal fungi, phosphorus and drought stress on the growth of *Acacia nilotica* and *Leucaena leucocephala* seedlings. *Plant and soil* 124: 7-14.

Miller, R.M. (1987) The ecology of vesicular-arbuscular mycorrhizae in grass and shrublands. In: G.R. Safir (editor), *Ecophysiology of VA Mycorrhizal Plants*. CRC. Press, Boca T=Raton, pp. 135-170.

Nielsen, J.D. (1983) Influence of vesicular-arbuscular mycorrhiza fungi on growth and uptake of varius nutrients as well as uptake ratio of fertilizer P for lucerne (Medicago sativa). *Plant and Soil* 70: 165-172.

Nye, P.H. and Tinker, P.B. (1977) *"Solute movements in the root-soil systems"* Blockwell. Oxford.

Osunubi, O., Okon, I.E. and Bamiduro, T.A. (1990) Effect of different fungal inoculation periods on performance of *Gmelina* seedlings under dry conditions. *Forest Ecology and Management* 37(4): 223-232.

Pearson, V.G. and Gianinazzi, S. (1983) The Physiology of vesicular-arbuscular mycorrhizal roots. *Plant and Soil* 71: 197-209.

Perrin, R. (1990) Interactions between mycorrhizae and diseases caused by soil-borne fungi. *Soil Use Management* 6: 189-195.

Reid, R.K., Parker, W.C., Mitchell, R.J., Garrett, H.E., henderson, G.S and Cox, G.S. (1988) Vesicular-arbuscular mycorrhizal influences on growth and aluminium tolerance of sugar maple seedlings. In proceedings, 10th North American Forest Biology Workshop, Physiology and genetics of reforestation; vancouver British Columbia, July 10-22.

Sanders, F.E. and Sheikh, N..A. (1983) The development of vesicular-arbuscular mycorrhizal infection in plant root systems. *Plant and Soil* 71: 223-246.

Sieverding, E. (1991) *Vesicular-arbuscular mycorrhiza management in tropical Agrosystems*. GTZ Press. Germany.

Smith, S.E., Nicholas, D. J. D. and Smith, F. A. (1979) Effect of early mycorrhizal infection on nodulating and nitrogen fixation in Trifolium subterraneum L. Aust, *Plant J. Physiol.* 6: 305-316.

Wang, G.M., Coleman, D. C., Freckman, D. W., Dyer, M. I., Mcnaughton, S.J. Acra, M. A. and Goeschl, J. D. (1989) Carbon partitioning patterns of mycorrhizal versus non- mycorrhizal plants: real time dynamic measurements using 11CO2. New Phytologist 112, 489-493.

Young, A. (1997) *Agroforestry for soil management.* CAB International. 320pp.

Zajicek, J. M., Hetrick, B. A. D. and Albrecht, M.L. (1987) Influence of drought stress and mycorrhizae on growth of two native forbs. *J. Amer. Soc. Hor. Sci.* 112(3): 454-459.

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Soil Invertebrate Macrofauna Composition within Agroforestry and Forested Ecosystems and their Role in Litter Decomposition in Embu, Kenya

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Abstract

Adequate food to meet the needs of an ever-increasing population is a major challenge for most developing countries, especially in the tropics. Despite this, few new technical packages capable of increasing net returns without deteriorating the environment have been developed. Crop yields in Embu, Kenya are poor due to declining soil fertility prompted by continuous cropping and application of fertilizers in non-sufficient quantities by farmers. Studies have shown that soil biota provides the means and regulates the transformation of organically bound nutrients into plant-available forms through mineralization.

An experiment was conducted to investigate soil macrofauna composition within agroforestry and forested ecosystems and their role in litter decomposition. This was anticipated to address poor crop yields in the study region. The study was conducted during the long and the short rains of the year 2000 on-station at Embu in an ongoing hedgerow intercropping experiment. Two types of Standard PVC litterbags with mesh size 7 mm and 1mm, were used. The 7 mm mesh size allowed macrofauna to enter while the 1 mm excluded the macrofauna. Two types of litter: *Calliandra calothyrsus* (low quality) and *Leucaena leucocephala* (high quality), were placed in the litterbags in duplicate in selected treatments of the Embu trials and were sampled at 1, 2, 4, 8, and 16 weeks. Decomposition rate constants (k) were estimated using a non-linear module in the EXCEL spreadsheet upon fitting first order exponential equations.

Results from the study depicted that different management practice and/or land use affect soil macrofauna in varied manner. Soil invertebrate macrofauna enhanced the rate of decomposition of *C. calothyrsus* and *L. leucocephala* litter.

Keywords: Agroforestry, Hedgerow intercropping, Litter decomposition, Macrofauna.

Introduction

Production of adequate food to meet the needs of an ever-increasing population is a major challenge for most developing countries and in particular those of tropical Africa, Borlaug (2000). The focus on food production should therefore, be widened to include the problem of how best to conserve natural resources and biodiversity while achieving optimum sustainable yields.

Soil fauna may affect soil function in a variety of ways, and could be used as indicators of nutrient status of soil in a given site (Doube, 1997; Rao *et al.*, 1998 and Vanlauwe *et al.*, 1996). Soil invertebrates are the major determinants of soil processes in tropical ecosystems, whereas pest management is an integral part of crop production, the potential for manipulating the beneficial soil animals has rarely been considered in designing management practices (Lavelle *et al*., 1994b). Practices that eliminate beneficial soil faunal communities are unlikely to contribute to the sustainable production in the long term, especially in low-input systems based on organic residues. Thus focus on food production should be widened to include the problem of how best to conserve natural resources and biodiversity while achieving optimum sustainable yields.

According to ICIPE (1997), the diversity and role of soil fauna have been largely ignored by traditional and conventional agriculturists due to limited knowledge on their impact on crop yields. In recent years, many well-documented articles and reports have established the importance and urgency of improved knowledge and management practice for tropical soils. There is relatively little data and information available regarding tropical soil biology. Moreover, technological developments in temperate zones may not be applicable or appropriate in the tropics. According to Bruyn (1997), soil degradation in the tropics is related to drastic decline in activity and diversity of soil fauna among other aspects. The challenge in the future will therefore be to shift the emphasis of soil fauna research towards understanding their function in soil processes essential to ecosystem functioning. The soil biota, including soil microbial biomass and soil fauna provide the means and regulate the transformation of organically bound nutrients into plant-available forms through mineralization (Vanlauwe *et al*., 1996; Lavelle *et al*., 1994 and Tian *et al*., 1997).

The process of litter decomposition is critical for maintaining the functioning of natural and managed ecosystems. This process occurs with partial involvement of soil invertebrates in the terrestrial ecosystems. Mugendi (1997) pointed out that studies on how litter quality affects decomposition in agroforestry systems are scanty. Studies done elsewhere depicts that the attributes of litter decomposition are determined by litter traits and climatic conditions (Thomas *et al*., 1993; and Kochy, *et al*., 1997). According to Upadhyay and Singh (1989), decomposition could be regulated by variables such as decomposer communities among others. Studies have also shown that rates and patterns of litter decomposition can be described as a function of season, climate and the conditions within the soil environment (Kwabiah *et al*., 1999 and Mafongoya *et al*., 2000).

This study mainly investigated the role of soil invertebrate macrofauna in litter decomposition within a hedgerow intercropping. Little research has been done on this aspect thus a need to undertake a study on the same. With this sort of experimental evidence, scientists can indicate to the farmer the state of the soil resource. The study specifically investigated the role of soil macrofauna on the rate of litter decomposition and compared the rate of litter decomposition of *C. calothyrsus* and *L. leucocephala*.

Materials and Methods

Experimental site

The study was conducted at the National Agroforestry Research Project (NAFRP) site at the Kenya Agricultural Research Institute (KARI) Regional Research Centre, Embu district in the Eastern province of Kenya. The centre is in the central highlands of Kenya on the southeastern slopes of Mt. Kenya at 0° 30'S, 37o 30'E and an altitude of 1480 m. The average maximum temperature is 25°C; the minimum is 14°C while the long-term monthly temperature is 19.5°C. The area receives a total annual rainfall of between 1200 and 1500 mm in two distinct seasons: long rains (March to June) average of 650mm and the short rains (mid October to December) average of 450 mm. The soils are mainly Humic Nitisols (FAO-UNESCO, 1989), derived from basic volcanic rocks (Jaetzold and Schmidt, 1983). They are deep, well weathered with friable clay texture with moderate to high inherent fertility.

Experimental treatments

Calliandra calothyrsus and *L. leucocephala,* were the two tree species selected for this experiment. The two hedgerow species had been identified as two of the most appropriate species for soil fertility management (Heinemann *et al.*, 1990). The hedgerows were planted in April 1992 while the application of experimental treatments started in the long rain season of March 1993. There were ten (10) treatments replicated three (3) times in randomized complete block design as shown in Figure 32.1.

Management of tree hedges and pruning incorporation

Calliandra calothyrsus and *L. leucocephala* tree hedges were lopped two days before maize was planted. Hedges were lopped at a height of 50 cm using sharp knives. Leafy biomass and succulent stems were separated from hardened stems that were removed for firewood. The leafy biomass were weighed, chopped into smaller pieces (5 to 10 cm) and spread evenly on the ground over the plot area. They were then incorporated in the soil using hand hoes in the plots that were designed to receive pruning (Figure 32.1) as the land was being prepared for maize planting. The rate of leafy biomass of each tree species applied to different treatments was approximately 2 Mg ha^{-1} season^{-1} on dry weight basis.

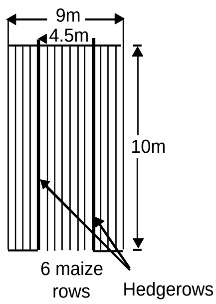
Figure 32.1: Field and plot layout, and experimental treatments within hedgerows at the National Agroforestry Research Project (NAFRP) site in Embu, Kenya

REP 1	P1 T8	P2 T5	P3 T9	P4 T4	P5 T6	P6 T3	P7 T1	P8 T2	P9 T10	P10 T7
REP 2	P20 T1	P19 T4	P18 T6	P17 T3	P16 T10	P15 T2	P14 T5	P13 T8	P12 T7	P11 T9
REP 3	P21 T6	P22 T3	P23 T2	P24 T1	P25 T7	P26 T10	P27 T4	P28 T9	P29 T5	P30 T8

MET STATION

N

	Crop	Cropping System	Tree Species	Incorporation	Fertilizer
T1	Maize	Intercrop	*C. calothyrsus*	Yes	None
T2	Maize	Intercrop	*L. leucocephala*	Yes	None
T3	Maize	Intercrop	*C. calothyrsus*	Removed to trt 5	None
T4	Maize	Intercrop	*L. leucocephala*	Removed to trt 6	None
T5	Maize	Monocrop	*C. calothyrsus*	Imported from trt 3	None
T6	Maize	Monocrop	*L. leucocephala*	Imported from trt 4	None
T7	Maize	Monocrop	*C. calothyrsus*	Imported from outside at rate of trt 6	50kg.N ha^{-1}
T8	Maize	Monocrop	*L. leucocephala*	Imported from outside at rate of trt 6	50kg.N ha^{-1}
T9	Maize	Monocrop	None	None	50kg.N ha^{-1}
T10	Maize	Monocrop	None	None	None



NB: Diagram not drawn to scale
P = Plot; T = Treatment

Sampling of soil invertebrate macrofauna

Sampling for macrofauna was done six weeks after the incorporation of the litter biomass. Using a monolith of size 25 cm x 25 cm x 30 cm, samples were taken in two seasons; the long and the short rainy seasons. At each observation, five samples were taken randomly from each plot three times per season. The monolith was placed over a randomly selected spot and using a metallic mallet, it was driven into the soil to the ground level. The soil from the monolith was removed by hand depthwise at 0-10 cm, 10-20 cm and 20-30 cm depths into plastic buckets. The soil from each depth was placed in different plastic trays (20 cm by 30 cm) and gently sorted out to locate the organisms. The organisms were separated into major taxonomic groups and then collected in glass and plastic bottles using a pooter. After sorting, soil was returned to the sampling sites to minimize site degradation. In the laboratory, counting and recording was done. Numbers of different category of organisms were expressed per metre square. After counting, the soil fauna were preserved in 75% alcohol for subsequent identification at the Department of Entomology, National Museums of Kenya, Nairobi.

Decomposition of incorporated litter within hedgerow agroecosystem

The experiment on litter decomposition was conducted within a hedgerow intercrop to investigate the role of soil macrofauna in litter decomposition and the relationship between resource quality and the rate of decomposition.

Two types of plastic (polyvinyl) bags with mesh size 1 mm and 7 mm respectively with an envelope configuration were used. The 7 mm mesh size allowed macrofauna to enter while the 1 mm excluded the macrofauna. The sides of the litterbags were bent to retain the shape of shallow box like container to prevent compression of the enclosed litter and also to allow or exclude free access to most macrofauna groups. 100 g (fresh weight) of *L. leucocephala* or *C. calothyrsus* was placed into the bags and the open edges of the bags then sealed with nylon thread and the litter spread evenly within the bags. Ninety (90) bags of each mesh size were buried in a completely randomized design (CRD), horizontally in the soil at a depth of 15 cm with the subtreatments replicated twice to allow retrieval of two litterbags (one of 1mm and another of 7mm), per each plot at 1, 2, 4, 8, and 16 weeks after incorporating the litter for dry matter analyses within the plots whose treatments involved litter incorporation (treatments 1, 2, 5, 6, 7, and 8). Throughout the period of the experiment, the experimental area was kept free of weed by hand weeding.

Dry matter loss analyses of *Calliandra calothyrsus* and *Leucaena leucocephala*

At each sampling, the soil attached to the litterbag was carefully removed and the litter was put in polythene bags and taken to the laboratory, where soil and organic debris were sorted out by hand from the decomposing plant materials. Samples were then cleaned and oven dried at 65° C to a constant weight for dry weight determination (Anderson and Ingram, 1993). The dry weights were expressed as percentage of the initial sample weight at time zero. Decomposition rate constants (k) were estimated using Wieder and Lang (1982), first order exponential equation:

$$L_R / L_I = e^{-kt}$$

Where: L_R = litter remaining after a given time.
L_I = initial litter weight at time zero.
t = time interval of sampling LR expressed in weeks.
k = rate constant (decomposition rate constant per week).
e = base of natural logarithm.

The k values were estimated using a non-linear module in the EXCEL spreadsheet.

This exponential model was considered to be close to the biological reality where the decomposition rate of fresh litter is rapid when hydrosoluble compounds are leached, but subsequently decrease over time.

Nutrients attributes of *Calliandra calothyrsus* and *Leucaena leucocephala*

The oven-dry samples of fresh plant samples taken at the onset (time zero) and during the experiment, were ground in a Wiley mill to pass through a 0.5 mm sieve. Sub-samples of the ground litter were analyzed for total nitrogen, phosphorus, potassium, calcium, and magnesium using ICRAF laboratory methods (ICRAF, 2000). Lignin contents were analyzed according to the methods of Rowland and Roberts (1994) and polyphenols by procedures detailed in the TSBF Handbook (Anderson and Ingram, 1993).

One gram (1g) of ground plant samples was ashed in a muffle furnace at 500°C for four hours to correct for soil contamination, when the samples were buried in the soil. The ashed samples were reweighed and percentage ash content determined as shown below:

Percentage Ash = [(crucible + unashed sample) - (crucible + ashed sample)] [(crucible + unashed sample) - (crucible weight)] x 100

The nutrient values were corrected on the basis of ash-free weight:

Ash free weight per g of material = 1 - 0.01x % ash.

Percentage Corrected value for nutrient (N, P, K, Ca, and Mg) = 0.01 x % nutrient (N, P, K, Ca, and Mg)

Decomposition over time was calculated following the formula by Giashudin *et al.* (1993):

Percentage of dry weight remaining = (DWt)/(Dwi) ◊ 100

Where: DWt = oven dry weight at time t and
Dwi = initial oven dry weight.

Results and Discussions

Soil invertebrate macrofauna abundance within the hedgerow agroecosystem

The macrofauna observed during the period of study were identified into their respective groups/orders. Whenever possible the fauna were identified up to the species level, but for some it was not possible as they were still in their juvenile stage and therefore indicated as not identified (NI). Different macrofauna groups were observed in varying numbers during the study period as shown in Table 32.1. The hedgerow agroecosystem recorded several distinct groups of macrofauna. This could have been as a result of the region offered a wide range of habitat for diverse faunal groups and therefore, it could be a rich ecosystem.

Table 32.1: Macrofauna groups observed within hedgerow agroecosystem during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya

Group/Order	Family/Subfamily	Genera/Species
1. Myriapoda (Millipedes)	NI*	NI*
2. Coleoptera (Beetles)	1. Scarabidae/aphodina 2. Staphylinidae. 3. Carabidae.	1. *Aphodius ividus* L. (chaffer grub). 2. *Philanthus* sp. (dark tiny beetles). 3. *Hyparpulus ornatus* Per.
3. Hymenoptera (Ants)	Formicidae/Myrmacinae	1. *Bothroponera* sp. (big dark ants) 2. *Euponera* sp. (brownish and small). 3. *Anoma* sp. (red ants).
4. Acarina (Mites)	NI*	NI*
5. Chilopoda (centipedes)	NI*	NI*
6. *Aranae* (Spiders)	Agriopidae	*Araneus drademauts* L.
7. Isoptera (Termites)	Termitinae/ Macrotermitinae	*Microtermes pusillas* Wasmann (tiny termites)
8. Diptera (Flies)	NI*	NI*
9. Lepidoptera (Moths)	NI*	NI*

* Not identified

Relatively higher numbers of fauna were observed within the hedgerows agroecosystem (Table 32.2) compared to the forested site (Table 32.3). This could have been because the macrofauna were able to utilize the benefits accrued from combining trees with crops than with trees alone as observed within the forested site.

Isopterans were the most abundant of the macrofaunal observed followed by Hymenopterans, Lepidopterans, Coleopterans, Chilopoda, Aranae, Myriapoda, Acarinas and Dipterans in that order. It was evident that in the hedgerow agroecosystem, termites formed the major macrofaunal group contributing 76.5% of the total macrofauna observed as depicted in Table 32.2.

Table 32.2: Total macrofaunal counts and percentages observed within hedgerow agroecosystem during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya

Faunal group	Total counts (m^{-2})	Total counts (%)
Isoptera	22406	76.5
Hymenoptera	3344	11.4
Lepidoptera	1466	5.0
Coleoptera	1126	3.8
Chilopoda	403	1.4
Aranae	205	0.7
Myriapoda	166	0.6
Acarina	106	0.4
Diptera	77	0.3

Table 32.3: Total macrofaunal counts and percentages observed within the forest ecosystem during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya.

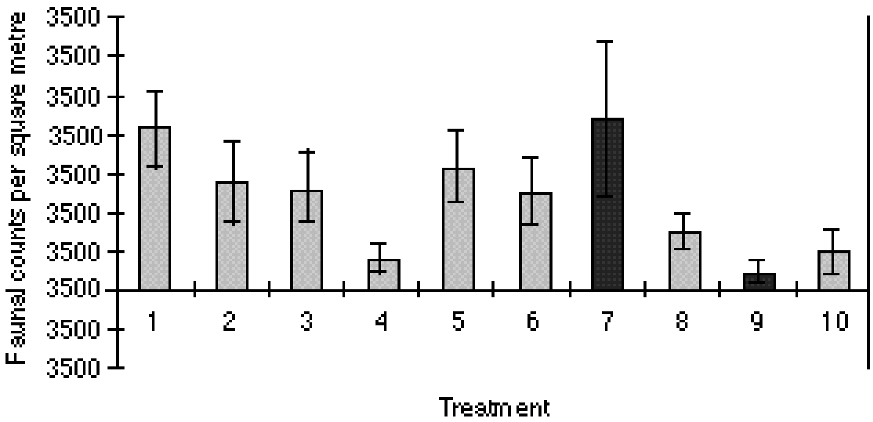
Faunal group	Total counts (m^{-2})	% Total counts
Isoptera	8470	64.87
Hymenoptera	705	5.4
Lepidoptera	1568	12
Coleoptera	934	7.2
Chilopoda	368	2.8
Aranae	213	1.6
Myriapoda	596	4.6
Acarina	106	0.8
Diptera	96	0.7

The presence of high number of termites in the hedgerow agroecosystem could imply that they were better able to withstand disturbed conditions as well as diminishing food resources resulting from such disturbances. It could also have been that the termites being ecosystem engineers, influenced the access of litter to other faunal groups hence their abundance over the rest. Termites may as such be able to survive a wide range of conditions. This corroborates with the work done by Christopher (1994) that showed that the influence of termites is not confined to certain litter qualities and that they control the accessibility of litter to other decomposers to an extent that exceeds their influence by direct consumption.

Total macrofauna abundance varied significantly ($p<0.05$), across treatments with higher numbers of fauna being recorded for treatments with *C. calothyrsus* than with *L. leucocephala* over the sampling period

(Figure 32.2) within the hedgerows. Treatments involving *C. calothyrsus*, biomass incorporation plus fertilizer (Treatment 7), recorded highest numbers of fauna.

Figure 32.2: Macrofauna counts within hedgerows during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya



Key:
1 & 2 = Alley cropping of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated and no fertilizer applied.
3 & 4 = Alley cropping of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with no prunings incorporated and no fertilizer applied.
5 & 6 = Maize only, no alley cropping, prunings of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated from outside and no fertilizer applied.
7 & 8 = Maize only, no alley cropping, prunings of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated from outside and fertilizer applied
9 &10 = Maize only, no alley cropping with and without fertilizer applied respectively fertilizer applied

Litter decomposition as influenced by soil invertebrate macrofauna within hedgerow intercropping in Embu, Kenya

Decomposition and nutrient release of the litter biomass are the key processes by which nutrients locked up in plant parts eventually become available to crops. The processes are regulated by variables such as the quality of the litter, climate, soil properties and decomposer communities (Upadhyay and Singh, 1989). Therefore, understanding the influence of these variables on biomass decomposition and nutrient release is a vital step to better management of organic inputs that are applied in different agroecosystems (Mafongoya et *al.*, 1997).

Nutrient analyses of the litter used in the decomposition study depicted that *C. calothyrsus* and *L. leucocephala* had varied nutrient content as shown in Table 32.4 and therefore, they could be varied in terms of nutritional value hence resource quality. The two species had varied lignin and/or polyphenols to nitrogen ratios (Table 32.5). T-test indicated that nutrient concentrations of the two species were significantly different ($p < 0.05$).

Table 32.4: Average chemical composition of *Calliandra calothyrsus* and *Leucaena leucocephala* within hedgerows in the year 2000/2001in Embu, Kenya.

Material	%N	%P	%K	%Ca	%Mg	% Lignin	%Poly-phenol
Calliandra calothyrsus	2.8	0.1	0.6	1.2	0.4	13.4	11.2
Leucaena leucocephala	2.8	0.1	1.9	1.3	0.3	9.5	8.1
SED	0.02	0.01	0.06	0.04	0.01	0.10	0.11

Table 32.5: Lignin and/or polyphenols to Nitrogen ratios of *Calliandra calothyrsus* and *Leucaena leucocephala* within hedgerows in the year 2000/2001in Embu, Kenya

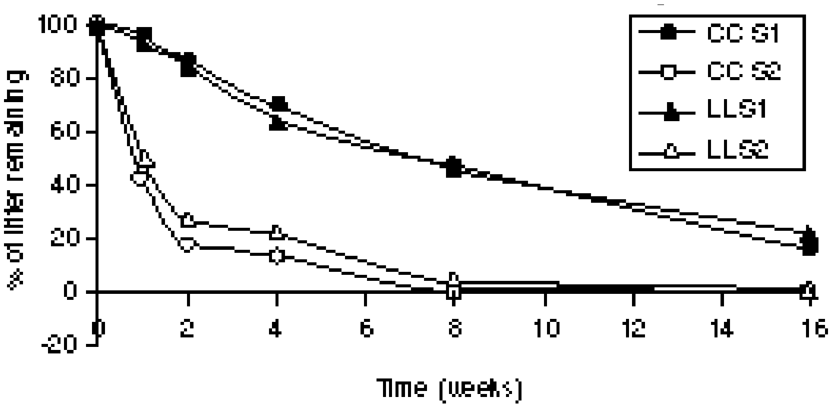
Plant Material	Lig/N	Pp/N	(Lig +Pp)/N
Calliandra calothyrsus	4.8	4.0	8.9
Leucaena leucocephala	3.4	2.9	6.3
SED	0.02	0.06	0.01

Key:
N = Nitrogen, Lig = Lignin, Pp = Polyphenol

In Figure 32.3, it is evident that *L. leucocephala* decomposed at relatively faster rate than *C. calothyrsus*, save for the second season when *C. calothyrsus* decomposed at faster rate than *L. leucocephala* during the second and the fourth week. The pattern of litter decomposition was gradual in season one and drastic in season two. This could have been due to different abiotic conditions in terms of moisture and temperatures experienced and therefore varied faunal population within treatments involving the two species. These findings agree with the observations made by Mugendi *et al.* (1994) in Machakos district of Kenya, during the short rains and the long rains, which gave an indication that faunal decomposition could be having some relation to climatic conditions and resource quality.

There was some litter remaining for both the species even after the 16th week for the first season, whereas all the litter had decomposed by the 8th week in the second season. The rate of litter decomposition was relatively slow within the first four weeks of the first season, after which it became fast. During the second season, the rate was slower for the first two weeks after which it proceeded at a faster pace.

Figure 32.3: *Calliandra calothyrsus* and *Leucaena leucocephala* decomposition within hedgerows during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya

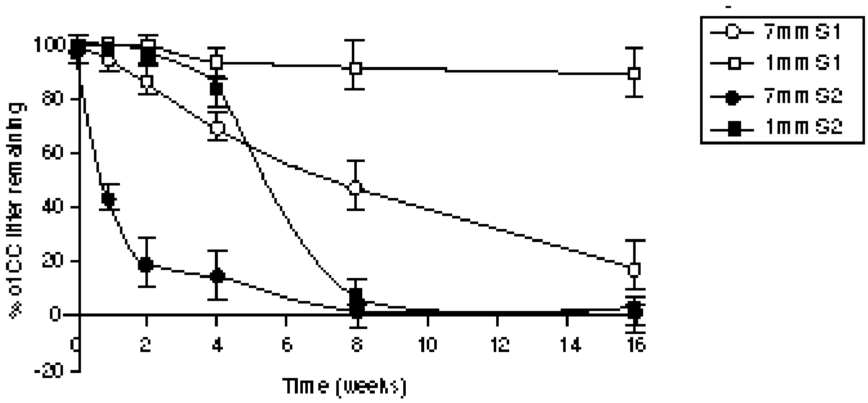


The varied rate of decomposition of *L. leucocephala* and *C. calothyrsus* could have been due to the varied litter substrate quality in which case, the former may be seen to be of higher quality than the latter as it had higher levels of nitrogen and phosphorus, and lower ratios of lignin and/or polyphenols to nitrogen. Lignin is known to be highly resistant to microbial decomposition, according to studies by Melillo *et al.* (1982) and Chesson (1997). This is also in agreement for instance with observation made by Thomas *et al.* (2000) that litter with low levels of lignin decomposes faster. According to Vityakon *et al.* (2000), Polyphenols exhibits a significant influence on nitrogen release from litter biomass hence decomposition. These findings are in agreement with studies conducted by Bubb *et al.* (1998), which indicated that litter-mass loss is strongly correlated with litter quality indicators such as nitrogen, phosphorus, carbon to nitrogen ratio, lignin and polyphenolics.

Overall, the rate of decomposition of *L. leucocephala* and *C. calothyrsus* was faster in the second season than in the first season. This could have been due to the presence of fully established crop that might have increased the decomposition of the residues of the prunings. This corroborates to findings by Vanlauwe *et al.* (1997) that crop cover may increase decomposition and nitrogen release of the residues.

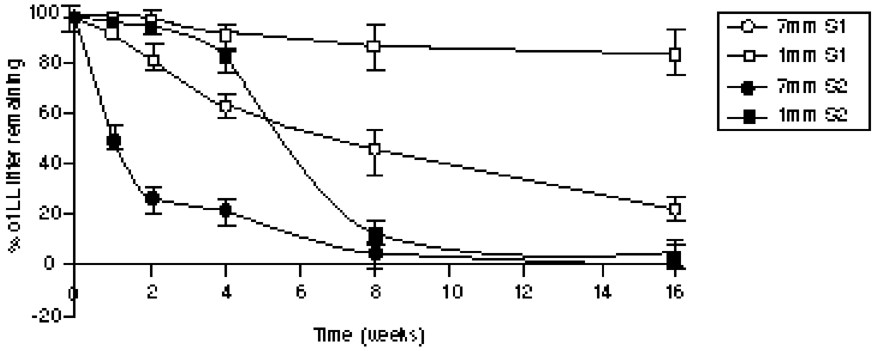
The litter enclosed in 7mm litterbags, decomposed at a faster rate than that in the 1-mm litterbags and the rates were higher in season two than in season one for both *C. calothyrsus* and *L. leucocephala* as depicted in Figure 32.4 and 32.5 respectively. These variations in decomposition could have been due to varied effects of the decomposers giving an indication that the presence of soil invertebrate macrofauna could have promoted the rate of litter decomposition. Season one was a dry season, and although the faunal biomass and counts was high during this specific season, the diversity was low (Table 32.6) as opposed to the second season where higher diversity of organisms was recorded. Therefore, higher faunal population and biomass could have enhanced decomposition in season one. This corroborates the studies by Rusek (1998), Gupta *et al.* (1998) and Beck, (2000) that fauna play an important role in plant litter decomposition processes.

Figure 32.4: The influence of litterbag mesh size on *Calliandra calothyrsus* decomposition within hedgerows during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya



Key: LL = *Leucaena leucocephala;*
S1 = season 1;
S2 = season 2

Figure 32.5: The influence of litterbag mesh size on *Leucaena leucocephala* decomposition within hedgerows during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya



Key: LL = *Leucaena leucocephala;*
S1 = season 1;
S2 = season 2

The moist conditions and favorable temperatures (Table 32.7), coupled with community composition in terms of diversity, may have played a great role in enhancing the rate of decomposition in the second season as opposed to the first season. Therefore, both the biotic and the abiotic factors could have influenced litter decomposition, though, decomposition may have been influenced more by the faunal diversity as opposed to faunal abundance. Different feeding habits resulting from the higher diversity recorded in the second season may have also promoted the rate of litter decomposition unlike in season one where the diversity was low.

During the second season, it could be that decomposition of *C. calothyrsus* was enhanced by more suitable moisture, temperature and soil condition that prevailed. Therefore, with favorable states of these abiotic factors, *C. calothyrsus* would have decomposed at a rate close or similar to that of *Leucaena leucocephala*. Overall results depicted that *L. leucocephala* decomposed and released nutrients faster than *C. calothyrsus*. This could be due to the varied chemical concentration as previously depicted in Table 32.4, hence varied nature of resource quality. *Leucaena leucocephala* had higher levels of nitrogen, phosphorus, potassium and calcium but low levels of magnesium and both polyphenols and lignin as opposed to *C. calothyrsus*. Higher lignin levels in *C. calothyrsus* than in *Leucaena leucocephala* may have slowed its rate of decomposition and may be even the release of nutrients.

Table 32.6: Macrofauna diversity as indicated by Shannon-Wiener index within hedgerows during the long and the short rain seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya.

Treatment	Season 1 Shannon-Wiener Index	Season 2 Shannon-Wiener index
1	-0.043(0.675)	-0.071(0.654)
2	-0.064(0.658)	-0.119(0.616)
3	-0.037(0.679)	-0.061(0.661)
4	-0.000(0.707)	-0.090(0.639)
5	-0.055(0.666)	-0.093(0.636)
6	-0.085(0.642)	-0.095(0.635)
7	-0.034(0.682)	-0.037(0.681)
8	-0.076(0.649)	-0.087(0.641)
9	-0.032(0.683)	-0.087(0.619)
10	-0.013(0.698)	-0.133(0.605)
SED (treatment)	(0.020)	(0.019)

Season 1: F test: P = 0.05;

Season 2: F test: P = 0.047

Values in parentheses are square root {(x + 0.5)} transformed.

1 & 2 = Alley cropping of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated and no fertilizer applied.

3 & 4 = Alley cropping of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with no prunings incorporated and no fertilizer applied.

5 & 6 = Maize only, no alley cropping, prunings of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated from outside and no fertilizer applied.

7 & 8 = Maize only, no alley cropping, prunings of *Calliandra calothyrsus* and *Leucaena leucocephala* respectively with their respective prunings incorporated from outside and fertilizer applied

9 &10 = Maize only, no alley cropping with and without fertilizer applied respectively fertilizer applied

Table 32.7: Average monthly temperature and total rainfall during the long (first season) and the short rain (second season) seasons of the year 2000 and 2000/2001 respectively in Embu, Kenya

Season	Temperature °C	Rainfall mm
1	18.7	262.0
2	17.5	340.9
Total	18.3	602.9

The higher concentrations of polyphenols in *C. calothyrsus* than in *L. leucocephala* could have caused immobilization of nutrients. Lignin and polyphenolics are known to be highly resistant to microbial decomposition according to studies by Melillo *et al.* (1982), Chesson, (1997) and Mafongoya *et al.* (2000). Therefore, based on these varied nutrients concentrations *L. leucocephala* is of higher quality than *C. calothyrsus* and this may explain why the former decomposed and released nutrients at a faster rate than the latter. Mafongoya *et al.* (1998) and Handayanto *et al.* (1997), made similar observations that the potential of the organic inputs from agroforestry species to supply nutrients depends on their quality and different tree species could be having varied chemical constituents. The results are in agreement with Hamada *et al.* (2000) that litter decomposition is affected by lignin content and that the relationship between lignin content and the decomposition rate is inverse. Supply of nutrients by an organic input is largely determined by the rate at which such organic decomposes and therefore, *L. leucocephala* may be of better quality than *C. calothyrsus*.

Generally, the decomposition rates were faster in the second season (which received some rains) as opposed to the first season (where rains failed). This could have been due to increase in moisture and faunal activity, which promoted the release of nutrients hence rate of decomposition. Decomposition and release of nutrients contained in *Leucaena leucocephala* and *Calliandra calothyrsus* is thus determined by their respective quality and/or the environment and the decomposer organisms present.

Conclusions and Recommendations

Results from this study depicted that different management practice and/or land use affect soil macrofauna in varied manner. Soil invertebrate macrofauna populations are high in management practices that entail incorporation of organic material into the soil as opposed to those that do not. Agroforestry system enhances the fauna population unlike forested ecosystems.

Soil invertebrate macrofauna enhanced the rate of decomposition of *C. calothyrsus* and *L. leucocephala* litter. *Leucaena leucocephala* decomposed faster than *C. calothyrsus* and the former had lower lignin and/or polyphenols to nitrogen ratio than the latter. Therefore, the rate of litter decomposition and nutrients release is related to tree species hence resource quality. *Leucaena leucocephala* could be more suitable for use to improve maize yields in alley cropping compared to *C. calothyrsus*.

Farmers should therefore be encouraged to use *L. leucocephala* as a source of nutrients for agricultural crops. *Calliandra calothyrsus* may be applied at some predetermined time before sowing, to make the nutrients released from the same be utilized by the growing crop. There is also a need to investigate litter decomposition trends in an agroforestry setting in arid and semi-arid lands, which forms the highest percentage of the Kenyan land.

References

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods*. (2nd edn). Wallingford, UK: CAB International.

Beck, L. (2000) Litter decomposition and soil fauna in temperate and tropical forests. In *Carolinea* 58: 243-256.

Borlaug, N. (2000) Meeting Africa's food production challenges in the 21st century. Paper presented on June 4th, 2000 by the President, Sasakawa Africa Association at ICRAF Nairobi, Kenya.

Bruyn, L.A. (1997) The status of Soil Microfauna as indicators of soil health to monitor the sustainability of Australian Soils. *Ecological Economics Amsterdam* 23:167-178.

Bubb, K. A. Xu, Z. H. Simpson, J. A and Saffigna, P.G. (1998) Some nutrient dynamics associated with litterfall and litter decomposition in hoop pine plantations of southeast Queensland, Australia. *Forest Ecology and Management* 110: 343-352.

Chesson, A.(1997) Plant degradation by ruminants: Parrallels with litter decomposition in soils. In Cadisch G and Giller (eds). *Driven by nature: Plant litter quality and decomposition.* CAB International, Wallingford, UK.

Christopher, M. (1994) Diversity and Ecology of Termites in Amazonian forests. *Pedobiologia* 38: 407-428.

Doube, B.M. (1997) Can the Abundance or Activity of Soil fauna be used to indicate the Biological health of soils? *Biological indicators of soil health*. CAB International; Wallingfors; UK. Pp. 265-295.

F.A.O. (1989) *Forestry and food security*. FAO forestry paper, *FAO (UN), 90:1-2*.

Giashuddin, M. M., Garrity, D.P. and Aragon, M.L. (1993) Weight loss, nitrogen content changes, and nitrogen release during decomposition of legume tree leaves on and in the soil. *Nitrogen Fixing Tree Research Reports* 11:43-50.

Gupta, P.K and Oli, B.P. (1998) Consumption and assimilation of evergreen oak litter by the slug *Anadenus altivagus* in Kumaon Himalayan Forests, India. *Ecoscience* 5: 494-501.

Hamada, Z., Steinberger, Y., Kutiel, P., Lavee, H. and Barness, G. (2000) Decomposition of A*vena sterilis* litter under arid conditions. *Journal of Arid Environments* 46: 281-293.

Handayanto, E. Giller, K. E. and Cadisch, G. (1997) Regulating nitrogen release from legume tree prunings by mixing residues of different quality. *In Soil Biology and Chemistry*. Vol. 29(9-10). Pp 1417-1426.

Heinemann, A. M., Mengich, E. K., Olang, A. D., and Otieno H. J. O. (1990) *Agroforestry Research Network for Africa Report no. 27. Maseno progress report for the period January 1988 to January 1990*. ICRAF, Nairobi, Kenya.

ICIPE, (1997) International Centre for Insect Physiology and Ecology. *Annual Report Highlights*. pp 2, Nairobi, Kenya.

ICRAF, (2000) International Centre for Research on Agroforestry. *Laboratory methods for soil and plant analysis,* Nairobi, Kenya.

Jaetzold, R. and Schmidt, H. (1983) F*arm handbook of Kenya: National conditions and farm management information of East Kenya (Eastern and Coast provinces),* Volume II A: 37-38. Typo-druck, Rossdorf, West Germany.

Kochy, M. and Wilson, S.D. (1997) Litter decomposition and nitrogen dynamics in Aspen forest and mixed-grass prairie. *Ecology*. Washinghton-D-C. l78: 732-739.

Kwabiah, A.B. Voroney, R.P. Palm, C.A. and Stoskopf, N.C. (1999) Inorganic fertiliser enrichment of soil. Effect on decopmsition of plant litter under subhumid tropical conditions. *Biology and Fertility of Soils* 30: 224-231

Lavelle, P., Dangerfield, M., Fragoso, C., Eschnebrenner, V., Hernadez, D.L., Pashanasi, B. and Brussard, L. (1994a) The relationship between soil macrofauna and tropical soil fertility. *In:* Woomer, P.L. and Swift, M.J. (eds). *The Biological Management of Tropical Soil Fertility*. Pp 136-169. A Wiley-Sayce publication.

Lavelle, P., Gilot, C., Fragoso, C. and Pashanasi, B. (1994b) Soil fauna and sustainable land use in the humid tropics. *In:* Greenland, G.A. and Szalbolcs, I. (eds), *Soil Resilience and Sustainable Land use* 18:291-307. CAB International, Wallingford.

Mafongoya, P.L., Barak, P. and Reed, J.D. (2000) Carbon, Nitrogen and phosphorus mineralisation from tree leaves and manure. *Biology and Fertility of soils* 30: 298-305

Mafongoya, P.L., Nair, P.K.R. and Dzowela, B.H. (1997) Multipurpose tree prunings as a source of nitrogen to maize under semiarid conditions in Zimbabwe. 3. Interactions of pruning quality and time and method of application on nitrogen recovery by maize in two soils types. *Agroforestry systems* 35: 57:70.

Mafongoya, P.L. Giller, K.E. and Palm, C.A. (1998) Decomposition and nitrogen release patterns of tree prunings and litter. *Agroforestry Systems*. 38: 77-97.

Melillo, J.M. Aber, J.D. and Muratore, J.F. (1982) Nitrogen and lignin control of hardwood leaf litter decomposition dynamics. *Ecology* 63: 621-626.

Mugendi, D.N. (1997) Tree-Biomass Decomposition, Nitrogen Dynamics, and Maize Growth under Agroforestry Conditions in the subhumid Highlands of Kenya. In, thesis submitted to the school of Forest Resources and Conservation, University of Florida.

Mugendi, D.N. Mochoge, B.O. Coulson, C.L. Stigter, C.J. and Arap Sang, F.K. 1994. Decomposition of *Cassia siamea* loppings in semiarid Machakos, Kenya. *Arid Soil Research and Rehabilitation* 8: 363-372.

Rao, M.R., Niang, A., Kwesiga, F.R., Duguma, B., Franzel, S., Jama, B. and

Buresh, R. (1998) Soil fertility replenishment in sub-Saharan Africa: New techniques and the spread of their use on farms. A*groforestry Today* 10: 3-8.

Rowland, A..P. and Roberts, J.D. (1994) Lignin and cellulose fraction in decomposition studies using acid-detergent fibre methods. *Commum. Soil Sci. Plant* 25: 269-277.

Rusek, J. (1998) Biodiversity of collembola and their functional role in the ecosystem. *Biodiversity and Conservation* 7: 1207-1219.

Thomas, K.D. and Prescott, C.E. (2000) Nitrogen availability in forest floors of three tree species on the same site: The role of litter quality. *Canadian Journal of Forestry Research* 30: 1698-1706.

Thomas, R.J., and Asakawa, N.M. (1993) Decomposition of leaf litter from tropical forage grasses and legumes. *Soil Biology and Biochemistry* 25: 1351-1361.

Tian, G., Kang, B.T., Brussard, L. and Swift, M.J. (1997) Soil fauna mediated decomposition of plant residues under constrained environmental and residue quality conditions. *In:* Cadisch, G. and Giller, K.E. (eds), *Driven by nature: Plant litter quality and decomposition, pp 125-134,* CAB International Wallingford, U.K.

Upadhyay, V. P. and Singh. (1989) Patterns of nutrients immobilization and release in decomposing forest litter in central Himalaya, India. *Journal of Ecology* 77: 127-146.

Vanlauwe, B., Dendooven, L., Merckx, R., Vanlangenhove, G., Vlassak, K. and Sanginga, N. (1996) Residue quality and decomposition under controlled and field conditions. *International Institute of Tropical Agriculture (IITA) Research Highlights and Annual Report. 12: 1-6.*

Vanlauwe, B., Sanginga, N., and Merckz, R. (1997) Decomposition of four Leucaena and Senna prunings in alley cropping systems under subhumid tropical conditions: the process and its modifiers. *Soil Biology & Biochemistry* 29: 131-137.

Vityakon. P. Meepech, S. Cadisch, G. and Toomsan, B. (2000) Soil organic matter and nitrogen transformation mediated by plant residues of different qualities in sandy acid upland and paddy soils. *Netherlands Journal of Agricultural Science.* 48: 75-90.

Wieder, R. K., and Lang, G. E. (1982) A critique of the analytical methods used in examining decomposition data obtained from litterbags. *Ecology* 63: 1636-1642.

Selection of Arbuscular Mycorrhizal Fungi for Inoculating Maize and Sorghum Grown in Oxisol/ Ultisol and Vertisol in Cameroon

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Abstract

Mycorrhizal plants have been shown to be more adapted to environmental stresses such as soil acidity, drought and low fertility in O*xisol/Ultisol or Vertisol*. Three group of experiments were carried out to identify *mycorrhizal* isolates that showed acidity tolerance, that improve plant P uptake using pearl millet and cowpea as test crops. Field studies were carried out to evaluate selected inoculants using maize in humid forest zone (HFZ) on *Ultisol*, to compare chemical fertilisers to bio-fertiliser using maize on HFZ in Oxisol and three inoculation methods were tested using *muskwari*, a dry season sorghum on Vertisol in savannah zones (SZ). Some local isolates from our microbial resource bank were identified and tested. Most of the *mycorrhizal* isolates were able to germinate at pH 3.8, but only some were significantly affected by acidity for their growth. Two isolates (*Glomus clarum*, GCDM and *Gigaspora margarita*, GiMV) were selected out of eleven for hyphal growth, plant dry weight and P uptake improvement. An improvement of 75 % and 86 % on efficiency were recorded over the control on dry weight basis for the best isolates. Field experiment showing significant improvement on biomass yield, grain yield and nutrient content of inoculated maize and sorghum were observed. A grain yield increase of 52 % to 66 % was recorded on maize after *mycorrhiza* inoculation in HFZ on *Oxisol/Ultisol*. *Mycorrhiza* inoculants produced a yield increase ranging from 7 to 48 % in sorghum on *Vertisol* in SZ according to the method of inoculation. These results support the idea that *mycorrhiza* inoculants may help improve on nutrient uptake, especially phosphorus or nitrogen which are limiting factors for cereal productivity in Oxisol/Ultisol, but also water uptake and yield in Vertisol. What are the limitations for the use of this technology in the tropics ? What can be done to reduce these limitations for extension ?

Keywords: Maize, *mycorrhiza* inoculation, Oxisol, sorghum, Ultisol, Vertisol

Introduction

To improve crop production in infertile African soils, chemical fertilisers have been intensively used, organic matter have been used in many East African countries and some soil management technologies such as fallow or legumes cultivation have also been used.

Recently, ecologically sound technologies were recommended for sustainable management of tropical soil. Reliance should be on biological processes by adapting germ-plasm to advance soil conditions, enhance soil biological activity and optimise nutrient cycling to minimise external inputs and maximise the efficiency of their use" (Sanchez, 1994). This approach has been developed for soil biota management for the tropics using key functional groups approach, such as earthworm and micro-symbionts (Woomer and Swift 1994; Swift, 1998).

These soil organisms may represent more than 90 % of soil biological activity and thus contribute to nutrient cycling, soil fertility and symbiotic processes in the rhizosphere.

Soil fungal diversity and activity have not been actively studied and understood (Hawksworth, 1991). *Mycorrhiza* represent an important group because they have a wide distribution; may contribute significantly to microbial biomass and to soil nutrient cycling processes in plants (Harley and Smith, 1983). Mycorrhizal associations are beneficial to plants and thus crop productivity for sustainable agriculture (Gianinazzi-Pearson et *al.* 1982; Bethlenfalvay, 1992). They improve on nutrient uptake, especially phosphorus, and also micronutrients such as zinc or cooper, they stimulate growth substances and may reduce stresses, diseases or pest attack (Sylvia and William, 1992; Davet, 1996; Smith and Read, 1997).

For an appropriate use of this technology, it is necessary to select the best *inocula* adapted to specific limiting environmental factors for crop productivity. Oxisol/Ultisol are acidic soils, low in nutrient availability, low in available phosphorus and P deficiency is common and available P is generally less than 5-10 ppm. They have high aluminium concentration which is highly toxic and may inhibit fungal spore germination and symbiosis, root growth, hence plant development and yield (Sanchez and Salinas, 1981; Janos, 1987; Robert, 1992). Vertisol are rather alkaline rich soils with a montmorillonite swelling clay, high cation exchange capacity (CEC) and water holding capacity but the main problem is water availability during dry season (Barrault *et al.*, 1972; Robert, 1992).

Maize and sorghum are the source of carbohydrates in the humid forest (HFZ) and the savannah zones (SZ) of Africa. In the HFZ, soil acidity couple with aluminium and manganese toxicity, limiting maize productivity. In Cameroon, acid soil cover 75 % of arable land and Al toxicity account for 40-80 % reduction or 1-2 t ha^{-1} loss in maize yield (Bindzi Tsala, 1987; The, 2000). In the SZ, drought and low soil fertility due to continuous cropping in the same field for a long time, are the main causes of low maize yields. Sorghum yield in Africa are very low, less than 0.7 t ha^{-1} compared to Asia or America, 1.2.-3.7 t ha^{-1} (Anonyme, 1991)

According to Hayman (1987), maize and sorghum form effective symbiotic association with indigenous arbuscular *mycorrhizal* (AM) fungi. Pot experiments using maize showed that shoot dry weight increase of biomass weight varying from 3%, 56% to 101%. (Harley and Smith, 1983). It is hypothesized that AM fungi may enhance maize tolerance to acidity and drought in tropical soils. There is limited available data on *mycorrhizal* diversity and their activity on diverse African land use systems, but according to Nwaga and Ngonkeu (1998), slash and burn agriculture may seriously reduce *mycorrhiza* inoculum potential in farming systems.

The main objective of this study was to isolate and select *mycorrhiza* strains that are tolerant to acidic environment, enhance P uptake leading to improved crop yield in soils of the humid forest and savannah zones of Cameroon.

Materials and Methods

Site description and soil characteristics

Site and soil characteristics of the experimental field are summarised in Tables 33.1 and 33.2.

Table 33.1: General characteristics of the experimental sites in Cameroon

Site (Village)	Altitude (m)	Climate	Rainfall (mm)	Temp. mean (°C)	Dominant vegetation (Land use)	Longitude	Latitude
Ebolowa (Nkoemvone)	500-700	Sub-equatorial	1500-2000	24	Forest (Hevea plantation)	11°20 'E	2°90'N
Maroua (Moutourwa)	200-500	Sahelo-soudanian	600-900	29	Steppe with spikes (Sorghum)	14°27'E	10°11'N
Yaoundé (Minkoameyos)	500-700	Sub-equatorial	1400-1600	23	Forest (Fallow)	11°27'E	3°51'N

Table 33.2: Physico-chemical parameters of the soil types used for experimentation in Cameroon

Site	Soil class (% Clay content)	pH	O.M. (%)	CEC (cmol(+)kg^{-1})	N (%)	Avail. P (mg kg^{-1})	Al (cmol(+)kg^{-1})
Ebolowa [1] (Nkoemvone)	Oxisol (52)	3.9	3.03	14.4	0.27	7	2.6
Maroua (Moutourwa)	Vertisol (45)	7.2	1.27	35.6	0.68	23	0.0
Yaoundé (Minkoameyos)	Ultisol (23)	4.9	2.75	14.6	0.17	6	0.0

[1] This site is one with the highest aluminium toxicity in the country

These rich clay soils are also high phosphates fixing from 1600 to 2000 ppm. (Barrault et *al*., 1972; Robert, 1992). Vertisol represents more than 1,200,000 ha in North Cameroon, their clay content is up from 35 %, to 70 %, the CEC is up to 35 meq/100 g soil and available P is generally more than 20 ppm (Seiny Boukar, 1980).

Source of mycorrhizal strains (isolates)

Arbuscular *mycorrhizal* spores used were isolated from soils obtained from four agroecological regions of Cameroon (Bafia, Ngaoundere, Ndupe and Ekona). Physical and chemical characteristics of these soils are given on Table 33.3.

After culture were trapped on millet (*Pennisetum americanum*) and cowpea (*Vigna unguiculata*), spores were extracted by wet sieving and decanting methods (Schenk, 1982; Sieverding, 1991; Brundrett *et al*., 1996). Pure cultures were obtained and multiplied on *Brachiaria decumbens* plants in pot containing sterilised soil and sand mixture (2:1), allowed to produce each inoculum with high number of similar spores per species (more than 10 000). The original strains are: GGMN1 (*Ndupe*), GMDE1 (*Ekona*), GACB1 (*Bafia*), SGMN1 and GMVN1 (*Ngaoundere*) (Table 33.3). A standard pure culture of GCXH were from the University of Hawaii (USA). The soil-based-inocula from our micro organisms bank were air dried and packaged for longterm storage and tests (Nwaga *et al*., 2000). Three experiments were carried out to select AM fungi and assess their potential on cereal crops.

Experiment I. *In vitro* selection of acid tolerant AM fungi strains

A pH ranging between 3.8 to 6.7 were obtained by using pH indicators mixed to the culture media. These range of pH correspond to most Cameroonian soils. Spores were sterilised in 2% chloramine T (Sigma) and 0.025 % of sulphate streptomycin for 20 min for each antibiotic (Schenck, 1982). Antibiotic solutions were prepared during the day of experiment and sterilised by millipore filtration. (0.22 µm). Then the spores rinsed 3 times in distilled sterilised water and placed to germinate on agar medium (Difco) at 0.7 % in Petri dish over filter paper square (9 mm x 9 mm), sterilised at 120°C for 20 min. Coloured indicators (at 0.02 % concentration) were mixed with agar medium at different pH: bromophenol blue green in colour at pH 3.8, the methyl red orange in colour at pH 5.3 and bromocresol purple of reddish colour at pH 6.0. Agar media at pH 4.5 and 6.7 did not receive coloured indicator. For each pH value, spores of 5 species were tested.

Table 33.3: Soil pH, phosphorus, origin and species of arbuscular mycorrhizal fungi tested

Strains code[1]	Species	Locality (host plant)	Soil pH	Available P (ppm)	*Mycorrhiza* colonisation (%)	Observations (spore type)
GABC1	Glomus *albidum*	Bafia (*Crotalaria*)	6.3	2.5	55	Yellow, 80-90 mm, A(EL)B(L)
GMVN1	*Gigaspora margarita*	Ngaoundéré (*Vigna*)	5.0	5.0	75	White, 300-410 mm, A(L)
SGMN1	*Scutellospora gregaria*	Ngaoundéré (*Manihot*)	5.0	3.5	62	Black, 310-420 mm, A(UL)B(L)C(M)
GGRN1	*Glomus geosporum*	Ndupe (*Rinorea*)	4.2	9.0	20	Brown, 120-200 mm, A(ELM)
GiMDE	*Gigaspora margarita*	Ekona (*Dioscorea*)	5.8	18.0	63	White, 180-210 mm, A(L)
GCHX	*Glomus clarum*	*Hawaï* University	-	-	60	Yellow to brown, 80-150 mm, A(EL)B(UM)
GISM (or GIYM)	*Glomus intraradices*	*Soa* (*Zea mays*)	6.3	3.5	78	Brown, 45-120 mm, A(EL)
GABC2	*Glomus albidum*	Bafia	6.3	2.5	58	Yellow or white, 80-120 mm, A(EL)B(L)
GCDM	*Glomus clarum*	*Doual*a (Manihot)	4.9	5.8	90	45-100 mm, A(EL)B(UM)
GAMN1	*Glomus aggregatum*	*Nkolbisso*n *(Manihot)*	4.3	10.0	52	Yellow, 45-100 mm, µm, A(EL)B(L)
GiMNV	*Gigaspora margarita*	Ngaoundéré (Vigna)	4.9	2.5	98	Whitish, 300-410 mm, A(L)
GiME13 *margarita*	*Gigaspora* (*Dioscorea*)	*Ekona*	5.8	18.0	76	Hyaline, 180-320 mm, µm, A(L)
GiXSC (or GiXYC)	*Gigaspora* sp	*Soa* (*Crotalaria*)	6.3	3.5	65	-
GVAM	*Glomus versiforme*	*Akokas* (*Manihot*)	5.6	11	32	Yellow, 45-80 mm

1- Internal code of the Applied Microbiology & Biofertiliser Unit (UMAB), University of Yaounde I

2- Using pearl millet as host-plant (*Pennisetum americanum*) and acid fuchsin dye for root staining (Kormanick and Mc Graw, 1982)

3- Spores characteristics were used for species identification (color, shape, size, number nature of membranes or muronymes)

For each AM fungi species, 10 spores were used per replicate and three replicates per treatment (30 spores /treatment). The Petri dishes were incubated at 30°C in the dark. Every three days, observations were made on the rate of germination and this lasted for ten days. The length of hyphal growth were also evaluated. The modifications of the colour of the media containing colour indicators were observed to evaluate acidity, neutrality or alkalinity of the strain. A spore was considered as germinated if hyphae length reached at least 100 µm. Analysis of variance are done and the means are compared according to Student Fischer test to know if the results were meaningful.

Experiment II. Identification of AM isolates that enhance P uptake using peal millet and cowpea

The spores and the roots of five species were screened in greenhouse on pearl millet and cowpea to evaluate their agronomic performances. The growth media was sterile soil and sand at a ratio of 3:1 (v/v). Ten kilogramme of the mixture was placed in polyethylene bags. The seeds of millet and cowpea were surface sterilised and pre-germinated in a growth chamber. The inoculum contained roots and spores of each of the six isolates (cultures) (GACB1, GCXH, GMVN1, SGMN1, GMDE1 and GGRN1). Each inoculum 50 g soil was diluted to 500 g of sterilised sand. The seeds were germinated on this inoculum containing 10 spores g^{-1}. After three weeks, plants were transferred in greenhouse in plastic bags containing 10 kg of substrate with five plants per bag. The experiment was laid out in a 6 x 2 factorial design replicated five times. A rotation for all bags was made once per week. Rorison’s solution was used for watering plants twice a week.

Cowpea and pearl millet were harvested after 45 days and 90 days respectively. Shoot dry weight were obtained after drying the shoots at 80°C for 48 hours. The fine roots were collected, stained and mycorrhizal colonisation rate assessed according to Kormanik and Mc Graw (1982). Shoot phosphorus content was evaluated after mineralisation according to Anderson and Ingram (1993). Efficiency was obtained using the formula according to Plenchette *et al.* (1983):

$$\frac{(\text{Mycorrhizal dry weight} - \text{control dry weight})}{\text{Mycorrhizal dry weight}} \times 100$$

Data were analysed for a comparison of means with GENSTAT software.

Experiment III. Evaluation of mycorrhiza bio-fertilisers inoculation in the field

The experimental design and methodologies are similar for the three tests. Soils physico-chemical characteristics of the sites were summarised on Table 33.1 and 33.2.

Selecting mycorrhizal fungi isolates for maize growth on Ultisol

The experiment was done in Minkoameyos-Yaoundé. The treatments applied were: control (without inoculum) and inoculated treatments: myco 1 (GCXH), myco 2 (GCXH+GiMVN1), and myco 3 (GCXH + GiMVN1 + GCDM + GGRN1). The total surface of experiment site was 384 m^2. The elementary plots were 6 x 4 m size. The experimental design was a randomised complete block with 4 treatments and 4 replications. The sowing density was 0.80 m x 0.25 m at the rate of 2 seeds per planting hole. Maize population was 50,000 plants per hectare. Before sowing, 10 g of inoculum were introduced in each planting hole, this correspond to 100 spores per plant. The stage of 50 % male flowering was evaluated by counting between 49^{th} and the 59^{th} days after sowing. The stage of 50 % flowering female was between the 55^{th} and the 58^{th} days after sowing. Root colonisation was evaluated (Giovannetti and Mosse, 1980) after root staining (Kormanik and Mc Graw, 1982). Plant were harvested 174 days after sowing on 20 plants per replicate. After drying the plants, their dry weight was determined. Dry seed weight was determined by the same process. Data analysis done using Student-Fisher and Duncan's tests.

Testing mycorrhizal fungi inoculation in two maize varieties for acid tolerance

The Orisol experiment was done in Nkoemvone-Ebolowa site. Height treatments were applied. Two varieties of maize: a tolerant variety ATP and a sensitive variety CMS. Three levels of fertiliser (F0: no fertiliser, F1: N-37, P-27, K-14; F2: N-37, P-87, K-14), and two levels of AM fungi (M0: no AM fungi and M+: 10 g hole^{-1} of myco 4 AM fungi mixture) were used in a combination of treatments. The mixture of strains *Glomus clarum*, *Gigaspora margarita*, *Glomus albidum*, *Glomus geosporum*, *Glomus aggregatum and Glomus occultum* were produced on a Vetiver grass at a concentration of 200 infectives propagules g^{-1} (MPN). The total surface of experiment site was about 1400 m^2. The elementary plot was 4 x 6 m size.

Evaluating inoculation methods using Sorghum on Vertisol

Four treatments were applied for this experiment. Nursery was raised for *Sorghum bicolor* (*Muskwari* variety). Half of the nursery surface was inoculated using 2 kg of inoculant (*Glomus clarum*, GCDM1 and *Glomus* *aggregatum*, GACB). The other half was non-inoculated. The three different treatments include: INS treatment (Inoculation in nursery at sowing) achieved while sowing seeds in nursery bed; IFS treatment (Inoculation in farm by steeping roots) done by soaking plant roots in inoculum solution (2 kg $litre^{-1}$) and IFP treatment (inoculation in farm on planting hole) achieved by introducing 5 g of inoculum in planting hole before. The control plants were not inoculated. A complete randomised block design with four replicates was used and 1m spacing between plants. The elementary plot had a surface of 76 m^2 and contained 200 plants (2 plants per pocket). The first harvest was done at the date of 50 % flowering and mycorrhizal colonisation was evaluated according to Giovannetti and Mosse (1980) and staining according to Kormanik and Mc Graw (1982). The efficiency of *mycorrhiza* was analysed using phosphorus uptake (Rodier, 1978), nitrogen content (Devani *et al.*, 1989). The second harvest was done at grain maturity and plant dry weight, seed yield were evaluated. Data analysis was done using STATITCF software. ANOVA and Newman-Keuls test was used to compare the treatments.

Results

In vitro selection of acid tolerant AM isolates based on germination and hyphal growth

After 3 days GMVN1 and GCXH from our microbial resource bank had germinated at acidic pH of 3.8 and by the 6th day all the spores had germinated (Table 33.4).

Table 33.4: Effect media acidity on *in vitro* spore germination (%) of 6 arbuscular mycorrhizal fungi after 6 days

Strains code1	Media acidity (pH)				
	3.8	4.5	5.3	6.0	6.7
GACB1	20.0^{a}	30.0^{b}	26.7^{b}	26.7^{b}	40.0^{c}
GMVN1	76.7^{b}	73.0^{b}	90.0^{c}	86.7^{c}	56.7^{a}
SGMN1	45.0^{a}	50.0^{a}	96.7^{b}	90.0^{b}	46.7^{a}
GGRN	03.3^{a}	13.3^{a}	13.3^{a}	16.7^{b}	20.0^{c}
GMDE1	50.0^{a}	46.7^{a}	60.0^{b}	83.3^{c}	50.0^{a}
GCXH	70.0^{c}	63.0^{ab}	86.7^{d}	60.0^{a}	66.7^{bc}
Mean	44.0	46.0	62.0	61.0	47.0

Means followed by the same letter in the same line are not significantly different at 5 % level of probability Duncan's new multiple range test. 1: Internal code of the Applied Microbiology & Biofertiliser Unit (UMAB), University of Yaounde I

However, the rate of germination varied with strains and pH of the media. An average of 44 % to 62 % spores germinated in the range of pH 3.8-6.7 but the optimum was around pH 5 and 6. *Glomus geosporum* (GGRN), a low germinating strain show no variation on germination accross the pH range tested. For hyphal growth, media acidity has a marked effect on some strains (Table 33.5).

Table 33.5: Effect of media acidity on *in vitro* hyphal growth (µm) of 6 mycorrhizal fungi after 6 days

Strains code1	Media acidity (pH)				
	3.8	4.5	5.3	6.0	6.7
GACB1	140[b]	140[b]	136[b]	109[a]	104[a]
GMVN1	650[a]	800[b]	2700[d]	2000[c]	800[b]
SGMN1	1000[b]	1000[b]	4000[d]	3000[c]	800[a]
GGRN	100[a]	101[a]	101[a]	130[b]	103[a]
GMDE1	100[a]	100[a]	123[b]	135[c]	120[b]
GCXH	450[c]	400[b]	400[b]	400[b]	350[a]
Mean	407	424	1243	962	380

Means followed by the same letter in the same line are not significantly different at 5 % level of probability Duncan's new multiple range test. 1: Internal code of the Applied Microbiology & Biofertiliser Unit (UMAB), University of Yaounde I

In some slow growing strains (GACB1, GGRN, GMDE1 and GCXH), the effect was at least 4 times lower at the optimum pH of 5.3 compared to pH 3.8. The optimum pH for hyphal growth for most strains is around 5 to 6. These six strains are adapted to a range of 3.8 to 6.7 pH, but pH up to 6 are inhibitory for hyphal growth. The results shows that *in vitro* pH 5 to 6 are optimum for spores germination and hyphal growth of these 6 isolates of AM fungi. Average spores germination at these pH are 61-62 %; hyphal growth are 1243-962 µm after six days respectively. The strains GiMVN1 and GCXH adapted to very high pH, also produce much more acidity in the culture media compared to other strains as indicated by the changes in colour indicators.

Selection of AM fungi for plant biomass, P uptake and efficiency under nursery

Eleven locally isolated AM isolates were tested using sterile soil in nursery with pearl millet and cowpea as test plants. The plants were harvested before flowering. Non-inoculated pearl millet show chlorotic symptoms, while inoculated ones were healthy and dark green in colour. Dry matter yield of cowpea and pearl millet ranged from 1.4-2.6 to 1.4-7.2 respectively (Table 33.6).

Table 33.6: Performance of arbuscular mycorrhizal inoculation on cowpea (*Vigna unguiculata*) and millet (*Pennisetum americanum*) under controlled conditions

Mycorrhizal strains 1	Mycorrhizal colonisation (%)		Dry weight (g)		P content (%)		Efficiency 2 (%)	
	Cowpea	Millet	Cowpea	Millet	Cowpea	Millet	Cowpea	Millet
GCXH	65	71	2.34^{ab}	6.86^{ab}	0.47^{de}	0.52^{d}	24^{a}	38^{b}
GISM	72	78	3.80^{bc}	9.08^{bc}	0.50^{def}	0.42^{c}	53^{ef}	53^{c}
GABC2	46	58	2.54^{a}	10.58^{cd}	0.52^{ef}	0.23^{ab}	30^{bc}	60^{d}
GCDM	53	90	2.50^{a}	17.18^{e}	0.62^{g}	0.68^{e}	29^{abc}	75^{f}
GAMN1	62	52	3.02^{b}	13.86^{de}	0.39^{c}	0.27^{b}	41^{d}	69^{a}
GiMV	89	98	3.78^{bc}	30.48^{f}	0.70^{g}	0.78^{e}	53^{ef}	86^{g}
GiME13	85	76	3.26^{b}	6.32^{ab}	0.45^{d}	0.44^{c}	45^{d}	33^{a}
GiXYC	85	65	4.60^{c}	5.86^{ab}	0.30^{b}	0.29^{b}	61^{g}	27^{a}
GVAM	58	32	3.40^{b}	7.50^{abc}	0.55^{f}	0.29^{b}	48^{de}	43^{b}
GGNR	23	19	2.60^{a}	10.88^{cd}	0.52^{ef}	0.28^{b}	32^{c}	61^{d}
^{GI}SM + GABC2	69	70	4.90^{c}	10.80^{cd}	0.79^{h}	0.44^{c}	64^{g}	61^{d}
Control	0	0	1.78^{a}	4.26^{a}	0.21^{a}	0.16^{a}	0	0
Treated/ Control 2	-	-	1.4-2.6	1.4-7.2	1.4-3.8	1.4-4.9	-	-
LSD (5 %)	-	-	1.12	3.51	0.38	0.46	5.3	5.4

Means followed by the same letter are not significantly different at 5 % level of probability Duncan's new multiple range test. 1: Internal code of the Applied Microbiology & Biofertiliser Unit (UMAB), University of Yaounde I. 2: Efficiency obtained using the formula according to Plenchette *et al.* (1983). 2 extreme values between treated/ uninoculated control

For pearl millet, the best strains were GiMVN1 and GCDM while for cowpea, the highest shoot weight were GiXYC, GISM and GiMVN1. Cowpea and pearl millet phosphorus content, ranged from 0.21-0.16 % in the uninoculated control. The inoculated cowpea plant contained 0.28% to 0.79 % phosphorus in the tissue. *Mycorrhiza* inoculation increased P biomass content from 40% to 280 % for cowpea and 40% to 390 % for pearl millet over the control. From these results, *Gigaspora* sp (GiXY strain) was selected for cowpea and *Gigaspora margarita* (GiMVN1 strain) and *Glomus clarum* (GCDM strain) for pearl millet production for inoculant use in field experiments.

Some other strains such as *Glomus intraradices* (GISM) were good candidates because their efficiency was stable on both cowpea and millet (53 %). For most other strains, there seemed to be a preference for a given plant. The mixture of strains (GISM + GABC2) also produce a good efficiency on both plants (61-64 %). *Mycorrhiza* root colonisation was generally high on both plants except for *Glomus geosporum* (GGNR), because only 23% and 19 % were recorded on cowpea and pearl millet respectively. For millet dry weight and P content, the most efficient strain is *Gigaspora margarita* (GiMVN1), the second one is *Glomus clarum* (GCDM), because their P content are 0.7-0.8 to 0.6-0.7 respectively and provide the highest biomass. The least efficient strains provided a shoot weight and P content increase of 40 % over the uninoculated control.

Maize response to AM inoculation in an Oxisol/Ultisol under field conditions

AM inoculant selection under Ultisol

In order to assess strains effect on maize yield under field conditions in oxisol this experiment were carried out. The number of days to 50 % flowering varied from 54 to 58 days (Table 33.7).

Table 33.7: Response of maize to 3 strains of *mycorrhiza* inoculation under farm conditions on Ultisol at Yaoundé-Minkoameyos (Centre, Cameroon)

Treatment strains	50 % flowering (days)	Colonisation (%)	Biomass yield (t ha^{-1})	Grain yield (t ha^{-1})	Yield increase (%)
Control	58	5	8.80^{b}	4.5^{b}	-
Myco 1	56	34	10.53^{a}	7.0^{a}	55
Myco 2	56	32	10.28^{a}	6.0^{a}	33
Myco 3	54	47	11.30^{a}	7.5^{a}	66

Myco 1: *Glomus clarum*, Myco 2: *Glomus clarum* + *Gigaspora margarita*, Myco 3: Mixture of strains (*Glomus clarum*+ *Gigaspora,* and others)
Means followed by the same letter are not significantly different at 5 % level of probability Duncan's new multiple range test.

Maize inoculation by all the strains produced a significant increase on plant biomass. Seed yield varied from 4.5-7.5 t ha^{-1} and all the AM fungi strains significantly increased productivity. The yield increase by *mycorrhiza* inoculation was between 33-66 %, representing 1.5-3.0 t ha^{-1}. This effect was correlated with the level of root colonisation which is very low on non – inoculated (5 %) compared to inoculated treatments (32-47 %).

Maize variety compared to chemical fertiliser under Oxisol field

The experiment was carried out in Ebolowa-Nkoemvone, which is the site with one of the highest aluminium toxicity in humid forest zone of

Cameroon. The number of days to anthesis (63-66), was not significantly different between the treatments for the susceptible variety CMS, while for the tolerant one it was lower (62-68) at the highest fertilisers and inoculated treatment, F2 M+ (Table 33.8).

Table 33.8: Response of two maize varieties to AM inoculation compared to chemical fertilizers (N-P-K) on station conditions on Oxisol at Ebolowa-Nkoemvone (South, Cameroon)

Treatment	Days to anthesis	Mycorrhiza colonisation (%)	Grain yield (t ha^{-1})	Yield increase (%)
Variety CMS (acid susceptible)				
F0 M-	62.50[a]	32.5	2.29[a]	58.8
F0 M+	63.50[a]	31.8	3.60[bc]	34.7
F1 M-	63.50[a]	08.0	3.09[b]	29.6
F1 M+	63.50[a]	35.5	2.97[b]	32.3
F2 M-	65.00[a]	12.3	3.04[b]	29.2
F2 M+	66.00[a]	60.0	2.96[b]	
Variety ATP (acid tolerant)				
F0 M-	68.00[a]	15.5	2.52[a]	-
F0 M+	66.50[a]	77.5	3.84[c]	52.3
F1 M-	65.25[a]	32.5	3.28[b]	30.1
F1 M+	64.25[a]	92.5	2.95[b]	17.1
F2 M-	64.00[a]	0.00	2.62[a]	4.0
F2 M+	61.50[b]	57.5	2.95[b]	29.5

Means followed by the same letter are not significantly different at 5 % level of probability Duncan's new multiple range test.
1 This site is one with the highest aluminium toxicity in the country
F0: no fertiliser (control), F1: NPK + Urea fertiliser: 37-24-14, F2: NPK + Urea + DAP fertiliser: 37-84-14; Urea (46-0-0), DAP(18-45-0).
M-: non-inoculated ; M+: *mycorrhiza* inoculation by *Glomus clarum* and *Gigaspora margarita*

The days to anthesis is reduced by 3 days in the acid susceptible variety CMS and significantly increased in the acid tolerant one ATP by 6 days. *Mycorrhiza* inoculation produced a significantly higher yield compared to the control on both varieties. For the variety CMS, yield of 58.8 % were recorded, corresponding to 1.3 t ha^{-1} after inoculation compared to the control. When fertiliser was applied alone yield increase was 34.7 % (0.8 t ha^{-1}). For the acid tolerant variety (ATP) AM inoculation improved grain yield by 52.3 % compared to the control, while fertiliser application yielded 30.1 % only. When *mycorrhiza* is assessed for the acid susceptible variety CMS, inoculation was able to increase root colonisation of AM fungi only for one treatment (F2 M+), from 32.5 % to 60 %; fertiliser generally reduce it for the non-inoculated fertilised treatments (F1 M-, F2 M-). The native *mycorrhiza* fungi was able to colonise maize roots as high as 35.5 % for the control (Fo M-). For the tolerant variety ATP, *mycorrhiza* inoculation increased root colonisation from 16 % to 78%, 93 and 58 % respectively for the uninoculated (F0 M-), and inoculated (F0 M+, F1 M+ and F2 M+) treatments. *Mycorrhiza* colonization in acid tolerant variety ATP are much more higher than in the acid susceptible variety CMS without any added fertiliser, 78 and 32 % respectively.

Influence of the inoculation method on sorghum performances under Vertisol field

The aim of this experiment was to evaluate three inoculation methods on a specific sorghum variety, muskwari on savannah zone of Cameroon. Compared to the uninoculated control, there was a reduction of 6 days by the method at sowing (INS) on the date to 50 % flowering (Table 33.9).

Table 33.9: Evaluation of AM inoculation methods on *Sorghum bicolor* performances under farm conditions on vertisol at Maroua-Moutourwa (Far-North, Cameroon)

Treatment	50 % flowering (days)	Root Colonisation(%)	Biomass yield (t ha^{-1})	Grain yield (t ha^{-1})	Yield increase (%)	Grain N uptake (kg ha^{-1})	N response (%)
Control (uninoculated)	62	20	3.07	1.54 ^{b}	–	28.34	–
At sowing (INS)	56	38	3.50	1.64 ^{ab}	6.5	22.96	- 19
On planting hole (IFP)	64	43	4.04	2.00 ^{ab}	29.9	40.00	+ 41
By steeping roots (IFD)	63	65	4.24	2.28 ^{a}	48.1	43.55	+ 54

Means followed by the same letter are not significantly different at 5 % level of probability Duncan's new multiple range test.

INS: *mycorrhiza* inoculation on nursery at sowing (inoculant-soil mixture: 2 kg /6 m^{2}); IFP : *mycorrhiza* inoculation on farm at planting on pocket (5 g hole^{-1}); IFD : *mycorrhiza* inoculation on farm at planting by steeping roots (inoculant-water mixture: 2 kg liter^{-1}).

All the *mycorrhiza* inoculation methods increased sorghum biomass from 0.43 t to 1.17 t ha^{-1} (14% to 38 %). The inoculation by steeping the roots on *mycorrhiza* inoculum (IFD) gave the best results, significant yield increase of 48 % were recorded when compared to the uninoculated control (Table 33.9). Mixing *mycorrhiza* with soil at sowing did not give high yield (7 %) probably because of the low inoculum density in this treatment. Seed N uptake evaluation shows that, when compaerd to the uninoculated treatment, there were a deficiency of -19 % nitrogen in the seeds of the treatment on nursery at sowing (INS), while at planting on the field (IFP, IFD) an important increase of 41% to 54 % were recorded.

Discussion

Mycorrhizal strains selection

These isolates of AM fungi may be differentiated into two groups: some strains are not influenced by acidity (*Glomus albidium*, *G. geosporum*, *Gigaspora margarita* and *Scutellospora gregaria*). This is in accordance with some authors (Hepper, 1984; Sieverding, 1991) who reported that the suborder *Gigasporineae* are better adapted to soil acidity than the suborder Glomineae (*Glomus* type). Theses strains (GMDE, GMV1 and SGMN 1) tend to have an acidifying culture media during their *in vitro* growth. The size of spore of most Gigasporineae (151-400 mm) are more larger than that of Glomineae (46-150 mm) of our collection. This may indicate that large reserves in these spores are important factor in maintaining AM fungi infectivity during plant root colonisation (Smith and Read, 1997). The mixture of strains (GISM + GABC2) are more performant than the individual strains, this confirm observations by Sieverding (1991). Criteria for AM fungi selection are: spore germination and hyphal growth, root colonisation, plant biomass and yield, nutrient uptake and adaptation to environmental constraint such as soil acidity and competition (Sieverding, 1991). These criteria have been used in this work to select few strains of our microbial bank *Gigaspora margarita* (Strains GiMVN1 and GiXYC) and *Glomus clarum* (GCDM) for acidity tolerance, plant biomass and P uptake performances (Nwaga *et al.*, 2000). Mycorrhizal isolates from three agroecological zones of Cameroon have shown an important diversity for symbiotic efficiency and P uptake of crops (Ngonkeu Mangaptche and Nwaga, 1998).

Field inoculation of maize under Oxisol/Ultisol

According to Harley and Smith (1983), pot experiment using maize provided 28-33 % *mycorrhiza* colonisation after inoculation on sterilised soil. These results indicate colonisation of 19 % to 98 % by eleven different inocula of AM fungi under controlled conditions using pearl millet. Under field conditions, maize inoculation resulted 32% to 47% colonisation at Yaounde-Minkoameyos while it was 32% to 93% at Ebolowa-Nkoemvone. These results can be compared with observations by Sylvia *et al* , (1993):10-61% and Sanginga *et al* . (1999): 17-33%) both working on maize after inoculation with AM fungi.

The grain yield increase obtained from maize crop at Yaounde-Minkoameyos was 1.5-3.0 t ha^{-1} with *mycorrhiza* inoculation as compared to 0.7 t ha^{-1} grain reported by Islam and Ayanaba (1981) on sterilised soil or 1.0-1.2 t ha^{-1} cobs by Baltruschat (1987) both on maize. Maize yield increase of 52-59 % after inoculation on Ebolowa-Nkoemvone site and the reduction of maize response to inoculation at higher fertiliser application are consistent with observations of Smith and Read (1997), according to which P concentration generally reduce root colonisation and thus response to inoculation. For example, on barley, a grain yield increase of 11-37 % were obtained by AM fungi inoculation, 60 kg P ha^{-1} application lead to 3-16 % decline in barley yield (Hayman, 1987). The acid tolerant maize cultivar (ATP) seemed to be less responsive to high fertiliser application compared to the susceptible cultivar (CMR). Conventional agriculture may significantly reduce spores number (100 times) and *mycorrhiza* colonization (2.5-10 times) when compared to low input agriculture (Douds *et al.*, 1993), but this situation is likely to happen only in tropical industrial plantations.

Field inoculation of *Sorghum* under Vertisol

Inoculation of finger millet with selected AM strain improved grain yield by 18 % compared to fertiliser (Powell, 1987). Sorghum yield increased from an average from 0.10 to 0.75 t ha^{-1} from either of the three inoculation methods which are commensurable with result obtained by Miranda (1982) from sorghum. According to observations by Simpson and Daft (1990), development of *mycorrhiza* inoculation have shown not to have interactions with water stress on maize and sorghum, but Douds *et al.* (1993) showed that the proportional plant response to inoculation increase with drought stress. The yield increase of muskwari sorghum observed could be attributed not only to a better nutrient uptake but also to a better water stress tolerance by *mycorrhiza* inoculation compared to indigenous populations on this vertisol. These results could be compared to those described by Powell (1987), on finger millet where a selected AM strain gave 18 % better grain yield than uninoculated plants over three fertiliser rates. The results in this study showed a yield increase of 14 % to 15 % by the inoculated maize over the best uninoculated plants for the two fertiliser rates in this aluminium toxicity site. Under field conditions, a preliminary result obtained on *Mucuna veracruz* inoculation by *mycorrhiza* produced a significant increase of

43 % on litter, 88 % on shoot biomass, 100 % on plant P content and for P use efficiency, from 13 % for the control to 39 % (Nwaga *et al* , 1999). The development of an integrated, ecosystem level, approach to soil management, including inoculation with micro-symbionts should be encouraged (Swift, 1998; TSBF, 2000).

Conclusion

It is not yet possible to produce pure AM fungi inoculant, since the fungi does not grow in artificial media which is a major drawback. Field responses to inoculation are sometimes low and erratic since there may be effective high populations of indigenous AM fungi for most common crops. In order to develop *mycorrhiza* technology for field application, many problems will have to be solved for example, to standardise large scale inoculation production (experimental conditions, spore numbers to increase their infectivity, reduce contamination with deleterious organisms), to develop assessments on the best inoculation methods for a specific crop. A preliminary screening of some AM fungal isolates for acidity tolerance was carried out and three of them were selected. It will be more effective to assess or select for their tolerance to aluminium or manganese toxicity which are more toxic than hydronium acidity. Using a mixture of selected AM fungi, many field assessments were done on the potential of inoculation of maize on Oxisol/Ultisol. The results obtained shows that significant yield were enhanced by inoculation under diverse poor soil. Also, sorghum produced a good yield using few quantity of inoculum under Vertisol which are known not to respond to chemical fertiliser for *muskwari* sorghum variety. In this study, it is clear that strain efficiency test may be beneficial as well as environmental factors such as fertiliser or variety effect.

Do we need to put efforts into this biotechnology ? Yes, because slash and burn agriculture may reduce indigenous populations of AM fungi. Most field evaluations done in Cameroon have shown that indigenous populations are low and poorly efficients; also because a minimum yield of twenty percent is good and the returns are much more higher in legume crops or fruit trees than cereal crops; the technology may help save currencies at farmer or country level. In order to minimise *mycorrhiza* inoculation technology cost for cereal, to quickly increase soil organic matter build up and fertility through biological means, we suggest an inoculation strategy of a legume (grain or cover crop) by selected and competitive rhizobial and mycorrhizal isolates. The development of a low input technology for farmers such as integrated biological management of soil fertility to enhance crop productivity in the tropics is urgently needed.

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References

Ambassa-Kiki, R. (1990) Un site d'expérimentation du réseau IBSRAM à Minkoameyos, Yaoundé. *IBSRAM Proceedings.* 10: 425-440.

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility. A handbook of methods.* CAB International, Walingford.

Anonyme, (1991) *Mémento de l'agronome.* Ministère de la Coopération, Paris.

Balthruschat, H. (1987) Evaluation of the suitability of expanded clay as carrier material for VA *mycorrhiza* spores in field inoculation of maize. Angew. *Botanik* 61: 163-169.

Barrault, J. Erkebil, J.P. et Vaille, J. (1972) Point sur les travaux de l'IRAD sur les sorghos repiqués du Nord-Cameroun. *L'agronomie Tropicale* 27(8): 791-814.

Bethlenfalvay, G. J. (1992) Mycorrhizae and crop productivity. In : Bethlenfalvay G. J. Linderman R.G (eds), *Mycorrhizae in sustainable agriculture. ASA Special Publication N° 54*, Madison, USA, pp 1-27.

Bindzi Tsala, J. (1987) Les sols rouges du Cameroun. 8e réunion du sous-comité ouest et centre Africain de correlation des sols pour la mise en valeur des terres. MINREST-FAO. Yaoundé, Cameroun.

Brundrett, M.C., Bougher, N., Dell, B., Grove, T. and Malajczuk, N. (1996) Working with *mycorrhiza* in forest and agriculture. *ACIAR Monograph* 32: 374 p.

Davet, P. (1996) Vie microbienne du sol et production végétale. INRA, Paris,

Devani, M.B., Shihoo, J.C., Shal, S.A. and Suhagia, B.N. (1989). Spectrophotometrical method for micro determination of nitrogen in Kjeldahl digest. *J. Assoc. Off. Anal. Chem.* 72(6): 953-956.

Douds, D.D. Jr, Janke, R.R. and Peters, S.E. (1993) VAM fungus spore populations and colonisation of roots of maize and soybeans under conventional and low-input sustainable agriculture. *Agric. Ecosyst. Environ.* 43(3-4): 325-335.

Gianinazzi-Pearson, V. and Diem, H.G. (1982) Endomycorrhizae in the tropics. In: *Microbiology of tropical soil and plant productivity.* Dommergues Y.R., Diem H.G. (Eds), Martinus Nijhoff /Dr Junk W. Publishers, The Hague.

Giovannetti, M. and Mosse, B. (1980) An evaluation of techniques for measuring vesicular arbuscular mycorrhizal infection in roots. *New Phytol.* 84: 489-500.

Harley, J.L. and Smith, S.E. (1983) *Mycorrhizal symbiosis.* Academic Press, London.

Hawksworth, D. L. (1991) The fungal dimension of biodiversity: magnitude significance and conservation. *Mycological Research* 95: 641-655.

Hayman, D.S. (1987) *Mycorrhiza* in field crop systems. In: *Ecophysiology of VA mycorrhizal plants.* Safir G.R. (ed), CRC Press Inc, Boca Raton, Florida. pp. 171-192.

Hepper, C.M. (1984) Isolation and culture of VA Mycorrhizal (VAM) Fungi. In: *VA Mycorrhiza.* Conway, L.I. P. and Bagyaraj, D. J. (Eds), CRC Press, Florida, pp. 95-112.

Islam, R. and Ayanaba, A. (1981) Growth and yield response of cowpea and maize to inoculation with Glomus mossae in sterilised soil under field conditions. *Plant and Soil* 63: 505-509.

Janos, D.P. (1987) VA *mycorrhiza* in humid tropical ecosystems. In: *Ecophysiology of VA mycorrhizal plants* . Safir G.R. (Ed), CRC Press Inc, Boca Raton, Florida pp. 107-134.

Kormanik, P. P. and Mc Graw, A. C. (1982) Quantification of vesicular- arbuscular mycorrhizae in plant roots. In : *Methods and principles of mycorrhizal research*, N. C. Schenck (Ed), The American Phythological Society, St. Paul, Minnessota. pp. 37-45.

Miranda, J.C.C. de (1982) Influencia de fungos endomicorrizicos inoculados a campo, na cultura de sorgo e soja em um solo sob cerrado. R. Bras. Ci. Solo 8, 31-36.

Ngonkeu Mangaptche, E.L. and Nwaga, D. (1998) Diversité, potentiel infectieux des mycorhizes à arbuscules de quelques sols du Cameroun, et réponse du niébé (*Vigna unguiculata*) à l'inoculation. *Cam J. Biol. Biochem. Sci.* 8(1): 56-67.

Nwaga, D. and Ngonkeu, M.E.L. (1998) Diversité des mycorhizes à arbuscules et biomasse microbienne du sol des écosystèmes du sud-Cameroun. *Biosciences Procedings*. 5:76-84.

Nwaga, D., Nolte, C., and Jemo, M. (1999) Field response of *Mucuna veracruz*, a leguminous cover crop to rhizobia and *mycorrhiza* inoculation compared to chemical fertilisers in humid forest zone of Cameroon. Paper presented for the 7th AfNet-TSBF Workshop, 11-15 September 1999, Kampala, Uganda.

Nwaga, D., Ngokeu M.E.L., Ogong M.M., Ngakou A., Abelong M.P. and Foko J. (2000) Soil beneficial microorganisms and sustainable agricultural production in cameroon: current research and perspectives. In: The biology and fertility of tropical soils. *TSBF report 1997-1998*. pp. 62 -65.

Plenchette, C., Fortin, J. A. and Furlan, V., (1983) Growth responses of several plant species to mycorrhizae in a soil of moderate P fertility. *Plant and Soil* 70: 199-209.

Powell, C.L. (1987) Field inoculation with mycorrhizal fungi In: *VA mycorrhiza*, Powell C.L., Bagyaraj D.J. (eds), CRC Press, Inc Boca Raton, Florida, pp. 205-222.

Robert, M. (1992) Le sol, ressource naturelle à préserver pour la production et l'environnement. *Cahiers Agricultures* 1: 20-34.

Rodier, J. (1978) *L'analyse de l'eau: chimie, physico-chimie, bactériologie, biologie.* 6e édition. Dunod Technique, Paris.

Sanchez, P.A. (1994) Properties management of soils in the tropics. Wiley-Interscience Publication, New-York.

Sanchez, P.A. and Salinas J.G. (1981) Low-imput technology for managing oxisols and ultisols in tropical America. Adv. in Agron. 34: 279-406.

Sanginga N. Carsky, R.J. and Dashiell, K. (1999) Arbuscular mycorrhizal fungi respond to rhizobial inoculation and cropping systems in farmers fields in the Guinea savanna. *Biol. Fert Soils* 30 (3): 179-186.

Schenck, N. C. (1982) Methods and principles of mycorrhizal research. American Phytopathological Society, St. Paul, Minnesota.

Seiny Boukar, L. (1980) Etude du niveau de fertilité de quelques sols de la région de Kolofata sous culture de mil de saison sèche. *Mémoire de Diplôme d'Ingénieur Agronome*, ENSA, Dschang, Cameroun.

Sieverding, E. (1991) Vesicular-arbuscular *mycorrhiza* management in tropical agrosystems, GTZ, Eschborn, Germany.

Simpson, D. and Daft M.J. (1990) Interactions between water-stress and different mycorrhizal inocula on plant growth and mycorrhizal development in maize and sorghum. *Plant and Soil.* 121: 179-186.

Smith, S.E. and Read, D.J. (1997) Mycorrhizal symbiosis. *Academic Press*, London.

Swift, M.J. (1998) *Toward the second paradigm: integrated biological management of soil.* Paper presented for the FERTBIO Conference, Brazil, September 1998.

Sylvia, D. M. and Williams, S.E. (1992) Mycorrhizae and environmental stresses. In : Bethlenfalvay G. J. Linderman R.G (eds), *Mycorrhizae in sustainable agriculture.* Madison. *ASA Special Publication* 54: 101-124.

Sylvia, D.M., Hammond, L.C., Bennet, J.M. Haes, J.H. and Linda, S.B. (1993) Field response of maize to a VAM fungus and water management. *Agron. J.* 85(2): 193-198.

The, C. (2000) Identification of heterotic groups for acids soil on some maize varieties in Cameroon. INCO 1 & 2 Meeting, June 2000, Yaoundé, Cameroon.

Woomer, P.L. and Swift, M.J. (1994) *The biological management of tropical soil fertility.* John Wiley and Sons, Chichester, TSBF & Sayce Publ., United Kingdom.

Macrofaunal Abundance and Diversity in Selected Farmer Perceived Soil Fertility Niches in Western Kenya

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Abstract

Most farmers in Kenya are resource poor and rely on the soil biological processes (nutrient cycling, decomposition and mineralization) for subsistence. Soil macrofauna is an integral part of such systems and their abundance and diversity has been suggested as an indicator of functional status. Most soil macrofaunal studies have however involved natural or controlled ecosystems but little of the farmers' fields. A study was therefore carried out between 1999 and 2000 to determine macrofauna abundance and diversity in farmer perceived soil fertility niches of Kabras Division, Western. Macrofauna were determined in sixteen niches within four farms that had previously been ranked as having similar soil fertility management. The soils within the farms were *humic Acrisols* and *mollic Gleysols*. Sampling was done using a monolith 20 cmx20 cmx30 cm in layers of 0-10cm, 10-20cm and 20-30cm. The organisms were hand sorted, preserved in 70% alcohol and taken to the laboratory for identification and determination of biomass. The physical and chemical soil characteristics of the niches were determined. Termites, earthworm and ants were the most dominant organisms. The niches varied significantly in abundance and diversity of these organisms. The diversity (Shannon –Werner) index was low compared to that of the natural ecosystem. This was attributed to the predatory macrofauna, microclimate and differences in food resources. It was concluded that abundance varied with management and environment. Diversity was however not different in niches within the agro-ecosystems.

Key words: Macrofauna, Termites *(Isoptera)*, Earthworm *(Lumbricus)*, Ants *(Formicidae)*, farmers fields, soil fertility management

Introduction

Only about 30% of Kenya is medium to high potential agricultural land. With the increase in population (about 28 million people in 2000), farmers are forced to abandon their local farming practices (shifting cultivation) for the high external input ones like continuous cultivation and use of pesticides. That most small-scale farmers are low resource and cannot afford inorganic fertilizers generally leads to the assumption that farmer practices impact negatively to soil fertility. Sanchez *et al*. (1997) observed that soil fertility is one of the most important factors limiting crop production in Kenya.

The advent of participatory approaches led to realization that farmers use alternative methods to counter resource limitation. Farmers use variation in soil fertility and crop management to maximize production, get product variety and avoid risks of crop failure. As an aggregate, a combination of practices such as fallowing, continuous cultivation and manuring within the farm perspective. This management can be understood better by disaggregating farms into management niches. This also forms a framework for integrated nutrient management (judicial manipulation of inputs and outputs) approach. Biological functioning of the soil is important in this framework.

Lavelle *et al*. (1997) defined macrofauna as organisms that are more than 10mm is size and manipulate the soil by making biogenic structures and galleries that sometimes persist longer than the organisms themselves. Through their activities, macrofauna influence the physical, chemical and biological status of the soil. They also communite organic resources and determine diversity and abundance of other organisms through availability of nutrients. They have thus been suggested as early ideal warning indicators of soil fertility decline because of their large body size, fast turnover rate and role in soil fertility management (Linder *et al.*, 1994).

Sometimes the farmer' practices like continuous cultivation and use of pesticides result in decline of soil organic matter, pH and pollution respectively. Diverse macrofauna interact to cushion the soil against such stress. Characterizing and understanding the way farmers' practices affect the macrofaunal level and soil processes is important for sustainable production.

In addition to their role as soil fertility indicators, macrofauna are also important resources which farmers can manipulate for subsistence. Termites with their mutual relationship with fungi (fungal gardens) and bacteria make the mounds rich in soil organic matter and nutrients (Lavelle *et al.*, 1997). In Zimbabwe, termite mounds (termitaria) is used as fertilizer (Murwira and Carter, 1994; Swift *et al.,* 1998) while in the Sahel, farmers add vegetation to the soil to enhance termite activity (Lamers *et al.*, 1994). Woomer *et al.* (1999); Murage *et al.* (1999); Murwira and Carter (1994) in Kenya and Zimbabwe, observed that farmers concentrated organic resources in homegardens where priority crops are grown. Apart from using macrofauna to compare natural eco-systems (forests) and cultivated land or in controlled experiments, (Okwakol *et al.*, 1994; Ayuke *et al.*, 1999; Lavelle *et al.*, 1997) macrofauna have rarely been used to characterize the farmers practices.

Objectives

i) Determine the faunal abundance and diversity in farmer perceived niches of western Kenya.
ii) Relate faunal abundance and diversity to the soil fertility and crop management in the farmer perceived niches.

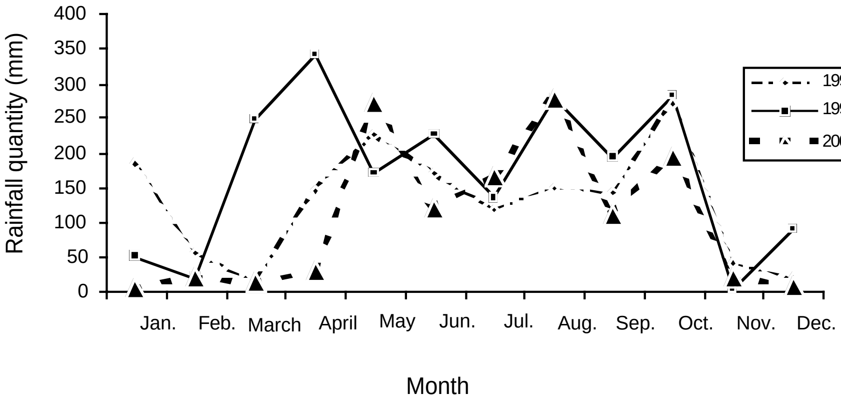
Material and Methods

i) Site decription

The study was carried out in four farms on *humic Acrisol* (uplands) and *mollic Gleysols* (valley bottomlands) in LUZ 8 (forest peripheral) of Kabras division, western Kenya. The area is densely populated with a maize/ sugarcane cropping system and situated between longitudes 34^0 20' and 35⁰E, latitude 00⁰ 15' and 10⁰N and altitude 1300-1900 metres above sea level. It receives bimodal rainfall of between 1000-2000 mm per annum (Figure 34.1) and mean minimum and maximum temperatures of 8⁰C and 25⁰C respectively.

Participatory mapping of the on-farm niches was carried out and scientific soil survey and classification used for truth proofing.

Figure 34.1: Rainfall distribution in Kabras Division, Western Kenya (1998-2000)



ii) Niche Characteristics

Since farmers cannot afford the inorganic fertilizers, they use a variety of soil fertility and crop management practices based on the holistic farm perception to optimize production and avoid the risk of crop failure. They organize their farms into spatial distributed soil fertility niches as follows:

Oboma/Homegarden – Old boma site i.e. a former kraal site which farmers used for maize and vegetables production. The niche represented a high soil fertility and crop management niche. As a result of the high soil fertility, this niche also had high cultivation intensity i.e. vegetables were planted immediately after maize.

Npasture – This niche was under fallow (natural pasture) for more than five years. It represented the farmers' common practice of leaving land fallow whenever soil fertility declined. The niche was overgrazed and soil was compacted.

Cmaize – This niche was continuously under maize cultivation. Maize was planted in March/April and harvested between October/ November.

The niche was depleted mainly through nutrient transfer i.e. maize market external to the farm and stover fed to livestock and the resulting FYM used elsewhere (homegardes and Oboma). Leaching and erosion was also high because of low soil organic matter. It therefore represented infertile (depleted) niches

Vbottom – High soil moisture and nutrient recharge from erosion characterized this niche. Although generally perceived as fertile, waterlogging was the main constraint. Farmers therefore used it for maize production between December and April. Between June and October the niche was usually waterlogged thus not used for crops.

Forest – represented the natural ecosystem. Data by Brown *et al*. (1996) from the nearby Malava forest was used as a reference point.

iii) Macrofauna sampling

Soil macrofauna characterization and identification was based on the body size as described in Blair *et al*. (1996) and Anderson and Ingram, (1993) and the existing species. Sampling was done using a monolith of size 25 cm x 30 cm x 30 cm to quantify the macrofaunal groups. The monolith was placed at randomly selected points within the niche and driven into the soil using a metal mallet. The soil from the monolith was removed by hand in order of the successive depths (0-10 cm, 10-20 cm and 20-30 cm) that were placed into different plastic buckets. The soil was later placed on plastic trays of size 20cm x 30 cm and gently sorted out to locate the animals. The organisms were hand sorted using a pointer put in 70% alcohol for preservation and taken to the laboratory for determination and identification of taxonomic groups and abundance. The method was preferred because it was easy to handle, different stages of macrofauna (sedentary and mobile) could be extracted, and did not depend on macrofaunal behavior or presence of substrate.

Species diversity based on the Shannon and Werner diversity index was used to assess changes in soil fauna across on-farm niches. The index was calculated using the following equation:

H = - (PilnPi), where:

H is the Shannon index,

Pi is the proportion of individuals found in the i species and estimated as ni/ N; where ni is the number of individuals of the i^{th} species and N the total number of individuals within the sample.

The diversity index assumes that individuals are randomly sampled from a large population and that all species are represented in the sample. The index combines species richness (total number of species present) and evenness (relative abundance).

iv) Soil analysis

For soil fertility analysis, samples were taken randomly from four spots within each niche and bulked to form a composite sample. A sub-sample of about 500gm was then taken, air-dried and ground to pass through a 2 mm sieve and analyzed in the laboratory for soil texture, total N, available P, pH, and CEC. Soil texture was determined by the hydrometer method, pH by the soil: water ratio of 1:2.5, organic carbon by oxidizing the soil with potassium dichromate and concentrated Sulphuric acid and the remaining concentration of dichromate and ferrous ions determined by titration (Okalebo *et al.*, 1989). Total nitrogen (N) was determined by semi micro-kjedhal digestion with sulphuric acid and selenium as a catalyst and copper sulphate to raise the boiling point (Bremner and Mulvaney, 1982). Phosphorus (P) was extracted using double acid (0.01M hydrochloric acid and 0.0025N sulphuric acid) and Ammonium Vanadate/Ammonium molybdate used to develop the colour whose intensity was measured by a spectrophotometer at wavelength 430nm (colorimetric method).

Cations exchange capacity (Ca, Mg, K, Na) was determined by the summation method. Five grams of air dried soil ground to pass through a 2mm sieve was extracted using the double acid (0.01 M hydrochloric acid and 0.0025 N sulphuric acid) and filtered using a Whatman No. 1 size 15cm filter paper (Anderson and Ingram, 1989; Okalebo *et al.*, 1992). The Mehlich extractable Ca and Mg were determined by spectrophotometer while Na and K were determined by flame photometer. Exchangeable acidity (Hp) was determined on soils with pH (H_2O) less than 5.5 and entailed extracting (Al +H) using 125ml 1M KCl followed by titrating the filtrate against 0.05M NaOH with phenolphthalein indicator (Anderson and Ingram, 1989).

Results and Discusion

i) Macrofaunal abundance

The fauna sampled within the farm included earthworms, termites, ants, beetles, centipedes, crickets and grubs (Appendix 1). In 1999, earthworms were the most abundant (46%), followed by termites (24%) and ants (19%). The remaining macrofauna species that were mainly litter dwelling (beetles etc) constituted about 10%. In 2000, ants (*Formicidae*) were dominant (81%) followed by termites (9%) and earthworms 8% with remaining macrofauna species accounting for 2%. The lower earthworm and termite population in 2000 compared to 1999 could be attributed to the high population of predatory ants (*Formicidae spp*). Lavelle *et al*. (1994) and Brown *et al*. (1996) also observed that termites and earthworms (ecosystem engineers and litter transformers) were the dominant macrofauna in agro-ecosystems.

Niche types also affected the abundance and composition of macrofauna. Termites (41.5%), earthworms (26%), and ants (24%) dominated the Oboma while beetles, spiders and centipedes together were the minority (less than 10%) (Figures 34.2 and 34.3). In the year 2000, ants increased to 89% at the expense of earthworms (4%) and termites (5%). The high percent population of termites and ants in "Oboma" in 1999 could be attributed to the large amounts of food resources present (Figures 34.2 and 34.3). Frequent cultivation that was common in Oboma may have contributed to the low population of earthworms through abrasion and overgrazing and trampling (Castilla, 1992).

In the "Vbottom", earthworms contributed (86%) while beetles and grubs accounted for 11% and 3% of the macrofauna respectively in 1999. Termites were absent from this niche in 1999. In 2000, earthworm population decreased to 64%, termites 10%, ants 22% and the remaining macrofauna 3%. The high earthworm and low termite population in the "Vbottom" was not a surprise because the former prefer moist conditions while the later are adapted to dry environments (Lavelle *et al*. 1997). As a result of the El Nino effect, 1999 was generally wet (Figure 34.1). This may have further occluded the termites from the "Vbottom".

In the "Cmaize" niche macrofaunal termites and earthworms consisted of about (47%) and (43%) respectively in 1999. In 2000, termites and earthworms constituted about 44% each. Ants and other macrofauna constituted about 10%. Maize stover in the "Cmaize" niche provided substrate (food resource) and a comfortable microclimate that may have contributed to the high population of termites and earthworms.

"Oboma" with higher nutrient level (Table 34.1) was expected to have higher macrofaunal population compared to "Cmaize" (soil fertility depleted niche). The higher intensity of cultivation (maize/vegetable in a year) compared to maize alone in "Cmaize" may have caused abrasion thus the lower density of earthworms and termites. The anisosymbiotic association of termites with fungi enables them to digest the low quality (lignin and tannin-protein complexes rich) crop residues (Wardle and Lavelle, 1997). Tian *et al*. (1993) and Ayuke (1999) also observed higher termite population in niches where mulch of low quality was applied. Tian *et al*. (1997) observed that soil fauna contributed more to the decomposition of low quality residue than high quality because they stimulated microbial activity. This may be the reason why "Cmaize" had a higher population of earthworms and termites than in the "Oboma". The strong and longer lasting mulching effect (reduced moisture loss and soil temperature) of the maize stover coupled with the substrate effect may have led to the high earthworm population in the "Cmaize".

Table 34.1: Chemical characteristics of the farmer perceived niches

Niche	pH	P	K	Ca	Mg	ECEC	Ex.	N	Organic Carbon
		ppm ←		→	Cmolkg^{-1}	←→	Acidity	←→	%↔
Oboma	5.41^{a}	2.91^{a}	1.09^{a}	1.61^{a}	2.68^{a}	6.8^{a}	0.95^{a}	0.08^{a}	2.27^{a}
S.E.	(0.09)	(0.31)	(0.07)	(0.14)	(0.38)	(0.51)	(0.33)	(0.01)	(0.09)
Npasture	5.5 ^{a}	2.55^{a}	1.28^{a}	1.79^{a}	2.40^{a}	5.95	0.76^{a}	0.08^{a}	2.15^{a}
S.E.	(0.28)	(0.1)	(0.22)	(0.44)	(1.21)	(1.63)	(1.06)	(0.04)	(0.29)
Vbottom	5.11^{a}	3.43^{a}	0.59^{b}	1.41^{a}	2.14^{a}	5.94^{a}	1.77^{a}	0.15^{b}	2.40^{a}
S.E.	(0.21)	(0.73)	(0.16)	(0.33)	(0.90)	(1.2)	(0.78)	(0.03)	(0.22)
Forest (Malava)	5.35	2.61	0.84	3.74	5.00	12.20	1.2	0.21	4.97
Outfield	4.99 ^{a}	2.51^{b}	0.65^{b}	1.31^{a}	2.01^{a}	5.67^{a}	1.54^{a}	0.07^{a}	1.90^{b}
S.E.	(0.09)	(0.34)	(0.08)	(0.15)	(0.42)	(0.56)	(0.37)	(0.56)	(0.10)

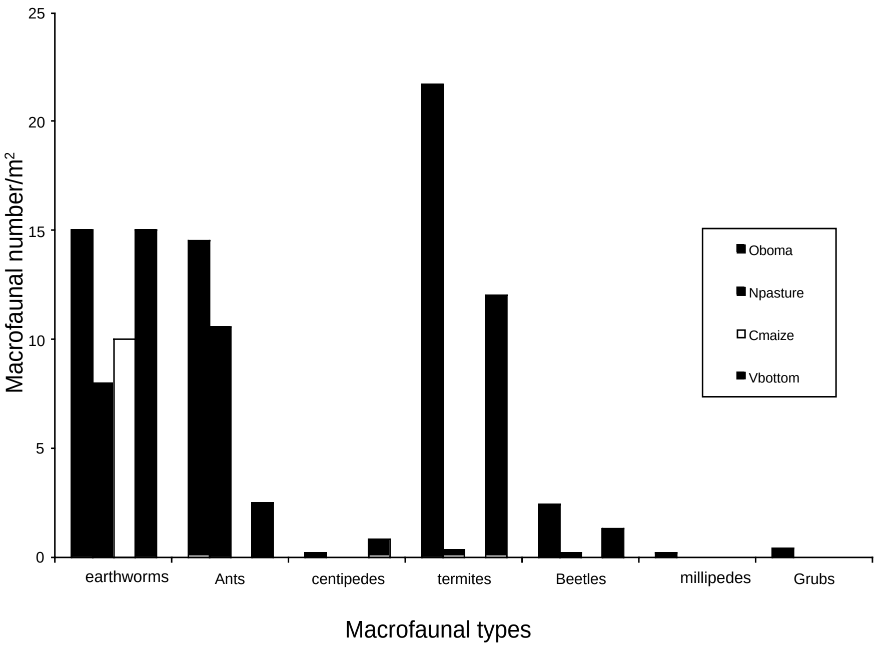
*Standard error in parenthesis

**Values followed by the same letter in a column are not significantly different

In the "Npasture", ants constituted 49%, earthworms 36% while termites, grubs and beetles constituted less than 5% each. Termite population in the "Npasture" was reduced probably because of the predating ants (*Formicidae spp*) and lack of food resource (litter) attributed to overgrazing. Endogenous earthworms dominated the "Npasture" compared to other surface feeding macrofauna probably soil compaction at the surface could allow only those macrofauna that could be sheltered. The earthworm population was lower in "Npastures" and "Oboma" compared to other niches. The most abundant macrofauna were mainly termites and earthworms, which had little functional diversity i.e., focus mainly on decomposition and soil structural changes. Generally, the population of litter dwelling and surface feeding macrofauna was low in all niches probably because of the low amounts of litter.

Farmer perception of macrofauna was varied. While in the two villages farmers did not appreciate the influence of termites on the soil fertility, their counterparts in the neighbouring village observed better performance of crops around the termite mounds. The contrasting observation was probably because soils in these villages were different and the influence of termite activity (transport and comminution of litter and supply the limiting nutrients (N, P and K) also varied. Through gallery and mound construction, termites turn the soil particles and increase the clay content thus affecting the soil physical conditions. In Cameroon, Hugulle and Ndi (1993) observed that termite mounds had more clay compared to the neighbouring site that did not have mounds.

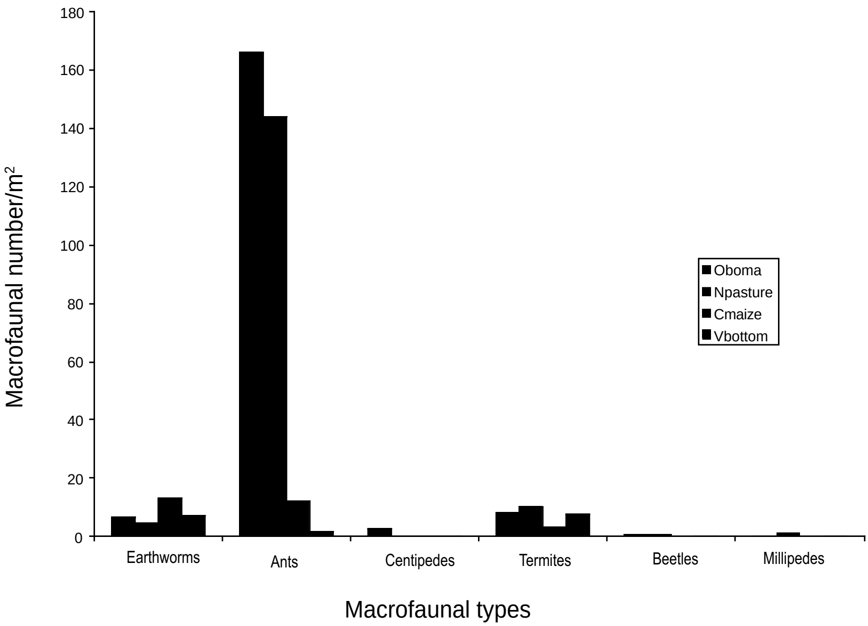
Figure 34.2: Distribution of macrofauna in farmer perceived niches (1999)



This may be responsible for the higher crop yields on termite mound located on sandy soils. Although farmers noted termite mounds as sources of variation in soil fertility, they ploughed over and did not flatten them thus preserving spatial variation in soil fertility. The cost of flattening these termite mounds may also have overshadowed the potential benefits. Most research about influence of termite mounds on soil fertility focuses on comparing the chemical properties of the termite mounds with those of the adjacent sites.

Conversion of forests into annual crops changed the food structure and may have eliminated a majority of macrofaunal species that rely on wood or leaf litter or required specialized microclimate. Okwakol (2000) also observed that cultivation of forests reduced variety in food types and ultimately the termite species. Efforts have been made towards manipulation of macrofauna seeding in earthworms and relating them to crop yield. Much more has also been done to relate them to soil structure. Although the termites' role tends more towards pests, farmers in a nearby village recognized its influence in soil fertility.

Figure 34.3: Distribution of macrofauna in farmer perceived niches (2000)

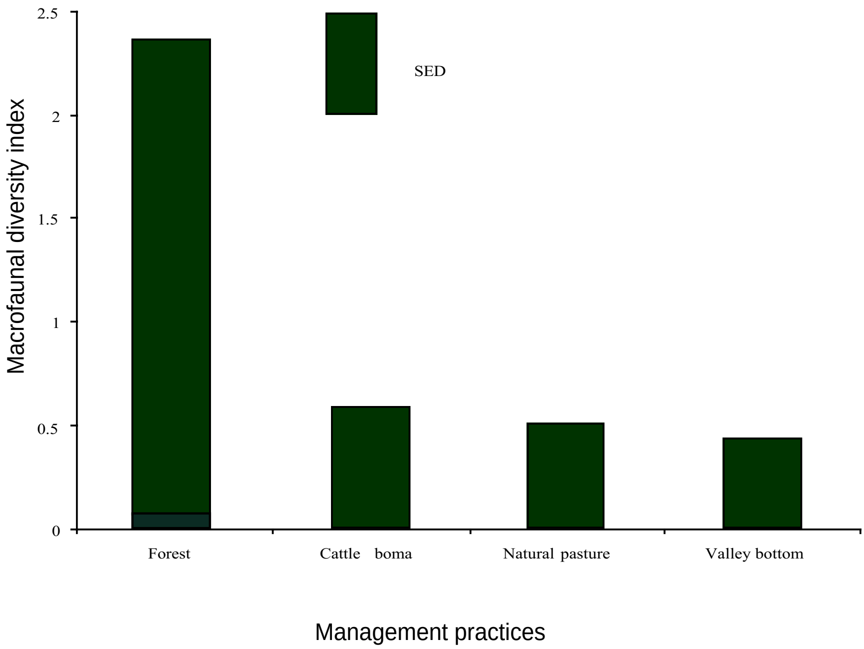


ii) Macrofaunal diversity

Niche management significantly affected the macrofaunal diversity (Figure 34.4). Agro-ecosystems had significantly lower diversity compared to the natural ecosystem's (forest) diversity of 2.31. The number of soil fauna was also generally lower within most cultivated niches. In 1999, "Oboma" had the highest diversity (0.59) followed by natural pasture (0.51), continuous maize plot (0.44) and lastly valley bottomland (0.21). In 2000, "Cmaize" had the highest diversity (0.42) followed by Vbottom (0.42) , "Npasture" (0.23) and lastly "Oboma" (0.2). The decrease in diversity in "Oboma" and natural pasture could be attributed to the high population of predatory ants that scavenged on other organisms. Brown *et al.* (1996) also observed comparable diversity in western Kenya.

The reduction in diversity could be attributed to the reduction in amount, range and diversity of food resources. Micro-climatic conditions (waterlogging and low temperatures) may have contributed to the low diversity in the valley bottomlands. Although "Oboma" was managed highly (with respect to nutrient availability), macrofaunal diversity was still low compared to that of the forest (natural ecosystem). This implies that the process in the farmer perceived soil fertility niches may be different. A shift from natural ecosystems (forest) to cultivated ecosystems therefore reduced macrofauna diversity. Apart from the periodic waterlogging, valley bottomlands are usually perceived as fertile (with respect to nutrient level). The macrofaunal abundance and diversity also appeared to respond to the waterlogging and temperature constraints.

Figure 34.4: Macrofauna diversity as indicated by Shannon-Wiener index under different management practices at Kabras, Malava, western Kenya



In comparison, even the highly managed niche ("Oboma") did not measure up to the forest in terms of macrofauna abundance and diversity. Giller *et al*. (1997) observed that it was difficult to revert to the original (forest) macrofaunal status probably because some of the organisms became redundant and subsequently extinct and others took up their functions. Thus comparing high and low management status in the agro-ecosystem may be a better indicator. Variations in macrofauna population imply that their effect on nutrient cycling was important.

Forests normally have mixed litter, a high soil organic matter and microclimate that support a wide range of fauna (high diversity). Cultivation however removes vegetation that buffers macrofauna against fluctuation in microclimate. It also alters soil structure, aeration and physical quantity of litter for decomposition, which subsequently lowers the abundance, and diversity of the decomposer community and physically damages the macrofauna. In harsh agro-ecosystem environment, only macrofauna that are buffered (in a nest or stay deep in the soil) will not immediately be adversely affected by cultivation. Brown *et al*. (1996) also observed lower diversity indices in cultivated sites than natural (forest) sites and associated it to the negative impact of cultivation on the ecosystem functions (comminution, decomposition) mediated by macrofauna.

Management practices such as continuous tillage alter the population structure, eliminate/reduce key groups and species of soil fauna (Beare *et al*., 1997). Warren *et al*. (1987) observed that microclimate, food resources and land use were major factors affecting diversity and abundance of soil fauna communities. Temporal activities also affected macrofauna population. In the "Vbottom" lands, higher diversity could be attributed to the diversity in food sources and improved aeration during 2000.

iii) Soil fertility of the niches

Generally, "Oboma" was more fertile (had higher soil organic matter, pH and ECEC) compared to "Cmaize" and "Npasture". The nutrient level was even comparable to those available in the forest (Table 34.1). That the macrofaunal status did not follow the same pattern implies that other parameters may have contributed to the macrofaunal performance.

Conclusion

Earthworms, ants and termites were the dominant macrofauna in the agro-ecosystem. The abundance and diversity was however lower than that in the forests. That the niches had different diversity indices confirms further that farmers' spatial-temporal management was translated into variations in biological status of the niches. Macrofauna abundance and diversity was related to both soil fertility management and the agro-ecological conditions in different niches. The use of Macrofauna as bio-indicators thus need further work i.e. relating with keystone species and associated processes. Temporal dynamics of this macrofauna should also be considered before fully using them to characterize niches.

References

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and fertility. A handbook of methods* (2nd edn) C.A.B. International, Wallingford United Kingdom. 221pp.

Ayuke, O.F. (2000) Diversity, abundance and function of soil invertebrate fauna in relation to quality of organic residues. M.Phil. Thesis, Moi University, Kenya.

Carter S. E. and Murwira, H. K. (1995) Spatial variability in soil fertility management and crop response in Mutoko Communal Area Zimbabwe. *Ambio* 24: 77-89.

Beare, M.H., Reddy, V.M., Tian, G. and Srivastava, S.C. (1997) Agricultural intensification, soil biodiversity and agricultural function in the tropics: the role of decomposer biota. *App. Soil Ecology* 6: (1): 87-108.

Blair J.M., Bohlen, P.J. and Freckman, D.W. (1996) Soil invertebrates as indicators of soil quality pp 273-289. In Doran J. W. and A. J. Jones (eds) Methods for assessing soil quality. SSSA Special publication No. 49.

Brown G.G., Moreno, A.G. and Lavelle, P. (1996) Soil fauna in Agricultural and Natural Ecosystems in Western Kenya and Central Tanzania. In Biological management of soil fertility in small scale farming systems in tropical Africa. 2nd Annual report, 1996.

Giller K.E., Beare, M.H., Lavelle, P., Izac, A.M.N. and Swift, M.J. (1997) Agricultural intensification soil biodiversity and agro-ecosystem function. *App. soil Ecol.* 6: 3-16.

Hullugalle N.J.R. and Ndi, J.N. (1993) Soil properties of termite moulds under different land uses in a Typic Kandult of Southern Cameroon. *Agric. Ecosy. and Env.* 43: 69-78.

Lavelle, P. Bignell, D. and Lepage, M. (1997) Soil function in a changing world. The role of invertebrate ecosystem engineers. *Eur. J. of soil Biology* 33:159-193.

Lavelle, P.M. Dangerfield, C. Fragoso V. Eschnebrenner, D.L. Hernadez, B. Pashanari, and Brussard, L. (1994) The relationship between soil macrofauna and tropical soil fertility. In Woomer P.L. and Swift M.J. (eds). The biological management of tropical soil fertility. pp.136-169. A wiley-Sayce publication.

Lamers, J.P.A. and Feil, P. R. (1995) Farmers knowledge and management of spatial soil and crop growth variability in Niger, West Africa. *Neth. J. Agric. Sci.* 43: 375-380.

Okalebo, J.R., Gathua, K.J.W. and Woomer, P.L. (1992) Laboratory methods of soil and plant analysis. A working manual. TSBF, Nairobi.

Okwakol, M.J.N. (1994) The effect of change in land use on soil macrofauna communities in Mabira forest, Uganda. *Africa J. Ecol.* 32: 273-282.

Okwakol, M.J.N. (2000) Changes in termite (Isoptera) communities due to the clearance and cultivation of tropical forest in Uganda. *Africa J. Ecol.* 38: 1-7.

Sanchez, P.A., Shepherd, K.D., Soale, M.J., Place, F.M., Buesh, R.J. and Izac, A.M.N. (1997) Soil fertility replenishment in Africa: An investment in natural resources capital. In: Replenishing soil fertility in Africa. SSSA special publication No.51.

Tian, G., Kang, B.J.T., Brussand, L and Swift, M.J. (1997) Soil fauna mediated decompositions of plant residues under custaed environmental and residue quality and conditions. In cadish G. and Giller, K.E. (eds) Driven by Nature: Plant lither quality and decomposition PP 125-134, CAB.

Wardle D.A. and Lavelle, P. (1994) Linkages between soil biota, plant litter and decompositions. In Cadisch G. and K.E. Giller. Driven by Nature: Plant litter Quality and decomposition PP 125-134, CAB.

Woomer, P.L., Karanja, N.K. and Okalebo, J.R. (1999) Opportunities for improving integrated management by smallhold farmers in the central highlands of Kenya. *African Crop Sc. J.* 7(4): 441-454.

Appendix 1: Macrofauna species sampled from the different farmer perceived niches in Kabras Division, western Kenya

Order/Group	Family/sub-family	Genera; species	Authority
Oligochaeta (earthworms)	Lumbricidae	Lumbricus sp.	Linnaenus
Isoptera (Termites)	• Termitinae/ Macrotermitinae	Pseudocanthotermes spp.	
	• Termitinae/ Macrotermitinae	Microtermes spp.	Wasmus
	• Termitinae/ Macrotermitinae	Microtermes pusillus.	
Coleoptera (Beetles)	• Staphylinidae	Philonthus sp. Leptocinus fuscipennsi com Hypothenemus sp.	
	• Scolytidae		
Chilopoda (Centipedes)	–	–	
Dermaptera (Earwigs)	Forficuldae/ Forciculoidea	Kaischella sp.	
Oligochaeta (Enchytraeid worm)	Enchytraeidae	–	

As special identification keys were not available for some fauna, identification was therefore based on already available collections. Identification at species level was not possible in the case of many samples.

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Understanding Soil in its Social Context: Integrating Social and Natural Science Research within AfNet

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Abstract

Continuing dialogue between the natural and social sciences means that the conception of integrated natural resource management (INRM) is evolving from largely discipline-based approaches to more integrative, holistic ones. This paper presents examples of opportunities for integrating natural and social sciences including understanding the social forces driving soil fertility changes, identifying the clients for new technologies, and improving the sharing of knowledge and information between farmers and researchers. It also outlines theoretical and methodological

[This is a substantially modified version of the paper by Ramisch, Misiko, and Carter entitled "Finding common ground for social and natural sciences in an interdisciplinary research organisation – the TSBF experience", presented at the Social Research conference *Looking back, looking forward: Social Research in CGIAR System*, hosted by CIAT, 11-13 September, 2002 in Cali, Colombia].

approaches for integrating social science into TSBF's research activities, and identifies strategic lessons from the past decade's research that would be relevant for TSBF's partners within the Africa Network for Soil Biology and Fertility (AfNet).

While individual disciplines still retain preferred modes of conducting fieldwork (i.e.: participant observation and community-based learning for "social" research, replicated trial plots for the "biological" research) a more "balanced" integration of these modes is evolving around activities of mutual interest and importance, such as those relating to understanding on-farm variability and providing decision support for farmers. Since TSBF works through partnerships with national research and extension services, it has an important role in stimulating the growth of common bodies of knowledge and practice at the interface between research, extension, and farming. To do so requires strong champions for interdisciplinary, collaborative learning from both natural and social science backgrounds, the commitment of time and resources, and patience.

Introduction

The Tropical Soil Biology and Fertility (TSBF) Programme (now Institute) was created in 1984 under the patronage of the Man and Biosphere programme of UNESCO and recently incorporated into the Future Harvest system of food and environment research centres as a research Institute of the Centro Internacional de Agricultura Tropical (CIAT). As an international research body, the underlying justification of TSBF's work has been that "the fertility of tropical soils is controlled by biological processes and can be managed by the manipulation of these processes" (Woomer and Swift, 1994).

Being an organisation with an explicitly biological and ecological mandate and origin, TSBF has nonetheless sought social science input into its research program. However, since TSBF has always been a small team (never more than six internationally recruited scientists), much of TSBF's considerable output has therefore been generated through collaboration with partner organisations (both national and international), with a special focus on sub-Saharan Africa through the African Network for Soil Biology and Fertility (Afnet). The decision to develop and maintain a core competency at the interface of social and natural sciences at TSBF has also provided a helpful nucleus for building social science competency with partners.

This paper explores the need for greater integration of social and natural science methods in dealing with soil biology and fertility management, and the potential for doing so within AfNet or other African organisations. It presents key programmatic areas where the potential for synergy is high, and suggests ways of building familiarity and competency with interdisciplinary methods and approaches.

The second half of the paper examines the historical record of TSBF and AfNet as "laboratories" for developing meaningful interdisciplinary dialogue and collaboration, and asks whether what has emerged so far has been "social soil science" or merely "soiled social science". Examples of theoretical and methodological evolution are drawn from "grey" project literature, personal commentary, and publications. The strategic lessons from these examples reflect in microcosm the much broader debates about the potential for "rigorous" science under competing disciplinary approaches to integrated natural resource management (INRM). They also address the all too common assumption that the responsibility for developing a common institutional culture and language within INRM falls more to social scientist "newcomers" than to biological or natural scientists.

Relating Natural and Social Sciences

Agriculture is a human endeavour, manipulating plants and soils in a complicated environment to sustain life and support economic and social livelihoods. As such, the management of soils always occurs in a social context and improvements to soil fertility management strategies will only come about if they satisfy the social and economic needs of farmers.

Traditional agronomic (or soil) research has tended to neglect these social components as "externalities" that merely impinge on the studied processes. However, there is great potential for synergy by understanding the social context of soil management, as the examples provided in the following sections will show. These examples are grouped around three key topics that can integrate natural and social sciences in integrated soil fertility management (ISFM) research:

a) Identifying the social forces **shaping soil fertility change**, including economic and demographic drivers, cultural factors, and policy environments.

b) Identifying the **clients for new or improved technologies**, the uses they will have for ISFM, and the decision-making criteria they use for evaluating both current and improved options.

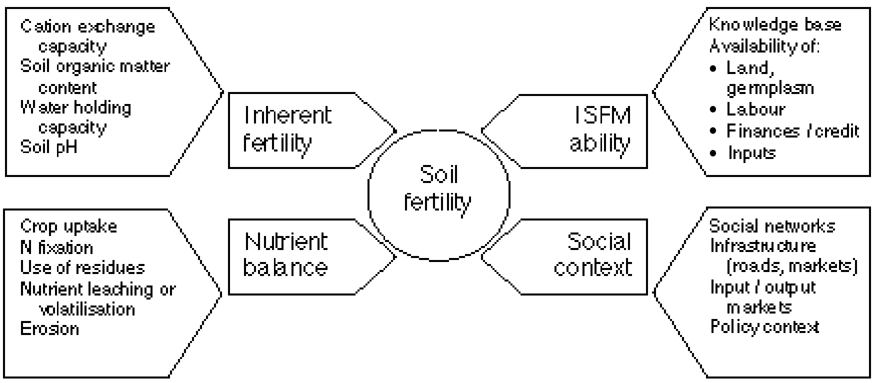
c) Improving the **sharing of soil fertility expertise**, by better understanding existing knowledge systems and improving communication and dissemination strategies to strengthen them.

The social context for fertility changes

Because the rural landscape is full of farms, and people living and working on them, it is often natural to conclude that rural people are therefore "farmers". Of course farming (whether for subsistence or market-oriented production) is only one of multiple rural livelihoods, such as artisanal work, petty trading, labour exchange, or seasonal migration.

Even people who indeed consider themselves "farmers" are not just soil managers, and management ability is a function of knowledge, and access to key resources (such as land, labour, germplasm, finances, and inputs). Beyond the farmer's management ability, the "fertility" of a soil is also function of inherent bio-physical properties, nutrient balances, and broader social contexts (Figure 35.1). As a result, decisions to manage (or to ignore managing) the soil resource are part of a trade-off analysis that considers the soil within a wider economic or livelihood sustainability framework. Research can play an important role here in understanding the conditions under which different interventions are likely to be profitable or attractive to farmers (cf. papers in this volume by Kaliba and Rabele, Kipsat *et al.*, and Mutiro and Murwira).

Figure 35.1: Soil fertility as an interaction of socio-economic and bio-physico-chemical properties.



Soil fertility changes, therefore, have their origins in many human-mediated processes that influence the rate and nature of the key biological and pedological processes (i.e.: erosion / sedimentation, organic matter decomposition / accumulation, etc.). Social differences between farmers (in terms of capital assets like land, labour, cash, and knowledge) and their institutional context will in turn systematically influence the types of soil management options available and the ultimate soil fertility status outcomes. Furthermore, social and soil fertility changes interact with each other over the long term – strong soil managers are likely to improve their economic and social well-being while weaker ones may become trapped in declining or vulnerable livelihoods.

For example, Vihiga district in western Kenya is one of the most densely populated regions in sub-Saharan Africa, with between 1200 and 1400 people per km^2. Although endowed with a high potential climate and inherently fertile soils, the region's political history has left long-distance markets and infrastructure poorly-developed. Out-migration (particularly by young men) is extremely high, which serves both to give households access to off-farm income, and also as a means to reduce pressure on households to sub-divide their land amongst sons. Wealth ranking conducted in this area (Table 35.1) shows that the "wealthiest" households have better access to off-farm income, which can be used to pay hired labour and to support more intensive soil management. Less intensive soil fertility management strategies are associated with the middle and "poor" households, which often have to sell household labour to others.

Table 35.1: Relationship between ISFM practices and wealth class in Vihiga District, Kenya

	Wealthiest farmers (n=34)	Poorest farmers (n=59)
Agricultural labour	Hired + family	Family only
Off-farm income	56 %	20 %
Use fallowing	12 %	0 %
Rotate crops	32 %	22 %
Make compost	53 %	42 %
Regularly use manure	91 %	59 %
Ever used inorganic fertiliser	68 %	42 %
Land has SWC terraces	91 %	39 %

(Carter and Crowley . Unpublished data)

It is apparent from these data that the soil fertility problems of the "wealthy" farms would therefore differ significantly from those of the other households, and that soil fertility changes (either improvement or decline) are strongly related to the socio-economic and political dynamics of households' access to resources. The notion of establishing farmer typologies that relate household characteristics to land use behaviours and soil fertility outcomes has therefore taken root as one of the most useful interactions between social and natural sciences within ISFM research. Not only do these typologies improve the ability to explain existing patterns of soil fertility, but they facilitate better targeting of recommendations and decision support advice.

Technologies for whom?

It is widely recognised that the adoption of new soil fertility management technologies is uneven. Since not all farmers have similar needs or constraints, many studies attempt to determine the adoption potential for new technologies based on farmer characteristics (cf. Kaliba and Rabele, this volume). Socio-economic differences (as discussed in the previous section) may indeed help explain why some farmers are better able to afford the land, capital, or labour needed to experiment with or to use a new technology.

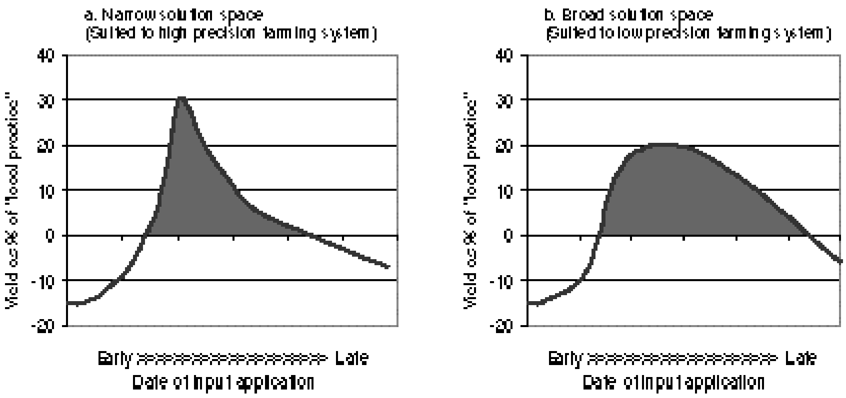
However, equally important for understanding the relationship between farmer difference and the acceptability of technologies is the notion of a farming system's "precision" (Reese and Sumberg, 2003). For a variety of reasons, farmers in rural Africa are often not in a position to act on or implement their decisions or plans in the precise manner, or at the precise times, that they might wish. Richards (1989) demonstrates that "how people actually farm" often contrasts sharply with how they might "ideally like to farm". The intervening reasons might be climatic (the rains may be early or late, too short or too heavy), institutional (the desired inputs such as seeds or fertilisers may not be available when required or at a reasonable price), or related to the household itself (labour appropriate to a specific task might not be available, because of competing demands, illness, or indeed simple "bad luck").

Farming systems where farmers exercise relatively little control over key components of their environment (*low precision* systems) differ markedly from those where they exercise more control (*high precision* systems). For example, maize in sub-Saharan Africa is often planted later than the ideal date because of labour constraints, risk considerations, and crop rotations, with consequent yield reductions of up to 75% compared to the optimal planting date (Byerlee and Heisey, 1996, using Zimbabwe as example).

The argument of Reece and Sumberg (2003) is that agricultural research has historically tended to neglect differences in farming system "precision", even while working to ensure that technologies continue to give acceptable yields across a range of environmental conditions. While plant breeding prioritises the yield "stability" of a crop variety over an environmental gradient (subject to minor location-specific adjustments) farmers who are unable to provide the precise management anticipated by the researcher may suffer significant yield losses. Clearly, research that is developing technologies for use in "low-precision" farming systems must acknowledge that farmers' management practices will vary, making questions of management adaptability as important as those of environmental adaptability.

Related to the concept of a farming system's "precision" is that of a technology's "solution space": the "area around an optimal set of operator-influenced conditions within which a technology will still yield 'positive' results" (Reece and Sumberg, 2003: 416). In Figure 35.2, the yield response of the crop in (A) is highly sensitive to the date of input application, whereas the option shown in (B) obtains a lower maximum but sustains favourable yields over a wider range of application dates. The area under the two curves represents the "solution space" of the two different technologies. The narrower solution space of technology (A) would be appropriate for a farmer who can control the management variable (in this case application date) with the needed precision. The second option (B) has a broader solution space and so would be more suited to a lower precision farming system.

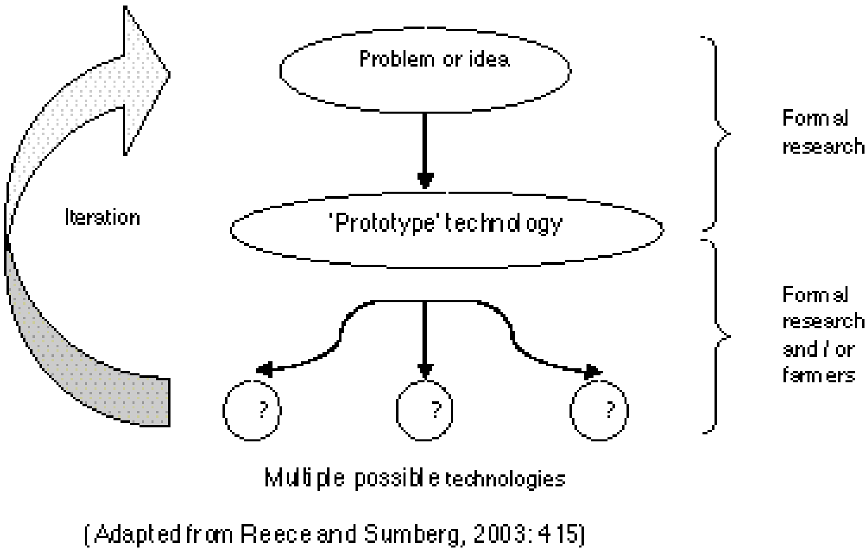
Figure 35.2: Comparing the response of two technologies with different "solution spaces".



(Adapted from Reece and Sumberg, 2003: 417)

To better match the precision of farming systems to technologies, technology design must involve the intended beneficiaries earlier. Figure 35.3 shows an idealised flowchart of a participatory technology design process, with control of the design moving from "formal" to "farmer-led" as soon as the comparative advantage shifts from researcher to farmer. The actual solution space of a given technology will become apparent as technology development takes place, defined as a direct result of the choices made (and options excluded) during this process by the people who will ultimately decide to use the technology. Thus the solution space that is defined for a given technology being perfected by its users will inevitably come to correspond to the precision of their farming system, and that space will also be smaller than the range of possibilities that had been open at the initial stages.

Figure 35.3: Participatory technology design process.



The role of research in this process is therefore to identify "prototype" technologies of interest to farmers, and then immediately involving the group(s) most likely to benefit in the next steps of designing and refining the technologies (cf. papers in this volume by Odendo *et al.*, and Miiro *et al.*). After all, most agricultural technologies in use today were designed by farmers. Such a collaborative research strategy is attractive not only because it empowers farmers to seek new options more confidently, but also because it reduces the likelihood of investment in "dead end" or non-adopted technologies, thereby ultimately reducing research costs.

Participatory research strategies, however, are only slowly taking root in TSBF and AfNet. It should be acknowledged, though, that the "over-designing" of technologies before involving farmers in their development is a natural consequence of scientists failing to a) trust in the innovative capacity of farmers or b) know how to apply farmers' knowledge and innovation as contributions to "formal" scientific activity. It limits farmers' role to relatively passive activities, such as selecting niches or adapting application rates to local circumstances, which ultimately discourages any sense of ownership of the technology development process. However, to recognise certain behaviour as an "innovation" requires channels of communication and trust to exist between farmer and scientist (see the next section), and a willingness to see all modifications of practice (including abandonment and complete reversals) as potentially useful.

Observations of innovative farmer practice can feed into researchable topics, such as the use of Tithonia as a nutrient-rich mulch (now a staple "technology" promoted by TSBF and others in East and Southern Africa). When translating the Tithonia biomass transfer technology to other farms, a commonly heard comment is that the cut-and-carry system is "labour intensive". Harvesting biomass from hedgerows all at once before planting one's crops is indeed a large, and previously non-existent task, even if pruning hedgerows or applying plant material on cropland are familiar activities already in the household calendar. As a result, many farmers have begun harvesting their Tithonia sporadically (as part of normal hedge maintenance) and transferring it to their compost pile (another familiar task). Clearly the decision not to continue with the cut-and-carry operation and instead supplement the compost pile with Tithonia should be seen as an "innovation" or indeed as a logical supplementation of existing practices. However, while Tithonia had been identified as a "best bet" for direct application to fields, it may not be the "best" option for materials to be added to compost piles. A natural entry point for truly interdisciplinary research would be experimentation based on farmers' own practices (many report that Tithonia speeds the "cooking" of compost piles making it ready for use sooner) to validate the use of Tithonia or other materials as part of the composting process.

Sharing experience better: local knowledge and decision support

If farmers' experience of soil fertility change is a function of their different socio-economic constraints and opportunities then there are also clear implications for dissemination and technology adaptation. One is that local knowledge of soil ecology ("Folk Ecology") is itself an important entry point for scientists wishing to understand and build on local practices. Building a shared language then facilitates the translation of strategic research principles into applied tools, such as those that can assist farmers making land use decisions. The second implication is that dissemination and adaptive learning strategies must acknowledge that not everyone will be reached by the same methods. This suggests that methods must be targeted towards the known potential users, and also that if a diversity of potential users is identified, multiple strategies might need to be employed to avoid favouring some groups over others.

The original starting point for scientists and farmers trying to build a common understanding of soil has been local taxonomies. Local names and descriptions of soils have the longest history of use by soil scientists, who recognised that the subtleties of farmers' terminologies reflect the intimacy of frequent interactions and reliance on the land around them.

However, it is also important to understand how local people recognise and monitor changes in the soils that support their livelihoods. Many local concepts of soil fertility mirror the terminology used to describe human health (this is also true of some scientist versions of these concepts). Farmers will refer to soils that are “tired”, “sick”, or “thirsty”, and also to soils that have become “addicted” to chemical fertilisers. However, many local knowledge systems treat soil in a much more holistic fashion, seeing its well-being as embedded within broader systems, for example recognising that crop-soil health is itself strongly influenced by pest dynamics and climate variation. The problems of soils may also be attributed to supernatural origins, such as the neglect of traditions, taboos, or rituals that would have renewed the soil’s fertility (cf. Richards, 1989).

These latter “cosmological” aspects of local knowledge are often the ones most criticised by scientists when minimising the importance of dialogue between local and scientific traditions. Nonetheless, it is not possible to ignore this local knowledge base, since local people will continue to make land use decisions based on its assumptions. Initiating a dialogue that will build on the strengths of local knowledge can also facilitate the process of filling the “knowledge gaps” that are also present, and modifying or replacing negative practices. The very fact that local knowledge often varies between individuals (as a function of gender, age, geography, ethnicity, or livelihood), and indeed that it is not necessarily organised as systematically, coherently, or comprehensively as more “formal” knowledge means that it is essential to find ways to bring local and new knowledge systems together.

Dissemination and decision support strategies must therefore confront this diversity. Materials and methods must recognise that farmers have greatly varying abilities, knowledge, and assets, and that “one size” will not “fit all”. As shown in Figure 35.3 above, any given project or technology can conceivably result in multiple finished knowledge outputs, depending on how well the initial ideas have been used and modified by the people who are likely to be interested in or able to benefit from that knowledge. The decision support guides to support improved knowledge should therefore reflect the production and livelihood goals of those clients / co-researchers, as well as their biophysical and socio-economic assets. These are daunting challenges, but with the help of better understanding of local conditions, local knowledge, and the use of better simulation and modelling tools TSBF and AfNet are helping to meet them (cf. Amede, this volume).

Evolution of Theories and Methods within TSBF and AfNet

The development of a TSBF research agenda that looked beyond the soil to the people cultivating it has moved from descriptive, characterisations of farming systems to more strategic study of social differentiation, power, and networks as they relate to soil fertility management innovation. An interest in dissemination has broadened into investigation of social dynamics, knowledge, and farm-level decision-making. There has also been a tradition of self-reflection, examining the consistency and coherence of TSBF's stated goals, methods, and actual practice, as well as the extent to which grassroots action conforms to its depiction to outsiders. As such, social science practice has developed quite healthily over the last ten years 1992-2002, driven significantly by the following factors:

- The ***disciplinary background*** of the Social Science Officer (and to a lesser extent, that of field staff). Three people have held this position – Simon Carter (1992-1997, Geographer), Patrick Sikana (1998-2000, Anthropologist), Joshua Ramisch (2001-present, Human Ecologist) – and each has had preferred research topics and interests. In addition, Eve Crowley (1994-1996, Anthropologist) worked with TSBF on a Rockefeller Social Sciences Fellowship; a position shared half time with ICRAF.
- The ***demand for "socio-economic" understanding*** of processes being studied by other TSBF staff and collaborators.
- The natural ***evolution of projects*** from inception to later stages. This organic growth has typically moved from characterisation using very descriptive studies to more explanatory work building on existing practices through to development of longer-term interactive learning activities.
- ***Evolving social science debates*** concerning knowledge, power, and participation. The co-supervision of MSc and MA students has been an especially useful vehicle for maintaining contact with these debates.
- Responding to ***donor agendas***, including but not limited to perceived needs for research results readily useful to farmers, a clearer understanding of agrarian change and its links to changes in soil fertility, livelihoods analysis, impact assessment, and identifying the most effective ways of "scaling up" organisational successes.

Demand driven – but by whom?

There has always been a tension between the research agendas demanded from *within* TSBF by social scientists (i.e.: disciplinary interests, evolving projects and debates) and those expected from *outside* (i.e.: from other TSBF staff, partners, donors). This tension results from different research paradigms and differing ideas about the role of research in relation to social change. From the natural science perspective, the key contribution of social science to INRM often appears to be identifying and understanding the social factors that limit "adoption" or the "appropriateness" of given technologies.

Other socio-cultural phenomena, such as “policy” might be acknowledged as important to the fate of different innovations, but most teams (even multi-disciplinary ones) lack the capacity to generate relevant policy-related questions, experiments or interventions. In other words, when the organisation is researching natural resource problems, the natural-social science dialogue has most often begun with identifying “black boxes” of external, *social* forces that need illumination, rather than defining truly *interdisciplinary* questions about how research (including technical research) can support positive change in rural societies.

This tension is reflected clearest in the history of the social science position itself (for fuller discussion, cf. Ramisch *et al.*, 2002). Created in 1992, the post was originally charged with “Resource Integration”. This step was perceived as a natural evolution for TSBF, which always held an ecological, systems-oriented approach to thinking. Although TSBF’s strength remained at the plot level, the diversity of forces impinging on the plot draws attention naturally towards a broader, systemic analysis (Scholes *et al.*, 1994).

The Resource Integration Officer was therefore initially charged with “developing a model for integrating biophysical and socio-economic determinants of soil fertility for small-scale farms” (Swift *et al.*, 1994). Under this rubric, social factors were expected to be integrated into holistic models as additional explanatory variables. Once key and perhaps universal variables were identified, these could then be added to a “minimum set” of characterisation data collected for TSBF sites (cf. Anderson and Ingram, 1993). However, the main contributions to the TSBF programme remained in terms of site selection, selection of themes for process research, and client group selection, with much less emphasis on experimentation, or monitoring and evaluation (Crowley, 1995). This can be seen in the earliest social science work of AfNet, which included developing simple GIS databases for East Africa, a more detailed one for western Kenya, detailed formal survey work in western Kenya, participatory characterisation of farmers’ recognition and management of farm and landscape-level management of soil variability in Kenya and Zimbabwe.

The most fundamental methodological evolution over the last decade has been from largely descriptive, empirical work towards developing more theory-driven, strategic research and the broader use of participatory approaches. At the same time, there has been a search for the optimal degrees of participation relating to the “fieldwork” aspects – which actors, doing which tasks, using which methods. This search has highlighted some of the still extant divides between the rhetoric of research aims and the realities of operational daily practice, as well as tensions that exist between different models of the role of research in stimulating change.

Social science within AfNet

The AfNet membership is still overwhelmingly natural scientists (over 150 soil scientists, biologists, agronomists) with social science represented in 2002 only by six (socio)economists. While there is a general appreciation that "social science" is important to the network, there is still great unfamiliarity with what can really be offered or understood. The emphasis remains on economic information about the "profitability" or "adoptability" of known technologies, with no expertise or experience in applying strategic, interdisciplinary research questions at the interface of human-environment interactions to soil fertility management. AfNet could have made it a higher priority to try to attract more social scientists, but soil and agricultural scientists need to be trained to recognise where social science can make their lives easier. This has to happen at university and in special training courses, and (rather like gender mainstreaming) has to have soil and agricultural scientists as its champions, not *just* the social scientists. Host institutions have also to provide the space for scientists to engage in interdisciplinary research. Unfortunately, while recognised by the various AfNet coordinators, this has tended to be subsumed, and therefore obscured, within the larger problem (true within AfNet as within the CG system more generally) of declining numbers of soil scientists faced with increasing obligations and expectations.

There has been significant turnover of personnel at TSBF since 1992, most notably the tragic loss of Patrick Sikana in the 2000 crash of Kenya Airways flight KQ431. Problems with the continuity of personnel at TSBF and within AfNet have had major impacts on developing an interdisciplinary and social science research agenda that is based on institutional memory and a coherent agenda. Within partner organisations, the retrenchment of public sector employees (as part of structural adjustment or other "reform" programmes) has gutted national research bodies and extension services. The relatively low numbers of social scientists present in national systems must also be seen in the light of the stark fact that they tend to be much more attractive to donors and thus more likely to move on from low paid national positions. Social scientists trained in participatory methods are also much less likely to return to agricultural research jobs when conservation and health present opportunities in more prominent and well-funded fields. Finally, staff turnover in African organisations has tragically been exacerbated by sudden deaths like Patrick's, attributable to accidents, disease, and general insecurity.

The 8th AfNet meeting held in Arusha in May 2001, also clearly demonstrated that amongst partners TSBF is still perceived essentially as a biology-based organisation with minimal social science input. Active recruiting of social scientists has begun through networking and proposal development, but has been complicated by the rapid expansion of AfNet in the past two years. The massive influx of new members and the expansion of activity into West Africa have simultaneously increased the potential demand for ISFM input and diluted the few interdisciplinary voices present within the network. The AfNet mandate of increasing the use of "integrated" approaches frequently takes a back seat to its more "traditional" and familiar mandate of increasing support of biological approaches to partner institutes through curriculum development and networked experiments. The role of social science within AfNet remains an unresolved problem, acknowledged as important (for "integrated" resource management, for greater "adoption", and ultimately donor approval of soil fertility management topics) but not backed by resources or strong champions within the network.

The lack of "champions" for social science research within TSBF can also be seen in the example of Ritu Verma, an IDRC-funded MA student who worked with TSBF in western Kenya from October 1997 to April 1998. Her research comprehensively examined gender and agricultural practice but without a strong link to the core of TSBF was never meaningfully integrated into other projects. Ironically, her book *Gender, Land, and Livelihoods in East Africa: Through Farmers' Eyes* (Verma, 2001) is the most extensive TSBF text produced by social science research but presents its arguments in such detail that it has been difficult to absorb or disseminate, making it a testimony to missed opportunities.

A final point to note is that all of the social scientists who have worked at TSBF have been relatively young and in the early stages of their careers, whereas the biological scientists have generally been more senior. The onus has been on the social scientists to communicate novel ideas in terms their colleagues could understand or accept; this was relatively easy with concepts such as spatial variability, but much harder with feminist political ecology. Furthermore, in the past, strong personalities or opinions have tended to block communication between individuals and to limit interactions within the team. The new team that came together in early 2001 has begun to overcome some of these historical difficulties, further stimulated by meetings held in conjunction with the union with CIAT and the formation of the strategic Alliance for ISFM between CIAT, TSBF, and ICRAF. However, without a more senior social scientist or generalist present to mentor or to mediate communication, interdisciplinarity will always be a challenge.

"Research" or "action research"?

The development of social science at TSBF has been implicitly predicated on two very different models of how change is brought about in rural communities and what role outsiders and scientists can play in that process:

- The more conventional approach suggests that a "good technology sells itself" and that working with communities merely requires that the "best bet options" are made available to the "categories of farmers" who are likely to benefit from them. In this model, which is still widely held by many natural scientists including TSBF partners, a "research" organisation has too few resources and no comparative advantage in doing dissemination, and is better placed to research and evaluate the dissemination and technology promotion activities carried out by partners (local NGO's or national agricultural bodies).
- The alternate approach argues that understanding local processes of innovation, resource distribution, resource allocation decisions, and information transfer is essential to developing technologies relevant to their users' conditions. Integral to this second approach is the development of meaningful communication and learning across disciplinary boundaries – something that TSBF has attempted to do repeatedly, but which still remains problematic.

As TSBF and its partners have become more versed in participatory methods, tension has developed between these models. The desire for more "development" oriented activity has been highlighted in the redesigning of the "Resource Integration" theme of TSBF in 2000 into the new Focus 1, demonstratively titled "Empowering Farmers", into which all the other bio-physical Foci's arrows flow. It may also have been further accentuated by the recruitment in the late 1990s of TSBF field staff for Kenya with NGO backgrounds in action research. The argument has been that without actively engaging in dissemination and community organisation the phenomena of interest to research (knowledge flows, further innovation and adaptation, etc.) will be too scarce to be viable or observable. Indeed, these staff members have found it difficult to define or implement "research" as an independent activity, devoid of extension or development components.

In reality, most partner organisations have lacked the resources (personnel, transport, and operating funds) to carry out such work, and indeed have often turned to TSBF for material or logistical support. The decision to devolve more of the research, experimentation, and dissemination activities to the host communities, therefore, is not so much ideologically driven as pragmatic. The increasing use of farmer-designed and farmer-run experiments, farmer-to-farmer training, and group-based activities has effectively begun to address the desire for more "action" oriented work while providing social processes worthy of investigation. What has emerged in the project areas of western Kenya (where TSBF and local groups have had a reasonably long, 5-8 year history of contact) are prolonged, one-to-one relationships between scientists and farmers. Interactive, two-way learning, through community-based interactive sessions and farmer-based demonstrations, has been enhanced by researchers, and is widely conducted in local dialects. The ongoing challenge, however, has been finding optimal roles for researcher, extensionist, and farmer participation under these continuing conditions of resource constraint.

Collaboration and "participation"

Under the prevailing orthodoxy of participation, it is difficult to find projects that do not describe themselves as using and embracing "participatory" methods, to the extent that the term invites dismissal or covert cynicism (cf. Cooke and Kothari, 2001). These methods are usually assumed to apply only to relationships between researcher / extensionist and "client", where they are used to "level" the power relationships between actors. Yet in the TSBF context, where planning and implementation of activities is explicitly done in partnership with national research and extension institutions, participatory methods of collaboration have had to evolve. If cross-disciplinary learning has been difficult within TSBF, it has been even more so between TSBF and its partners, a fact which must be acknowledged before looking at the effectiveness of "participation" in the dealings of "researchers" with farmers.

This point needs to be based on what might be called "realistic expectations" of change. True collaboration must recognise (however reluctantly) that working with the human resources that are on hand within networks means starting from the perceptions and skills of those partners and moving at the best pace possible. It would have been easy to "cook" fancy results about participation if the social scientists had simply gone it alone. Working in partnership through AfNet, however, has forced TSBF to confront the realities of public funded research in Africa, the conservatism and logistical difficulties of which demand considerable patience. It is relatively easy for partners to influence each other's rhetoric, harder to alter each other's conceptualisations of problems, and harder still to make lasting changes in the way each carries out research tasks. "Participation" is not an approach whose benefits are learned or appreciated quickly and the socialisation of knowledge backwards and forwards between scientists and farmers depends fundamentally on the generation of experience.

The progress of AfNet towards "internalising" the rhetoric of farmer participatory research may seem slow even if it is one of the more advanced scientific networks (cf. review of on-farm research in the EU-funded project, Carter *et al.*, 1998). As mentioned above, the scarcity of AfNet members trained in participatory methods able to act as "champions", and the lack of continuity in many institutions facing financial crisis, hinder the development of a more interdisciplinary research culture.

However, progress is being made in learning new attitudes and unlearning old ones. For example, in the EU-funded project, the Zambian team decided to work on the local *fundikila* mound systems and to replicate the farmers' practices on-station to validate the system in full view of their peers. Among other AfNet partners, research teams in Zimbabwe and Kenya now acknowledge the various micro-niches that farmers recognise and manage and have incorporated these into various research designs. Increasingly sophisticated understanding of wealth and gender differences as they relate to soil fertility management have also been incorporated into more recent project designs. Finally, previously distinct elements of process and on-farm research have been combined in activities where complex soil-crop scenario modelling has been fed back into negotiation or decision support work conducted with farmers.

The politics of community-based research

It is, of course, never easy to surrender control of research agendas, even where the research is ostensibly for the benefit of the rural poor (i.e.: TSBF's Theme 1 is "Empowerment of Farmers" with new technologies). If TSBF has truly embraced the devolution to farmers (or other stakeholders) the major responsibility for adaptive testing and sharing of accountability for quality control over research, what have the political implications of this move been?

As TSBF placed more attention on building capacity in its partners for farmer participatory research, it also shifted to working with local farmers as groups and individuals. In the earlier 1990s, on-farm trials were based on individuals' farms. In such arrangements, host farmers were expected to define and explain experiments to other local and visiting farmers. While we do not know the exact accomplishment through this arrangement, there are indications in Kabras and Vihiga that selecting "model" farmers to work with disaffects them from many other farmers.

Down the road, focus shifted to the group approach. Initially, it seemed obvious that involving many farmers would have a multiplier effect. However, it soon became apparent that the *manner* in which TSBF talks (and to *whom*) is more important than mere numbers. Groups are frequently unstable and many are not especially open to new membership. When researchers request farmers to work with them collectively, "new" groups emerge. But these "new" groups usually comprise members of a previous, defunct group. This means that one has to *deliberately* seek the inclusion of all types of farmers (within and outside groups) in research and dissemination. This role of a local unifier is tricky and can even appear comical before local farmers.

Intervening research on the nature of social capital and the role of local groups and networks in passing agricultural information (Misiko, 2001) has shown that there is still a tendency for some groups or individuals to view their participation in TSBF as “secret knowledge” that is not to be shared with others. Likewise, non-participants are often wary of inquiring about project activities, assuming that they are not welcome or need to be invited by some patron. This attitude has persisted for multiple reasons, and in spite of the considerable efforts of TSBF and other research bodies to present their work as “open to all” by actively seeking to include marginalized groups. Because local politics takes precedence even over the “good intentions” of outsiders, the vast exposure that many farmers have had to project work in western Kenya does not, therefore, translate into widespread use or understanding of ISFM.

The initial willingness of TSBF to accept “groups” as representatives of community interests has led to numerous problems. After all, groups exist and persist when they have strong roles and identities, histories of their own which often only become known with time. For example, the most vocal members of groups have frequently been people who are either not well respected by others locally, or possessed of agendas that run far beyond ISFM. This later group tends to see the research project as a vehicle for access to new resources and political leverage than as an opportunity for new learning (Sikana, 1995), although it may take project staff a long time to appreciate this reality. Since much of TSBF’s on-farm work has been initiated in the context of structural adjustment programmes and the cessation of donor funding for major local development projects, it is natural that farmer concerns about water, health, poor infrastructure, or education would be mapped onto the “research” activities if TSBF was the only “development” agency working in their area. Beyond such explicit “hijacking” of groups, there are frequently tensions between participants over the definitions of goals, membership, and indeed the “success” of the group’s activities.

Nevertheless, working through groups provides an opportunity to diffuse risk and broaden responsibility and ownership of activities. Groups should be seen neither as a panacea for community-based management’s difficulties, nor as a replacement for effective dissemination strategies. When setting up experiments or demonstrations at the local level, having wider input about where in the landscape, whose land, or which soils are suited to which types of research activity has proven invaluable. With our broadened knowledge of the diversity of local soil types, requests by farmers to have activities replicated on different soils become logical and understandable, when previously they might have been dismissed as unjustified demands for a share of a perceived research “pie”. In the end, such replication turns out to be both good science and good politics.

Strategic Lessons: Finding Common Ground

Building on the easiest topics

The challenges that TSBF has tried to address are highly complex in both biophysical and social terms. As such, interdisciplinary collaboration depends on developing a better understanding of what changes are taking place, and of developing a modus operandi that can generate useful knowledge as part of an on-going dialogue between scientists and farmers.

The parallel dialogue that must take place, between social and natural scientists, has been easiest around themes that integrate themselves readily into natural science work, including spatial variability, wealth ranking or farmer typologies as they relate to ISFM practice, and understanding the strengths and weaknesses of existing local knowledge. It has been considerably harder to incorporate elements that relate to the political nature of "research", such as using livelihoods analysis or feminist political ecology to find the place of ISFM and research interventions within local practice.

Championing workable models

If AfNet, collaborators have been slow to adopt interdisciplinary and participatory approaches. It is due in part to the relative lack of successful, convincing models of how such approaches pay short or long-term benefits to ISFM research. Further constraints have been staff turnover (which leads to fragmented agendas and loss of institutional memory), scarcity of time and resources, and a shortage of generalists or social scientists within partner organisations. The rhetoric of interdisciplinarity and participation have rapidly infiltrated research bodies because they are relatively cost free and often there is the perception that donor funding is linked to such language. Simplified versions of interdisciplinary activities, linking ISFM with participatory wealth ranking, or moving from local soil taxonomies to broader understanding of how soil fertility is managed locally, have also begun to take hold within local practice. While some natural scientists are "afraid of having to become social scientists", there is a slowly growing constituency within AfNet that sees advantages for interdisciplinary collaboration. Nevertheless, without relatively senior "champions" for interdisciplinary or socially oriented approaches within TSBF, new methods and approaches are at a disadvantage compared with the more familiar status quo.

Negotiating the role and nature of "research"

Given the variables of donor climate, institutional and personnel changes, and socio-political change on the ground, truly interdisciplinary ISFM research will need to develop a common language and common priorities that can form a core identity in dealing with outside forces. This requires an iterative process of negotiating the role of "research" in the development of local communities. If donors, researchers, and extensionists feel the need to "scale up" local successes and achievements to *broader* communities, it must be reconciled with the desires of the initial community members for taking research accomplishments to greater *depth*. If moving towards group-based research methods means shifting the burden of implementation to national partners, a common path for "participation" will need to be negotiated. In particular, the skills and attitudes necessary to support more decentralised forms of research need to be cultivated by the scientists, agents, and farmers involved.

Despite the rhetoric of interdisciplinary collaboration, cross-disciplinary learning and communication remain complicated by the divergent ideas of what role "research" can and should play in bringing about change in rural communities. Resolving these divergences often falls to social scientists, since their disciplinary orientation predisposes them to thinking about such issues and their colleagues are more likely to see these issues as somehow separate from their daily activities of research. However, building common bodies of knowledge and practice can only happen with the full participation of all disciplines involved in ISFM.

References

Anderson, J.M. and Ingram, J.S.I. (1993) *Tropical Soil Biology and Fertility: A Handbook of Methods.* 2nd edition. Wallingford, UK: CABI.

Byerlee, D. and Heisey, P.W. (1996) Past and potential impacts of maize research in sub-Saharan Africa: a critical assessment. *Food Policy*. 21(3): 255-277.

Cooke, B. and Kothari, U. (2001) *Participation: The New Tyranny?* London: Zed Books.

Carter, S.E., Chuma, E., Goma, H.C., Hagmann, J., Mapfumo, P., Ojiem, J., Odendo, M., Riley, J. and Sokotela, S.K. (1998) On-farm research in the TSBF Programme: Experiences in smallholder systems of tropical Africa. Chapter XI in, Carter, S.E., Riley, J. (eds.) Final Report: *Biological Management of Soil Fertility in Small-scale Farming Systems in Tropical Africa* (EU Project ERBTS3*CT940337). Pp 189-206.

Crowley, E.L. (1995) Some methods for characterising social environments in soil management research. In, Carter, S.E. (ed.) P*roceedings of the 1st project* *workshop (Annual Report to the EU for 1995)*, held at Sokoine University of Agriculture, Morogoro Tanzania, April 19-24, 1995. Project ERBTS3*CT940337: Biological management of soil fertility in small-scale farming systems of tropical Africa. Pp. 99-110.

Crowley, E.L. and Carter, S.E. (2000) Agrarian change and the changing relationship between toil and soil in Kakamega, Western Kenya, 1900-1994. *Human Ecology*. 28(3): 383-414.

Misiko, M.T. (2001) *The Potential of Community Institutions in Dissemination and Adoption of Agricultural Technologies in Emuhaya, Western Kenya.* MA Thesis. Nairobi: Institute of African Studies, University of Nairobi.

Ramisch, J.J., Misiko, M.T. and Carter, S.E. (2002) Finding common ground for social and natural sciences in an interdisciplinary research organisation – the TSBF experience. *Looking back, looking forward: Social Research in CGIAR System*, CGIAR conference hosted by CIAT, 11-13 September, 2002. Cali, Colombia.

Reece, J.D. and Sumberg, J.E. (2003) More clients, less resources: towards a new conceptual framework for agricultural research in marginal areas. *Technovation*. 23: 409-421.

Richards, P. (1989) Agriculture as a performance. In, Chambers, R., Pacey, A., Thrupp, L.A. (eds.) *Farmer First: Farmer Innovation and Agricultural Research*. London: Intermediate Technology (IT) Publications. Pp 185-195.

Sikana, P.M. (1995) "Who is fooling who? Participation, power, and interest in rural development" Paper presented by special invitation at the International Development Research Centre (IDRC), June, 1995. Ottawa, Canada: IDRC (unpublished).

Scholes, M.C., Swift, M.J., Heal, O.W., Sanchez, P.A., Ingram, S.J.I. and Dalal, R. (1994) Soil fertility research in response to the demand for sustainability. In, Woomer, P.L. and Swift, M.J. (eds.) *The Biological Management of Tropical Soil Fertility*. Chichester, UK: John Wiley-Sayce. Pp 1- 14.

Swift, M.J., Bohren, L., Carter, S.E., Izac, A.M. and Woomer, P.L. (1994) Biological management of tropical soils: Integrating process research and farm practice. In, Woomer, P.L. and Swift, M.J. (eds.) *The Biological Management of Tropical Soil Fertility*. Chichester, UK: John Wiley-Sayce. Pp 209-228.

Verma, R. (2001) *Gender, Land, and Livelihoods in East Africa: Through Farmers' Eyes*. Ottawa: IDRC.

Woomer, P.L. and Swift, M.J. (eds.) (1994) *The Biological Management of Tropical Soil Fertility*. Chichester, UK: John Wiley-Sayce.

36

Linking Research Results with Rural Development Projects: Experiences from Southern Africa

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Abstract

This paper presents an approach that has been used to translate research results into farm practice within the context of rural development projects in Malawi, Zambia and Zimbabwe. It is an impact oriented approach designed to ensure that research that is conducted with a development focus should take account of beneficiary interests and be able to address problems in a more holistic fashion. Examples are drawn from the work on the crop-livestock systems that are predominant in much of southern Africa. The main conclusions drawn are that soil fertility management is context specific and requiring adaptive responses that consider local knowledge of the farmer as a starting point in addressing problems. Research for development is not just about technologies, it is also about the people and enhancing their decision-making processes. To achieve greater impact of integrated soil fertility management research requires interdisciplinary teamwork, inter-institutional partnerships, stakeholder involvement, participatory approaches and systems thinking.

Introduction

The Context of Rural Development Projects

These are most often investment projects co-financed by governments and development agencies in this case, the International Fund for Agricultural Development (IFAD). These investment projects are varied in their nature but are often aimed at infrastructure development, food security, irrigation and market development. The soil fertility constraint is often ill defined within these projects even for those focussing on food security, yet it is a pervasive issue contributing directly to poor land quality and low productivity (Figure 36.1). The result is that most of these projects do not give soil fertility issues the prominence required nor is there sufficient involvement of relevant expertise. The challenge of linking soil fertility research results to these development projects is therefore great and entails recognizing that needs between projects vary, and that there is a complexity of problems addressed. Relevance of results is dependent on how the research addresses the hierarchy of needs and the multiplicity of objectives of target clients. This is the essence of research for development. This paper is an attempt to show an approach for linking soil fertility research results with development projects using examples from southern Africa.

Research for development is research carried out in response to the needs of the beneficiary communities. It is impact oriented and by design involves participatory evaluation of options. The overall framework includes the whole research continuum from process research to adaptive research and dissemination though with a bias towards the latter two (Figure 36.2). At the process level, the research is designed to generate an understanding of the regulation of nutrient supply, and of local knowledge about farmers' priorities, access and management of resources and how they are socially differentiated. The key challenge is to use knowledge of social and biophysical processes to facilitate the process of change to achieve more impact on livelihoods and on the way that resources are managed. There are different methodologies that can be used to facilitate change in farm practice. They all entail bridging the gap between researchers and farmers through approaches that encourage participatory diagnosis and evaluation of problems and solutions. This whole process is complemented by the use of decision support tools that aid both the farmers and researchers in making decisions.

Figure 36.1: Constraint diagnosis of rural development projects

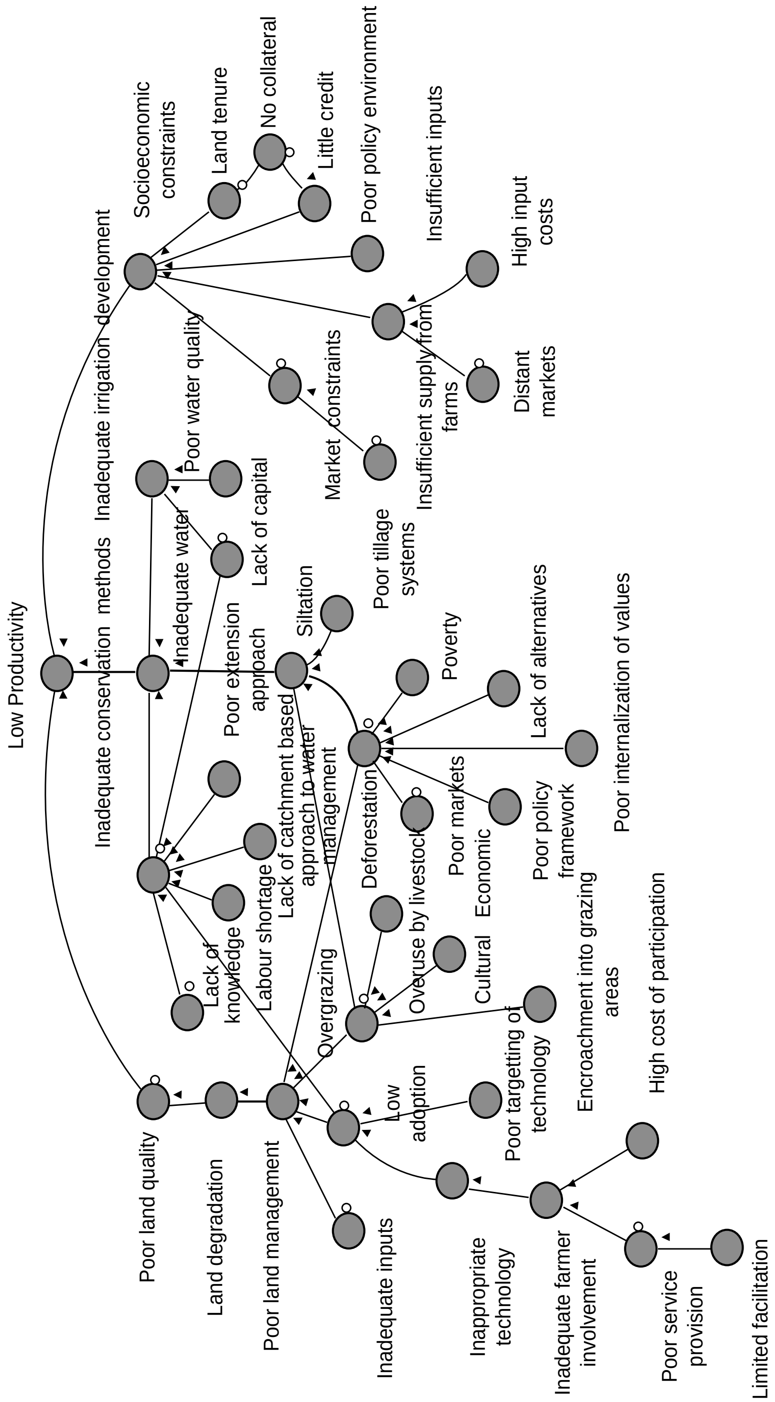
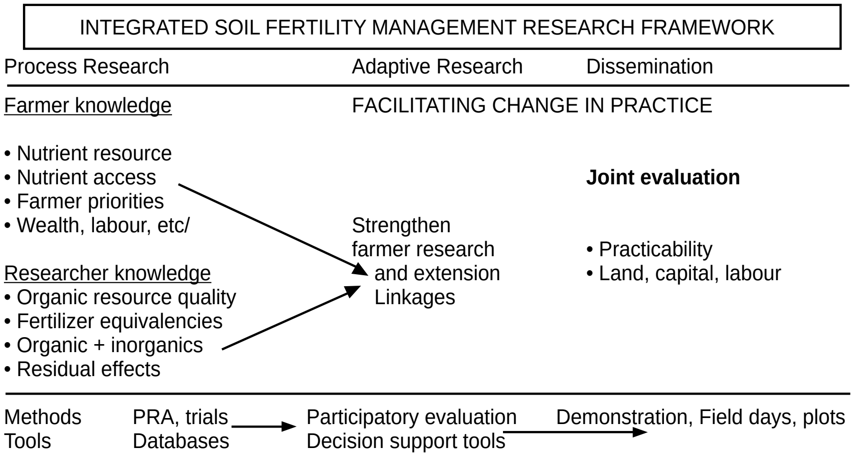
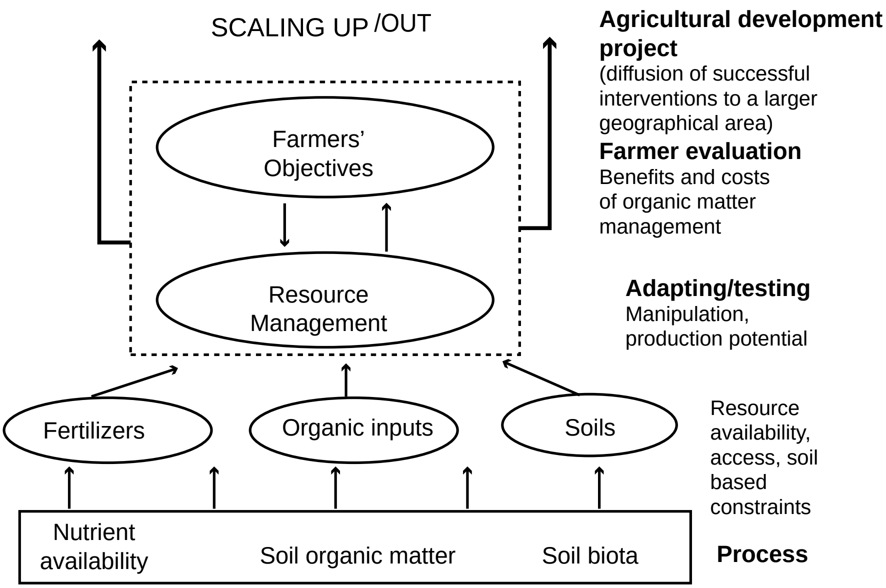


Figure 36.2: A framework for linking integrated soil fertility management research with farm practice



Successful practices can be scaled out with partners within rural development projects but recognizing that the project sites and conditions are not amorphous (Figure 36.3). Soil fertility management is context specific and requiring adaptive responses that consider local knowledge of the farmer as a starting point in addressing problems.

Figure 36.3: Linking research results into the development process



The case of crop-livestock systems

Crop-livestock systems pre-dominate in much of southern Africa and several investment projects are being implemented in the region (eg Southeastern Dry Areas Project and Smallholder Dry Areas Resources Management Project in Zimbabwe Southern Province Household Food security Project in Zambia) to address food security concerns. It is clear from an analysis of the literature that livestock provide an immense contribution to livelihoods and that crop production is intricately linked to the herd size that a household might have (Table 36.1). This is related to both the capacities to produce manure and the provision of draft power from livestock. The sources of manure and the management strategies that farmers use are very diverse (Table 36.2) making prescription of best manure utilization practices difficult. The manure produced is often of poor quality hence options are needed to improve on efficacy of this key resource (Murwira *et al.* 1995). This is not only true from the research perspective, but also from numerous discussions with farmers on their perceptions on how effective communal area manures are (Nzuma *et al.* 1998).

Table 36.1: Grain yield per household and production in relation to the size of the cattle herd in five communal areas of Zimbabwe, 1986

Size of cattle herd per household	Maize grain yield (kg ha^{-1})	Maize grain production per household/year (kg)
0	669	629
1-4	903	876
5-8	1148	1366
9-12	1249	1599
> 12	1831	2362

Source: Adapted from GFA, 1987 (report covering Chivi, Makoni, Nswazi, Chirumanzi and Merengwa communal areas)

One simple approach taken in the study areas was to look at ways in which farmers could manipulate biological processes to enhance quality of the manures. Anaerobic composting of manure in pits, an innovation on the conventional practice of curing manures in heaps, was proved to be a more efficient process that resulted in higher N contents in the manure. The pitted manure produced higher maize yields in the first year of application than heaped manure at the equivalent N application rate of 100kg ha^{-1}.

Table 36.2: Diversity in manure management and fertilizer use strategies for different farmers in Shurugwi District, Zimbabwe

	Manure Management and Use			Mineral Fertilizer Use	
	Rare of application	Method of application	Manure application rotations	Type of Fertilizer	Rate of Application
Farmer 1	4 t ha^{-1} 17th t ha^{-1}	Broadcasted Banded	2 year rotation maize-g/nut-maize	Ammonium nitrate (AN) applied	Uses Coca-cola bottle top for pit stored manure and cup number 2.5 for heap stored manure
Farmer 2	21 t ha^{-1} first season 16th t ha^{-1} second season	Broadcasted	3 year rotation maize-maize g/nut	No mineral fertilizer for pit stored manure Used to apply AN when using heap stored manure	Could not give the rate of application of AN when heap stored manure was use
Farmer 3	3 t ha^{-1} banded and additional 4 t/ha broadcasted	Banding and broadcasting	3 year rotation maize-maize-g/nut	No amonium nitrate applied	Seems application of AN is targeted or done only when crop deserves it
Farmer 4	Banded at 2 cm depth in ridge	Banding	2 year rotation maize-g/nut-maize	No amonium nitrate applied	Seems application of AN is targeted or done only when crop deserves it

Note: Application rates were converted from scotch carts to tonnes per hectare and each scotch cart can carry approximately 400 kg of manure.

Residual yields were however lower in the second and third years in the pitted manure but overall yields after 3 years (including the 1st year) were higher (Figure 36.4). This demonstrates that farmers can benefit from putting science into practice and from the choices provided on how they can maximize on immediate returns or alternatively build on soil fertility and lose on the short term benefits (Table 36.3) (Refer to Mutiro and Murwira in this volume). These results need to be interpreted in terms of the social discount rates that poor people use and the impact it will have on the soil fertility investment strategies (Figure 36.5). Discount rates are quite often higher for poorer households, which might negate on investments with a lower immediate return.

Table 36.3: Overall benefits over 3 years of using pit and heap stored manure

Factor	Control	Pit	Heap
Total harvest (tonnes)	1.83	9.82	8.79
Total Gross Benefit (Z$)	552.24	2835.35	2885.87
Total Variable Cost (Z$)	1748.22	1814.25	1818.32
Total Financial Benefit (Z$)	-1195.98	1021.10	1067.55
Net Present Values (NPV)	-801.46	767.04	497.64

Noe: 1 US$ = Z$ 55

Figure 36.4: Effect of different manure storage methods on maize yield

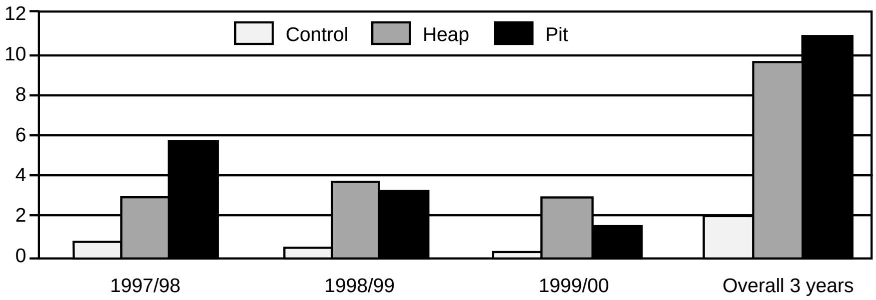
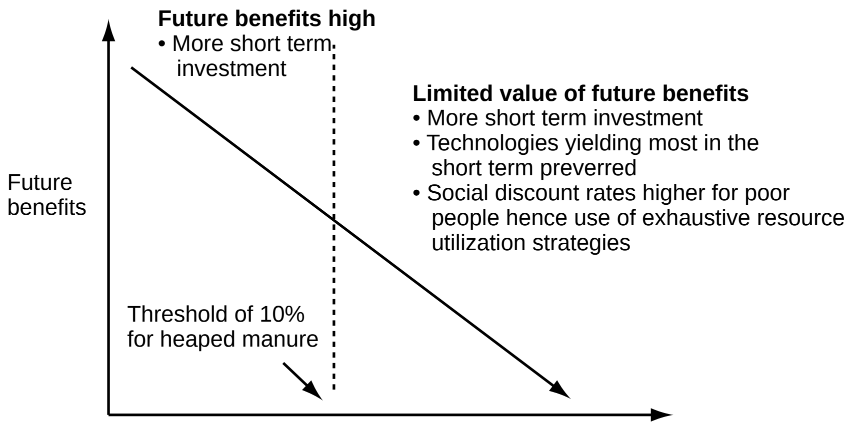


Figure 36.5: Discount rates and their implications on soil fertility management investment strategies



A key lesson from these results is that farmers need to be engaged in a dialogue on how they can arrive at solutions that suit their requirements and circumstances. Developing a framework for such a learning process can be very fruitful but demanding. Attempts have been made to come up with a framework for manure decision making in Zimbabwe (Figure 36.6). The framework looks complex but has been widely tested on its usefulness and it has been demonstrated that it can stimulate discussions on various aspects of manure management and the decisions that farmers take before and after application of manure to soil. It is important to emphasize that the decision tree is more of a conceptual framework for social learning rather than a clear guide for decisions.

The arguments above point to the fact that translating research results into farm practice is not just about technologies, its about people and reinforcing their decision making and their capacity to analyze trade-offs and options. This has to be firmly grounded in their livelihood objectives and aspirations. Livelihood income is diversified and dependent on the opportunities presented to farming households by proximity to markets, crop/livestock productivity and other off-farm activities (Figure 36.7). The contributions (potential and actual) of each of the enterprises needs to be known in order to set priorities for technology testing. It is no point over-emphasizing on manure use and cropping in an environment where farmers can get little recompense from these activities. However opportunities can also be identified where livelihood strategies can be reinforced.

Figure 36.6: Farmer manure decision guide developed using a spidogram analysis

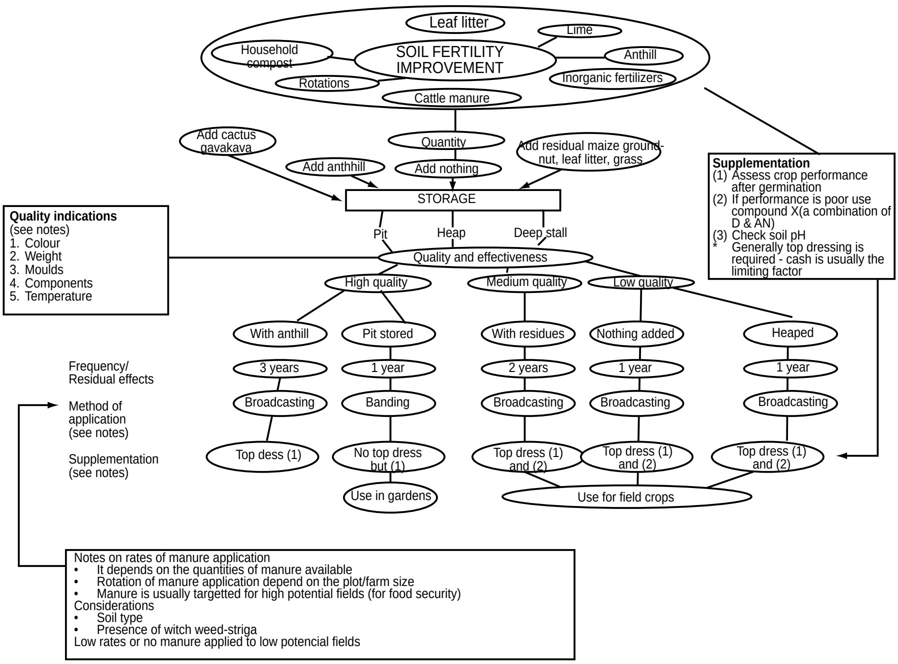
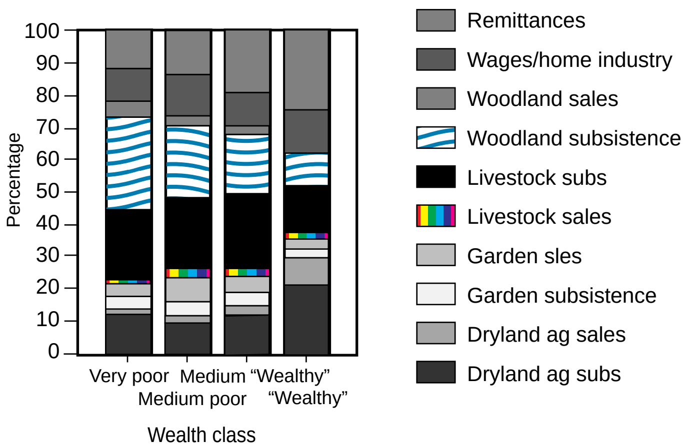


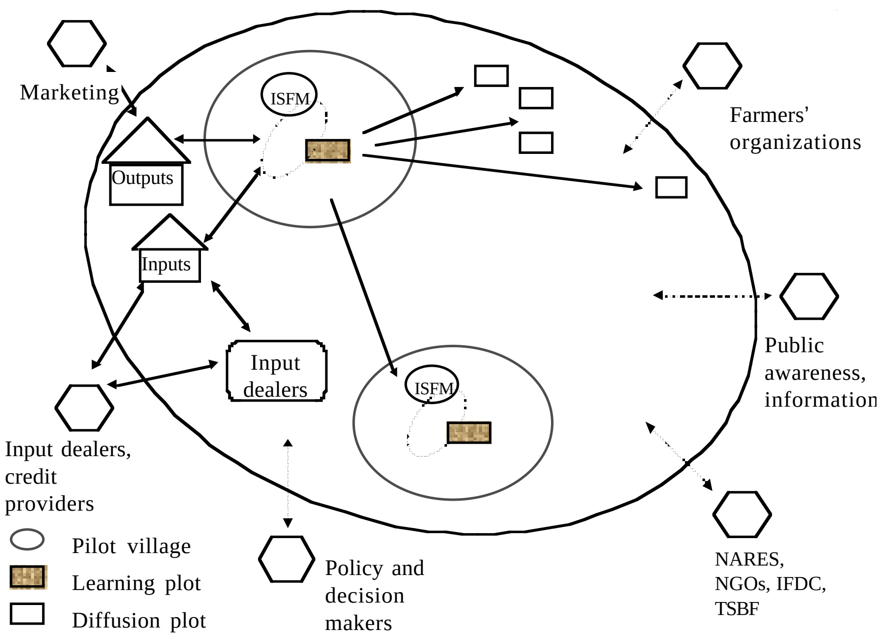
Figure 36.7: Livelihood incomes of smallholder farmers in Chivi, Zimbabwe



From Research Results to Creating Partnerships for Development

Successful interventions in any project area require the participation of key stakeholders (Figure 36.8). This derives from possible institutional synergies that can obtain, and from the need to analyze diffusion pathways to increase impact beyond the plot level and pilot villages. In implementation of work in rural development, research and innovation, institutions are more and more confronted with issues that are too complex to be resolved by a single organization on its own. Nowadays, rural development has to meet many objectives such as improving the livelihoods of poor people, promoting sustainable use of natural resources and biodiversity, linking small-scale farmers to markets and enhancing food security and safety simultaneously. A single institution can no longer make isolated contributions to rural development in their specialized field, but need to ensure that their products and services, jointly with those of other organizations, contribute to these broader objectives. For this to happen, organizations need to combine different kinds of expertise and to work in partnership with other rural development and research organizations. Together, these partners need to work closely with the beneficiaries of rural development activities. They also need to involve and collaborate with other groups that have a role to play in tackling the issues and achieving the broader development objectives such as the private sector (agro-dealers), policy makers and other interest groups (Figure 36.8).

Figure 36.8: Creating partnerships for effective diffusion of integrated soil fertility management research (Murwira and Wopereis, 2003)



The major challenge observed to date in linking research results with rural development projects in southern Africa has been in bringing together the critical mass of expertise required to effect a coherent participatory research and development program. There has been huge staff turn-overs in most of the key national agricultural research systems (e.g. Zambia and Zimbabwe) or the personnel are simply not there (e.g. Malawi).

Conclusion

The main lessons from the work in southern Africa are that translating research results into farm practice is not just about technologies, its about people and reinforcing their decision making and their capacity to analyze trade-offs and options. All this calls for a new approach to doing business in rural development and research. This new way should put emphasis on interdisciplinary teamwork, inter-institutional partnerships, stakeholder involvement, participatory approaches and systems thinking. It sees rural development and innovation and the knowledge needed for it as the result of collective learning to which all these actors contribute, not as the result of the transfer of knowledge generated by a single organization. Most of the work reported is still on-going but it is hoped that the approaches expounded in this paper could lead to more tangible benefits at the farm level.

Acknowledgements

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References

Murwira, H.K., Swift, M.J. and Frost, P.G.H. (1995) Manure as a key resource in sustainable agriculture: a case study of communal area farming systems in Zimbabwe.p131-148. A keynote address. In Livestock and Sustainable Nutrient Cycling in Farming Systems of Sub-Saharan Africa, Vol.II ILCA, Addis Ababa, Ethiopia, 22-26 Nov, 1993. Ed. J.M. Powell, S. Fernandez-Rivera, T.O. Williams and C. Renard.

Murwira, H.K. and Wopereis, M. (2003) Collaboration with rural development projects. Proceedings of the IFDC/TSBF-CIAT project results and planning workshop held in Nairobi, Kenya, 28-30 April, 2003. Unpublished.

Nzuma, J.K., Murwira, H.K. and Mpepereki, S. (1998) Cattle manure management options for reducing nutrient losses: farmer perceptions and solutions in Mangwende, Zimbabwe. P183-190. In: S.R.Waddington, H.K. Murwira, J. Kumwenda, D.Hikwa and F. Tagwira (eds). Soil fertility Research for Maize-based farming systems in Malawi and Zimbabwe. Proceedings of the Soil Fert Net Results and Planning Workshop held from 7-11 July at Africa University, Mutare, Zimbabwe. 312pp.

Economic Analysis of Non-Conventional Fertilizers in Vihiga District, Western Kenya

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Abstract

Most farmers in Vihiga district are faced with the problem of low income. Population pressure is high, land sizes are small and the cost of hired labour is high. With the onset of market liberalisation, prices of conventional fertilizers have been rising faster than farm produce prices. There are many available soil fertility technology options but their adoption is subject to farmers' perception of benefits and limitations to their use. The overall objective of this study was to carry out an economic analysis of some non-conventional fertilizer materials used to improve food production in Vihiga district. A random sample of 150 farmers was selected from three of the six divisions of Vihiga district. Primary and secondary data were used. Gross-margins and cost to benefit ratios were used as the main tools in data analysis. Evaluation of the use of the organic matter technologies on maize/ bean production indicated that there were significant profitability differences between them at 95 % confidence level. Among the organic matter technologies considered, use of agroforestry shrubs in food (maize and bean) production gave the highest profitability. Increasing availability of seeds of agroforestry shrubs to farmers can therefore improve food production in the study area.

Introduction

Vihiga is one of the eight districts of western province. It has an altitude range of between 1750 and 2000 meters above sea level. It is characterized by undulating hills and valleys with vast network of streams and brooks that are tributaries of rivers Esalwa and Yala. Its bimodal, reliable, adequate and well distributed rainfall of between 1800 and 2200 mm per annum peaks in April and June for long rains and September and November for short rains. Ninenty five percent (95%) of the District is in the Upper Midland Zone (UM1) while the rest (5%) is in the Lower Midland Zone (LM1).

The district's warm and humid climate supports growing of many crops. However, soils are of low fertility, limited water-holding capacity and are prone to erosion due to their sandy texture, high land use intensity and heavy rainstorms. Widespread N and P deficiencies in soils due to continuous cropping (Niang' *et al.*, 1996) and inability of smallholder farmers to invest on fertilizers to replace the lost nutrients (Okalebo *et al.*, 1996) has led to low agricultural productivity in the district. The high population densities of 1100 people or 294 households (of on average 8 persons) / km^2 has resulted in land subdivision into small units, further lowering agricultural productivity of the area. Vihiga was expected to have 80,000 households in the year 2001. The average land holding is 0.6 ha and this is considered to be below the FAO recommendation for subsistence food purposes of 1.4 ha / household (FAO, 1999).

The problem of persistently low agricultural productivity in Vihiga district has resulted in a vicious cycle of soil degradation and food insecurity. Crop yields have continued to decline despite the existence of a wealth of already developed technologies that farmers could use to improve soil fertility. In 1982 when the Ministry of Agriculture conducted fertilizer trials in various districts of western Kenya, maize yields in Vihiga increased from 3800 kg ha^{-1} (without addition of fertilizer) to 6100 kg ha^{-1} with addition of (60-60-0) NPK fertilizer. The highest maize yields of 14220 kg ha^{-1} with addition of 178 kg N and 104 kg P ha^{-1} was also recorded. This high yield increase realized in the 1980s contrasts greatly with 1990's report of maize yields of on average 122 kg ha^{-1}, (Aritho, 1994). This shows a drastic decline in land productivity in Vihiga over the years.

Adoption rates of chemical fertilizers in western Kenya are low despite farmers knowing the benefits to their use (Hoekstra and Gorbett, 1995). Use of commercial fertilizers on subsistence food crops such as maize and beans in the area has been restricted to only a few farms with high endowment of resources such as cattle and land (Shepherd and Soule, 1998). Fertilizer recommendations as given in the MoA Bulletin are infeasible in most districts in western Kenya (Okello, 1997). This is mainly due to increased prices after SAPs, unavailability of cash, or lack of access to appropriate fertilizer materials that can be reached easily and at the right time (Nandwa *et al.*, 1997). Research has shown that non-conventional fertilizers are major resources available to farmers to manage soil fertility. They are environmentally friendly and provide longer term beneficial effects to the soil than chemical fertilizers. Non-conventional fertilizers refer to soil fertility management technologies other than the exclusive use of chemical fertilizers. They include organic matter of plant and animal origin used alone or fortified with inorganic materials. Non-conventional fertilizers in this study also include Phosphate Rock (PR), a source of P that naturally occurs in some parts of Africa.

There is a high potential for using non-conventional fertilizers in Vihiga because farmers are keen on improving the fertility of their soils. They have a long history of using traditional soil fertility improvement strategies such as fallowing and farmyard manure in their fields. Nearly ten years of collaborative research by government institutions and Non Governmental Organizations (NGOs) in western Kenya has addressed soil fertility improvement using non-conventional fertilizers. The crop response trials with the most commonly used non-conventional fertilizers have produced technically good yield responses. It also comes out so clearly from research publications that technologies have been studied for potential yields but comparative economic analysis has not been part of it. Economically speaking, however, output (maize and bean yields) alone does not reflect much about efficiency of production. Research scientists in the past laid more emphasis on the ability of technologies to achieve high crop yield responses than on the performance of the technologies based on economic considerations. This explains why some technologies that appear superior in improving crop yields under research conditions are not always the most adopted in farmers' fields. This has resulted in problems of determining the superiority of the existing non-conventional fertilizer technologies based on efficiency of use of the productive resources. Health conscious consumer groups are also lobbying for the use of organic materials but the viability of the option has not been assessed economically.

Non-conventional fertilizers when used in the right amounts have as high yield responses as those of chemical fertilizers used at required levels. The overall objective in this study was to economically evaluate some of the commonly used non-conventional fertilizer materials, namely, agroforestry shrubs, farmyard and compost manure and *Tithonia diversifolia* on improved and sustained maize and bean production in the populous Vihiga district. The hypothesis that was held in this study was that there is a significant profitability difference in maize-bean intercrop when the selected organic matter technologies are used. This implies that farmers need to consider profitability of use of the technologies in adoption. The technologies have comparable yield responses but the cost of adoption vary from technology to technology resulting in profitability differences.

Methodology

The study was based on three out of the six divisions of Vihiga district, namely Sabatia, Emuhaya and Luanda. According to Vihiga District Development plan 1997-2001, Emuhaya has a total area of 75 km^2, of which 60 km^2 is arable land. It has a population estimate of 89,952 persons and 11,244 households, farm sizes of on average 0.4 ha and a population density of 1,199 persons km^{-2}. Sabatia has an area of 115 km^2 with 101 km^2 of arable land expected to be supporting 150,000 people. It has 21,428 households with average farm sizes of 0.5 ha. Luanda has a population estimate of 114,936 people and 14370 households in an area of 104 km^2, of which 68.5 km^2 is arable. Like the rest of the district, Luanda, Emuhaya and Sabatia divisions have generally good climate for production of most crops but soils are depleted of N and P.

Primary and secondary data was used in this study. Primary data was collected through administration of structured questionnaires in some purposively selected households. Secondary data was mainly from research institution and government publication such as agricultural annual reports. Information collected included those on operation costs of use of the selected technologies in maize and bean intercrop, input and output prices, application rates of the specified non-conventional fertilizers by farmers and the associated average maize and bean intercrop yields. The average output and input prices were obtained from time series data in the study area divisional Agriculture Offices. Operational costs considered included costs such as those of crop management (planting, pest control, harvesting, shelling and collecting, preparing, carrying and application of organic materials) and marketing of produce. The opportunity cost of second season maize and bean crop was considered as a cost in case of improved fallows because no crop was planted in the second rainy season as agroforestry shrubs were left growing in the crop field during the season. The value of labour used on various operations in the production was based on survey of farmers estimation, while the cost of land included the land rent in the area. Costs were arrived at after grants and subsidies on agricultural products have been excluded. The benefits included increased maize and bean yields and wood fuel (in case of agroforestry shrubs). Information on use levels of fortified or unfortified organic materials and associated crop yields were obtained from some selected farmers, who were known to enumerators employed in this study as using the organic matter technologies considered in this study on maize and bean intercrop. Interview of farmers who did not use fertilizer in subsistence food (maize and bean) production provided data that was used as control.

The population was divided into three sampling units represented by three selected divisions (Sabatia, Emuhaya, and Luanda). The selection was based on agro-ecological zones and prevalence of organic matter technologies under consideration. The three divisions provided the survey sites for the study. From the selected divisions, households that were known to the enumerators as using the selected organic matter technologies were selected randomly from each location. The exact number of farmers selected in each location depended on prevalence of organic matter technologies that the study focussed on in the location. At least two farms were selected from each sub-location and this study collected data from 20 sub-locations in which a total of 150 households were interviewed.

Data collection exercise was done between August and December 2000. Ten enumerators were appointed, trained for the enumeration exercise and provided with questionnaires. Single visit formal surveys that were conducted using structured questionnaires were orally administered to farmers with the help of the enumerators who knew and were conversant with the farmers' local language and customs. During the survey the enumerators made arrangements to meet the sample farmers in farmers' fields.

The economic analysis of the technologies involved the Net Present Value (NPV) or the net worth and Benefit- Cost Ratios (BCR). NPV is defined as the present worth of the benefits less the present cost of a project. In this study each of the four organic matter technologies is taken as a project. BCR is a discounted measure of project worth. It is given as the present worth of the benefit stream divided by present worth of the cost stream. The NPV and B/ C analyses were used in economic evaluation of non-conventional fertilizer technologies in this study to ensure that the residual effects of use of organic matter technologies are captured. Mathematically NPV is given as:

$$\sum_{t=1}^{t=n} \left(B_t - C_t\right)(1 + i)^{-t}$$

B_t = benefits in year t,
C_t = cost in year t,
t =1,2,....n, time in years
n = year n/last year under consideration
i = interest/compounding rate, taken as the interest rate in commercial banks.

Results and Discussions

Evaluation of soil fertility technologies in terms of maize and bean yields

Farmers interviewed in this study fortified organic materials with half the recommended levels of inorganic materials mainly DAP and CAN. Very few farmers used Phosphate Rock (PR) due to its limited availability in retail shops in the area. Table 37.1 shows the three-year (1998-2000) average maize and bean yields among the farmers interviewed in Vihiga district when the specified soil fertility technologies are used. The yields considered in this study refer to averages obtained when maize and beans were intercropped. Control is taken as the current crop yields obtained in a maize-bean intercrop in the study area when no fertilizer is applied.

Table 37.1: Average yield responses to soil fertility management technologies

Soil Fertility Management Technology	Fertilizer use level/ Seed Rate	Maize Yield kg ha^{-1}	Bean Yield k g ha^{-1}
Zero fertilizers added (control)	-	970	100
Tithonia diversifolia alone	5 t ha^{-1}	1674	165
Fortified Farmyard manure	2.5 t ha^{-1}	2025	182
Fortified Compost manure	2.5 t ha^{-1}	2109	180
Use of *Tephrosia vogelii*	2.5 t ha^{-1}	2174	185.5
Fortified *Tithonia diversifolia*	2.5 t ha $^{-1}$	2270	193.7
Use of *Crotalaria grahamiana*	2.5 t ha^{-1}	2490	212.5
Inorganic fertilizer (DAP and CAN)	DAP 2.5 Bags CAN 2.5 bags 1 bag = 50 kg	2700	225

Table 37.1 shows that yields of both maize and beans were higher with application of conventional fertilizers than with non-conventional fertilizers. Using fortified organic materials however, also improves crop yields. Fortifying tithonia for example increased maize yields by 36% relative to tithonia applied on its own and 134% compared to maize produced under conditions of no fertilizer. Table 37.2 shows the % change in crop yields arising from the use of the specified soil fertility technologies in the study area compared to the control of no fertilizer use. Applying

organic materials results in substantial crop increases of between 72 and 157 %. Fortifying organic materials is thus recommended because of the low levels of N and P in organic materials. Table 37.2 indicates the % crop yields increases arising from use of fortified organic materials.

Table 37.2: Yield Increases with Use of Fortified Organic Materials in Vihiga District

Soil Fertility Management Technology	Percent (%) improvement in crop yield	
	Maize	Beans
Zero fertilizers added (control)	0	0
Use of *Tithonia diversifolia* alone	72	65
Use of fortified farmyard manure	109	82
Use of fortified Compost manure	117	80
Use of fortified *Tephrosia vogelii*	124	85.5
Use of fortified *Tithonia diversifolia*	134	93.7
Use of fortified *Crotalaria grahamiana*	157	112

Table 37.2 shows that *Crotalaria* is the best of the organic matter technologies in improving yields of both maize and beans in Vihiga by on average 157 and 112 % respectively. This means that based on crop yield responses, organic materials are the best alternatives to inorganic materials in crop production in Vihiga district. A single factor ANOVA carried out to make comparative yield analyses indicate significant maize and bean yield differences arising from the use of the organic matter technologies at 5% level.

Economic evaluation of soil fertility technologies in vihiga

Cost of labour form a major part of the total cost in the use of organic materials in western Kenya, particularly in Vihiga district (Kipsat, 2001). Table 37.3 gives a comparative analysis of the total variable and labour costs of using the reviewed technologies in maize and bean intercrop production in the study area. The table indicates that labour form more than half of the total variable cost of production when the organic matter technologies are used. This is because use of organic materials is labour intensive.

The figures in parentheses in Table 37.3 indicate the proportion that labour costs make of the total variable costs of using the specified technologies in maize/ bean production in Vihiga. The cost of labour forms over 60% of the total variable costs in all cases. Labour contributes less to total variable costs (60.74%) when inorganic fertilizers are used than it does in use of organic fertilizers, where it contributes between

65.71 and 74.76% of the total costs in maize and bean production. This is explained by the differences in labour requirements for using organic and inorganic materials in crop production.

Table 37.3: Costs associated with soil fertility technologies in Vihiga District

Soil Management Practice	Total costs (Kshs ha^{-1}) of Maize and Bean Inter-crop	Cost of labour (Kshs ha^{-1}) of Maize and Bean Inter-crop
Inorganic Fertilizer	47031.10	28565.00 (60.74 %)
Fortified Crotalaria	43126.00	28337.80 (65.71%)
Fortified *Tephrosia vogelii*	42304.55	27972.50 (66.12%)
Fortified *T. diversifolia*	46231.70	30861.10 (66.75%)
Fortified Compost Manure	44220.80	29897.50 (67.61%)
Fortified Farmyard Manure	42996.35	28897.50 (67.21%)
Unfortified *T. diversifolia*	44995.80	33639.10 (74.76%)
Zero fertilizer (control)	35560.70	26630.50 (74.88%)

In economics the goal or standard for return to labour and management should be an amount at least as great as the opportunity cost of owner's labour and management in a non-farm occupation. The minimum standard or goal for return to capital is that the rate of capital return should approximate the interest rate of borrowed capital. The above goals though desirable are not achievable in farmers' production conditions as seen in Vihiga district. The aim should therefore be that farmers select technologies that are more economically efficient than others in the use of resources. Table 37.4 shows the economic evaluation of organic matter technologies.

Table 37.4: Results of economic evaluation of organic matter technologies

Soil Fertility Management Technology	Net Present Value NPV ha^{-1} in (Ksh ha^{-1})	Benefit to Cost Ratio	Rank based on NPV
Fortified Crotalaria	33 568.20	1.27:1	1
Fortified Tephrosia	13745.90	1.13:1	2
Fortified Tithonia	11047.20	1.08:1	3
Fortified Compost Manure	6020	1.05:1	4
Fortified Farmyard Manure	4592.10	1.036:1	5
Tithonia alone	-2130	0.87:1	6
No fertilizer (control)	-11719	0.61:1	7

Table 37.4 indicates that the use of agroforestry shrubs (Crotalaria and Tephrosia) on maize and bean production gives the best profitability in relation to the other non-conventional fertilizers considered. Although

tithonia is associated with high crop yield, the net worth is lowered by the high labour demands that translate into high cost of using it. Fortified farmyard and compost manures have relatively low crop yields and high labour costs lowering the returns to their use. The NPV of using unfortified tithonia and production under conditions of no fertilizers are negative. This means that those farmers who produce under the two systems are incurring losses in maize and bean production and should be advised to find alternative use of the invested labour, land and capital. The two production systems result in very low BCR while the rest of the soil fertility management technologies under consideration have favourable (greater than one) BCR values. This means that apart from using tithonia, a farmer can make positive returns by using the rest of the Non-Conventional fertilizer technologies in maize bean production although the relative returns vary from technology to technology.

To test the null hypothesis that there are no significant profitability differences arising from the use of the four organic matter technologies on maize and bean production, a single factor ANOVA was carried out. The results indicate that there are significant profitability differences between the Non-Conventional fertilizers at 95 % confidence level and therefore agricultural extension agents should consider profitability differences in choice of technologies to promote in Vihiga district.

Conclusion and Recommendations

Resource limitations are a major hindrance to adoption of soil fertility improvement technologies in Vihiga district. The district is characterized by high cost of land, labour and capital. To improve food security in the district, policy makers should focus more on measures to improve the resource base of the resource poor farmers than on aspects of generating more technologies in the area.

Promotion of agroforestry can improve food production in the study area. From the survey, it was realized that farmers have a problem of accessing agroforestry shrubs' seeds to use in their fields. To promote agroforestry as a technology, therefore, involves providing agroforestry shrubs' seed to the farmers and teaching them on how to propagate and manage the plants for soil fertility improvement. The economic analysis of other soil fertility management technologies not covered in this study should be made and information availed to the farmers to enable them make informed decisions. The benefits of using organic materials can be improved by fortifying it with PR that is a cheaper source of P than inorganic P fertilizer. The availability of PR in retail shops should thus be improved. From the research, it was realized that farmers were aware of the benefits in the use of PR but complain of the material not being available.

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References

Aritho, R. (1994) *The Effect of Household Income and Seasonal Price Changes on Household Food Expenditure Patterns*. Fertility and Nutrition Studies Project, Egerton University.

FAO, (1999) FAO *Fertilizer yearbook (1998)* Vol. 44. Food and Agriculture Organization of the United Nations, Rome.

Hoekstra and Gorbett (1995) *Sustainable Agricultural Growth for the Highlands of East and Central Africa: Prospects to 2020*. International Food Policy Research Institute, Washington D.C.

Kipsat, M.J. (2001) Economics of Non-Conventional Fertilizers in Vihiga District, Western Kenya. M.Phil. Thesis Department of Agricultural Resource Economics, Moi University. Kenya.

Nandwa, S.M., Kanyanjua, S.M., and Thuraniva, E.G. (1997) Soil Phosphorus Recapitalization of Western Kenya Soils with Minjingu Rock Phosphate; Some Evidence of Limited Soil P Availability and Maize Response to Fertilizer Application.

Niang', A.I., Amadolo, B.A., Gathumbi, S.M., Otieno, J.H., Obonyo, C.O. and Obonyo, E. (1996) KEFRI/ KARI/ ICRAF – AFRENA, Maseno Project Report no.10.

Okalebo, J.R., Woomer, P.L., Maritim, H.K., Kapkiyai J. and Mwakuko, P.E. (1996) *"Phosphorous Research Exploratory Project for Western Kenya (PREP)"*. Project Proposal Presented to "Rockefeller foundation, Forum on Agricultural Resources Husbandry."

Okello, D. (1997) *Improving Food Production through Improving Soil Fertility in Siaya District*. A paper presented at PREP workshop Chepkoilel campus 12th–15th May 1997.

Shepherd, K.D. and Soule M.J. (1998) Assessment of the Economic and Ecological Impacts of Agroforestry and other Soil Management Options on Western Kenya Farms Using A Dynamic Simulation Model. Agricultural Ecosystem Environment (in Press).

Early Farmer Evaluation of Integrated Nutrient Management Technologies in Eastern Uganda

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Abstract

There has been widespread recognition of the need to rejuvenate the fertility of soils for sustainable agricultural productivity, food security, household income, and poverty alleviation in sub-Saharan Africa. Since 1999 different Integrated Nutrient Management (INM), technologies have been under on-farm adaptive/ dissemination trials in Tororo district, eastern Uganda. The area is well known for its highly unproductive sandy ferralsols. Options promoted included the use of leguminous trees/shrubs and cover crops such as, Mucuna, Canavalia, Tephrosia, and Crotalaria species. Also promoted were Tithonia biomass transfer and Rhizobia inoculation. For the P deficient soils, various P fertilizers were evaluated including Busumbu Phosphate Rock from nearby deposits, TSP and Minjingu Phosphate rock from Tanzania. Initial assessments by farmers indicate wide-scale testing in the pilot areas and farmer adaptation and innovation of the options promoted. Eighty eight percent (88%) of the farmers who tested the options indicated willingness to expand 56% of these to more than one acre of land. To scale up these efforts to the entire district and to address constraints like seed availability, awareness creation and training, a consortium of R&D partners through a project called Integrated Soil Productivity Initiative through Research and Education (INSPIRE) steered by the District administration has been initiated. Farmer to farmer extension, participatory crop management training, fertiliser use, green manure crop/ shrub husbandry frame the way forward of the project.

Key words: Integrated Nutrient Management, Green manure legume cover crops, Participatory evaluation, Dissemination.

Introduction

Soil fertility depletion in smallholder farms is recognised as a major biophysical root cause of the declining per-capita food production in most of sub-Saharan Africa (Sanchez *et al.*, 1997). Soil fertility rejuvenation for increased productivity, food security and income has been recognised by the Government of Uganda as a strategy towards poverty alleviation (Soil Fertility Initiative –SFI, 1999). The widespread belief by many, including politicians that Ugandan soils are fertile has also been corrected to a recognition that there has been a lot of soil degradation of all forms leading to poorer soils (PMA, 2000).

The government has set up a strategy to combat soil degradation under the Plan for modernisation of agriculture through the Soil Fertility Initiative (SFI).

The SFI in Uganda aim at correcting the negative nutrient balance in smallholder farming. Households needs to move beyond the two extremes of high external input agriculture and the low external input agriculture to integrated forms of agriculture such as integrated nutrient management. The advantage of the integrated approaches to agriculture is the synergism between locally known practices and introduced or research inputs and practices that are developed either through a participatory technology development (PTD) process or participatory learning and action research (PLAR) process. These processes are part of development thinking for poverty alleviation that promotes empowerment of the beneficiaries through partnerships and pluralism (RoU, 1997; Ashley & Carney, 1999).

In Tororo District since 1997, various efforts by the National Agricultural Research Systems (NARS) and an international NGO, (Africa 2000 Network), have been in place to fight poverty of farm households by increasing food security through the promotion of integrated nutrient management technologies. This has been through a consortium involving civil society, NGOs, national agricultural research systems, international agricultural research systems and government, called the Integrated Soil Productivity Initiative through Research and Education (INSPIRE) project. The efforts of the consortia have been directed to Tororo District, because of its dense population of over 280 persons per square kilometre, poorly endowed natural resources, acidic and sandy soils, and a reversion to mainly annual crop system. About 82 % of the district land is farmed making this area a high incidence poverty area (RoU, 1991; Zake *et al.*, 1998; World Bank, 1993).

The INSPIRE Project

The INSPIRE project is a broad based consortium of district based development organisations, the NARS and district local government, formed to address increasing poverty and food insecurity by promoting appropriate soil management technologies for increased agricultural productivity. The partners include: the district government's department of production, Africa 2000 Network (A2N), Sasakawa Global 2000 (SG2000), Tororo District Farmers Association (TODIFA), the Food Security and Marketing organisation (FOSEM) and appropriate Technology (AT) Uganda; a local branch of Enterprise Works Worldwide. Others are Plan International, the International Centre for Research in Agroforestry (ICRAF) of western Kenya and Uganda, Tropical Soil Biology and Fertility (TSBF), The International Centre for Tropical

Agriculture (CIAT), Makerere University, Faculty of Agriculture and the National Agricultural Research Organisation (NARO). The consortium is overseen by a steering committee led by the District Production Officer and the project activities are co-ordinated by Africa 2000 Network.

A five-year activity plan has been made to address the soil needs of the district using an integrated approach. The project goal is the improvement of livelihoods of farmers in eastern Uganda by empowering them to overcome food insecurity and poverty. The project purpose is to improve the soil fertility productivity in Tororo District in a sustainable manner. Four outputs are expected:

1. Establish through baseline studies the current soil fertility levels and farmer management practices, and develop, test and verify with farmers the appropriate and sustainable soil management technologies,
2. Disseminate verified soil management technologies and practices,
3. Improve access to soil fertility enhancing agricultural inputs in the district such as fertilizers, cover crops, seeds, Rhizobia, compost inputs, tree seedlings, and mulching materials and
4. Enhance capacity of the stakeholders to implement sustainable soil fertility management technologies.

To date, the technologies tested on-farm include the use of leguminous trees/shrubs and cover crops such as Mucuna, Canavalia, Tephrosia and Crotalaria species. Also promoted is Tithonia biomass transfer and the use of rhizobium inoculum for legume crops. Since the soils in the district are highly P deficient, P fertilisers including Busumbu Phosphate rock from the nearby Tororo hills have been evaluated in comparison with other sources such as Triple Super Phosphate (TSP) and Minjingu Phosphate rock from Tanzania. The demonstration/ dissemination strategy used several farmers from a farmer research group, who hosted the trials on behalf of the group. Training, field days and farmer evaluation of these trials are conducted throughout the season. Exchange visits between farmer groups were conducted to allow different farmer groups in the District and from outside the District to visit and learn from each other.

This paper that provides an overview of the INSPIRE project, does share results of an early qualitative evaluation of the soil fertility enhancing adaptive trials. The study established the performance of the technological options tested, the initial benefits and constraints, adaptations, relevance of pre-trial training, on farm expansion, continuity and dissemination/diffusion. The future direction of the consortium's planned activities is outlined.

Methodology

The study was conducted in the district of Tororo in Osukuru and Kisoko sub-counties. Tororo district is found in eastern Uganda bordering Kenya. Most of the district is flat, lying at an altitude of 1,097 to 1,219 m above sea level and a temperature range of 15.7° to 30.6° C. The annual rainfall is more than 1,200 mm per year. It has a population density of about 280 persons per sq. km, with over 82% of the land under agriculture. Soil type in the area is sandy loam often acidic and K deficient. Soil erodibility and erosivity is moderate (Wortmann and Eledu, 1999).

There were two stages to the qualitative analysis:

1. Data were collected using a structured interview schedule, developed by the NARS partners of the INSPIRE project. The sample size was 25 out of the 92 farmers who conducted demonstration trials between 1998 and 2000 (Table 38.1). Data were collected in June-July 2000 by the extension workers of A2N who had been trained on the data collection processes.
2. A qualitative group evaluation of the legume cover crops to capture their performance was conducted in February 2001. A pair-wise ranking of the legume cover crop preferences was done with the farmers. Farmers hosting the green manure trials were invited along with those who were interested in trying out the technologies. Sixty farmers were in attendance in the Kisoko meeting and more than 70 from Osukuru. Only data from Kisoko will be presented in this paper.

Table 38.1: Numbers of farmers who hosted the trials

Trial description	No. of farmer trials	Number of evaluated farmers
1. Determining the effectiveness of Busumbu rock phosphate as a source of P using maize as a test crop	20	14
2. Determining the effectiveness of Busumbu rock phosphate as a source of P using groundnuts as a test crop	20	7
3. Determine the contribution of Nitrogen by inoculated groundnuts	16	10
4. Compare the integration of Tithonia biomass with TSP to the sole application of inorganic fertilizer at an equivalent rate of NPK	10	5
5. To determine the effectiveness of using legume cover crops (LCCs) as an organic source of fertilizers on maize	10	6

Results and Discussion

Farmer evaluations of phosphate rock, biomass transfer and rhizobia innoculum

Farmers evaluating the technologies were asked about what they had feared before hand and what had actually been constraints or problems during the trials. They also explained what they had learned from the trials, and how the technologies compared with each other. Nearly half of the farmers (48%) indicated that their main fear prior to testing the different options was related to their experience with inorganic fertilizers (Table 38.2). In particular, Busumbu phosphate rock was unfamiliar to nearly a third of the farmers (32%). In contrast, few farmers were unfamiliar and worried about the use of the organic fertilizers. Worries about lack of funds to buy inorganic inputs or hybrid maize seed were also common (28%). Lack of funds for inputs was not an issue for the use of Tithonia, compost and Rhizobia, because these relied more on labour than capital inputs, the former being cheap.

Table 38.2: Fears held by farmers before the trials were hosted (n=25)

	Impro-ved maize	Busu-mbu blend	Busu-mbu PR	Minji-ngu PR	TSP	Urea	P and K	Titho-nia	Com-post	Rhiz obia
Had never used it before	_	40%	40%	40%	40%	40%	40%	_	_	_
Lack of funds to buy inputs	28%	28%	28%	28%	28%	28%	28%	8%	4%	4%
Not known as a fertilizer	_	32%	32%	_	_	_	_	_	_	_
Source not known or not available	16%	_	_	28%	28%	28%	28%	_	_	_

Amongst the things learned from the trials (Table 38.3), the most indicated was the use of inorganic fertilisers (69%). It is also interesting to note that most of the new knowledge farmers indicated to have learned addressed general techniques of crop management, such as using fertilisers, line planting, thinning, weeding and top dressing, rather than specific organic technologies such as the legume cover crops (12%) or applying tithonia biomass (4%).

Table 38.3: Things farmers learnt from the trials (n=25)

Things farmers learnt	Frequency	Percentage
Use of fertilizers	18	69
Line planting/spacing	11	42
Inoculation with Rhizobia	4	15
Thinning	3	12
Top dressing	3	12
Planting legume cover crops	3	12
Frequent weeding	2	8
Planting tithonia	1	4
Measuring of harvest area	1	4

Table 38.4: Current impressions of the soil fertility enhancing options (n=25)

	Busu-mbu	Busu-mbu blend	Minji-ngu PR only	TSP	Urea	P and K	Titho-nia	Com-post	Rhiz obia
	Percentage (%)								
Gives higher yields	48	48	48	48	48	48	16	_	16
Not well known	28	28	28	28	28	28	_	_	_
Poor performance	4	4	_	_	_	_	_	_	_
Not aware of option	4	4	4	4	4	4	_	_	4
Increased number of groundnut pods	_	_	_	_	_	_	_	_	16

In general, nearly half of the farmers (48%) felt that yields had improved from the use of inorganic fertilisers and only 4% felt that the Busumbu PR or Busumbu blend had performed poorly (Table 38.4). The use of organic materials appeared less compelling – 16% said *Tithonia* had increased yields, while a similar proportion felt that the use of *Rhizobia* had increased yields or the number of groundnut pods. When asked about whether they wanted to expand the areas dedicated to the trials, 83% were prepared to do so. Over half (56%), would increase the area to between one and ten acres, 28% would dedicate at least half an acre , and 8% would allocate a quarter acre.

Farmers' own experiments and dissemination efforts

Farmers learnt how to conduct own experiments following contact with the INSPIRE project activities. The own experiments given as provided by the farmers included planting:

1) maize with compost,
2) maize with FYM manure,
3) groundnuts with compost,

4) groundnuts and spraying with urine to control pests and diseases,
5) pineapples with and without compost and ash,
6) beans with compost,
7) sorghum with compost and
8) maize with and without Di-Ammonium Phosphate (DAP).

Farmers indicated to have had regular discussions about the trials and the newly learned techniques with their neighbours. Over three quarters of the farmers (76%) had discussed the trials specifically, while 92% said they had discussed related topics. These topics included: use of both organic and inorganic fertilisers to increase yields, spacing and line planting of maize and groundnuts, timely planting as well as group formation and working together. In the process, a total of 179 other farmers were talked to (Table 38.5). On average each farmer had talked to 9 farmers. These discussions resulted in neighbouring farmers wanting to participate in the evaluation of some of the technologies, line planting and spacing (48%), planting maize with fertilizers/Tithonia (20%) and use of compost (4%).

Table 38.5: Number of neighbours the farmers told about the technologies

Number of other farmers contacted	Frequency	Total
20	4	80
15	1	15
10	4	40
6	3	18
5	2	10
3	5	15
1	1	1
None	5	
	25	179

Participatory group evaluations of the legume cover crops/shrubs

Six farmers who hosted the legume cover crops/improved fallow experiments for two seasons were involved in the participatory evaluation of the cover crops. In addition over 60 farmers who included those who had grown the fallows and were about to incorporate the fallows and those who wanted to start the on-farm test trials, were present at the evaluation. A number of issues arose from the evaluation of the technologies and the highlights based on specific criteria/aspects are given in Table 38.6.

Table 38.6: Qualitative evaluations of the legume cover crops/shrubs

	Legume cover crops/shrubs					Legume shrubs/trees		
	Crotalaria grahamiana	Tephrosia	Mucuna	Canavalia	*Crotalaria pancilla*	Sesbania	Calliandra	Leucena
Germination	Took a week to germinate					Took 4 days if seed is soaked in hot water		
Vegetative growth	Good		Very good	Good	Fair			
Pests	Attacked by caterpillar when its moist							
Solutions to pests	Spray with pesticides or use ash							
Drought resistance	Good if planted closely	The Best			Good if planted closely			
Labour require-ments	High for weeding	High for weeding						
Harvesting seed	Seed harvesting need a lot of labour							
Family labour contributor	All participate but the men do more work on the crops							
Seeding		Easily attacked by cater-pillars,	Gives higher seed yields		Easily eaten by cater-pillars			
Seed	Farmers have their own seed stands				Most scarce	Farmers have their own seed stands		
Seed needed		Want more seed			Want More seed			

Initial benefits of the green manure cover crops

The farmers indicated the initial benefits of growing the green manure cover crops. With germination, mucuna was considered the best, followed by canavalia and *Crotalaria grahamiana*. Mucuna was indicated to rapidly produce thick vegetation on the land that smothered weeds.

Maize planted with mucuna grew very fast and looked healthy. It was rated the best in terms of drought resistance, while *C. grahamania*, and *C. pancilla* were good at drought resistance if planted closely. Mucuna also gave the highest seed yields. It was used as a livestock feed, and its boiled seeds were edible to humans.

Tephrosia rejuvenated soil fertility, killed mole rats and was quick maturing. It could also be used for harvesting fish.

Sesbania improved soil fertility and could eradicate the striga weed if planted as a fallow. It also provided firewood and its poles were used to make fences. Canavalia controlled weeds when planted in banana plantations, and its seed were edible after boiling. Tithonia could be used as medicine against cough, and stomach pains. As a measure to ensure seed sufficiency, farmers had established own seed stands for most of the legume cover crops/shrubs except for *C. pancilla*. However, they wanted more seeds for those crops with seeding difficulties (*C. grahamania*, and *C. pancilla*). Apparently men worked more on the green manure crops than women.

Difficulties with the fallows planted

Farmers indicated the difficulties they encountered with the fallow crops. Crotalaria species had small seed and were easier to broadcast than to plant in lines. Weeding crotalaria before it establishes was a laborious exercise and it needed spraying or use of ash when infested by the caterpillars. All legume cover crops and shrubs were indicated to have difficulties in getting seeds. Sesbania had beetles that ate the leaves and young shoots, which tended to kill the plants. Sesbania pods were usually sharp pointed at the end and pierced during transportation. Mucuna which has climbing characteristics increased the labour demands to have it removed from the crops it was intercropped with such as maize. Canavalia pods were hard to split during threshing, while tephrosia was difficult to weed and produced itching dust when threshing. Tithonia was observed to leave a bitter taste in ones hands after working with it. A number of these findings concur with those in Miiro *et al. (in press)* who reported on the integration of green manure cover crops in the farming systems of small scale farmers in Iganga district. They particularly point out labour difficulties associated with mucuna intercrops, and harvesting crotalaria.

Table 38.7 shows the pairwise ranking that was done for six legume crops including mucuna, canavalia, *Crotalaria pancilla, Crotalaria grahamiana*, sesbania, and tephrosia. The criteria for evaluating the crops included their ease to germinate, vegetative production, and ease to manage. Results show that farmers ranked mucuna first followed by sesbania then *Crotalaria pancilla, C. grahamiana*, tephrosia and canavalia. In Iganga district, small holder farmers integrated mucuna more than the other species because of its fast growing nature, and ability to improve soil fertility (Miiro *et al. in press*)

Table 38.7: Pairwise ranking of the five important legume crops/shrubs in Kisoko

Mucuna	Canavalia	*Crotalaria pancilla*	*Crotalaria grahamiana*	Sesbania	Tephrosia	Score	Rank	
	M	M	M	M	M	5	1	Mucuna
		P	G	S	T	0	6	Canavalia
			P	S	P	3	3	*C. pancilla*
				S	G	2	4	*C. grahamiana*
					S	4	2	Sesbania
						1	5	Tephrosia

Conclusions and implications for the INSPIRE project

The testing on-farm of the various inorganic and organic sources of nutrients by farmers in eastern Uganda, seems to yield useful learning experiences to both the farmers and the INSPIRE members. Initial worries about the experiments were hinged around the use of inorganic fertilisers and their being expensive. This however reveals a knowledge gap and need to expose farmers to the various soil fertility options including their crop yield and cost implications. Further sustainable promotion of integrated nutrient management system should take care of this. The choice of fallow species depends very much on the production constraints that the farmer wants to address; whether smothering invasive weeds like couch grass, or introducing a multi-purpose legume for livestock feed or fuelwood not just soil fertility. Not surprisingly, due to financial constraints farmers are more inclined towards technologies that do not require a large capital investment and would rather allocate their time to production and management of legume cover crops and improved fallows.

Farmer to farmer communication was seen as a very successful way of disseminating new technologies to a wider audience. This should be reinforced with farmer exchange visits, field days, and training farmer extensionists or farmer to farmer training. There was willingness among the farmers of Tororo district to test new technologies. Interestingly, after many years of extension services on crop production, one of the main results from the technology testing was the increased knowledge on crop management in terms of planting, thinning and weed management. Understanding of farmer priorities and constraints, decision making and how farmers trade-off production technologies and their time will be increasingly important in targeting interventions/

technologies to smallholder farmers. The INSPIRE project needs to refine these technologies through more participatory technology testing approaches to foster adaptability to farmer conditions and empower farmers with a sustainable green manure husbandry system that includes a strategy to ensure seed sufficiency.

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References

Ashley, C. and Carney, D. (1999) *Sustainable Rural Livelihoods: Lessons from early experience*. Department for International Development (DFID) Russel Press Ltd. Nottingham United Kingdom.

PMA, (2000) *"Plan for the Modernisation of Agriculture: Eradicating Poverty in Uganda" Government Strategy and Operational Framework*. Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) and the Ministry of Finance. Planning and Economic Development (MFPED). Government of Uganda.

Miiro, R., A. Esilaba and S. David (in press). Integration and dissemination of green manure cover crops in African small scale farming systems: Successes and constraints in Eastern Uganda. *Paper accepted by the Makerere University Agricultural Research Institute Kabanyolo Bulletin*

Republic of Uganda (1991) *Housing and Population Census*.

Republic of Uganda (1997) *The Local governments Act 1997* and *the Local Governments (Amendments) Act, 1997*.

Sanchez, P., Izac, A.M., Buresh, R., Shepherd, K., Soule, M., Mokwunye, U., Palm, C., Woomer, P. and Nderitu, C. (1997) Soil Fertility Replenishment in Africa as an Investment in Natural Resource Capital. In: Buresh, R., Sanchez, P. (eds.), *Replenishing Soil Fertility in Africa*. SSSA Special Publication 51 Madison WI: Soil Science Society of America (SSSA).

SFI (1999) *Uganda. Soil Fertility Initiative*. Concept Paper. Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), National Agricultural Research Organisation (NARO), Food and Agricultural Organisation (FAO) and Investment Centre Division FAO/WORLD BANK Co-operative Programme. The Republic of Uganda.

Zake, J.Y.K., Nkwiine, C., Miiro, R. (1998) A baseline study of the Farming Systems of Client Farmers of Africa 2000 Network in Tororo District, Eastern Uganda.

Wortmann, C.S., Eledu, C.A.. (1999) *Uganda's Agro-ecological Zones: A guide for planners and policy makers*. Kampala Uganda: Centro Internacional de Agricultura Tropical (CIAT).

World Bank (1993) *Uganda Growing out of Poverty*. World Bank Country Report.

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Potential for Adoption of Legume Green Manure on Smallholder Farms in Western Kenya

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Abstract

Low soil fertility is a major constraint to increased agricultural productivity amongst smallholder farmers in Kenya. The use of inorganic fertilizer to alleviate the constraint is limited mainly by its high cost, untimely availability and low producer prices. Under the Legume Research Network Project (LRNP), various legume species that can be utilized as green manure to supplement the use of inorganic fertilizer were screened and the species well adapted to different agro-ecological zones of Kenya were selected. This study was conducted when the species selected for western Kenya were being tested on the farmers' fields to assess their effect on soil fertility improvement and crop yields. The legumes, as a component of integrated nutrient management (INM), were grown in rotation with maize. Seven treatments composed of inorganic fertilizers, farmyard manure, green manure and combinations of these compounds were evaluated. A significant maize grain yield response to treatments was observed during experimentation.

The objective of this study was to assess diffusion and potential for farmers' uptake of the various components of the green manure technology introduced to them and determine technological and socio-economic predictors to adoption. A survey was conducted in Kabras cluster site, Kakamega District, one of the six LRNP cluster sites in Kenya. The study involved a survey of key informants and farm households, comprising 11 farmers who hosted the green manure trials and 34 randomly selected households that were non-participating in the trials. Results show that most farmers were not aware of performance and mechanisms of carrying out the various components of the technology. Although none of the respondents had adopted legume green manure, all the experimenting farmers expressed willingness to adopt. High labour demand, especially for establishment and timely incorporation of the manure and inadequate availability of legume seed were the most important constraints envisaged by the farmers. More farmers should be involved in testing of the technology and efforts should be made to sensitize farmers on the potential of the technology. There is need to synchronize the recommended activities for management of the manure in order to combine certain operations to minimize labour demand.

Key words: Adoption, green manure, legume, smallholder, soil fertility

Introduction

Smallholder farming in many parts of Kenya is mainly constrained by declining soil fertility. Recent studies in western Kenya have identified soil fertility decline as one of the most important biophysical constraints to increased agricultural productivity (KARI, 1994; Odendo and Ojiem, 1995; Ojiem and Odendo, 1996). The use of inorganic fertilizers to mitigate soil fertility decline is limited by mainly high costs, low producer price of most food crops and erratic availability of the fertilizers. A few farmers that use inorganic fertilizers cannot afford recommended rates. Under such conditions, one of the alternatives is to supplement inorganic fertilizers with other sources of plant nutrients such as green manure. Integration of legume green manure into the farming systems can be a cheaper alternative of alleviating low soil fertility and erosion problems (KARI, 1997; Kanyanjua *et al.*,2000). To enable introduction and integration of legume green manure into farming systems in Kenya, legume screening under the auspices of Legume Research Network Project (LRNP) was set up to screen legume species and select those adapted in various regions of Kenya. After two years of on-station screening in the regions, the well adapted legume species were selected (Ojiem and Okwosa, 1999; Kanyanjua *et al.*, 2000). About 8 legumes were selected for western Kenya, of which two; velvet beans (*Mucuna pruriens)* and sunnhemp (*Crotolaria ochroleuca)* were introduced in Kabras Division (Ojiem and Okwosa, 1999; Ojiem *et al.*, 2000). Seven treatments comprising recommended rate of inorganic nitrogen (60 kg N ha^{-1}) (full N), recommended rate Farm Yard Manure (5 t ha^{-1} FYM), legume green manure biomass (GM) alone, GM + half N, GM + half FYM, half N+ half FYM, and GM+ half N + half FYM were evaluated against the farmers' practices in Kabras division in 1998 and 1999. Phosphorus was applied at a blanket rate of 30 kg P_20_5 ha^{-1} as Triple super phosphate. Half the farms were planted with *Crotalaria ochroleuca* and the other half with *Mucuna pruriens*. *Crotalaria ochroleuca* and *Mucuna pruriens*, as components of integrated nutrient management (INM), were grown in rotation with maize. The legumes were established in the short rain season, incorporated into the soil in the long rain season and then maize (H512), was grown in the fields as a test crop. Significant ($p=0.05$) maize grain yield response to treatments were observed in 1998 and 1999. Over the two years, maize grain yield was 3.98 t ha^{-1} for full N, 3.67 t ha^{-1} for GM+ half N, and 3.67 t ha^{-1} for GM + half N + half FYM. The maize grain yield of GM + half FYM was 2.24 t ha^{-1} and was slightly lower than the farmers' practices (2.5 t ha^{-1}). These results indicate that inorganic N requirements can be reduced by 50%, but high maize grain yields maintained by supplementing with N from GM and FYM (Ojiem *et al.*, 2000).

There is often time lag between technology development and adoption (Mills *et al.*, 1998). In order to monitor adoption, it is important to have a close working relationship between farmers and researchers, as a technology is being developed and tested. This interaction provides early indication of whether or not a new technology is acceptable. Experimenting farmers are very important in assessing acceptability of a technology because such farmers provide insights about potential adoption of a new technology such as green manure. These farmers have relatively more experience with the components and performance of the technology than the rest of the farmers. A technology may be changed or modified by a user in the process of diffusion and adoption. As Rogers (1983) observes, potential users may play an important role in the process of technology generation by being involved in the generation process, rather than being merely passive recipients of innovation once it has been generated.

A review of adoption studies in developing countries reveals that no study had analysed the direct effects of farmers' subjective assessment of agricultural technology on adoption decisions (Feder *et al.*, 1985). Most adoption studies analyse the reasons for adoption or non-adoption at a point in time, principally in terms of socio-economic characteristics of adopters and non-adopters. Recent studies (e.g. Adesina and Zinnah, 1993; Adesina and Baidu-Forson, 1995), however, demonstrate that farmers' perceptions of the characteristics of the technology significantly affect adoption decisions. In view of the recent studies, this study considers both characteristics of potential users and the technology attributes as important explanatory variables for farmers' decisions to adopt legume green manure.

Measuring adoption of soil fertility improvement technologies is a major challenge facing researchers who attempt to model soil fertility management decision processes (Ervin and Ervin, 1982; Lynne *et al.*, 1988, Purvis *et al.*, 1989). Some of the measures that have been used include willingness to adopt, actual adoption decision and the extent of adoption. Purvis *et al.(*1989), for instance, measured the willingness of Michigan farmers in the USA to accept yearly payments for participating in filter strips program using contingent valuation method (CVM). The CVM involves eliciting values; people are asked directly to state or reveal what they are willing to pay for some change in provision of a good or service or what they are willing to accept to forego a change or tolerate a change (Mitchel and Carson, 1989). For this study, since there was a short duration between technology testing, diffusion and assessment of adoption, farmers' willingness to adopt legume green manure was a plausible method of assessing adoption and CVM was applied. However, because the actual values (amounts) the farmers were willing to pay in order to adopt the technology was not elicited, only some principles of CVM were adapted.

The objective of this study was to assess diffusion and potential for farmers' uptake of the various components of legume green manure technology introduced to them and determine technological and socio-economic predictors to adoption. The knowledge gained from the study could be used by both researchers and farmers to fine-tune the technology with a view to enhance relevance and likelihood of adoption.

Methodology

The study area

This study was conducted in the LRNP cluster site in Kabras Division of Kakamega District in western Kenya. Kabras Division covers an area of about 429 km^2, of which 367 km^2 is arable. With population of about 169,000 persons and density of 386 persons per km^2, Kabras division is relatively sparsely populated in relation to other Divisions of Kakamega district. The average land holding per household is about 1.4 ha (MoRD, 2000; Ministry of Agriculture staff, Kabras, *pers. comm.*).

The Division falls within a relatively high agricultural potential area, with a third of its landmass falling within the high potential Upper Midland and Lower Midland agro-ecological zones (Jaetzold and Schmidt, 1983). It falls at an altitude of 1300-1500 m above sea level. The mean annual temperature is 22-29°C, which is one of the highest in the District. Annual average rainfall is 1500-1800 mm, with peaks in April and August. The rainfall pattern is bimodal, providing for two cropping seasons per annum. The long rain season (March-July) receives 650-750 mm and the short rain season (August-November) 500-600 mm of rainfall, whilst the mean annual pan evaporation ranges between 1600 and 1800 mm. There is a significant variability of soils; the major soil types are Nito-rhodic Ferralsols, Acrisols, Combisols and Gleysols. However, the predominant is Nito-rhodic ferralsols. These are mainly developed from granites and are well drained, very dark, dusky red to yellowish red and in some places friable clay loams with acid humic topsoil (Jaetzold and Schmidt, 1983; Ministry of Agriculture staff, Kabras, *pers. comm*).

Agriculture is not only the main economic activity, but also has a social function as it is involved in food security (Ministry of Agriculture staff, Kabras, *pers. comm*). The farming system incorporates crops and livestock. The main food crops grown include maize/beans (the staple food), sweet potato, sorghum, groundnuts, pineapples, kales, tomatoes and cabbages. Major cash crops are sugar cane and maize. Most of the sugar cane is grown in south and west Kabras locations, which are situated near the sugarcane-processing factory. Livestock comprise mainly of zebu cattle, though some crosses and grade cows are found in areas bordering Nandi District. Milk is the main livestock product. The rearing system is commonly free range coupled with tethering. Other livestock types include sheep, poultry and rabbits. Cattle rearing has been ranked third after maize and sugarcane in priority ranking exercises. The ranking exercises considered the enterprise distribution in scale (number of households), significance in meeting subsistence needs and the level of income generated from the enterprises.

Low maize harvests and low milk yields are identified as the major problems affecting the farming households in the area. Potential solutions to these problems include improvement in quality and quantity of feeds for livestock and improvement of soil fertility for increased crop yields, especially maize. A cursory observation of the two problems and solutions suggest that an integration of crop and livestock enterprises would address the problem to some extent. Thus, the manure from livestock, especially cattle, would be used to improve soil fertility, more so when the livestock is fed on high quality feed such as legumes, whilst crop residues from increased crop yields would be used to increase livestock productivity. Integration of legume green manure in the farming system would contribute a great deal in improving soil fertility for increased crop production and improved livestock productivity through provision of high quality legume feeds.

Sampling procedure

The sites for on-farm green manure experimentation and for this study were distributed in three administrative Locations; Chemche, Mahira and Lukume, to represent biophysical and socio-economic variability. A list of all households in the study clusters, which formed the sampling frame, was obtained from the local elders (*liguru*). A sample of 11 out of the 20 households that hosted LRNP experiments and a sample of 34 non-participating households from within the villages where the on-farm trials were being conducted and contiguous villages, were sampled from the household lists.

Data collection and analysis

A structured questionnaire composed of both open and closed ended questions was designed by socio-economists in collaboration with LRNP implementing scientists, to help collect relevant primary data. In addition to the questionnaire, personal field observations and interview of key informants such as extension officers, KARI researchers, local leaders and farmers were conducted using a checklist to supplement the questionnaire. A draft questionnaire was pre-tested on five farm households in the vicinity of the study clusters and two trial participating farmers. The result of the pre-testing helped in final restructuring of the questionnaire by incorporating missing variables or information, omitting irrelevant questions and paraphrasing questions that appeared ambiguous to the respondents. The final questionnaire had three sections. The first section consisted of general questions, including demographic and socio-economic characteristics of the respondents and their households, as well as farming systems under which they operate. Questions in section two focused on technological components of legume green manure that respondents were aware of, were willing to uptake or had adopted and any modifications they had made, and factors affecting uptake of the components.

Prior to the interviews, the implementing team was trained on a number of relevant aspects of green manure. These included elements of legume green manure as a component of integrated nutrient management, general information about the legumes (growth habits), methods of establishment, weed control and biomass incorporation. Others were management, storage and application of farmyard manure, time and rate of application of inorganic nitrogen and agronomy of maize. The authors and research technicians as well as extension officers conducted personal interviews. Heads of the households were interviewed however in their absence, a household member conversant with farm activities was interviewed. For the LRNP participating farmers, the interviews focused on application of technological components on fields or plots other than the experimental ones.

Respondent farmers were asked to state their willingness to adopt legume green manure by exposing them to costs and benefits, not necessarily in monetary terms, involved in utilisation of the technology. Willingness to adopt reflects individuals' preference for a good (or service) in question such a component of soil fertility management technology. We presented the non-participating farmers with a hypothetical opportunity on use of legume green manure, especially *Mucuna pruriens* and *Crotolaria ochroleuca* as components of integrated nutrient management. Two types of information were provided to respondents. First, was a detailed description of components of legume green manure, their purpose and expected outcomes of their usage in form of a scenario. Immediately following this scenario, respondents were asked whether or not they were willing to uptake the manure. In addition, they were asked to give reasons for their willingness to adopt using an open ended format. Such follow-up questions were essential in order to probe respondents' perceptions and their reasoning behind the responses. The data were analysed by descriptive statistics using Statistical Package for Social Sciences (SPSS) software.

Results and Discussion

Socioeconomic and demographic characteristics of sampled households

The selected socioeconomic and demographic profiles of the sampled households are presented in Table 39.1. Over 90% of the households were male-headed. The mean age of the household heads was 42.5 years. The highest education level for a majority heads of households was primary, whilst the mean number of persons per household was nine. A paltry 31.1% of the farmers received some credit in the last 5 years, while 35.6% received some off-farm incomes. The mean land size was 6.5 acres. Majority of the households owned cattle, mostly local zebus at an average of four cattle per household.

Table 39.1: Socioeconomic and demographic profiles of sample households

Characteristic	n=45	
	Mean (S.D.)	Percent
Farm Size (Acres)	6.5 (2.0)	
Household head:		
Male	–	91.1
Female	–	8.9
Age (Years)	42.5	–
Highest Education:		
None	–	18
Primary	–	45.5
Secondary	–	34.4
College	–	2.1
Household size	8.7 (3.9)	–
Number working on farm full-time	2.6 (1.7)	–
Number working on farm part-time	3.0 (2.0)	–
Received credit in last 5 years	–	31.1
Received off-farm income	–	35.6
Number of cattle/household	4.3 (3.8)	–

Notes:
1) The sample (n) includes 11 households that hosted the green manure experiments.
2) Figures in parentheses are standard deviations (S.D)

Farmers' awareness and uptake of components of integrated nutrient management

Awareness of the potential benefits of a new technology is a commonly acknowledged prerequisite for farmers to decide whether to or not adopt a technology. Farmers' awareness and the rate of adoption of some recommended components of integrated nutrient management (INM) are shown in Table 39.2.

Table 39.2: Percentage of farmers who are aware and/or are practicing some INM components

Technology components	Percentage of farmers Aware	n=45 Practicing
Inorganic fertilizer	100.0	35.5
Organic fertilizer	100.0	88.9
Green manure	28.9	0.0
Maize spacing	68.8	33.3

Note: Percentages are computed independently, hence do not add up to 100

All respondents knew some *Crotalaria sp*, which they grow and utilize mainly as a vegetable in the area and most of them were not aware whether the species or other species could be used as green manure. About 29% of the respondents were aware that legume green manure, especially *Mucuna pruriens* and *Crotolaria ochroleuca*, could be utilized to improve soil fertility. These are the farmers who were either hosting legume green manure trials or had interacted with experimenting farmers, researchers or extension agents.

Farmers were utilizing certain components of INM technology on maize crop. About 36% had adopted inorganic fertilizers, particularly Calcium Ammonium Phosphate (CAN) and Di-Ammonium Phosphate (DAP), whilst nearly 90% of the study households applied some organic manure, mainly on maize. The doses of organic and inorganic fertilizers were lower than the recommended rates. For example, the mean rate of application of DAP, which the most popularly used basal fertilizer in Kakamega district, was 37.6 kg acre^{-1} compared to recommended 50 kg acre^{-1} . Only about 18% of the respondents top dressed their crops, especially using CAN at the mean rate of 26.7 kg acre^{-1} , instead of the recommended 50 kg acre^{-1}. This was attributed to high costs of the fertilizers, low cash incomes of the households and lack of adequate knowledge about the recommended types and rates of inorganic fertilizers. The low doses of farm yard manure were mainly associated with the small number of cattle kept which could not produce enough manure in a season, and free range rearing system that does not allow efficient collection of manure. The recommended maize spacing of 75cm × 30cm was adopted by 33% of the households. In most cases wider inter-row spacing, ranging between 80cm to 100cm, were used. This was meant to create more space for inter-cropping with other crops, especially beans.

None of the respondents had actually adopted legume green manure for soil fertility management. The low adoption was associated with lack of exposure of the technology to the farmers. Even the experimenting farmers indicated that they wanted to have more experience about the use and performance of the technology via experimental plots, before trying on their own plots. This is in line with what is fairly general agreement that most people, including farmers are risk averse (Upton, 1987) . This means they are willing to forego some income or face extra costs in order to avoid risk, and are hence cautious in their decision-making.

Although 63.4% of the experimenting farmers indicated that application of green manure technology in the experimental plots did not require much labour, they foresaw that more labour would be needed on their own larger fields since legumes for green manure require establishment at onset of rains when they are busy preparing land and planting other crops. High labour demand was also perceived to be required for incorporation—chopping before incorporation and timely incorporation. Mucuna was perceived to have highest labour requirement because of its high biomass. Although the mean number of persons per household was large (Table 39.1), the proportion that works on-farm on full-time basis was only about one-third, indicating labour shortage. Farmers also lacked access to the green manure legume seed. These notwithstanding, all the experimenting farmers expressed willingness to adopt green manure legumes for soil management. However, it was not easy to assess whether this was the actual farmers' expressed preference. As Swinkles and Franzel (1997) and Franzel *et al.* (1999) observe, farmers often state that they like a technology, even if they do not, because they hope to obtain material or social benefits from interacting with technology facilitators or because of cultural taboos against criticism or they simply try to please researchers.

In the on- farm experiments, the legumes for green manure were grown in rotation with maize in the first season. The farmers initially proposed the rotation system whereby the green manures were established in the short rain season and incorporated in the long rain season, expecting dramatic yield increment in the long rains. On the basis of the yields obtained from the trial plots, farmers expressed preference for either intercropping or relay cropping the legumes in maize. It was also noted that although 84% of the farmers practiced some fallowing, especially in the short rain season, the fallows were mostly utilized as grazing land. Furthermore, the farmers preferred some yield in the season, rather that having no crop at all in the fallows. Therefore, rotation system of green manure application tested in Kabras Division conflicted with grazing of livestock and other farmers' preferences. Similar observations were reported by Franzel *et al.* (1999) in a study conducted in western Zambia. Whereas farmers recognized that intercropping of improved fallows such as sesbania and tephrosia appeared to reduce maize yields and tree growth during the year of establishment, many farmers preferred inter-cropping because it economizes on land and labour use relative to planting pure tree stands.

This finding is in line with high discount rate that is associated with most resource poor farmers. They prefer short-term benefits to satisfy their basic needs.

Technology characteristics affecting potential adoption

Farmers considered certain characteristics of the various legume species in deciding to adopt green manure (Table 39.3). High biomass was cited as both a constraint and an opportunity. *Mucuna pruriens* was preferred because of its high biomass production. The legume was perceived as being able to improve soil fertility within a short time because of its high biomass. Again, high biomass was considered a constraint because it requires more labour to manage and does not allow for intercropping with other crops, especially maize because of its climbing growth habit and high ground cover. *Crotolaria*, on the other hand, was highly preferred because of its potential multiple uses as a vegetable and for soil fertility improvement. It was also considered to have medicinal value. The farmers had, however, not explored other alternative uses of *Mucuna* since it was a relatively new crop in the farming system.

Table 39.3: Major farmer desired legume characteristics for green manure use in western Kenya

Legume characteristics	% farmers citing preference for the characteristic
High biomass	67.0
Suitable for intercropping with maize	91.0
Multiple uses	100.0

Note: percentages were computed independently and do not add up to 100.

Conclusions and Recommendations

Assessing potential adoption of a new technology such as green manure legumes only a few years of technology testing is a difficult task. Except for farmers hosting the experiments, most farmers were unable to conceptualize how the technology is applied, how it works and its performance. Indeed, even most experimenting farmers were not able to confidently perceive the performance of the technology because of the short duration experience they had had with the technology. The technology takes a relatively long time to realize full benefits. More time is required for testing and dissemination of the technology to many farmers so as to create awareness and enable farmers make informed decisions on whether they are willing to adopt or not. A larger number of farmers should be involved in the technology testing and field days should be held to disseminate the technology. It is only after this that actual adoption can be meaningfully assessed.

The key socio-economic factors that constrained the technology uptake across the sites was high labour demand at the time of planting and incorporation of the green manure legumes and unavailability of adequate amount of the legume seed. To minimize labour demand for establishment and incorporation of the legumes, research should devise ways of saving labour such as relay cropping the legumes in maize in the first season and synchronize incorporation the legumes so that it coincides with land preparation in the second season, whilst considering the trade-offs and synergies.

To fit the green manure into the existing farming system, emphasis should be on inter-cropping or relaying of the green manures rather than establishing them in a rotation. Although most households practiced some fallowing in the second season, most of the fallows were utilized as grazing land. Seed for legume establishment was one of the main constraints. There is need to develop a local farmer-managed legume seed production system to enable farmers have access to seed. Further research is required to investigate opportunity costs of the alternative fallowing systems such as *Mucuna* or *Crotolaria* in relay and rotation systems. This will help in assessing farmers' willingness or unwillingness to forego one season's crop for the future expected benefits from green manure legume rotation system. A more in-depth investigation is required to assess competitive demand for legume species with multiple uses.

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References

Adesina, A. A. and Zinnah, M.M. (1993) Technology Characteristics, Farmer Perceptions and Adoption Decisions: A Tobit Model Application in Sierra Leone. *Agricultural Economics* 9:297-311.

Adesina, A.A. and Baidu-Forson, J. (1995) Farmers' Perceptions and Adoption of New Agricultural Technology: Evidence from Analysis in Burkina Faso and Guinea, West Africa. *Agricultural Economics, 13:1*-9

Ervin, C.A. and Ervin, D.E., (1982). Factors Affecting the Use of Soil Conservation Practices: Hypotheses, Evidence and Policy Implications. *Land Economics*, 58:277-292.

Feder, G., Just, R.E. and Zilberman, D. (1985) Adoption of Agricultural Innovations in Developing Countries: A survey. *Economic Development and Cultural change* 33:255-297.

Franzel, S., Phiri, D. and Kwesiga, F. (1999) Assessing the Adoption Potential of Improved Fallows in Eastern Zambia. AFRENA Report No. 124. Nairobi: ICRAF.

Lynne, G.D. , Shonkwiler, J.S. and Rola, L.R. (1988) Attitudes and Farmers' Conservation Behaviour. *American Journal of Agricultural Econ*omics 70(1): 12-19.

Jaetzold, R. and Schimdt, H. (1983) *Farm Management Handbook: Natural and Farm Management Information Vol.II/B.* Nairobi: Ministry of Agriculture, Livestock Development and Marketing.

Kanyanjua, S.M.; Mureithi, J.G.; Gachee, C.K.K. and Saha, H.M. (2000). Soil Fertility Management Handbook for Extension Staff and Farmers in Kenya. *KARI Technical Note Series No. 6.* Nairobi: KARI and LRNP.

KARI. (1994) Participatory Rural Appraisals (PRAs) for Inception Phase of the Netherlands Funded Regional Research Programme at KARI-Kakamega Mandate Region. Kakamega: Kenya Agricultural Research Institute (KARI).

KARI. (1997) Legume Screening Network Research Project Proposal. Nairobi: KARI - National Agricultural Research Laboratories, Nairobi.

Mills, B., Hassan, R.M and Mwangi, P. (1998) Estimating Potential Benefits from Research and Setting Research priorities for maize in Kenya. In: Hassan, R.M. *Maize Technology Development and Transfer: A GIS Application for Research Planning in Kenya.* Cambridge University Press

Mitchel, R.C. and Carson, R.T. (1989) Using Surveys to Value Public Goods: The Contingent Valuation Method: Resources for the Future. Washington DC.

MoRD. (2000) Annual Report, Kabras Division, Kakamega District. Kakamega: Ministry of Agriculture and Rural Development (MoRD) Kakamega.

Odendo, M. and Ojiem, J. (1995) Socio-Economic Characterisation of Farmers: A Case Study of Kabras Division, western Kenya. Paper presented to FARM-Africa/IIED Nutrient Cycling Workshop, Soddo, Ethiopia, November 27 - December 2, 1995.

Ojiem, J. and Odendo, M. (1996) Biological Management of Soil Fertility in Kabras and Vihiga Divisions of Western Kenya. Second Annual Report to the European Union. In: Carter, S.E.(ed.) *Biological Management of Soil Fertility in Small-Scale Farming Systems in Tropical Africa*. Nairobi: TSBF.

Ojiem, J. and Okwosa, E.A. (1999) Role of Legumes in Small-Scale Productivity Improvement. A News Bulletin. Kakamega: Kenya Agricultural Research Institute.

Ojiem, J.O. Mureithi, J.G. and Okwuosa, E. A. (2000) On-farm Evaluation of Promising Organic-inorganic Soil Fertility Management Options for Smallholders in western Kenya. Paper presented at the 2nd Conference of the Soil Management Project and Legume Research Network Project (LRNP), Continental Hotel, Mombasa; June 26 - 30, 2000.

Purvis, A., Hoehn, J.P., Sorenson, V.L. and Pierce, F.J. (1989) Farmers' Response to a Filter Strip program: Results from a Contingent Valuation Survey. *Journal of Soil and Water Conservation* 44(5): 501-504.

Rogers, E. (1983) *Communication of Innovations*. New York: Free Press.

Swinkles, R. and Franzel, S. (1997). Adoption Potential of Hedgerow Inter cropping in Maize - based Cropping Systems in the Highlands of Western Kenya 2. Economic and Farmers' Evaluation. *Experimental Agriculture* 33:211-223.

Upton, M. (1987). African Farm Management. New York: Cambridge University Press.

The Profitability of Manure Use on Maize in the Small-holder Sector of Zimbabwe

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Abstract

Several manure use options were analysed for profitability using results from farmer participatory trials conducted in the small holder farming sector of Zimbabwe. The options analysed were

a) not using any manure
b) using aerobically composted (heap stored) manure,
c) using manure improved through anaerobic storage (pit stored),
d) different manure application methods such as banding, broadcasting and station placement, and
e) supplementing manure with mineral fertilizer.

The use of manure provided a marginal rate of return (MRR) of at least 215% compared to not using manure. The MRR on manure use was increased significantly by composting manure in pits. Financial benefits obtained from pit stored manure were much higher in the first year of manure application compared to those of heap stored manure. Higher returns from heap stored manure were obtained in the second and third seasons after manure application. Overall undiscounted financial benefits for the three years were marginally higher for pit stored manure. Higher financial benefits were obtained from supplementing manure with mineral fertilizer compared to using manure alone. Banding and placing manure on-station increased returns from using both pit and heap stored manure. The conventional practice of broadcasting manure was found not to be profitable.

Key words: Economic Returns, Profitability, Manure, Mineral Fertilizer, Smallholder, Zimbabwe

Introduction

Soil fertility depletion in the smallholder farms is the fundamental cause for declining per capita food production in sub-Saharan Africa (Sanchez *et al.*, 1997). Increased food insecurity, reduced farm incomes, limited returns from agricultural investment and rural poverty are some of the consequences of declining soil fertility. Input purchases by smallholder farmers have not been enough to cover for the nutrient outflows (Smaling *et al.*, 1997). Mineral fertilizers have become unaffordable for most smallholder farmers since the removal of subsidies in 1991 when the Zimbabwe government embarked on the Economic Structural Adjustment Program (ESAP). Most smallholder farmers in Zimbabwe have turned to the use of manure as a low cost option. However the effective utilisation of manure is constrained by severely limited quantities available, poor quality of the manure with most manures having less than 1 % nitrogen and a high sand content (Mugwira, 1985; Tanner and Mugwira, 1984). Improving manure management and storage is an important option for improving yields and returns to investment in crop production.

This paper is an economic appraisal of the promising manure related soil fertility management options that were tested in the smallholder farming environment.

Materials and Methods

Three sets of different farmer participatory trials were conducted in the smallholder farming area of Murewa. The trials were on (1) the effect of supplementing 5 tonnes of manure with varying levels of fertilizer N (0, 20, 40, 80, 100 kg N ha^{-1}) on maize yield, (2) the effect of differently cured manure (aerobic and anaerobic) on maize yield and residual effects in subsequent seasons and (3) the effect of different manure placement methods on maize yield. All the trials were implemented in Murewa, north east of Harare. The trials were conducted on sandy soils, typical of most smallholder farming areas of Zimbabwe.

In the trial on supplementing manure with mineral fertilizer, the nitrogen was applied twice, at 6 and 10 weeks after planting and this conforms to the normal farmer practice. Manure was broadcasted at planting. The trial was conducted for two seasons, 1997/98 and 1998/99.

Most smallholder farmers store their manure for at least three months before application in the field. The conventional way involves digging manure out of the kraal and heaping it beside the kraal for 3 months. This was compared to the new innovation of digging a pit beside the kraal and then putting manure in the pit that is then covered to ensure anaerobic decomposition. The manure is kept in the pit for three months. The manure was banded and applied at a rate of 10kg N ha^{-1}.

The other option was to test different manure placement methods; broadcasting, banding and spot application. Broadcasting is the conventional method of applying manure used by most smallholder farmers in Zimbabwe. For the comparison of different application methods an application rate of 100kg N ha^{-1} equivalent was used basing upon the total N concentrations of the manures.

A financial analysis was conducted to appraise the different options for private profitability. A cost benefit analysis was conducted for the trial on different manure storage systems and their residual effects. A full budget for the maize enterprise under the different treatments or trials was prepared based on marketable output. The trial yields were adjusted by 10% to cater for field losses. Factory gate maize price was used in the analysis. The cost of transporting the maize to nearest depot was included in the analysis. Farm gate prices were used for all the inputs namely mineral fertilizer, seed and insecticides. The prices of inputs were collected from the nearest rural service centre offering such inputs.

One of the major costs in the utilization of manure is the labour used in the digging, curing, transportation and application of the manure. A survey was undertaken in two communal areas, Murewa and Tsholotsho, to collect information on labour. Farmers were asked to state the time they take and the cost of the labour used in the management and utilization of manure. Information was collected for each manure related operation, digging manure from the kraal, heaping or placing manure into the pit, transporting manure to the field and application of manure in the field. Discussions were also held with farmers to confirm survey findings.

The survey results and discussions with farmers revealed that pitting of manure require an additional 5 person days compared with curing manure on the heap. Farmers also indicated that heap stored manure has a lot of weed seed compared to pit stored manure and farmers allocate more labour days on weeding fields where heap stored manure is applied compared to where pit stored manure is applied.

Financial returns from the technologies are a function of the maize yield obtained from the technology, cost of implementing the technology and improvement in the fertility status of the soil (residual effects) over time.

The financial returns are given by the function:

$$\frac{\Delta R}{\Delta T} = f\left[\frac{\Delta Q_o}{\Delta T}, \frac{\Delta C_o}{\Delta T}, \frac{\Delta SF}{\Delta T}\right]$$

where

$\frac{\Delta R}{\Delta T}$ = returns from the technology

$\frac{\Delta Q_o}{\Delta T}$ = yield

$\frac{\Delta C_o}{\Delta T}$ = total cost

$\frac{\Delta SF}{\Delta T}$ = residual benefits

Residual benefits are a function of the change in the fertility status of the soil over time and are given by the function:

$$\frac{\Delta Q_{t+i}}{\Delta T} = f\left[\frac{\Delta SF_{t+i}}{\Delta T_o}\right]$$

where

$\frac{\Delta Q_{t+i}}{\Delta T\Delta}$ = yield obtained the following year

$\frac{\Delta SF_{t+i}}{\Delta T_o}$ = residual soil fertility

Residual soil fertility is a result of the improvement of the soil due to additions of manure. Economic quantification of other benefits related to residual soil fertility other than the yield obtained is beyond the scope of this paper.

Net Present Values (NPV), present value of expected future earnings or benefits (Gittinger, 1982), were calculated for the future stream of benefits from residual soil fertility. Normally the going interest rate is used as the discount rate. Most smallholder farmers obtain farming loans from the Government owned commercial bank, Agribank at 20% interest rate. A 20% discount rate was therefore used to discount future benefits into today's values.

The Benefit Cost Ratio (BCR) was also calculated with the provision that if the BCR ≥1 then it is profitable to adopt the technology when the cost and benefit streams are discounted at the opportunity cost of capital (Gittinger, 1995).

Results

Supplementing manure with mineral fertilizer

Greater benefits were obtained when manure was supplemented with some mineral fertilizers. Using 5 t ha^{-1}of manure produced a yield advantage of 84% compared to not using any fertility inputs. The addition of 20 kg N provided a further 45% yield gain compared to using manure only (Table 40.1). The maize yield increased at a decreasing rate with successive additions of mineral fertilizer.

Table 40.1: Marginal rates of return for manure and mineral fertilizer combinations

Variables	0 Manure+	5 t/ha manure +				
	0 fertilizer	0 fertilizer	20kgN ha^{-1}	40kg N ha^{-1}	80kg N ha^{-1}	100kg N ha^{-1}
Yield (t ha^{-1})	1.18	2.17	3.14	3.96	4.59	5.03
Adjusted yield (10%)	1.06	1.95	2.83	3.564	4.13	4.53
Selling Price(Z$ ton^{-1})	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00
Gross Benefit(Z$)	9027.00	16600.50	24021.00	30294.00	35113.50	38479.50
Total Variable Costs (Z$ ha^{-1})	7877.40	8745.90	10555.80	12365.70	17795.40	19605.20
Net Benefit (Z$ ha^{-1})	1149.60	7854.60	13465.20	17928.30	17318.20	18874.30
Rate of Return (%)	15	90	122	134	105	100
Marginal Net Benefit(Z$)	NA	6705.00	5322.10	4174.60	622.70	1267.60
Marginal Variable Cost (Z$)	NA	868.60	2098.40	2098.40	4196.80	2098.40
Marginal Rate of Return (MRR) %	NA	772%	254%	199%	15%	60%

Note: 1US$ = Z$55

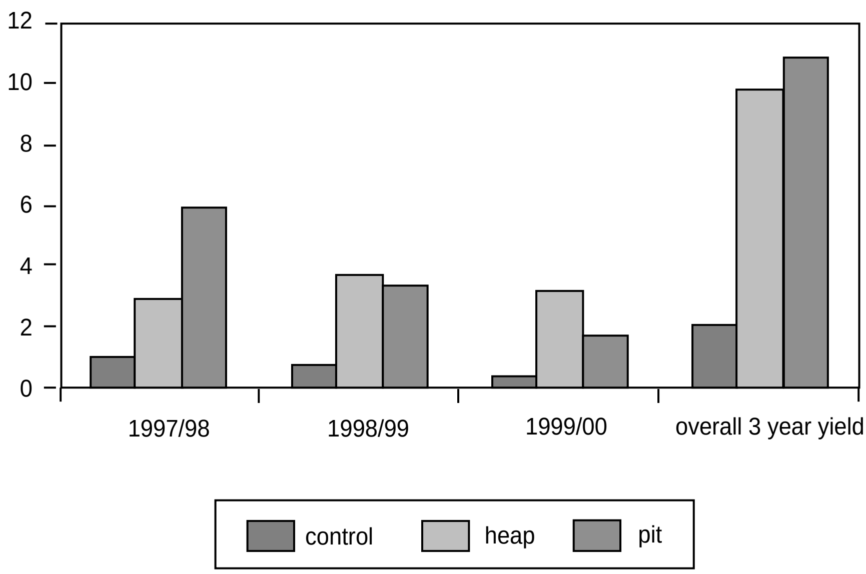
All treatments produced positive net financial benefits including the no fertility inputs option (Table 40.1). Supplementing 5 t ha^{-1} of manure with 40 kg N ha^{-1} produced the highest rate of return (134% \$$^{-1}$) invested (Table 40.1). Higher levels of N offered lower returns per dollar invested compared to 20 and 40 kg N ha^{-1}. The practice of not using any manure and mineral fertilizer only offered a 15% return on investment. The use of 5 t ha^{-1} of manure without any mineral fertilizer increased the rate of return 6 fold to 90% (Table 40.1), compared to not using any manure and mineral fertilizer. Use of manure alone offered a marginal rate of return of more than 300% compared to not using manure. The marginal rate of return increased to more than 400% by supplementing the 5 t $ha^{-1}$of manure with 20kg N ha^{-1}. The marginal rate of return declined with higher levels of mineral fertilizer (Table 40.1).

Marginal net benefit first increased with the first 20 kg of N but declined with successive additions of N. On the other hand the marginal variable cost, which is the extra cost incurred by using an additional bag of mineral fertilizer, remained constant, since it is the price of each additional bag of fertilizer. On the basis of the Marginal Approach in evaluating profitable level of input use, the most profitable level of fertilizer is given where the marginal benefit will be equal to the marginal cost (Hill, 1990). The most optimum level of N to apply per hectare was found to be 43 kg N ha^{-1} .

Comparisons of the effectiveness of pit and heap stored manure

In the first year of manure application, manure stored anaerobically in pits produced a 104% yield gain compared to that aerobically stored on a heap (Figure 40.1). Heap stored manure offered 11 and 88 % yield gain in the second and third seasons respectively and offered higher residual fertility compared to storing manure in pits.

Figure 40.1. Residual effects of pit and heap stored manure on maize yield on a sandy soil in Murewa, 1997/98 to 1999/00 season



The two manure storage methods all produced positive net financial benefits in all the three seasons. (Table 40.2). Negative financial returns were obtained in all the three seasons for the control. In the first season of application, a rate of return of 219% was obtained from pit stored manure compared to 70% from heap stored manure. The trend was reversed in the second season in which manure stored on a heap offered a 244% return compared to 210% from pit stored manure (Table 40.2). Investment in the use of heap stored manure provided a more than 200% MRR compared to the control in the first year of application. A MRR of more than 1900% was obtained from pit stored manure in the first year of application compared to heap stored manure (Table 40.2).

Table 40.2: Analysis of the profitability of using pit and heap stored manure and residual effects over 3 years at prices deflated for inflation

Variables	1997/98 Season			1998/99 Season			1999/2000 Season		
	Control	Heap	Pit	Control	Heap	Pit	Control	Heap	Pit
Yield (t ha^{-1})	0.94	2.89	5.88	0.69	3.71	3.34	0.41	3.17	1.69
Adjusted yield (10%)	0.84	2.60	5.29	0.62	3.34	3.01	0.37	2.85	1.52
Selling Price (Z$ ton^{-1})	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00
Gross Benefit (Z$)	7191.00	22108.50	44982.00	5278.50	28381.50	25551.00	3136.50	24250.50	12928.50
Total Variable Costs (Z$ ha^{-1})	8247.40	12982.70	14096.60	8247.40	8247.40	8247.40	8247.40	8247.40	8247.40
Net Benefit (Z$ ha^{-1})	-1056.40	9125.80	30885.50	-2968.90	20134.10	17303.60	-5110.90	16003.10	4681.10
Rate of Return (%)	-13	70	219	-36	244	210	-62	194	57
Marginal Net Benefit	NA	10182.20	585.30						
Marginal Variable Cost	NA	4735.40	5.60						
Marginal Rate of Return (MRR)	NA	215%	1954%						
Net Present Values (NPV)	-1056.40	9125.80	30885.50	-2474.00	16778.50	14419.70	-4259.00	13336.00	3901.00

Note: 1US$ = Z$55

Undiscounted overall three year net financial benefits were 17% higher for pit than for heap stored manure and the benefits increased to 25% when discounted using a 20% discount rate (Table 40.3). Sensitivity analysis revealed that the higher the discount rate, the higher the benefits from pitting manure compared to heap stored manure. Pit stored manure had a higher BCR, 1.72 compared to 1.49 from heap stored manure. This further confirms the profitability of pit stored manure compared to heaping. A 47% increase in all costs will render heap storage unprofitable with a BCR of less than 1 whereas it will take more than a 77% increase in overall costs to make pit storage unprofitable. Another sensitivity analysis on labour revealed that a 200% increase in the price of labour would make storing manure on heaps unprofitable. It would take a 600% increase on the current labour prices to make pit storing manure unprofitable. The break even grain price for heap and pit stored manure is $3400 and $ 3100 respectively all being equal.

Table 40.3: Overall benefits over 3 years of using pit and heap stored manure on sandy soils in Murewa

Factor	Control	Pit	Heap
Total harvest (tonnes)	1.83	9.82	8.79
Total Net Financial Benefit (Z$)	-9136.10	52870.20	45263.10
Net Present Values (NPV)	-7789.50	49206.10	39240.20

Note: 1US$ = Z$55

Effect of Manure Placement Methods on Maize Yield

Banding and placing manure on-station produced higher yields for both pit and heap stored manure compared to the farmer practice of broadcasting manure (Table 40.4). Pit stored manure yielded more than heap stored manure in all the different placement methods, banding, broadcasting and station placement. Banding heap stored manure yielded more compared to placing it on-station or broadcasting it. On-station application of pit stored manure marginally out-yielded banding though it was not statistically significant. Broadcasting manure gave the least yield compared to the other two methods, (banding and station placement).

The rate of return for heap stored manure was negative for broadcasting and station placement. A 6% rate of return was obtained for banded heap stored manure (Table 40.4). Net financial benefits for pit stored manure were positive for all the three different placement methods. Banding and station placement produced more than a 70 % rate of return while broadcasting offered a 50% return to investment (Table 40.4). A sensitivity analysis on labour rates revealed that a 50% increase in labour costs made heap stored manure unprofitable. Increases in labour rates of more than 100% reduced rates of return for pit stored manure to less than 20%.

Table 40.4: Marginal rates of return for pit and heap stored manure using different application methods (banding, on-station and broadcasting)

Variables	Heap, Broadcasted	Heap, Banded	Heap, On-station	Pit Broadcasted	Pit, Banded	Pit On-station
Yield(t ha^{-1})	1.01	1.79	1.39	2.76	3.22	3.30
Adjusted yield (10%)	0.91	1.61	1.25	2.48	2.90	2.97
Selling Price(Z$ ton^{-1})	8500.00	8500.00	8500.00	8500.00	8500.00	8500.00
Gross Benefit(Z$)	7726.50	13693.50	10633.50	21114.00	24633.00	25245.00
Total Variable Costs (Z$ ha^{-1})	12804.30	12891.20	13291.80	13964.00	14050.80	14451.40
Net Benefit (Z$ ha^{-1})	-5077.80	802.30	-2658.30	7150.00	10582.20	10793.60
Rate of Return (%)	-40	6	-20	51	75	75
Marginal Net Benefit (Z$)	NA	-1574.10	-1564.70	1861.70	1516.10	2031.50
Marginal Variable Cost (Z$)	NA	-56.70	85.10	28.40	28.40	28.40
Marginal Rate of Return (Z$)	NA	2776%	-1840%	6567%	5348%	7176%

Note: 1US$ = Z$55

Discussion

The use of manure with smaller quantities of mineral fertilizers offers much larger productivity gains compared to using mineral fertilizer alone or manure alone. Combinations of mineral fertilizers and manure generally yield better though responses are very variable across sites because of the variability of the manure quality and site characteristics (Murwira *et al.*, 1998). From this study the most optimum level of supplementing 5 tonnes of manure was 43 kg N ha^{-1}. Sensitivity analysis revealed that an increase of more than 50% in the price of mineral fertilizer would make higher rates of supplementation less favourable with MRR. The variation in responses across different sites makes blanket recommendations impractical. Recommendations on supplementing organic materials with mineral fertilizers should be area specific. Application of inorganic fertilizer with manure can reduce the risks of economic losses and increase the probability of higher financial returns. Results from the study indicate that supplementing manure with mineral fertilizers can significantly increase net financial returns.

The improvement of manure quality through pit storage on the farm provides a realistic option for improving productivity in the smallholder sector. For resource constrained households that cannot raise enough cash to buy mineral fertilizers, pit storage is a technology which makes it possible for farmers to substitute cash requirements for soil fertility management with their labour. Despite the evident benefits of storing manure in pits, more than 65% of smallholder farmers who use manure in Murewa store their manure on a heap. Extension is silent on how farmers can improve their manure for effective utilization despite the research evidence that manure from the smallholder farming sector is of very poor quality. Most farmers are likely to adopt this technology given that technologies that offer larger benefits in the first season of adoption are likely to be adopted than those which yield benefits later in the project cycle like heaping manure (Gittinger, 1995).

The yield benefits from manure application can be increased for both heap and pit stored manure if the appropriate method of application is used. Pit stored manure produced higher rates of returns on all the different application methods compared with heap stored manure. Studies done in Zimbabwe have identified banding and station placement as the most rewarding placement methods (Mubonderi *et al.*, 1999).

Though most farmers in Zimbabwe broadcast their manure, results from this analysis show that this is not a profitable option especially for heap stored manure. Farmers can realise greater returns by either banding or station placement of the manure. However labour requirements for banding and station placement make these options unattainable for labour constrained households. Manure application methods are becoming more targeted in reaction to reduced livestock numbers and increase in the prices of mineral fertilizers (Snapp *et al.*, 1997; Ahmed *et al.*, 1997).

Smallholder farmers in Zimbabwe supplement manure with varying levels of mineral fertilizers but yields are still below potential due to inadequate amounts, poor quality of organic materials and inefficient combinations (Murwira and Palm, 1998). To these farmers what is more critical is how much of mineral fertilizer should supplement the manure for maximum benefit. A range of combinations that are profitable should be recommended to farmers given their different resource endowments and variability of the quality of manure from 0.1 to 1.9% N content depending on the management and handling of the manure (Nzuma and Murwira, 2000). Specific decision guides could be developed to provide farmers with guidelines for supplementing different quality manures with mineral fertilizers (Figure 40.1). These decision guides need to be farmer-friendly and take account of available quantities of manure and fertilizer N, farmer perceptions of quality and other management factors like soil type and methods of application.

Conclusion

Economic returns are an important determinant of technology use (CIMMYT, 1988). The options that offer higher economic returns have been identified in this study and merit further testing with farmers.

Extension can play a major role in expanding further testing and adoption of these options by farmers. Information on how farmers can realise maximum returns by supplementing organic materials with mineral fertilizer seems not available or if available it is scanty yet this option provides substantial opportunities for increasing productivity in the smallholder farming sector.

Most farmers find it difficult to raise the capital required for investments in mineral fertilizer and find it cheaper to invest their labour than capital. Despite the additional labour requirements of pit storing, manure farmers can invest their labour and be able to realise returns of more than 100% from utilizing pit stored manure. Concerns have been raised about labour availability in the smallholder farming sector especially considering the high incidences of HIV. Labour shortages are likely to discourage adoption of pit storing but an in-depth study is required to ascertain labour availability and its impact on adoption of labour intensive technologies.

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References

Ahmed, M.M., Rohrbach, D.D., Gono, L.T., Mazhangara, E.P., Mugwira, L., Masendeke, D. and Alibaba, S. (1997) *Soil fertility management in communal areas of Zimbabwe: current practices, constraints and opportunities for change*. Results of a diagnostic survey. Southern Eastern Africa Region Working Paper no. 6. International Crops Research Institute for the Semi-Arid Tropics (ICRISAT).

CIMMYT, (1988) *From Agronomic data to farmer recommendations: An economic Training manual.* Completely revised edition. CIMMYT, Mexico, D.F.

Gittinger, J.P. (1995) *Economic analysis of agricultural projects*. The John Hopkins University Press, Baltimore, Maryland 21218, U.S.A.

Hill, B. (1990) *An introduction to economics for students of Agriculture*. Pergamon Press plc, Headington Hill Hall, Oxford, England.

Mubonderi, T.H., Mariga, I.K., Mugwira, L.M., and Chivinge, O.A. (1999) Maize response to method and rate of manure application. *African Crop Science Journal* Vol. 7. No. 4. pp. 407-413.

Mugwira, L. M. (1985) Effects of supplementing communal area manure with lime and fertilizer on plant growth and nutrient uptake. *Zimbabwe Agricultural Journal* 82: 153-159.

Murwira, H.K. and Palm, C.A. (1998) Developing multiple fertilizer use strategies for smallholder farmers in Southern Africa in CIMMYT and EARO.1999. *Maize Production Technology for the future: challenges and opportunities:* Proceedings of the Sixth Eastern and Southern Africa regional maize conference, 21-25 September, 1998, Addis Ababa, Ethiopia: CIMMYT(International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organisation). Pp 205-209.

Murwira, H.K., Tagwira, F., Chikowo, R and Waddington S.R. (1998) An evaluation of the agronomic effectiveness of low rates of cattle manure and combinations of inorganic N in Zimbabwe in CIMMYT and EARO.1999. *Maize Production Technology for the future:* challenges and opportunities: Proceedings of the Sixth Eastern and Southern Africa regional maize conference, 21-25 September, 1998, Addis Ababa, Ethiopia: CIMMYT(International Maize and Wheat Improvement Center) and EARO (Ethiopian Agricultural Research Organisation). pp 179-182.

Nzuma, J.K., and Murwira, H.K. (2000) *Improving the management of manure in Zimbabwe in Managing Africa's Soils No. 15.* Russel Press, Nottingham.

Sanchez, P.A. (1997) Soil fertility replenishment in Africa: An investment in natural resource capital. In R.J. Buresh *et al.* (ed), *Replenishing Soil Fertility in Africa.* SSSA Special Publication no. 51. SSSA. Madison, USA. pp 1-46.

Palm, C.A; Murwira, H. K and Carter S., E. 1998 Organic matter management: from science to practice. In: Waddington, S. R., H.K. Murwira, J. D. T. Kumwenda, D. Hikwa and F. Tagwira (eds) *1998. Soil Fertility Research for Maize-Based Farming Systems in Malawi and Zimbabwe.* Proceedings of the Soil Fert Net Results and Planning Workshop held from 7 to 11 July 1997 at Africa University, Mutare, Zimbabwe. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.pp 21-28.

Smaling, E. M. A., Nandwa, S. M and Janssen. (1997) Soil fertility in Africa is at stake. In: R.J. Buresh *et al.* (ed) *Replenishing Soil Fertility in Africa.* SSSA Special Publication no. 51. SSSA. Madison, USA. pp 47-62.

Snapp, S., Phiri, R and Moyo, A. (1997) Soil fertility experimentation and recommendations for drought-prone regions of Zimbabwe and Malawi. In CIMMYT. 1999. *Risk management for maize farmers in drought prone areas of Southern Africa:* Proceedings of a workshop held at Kadoma range, Zimbabwe, 1 –3 October 1997. Mexico, D. F. pp13-24.

Tanner, P.D and Mugwira, L.M. (1984) Effectiveness of communal area manure as sources of nutrients for young maize plants. Zim. Agric. J.81:31-35.

Improved Food Production by Use of Soil Fertility Amendment Strategies in the Central Highlands of Kenya

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Abstract

Declining soil and crop productivity is a major problem facing smallholder farmers in eastern and central highlands of Kenya. This is caused by continuous cropping without addition of adequate external soil fertility inputs. A multidisciplinary and farmers participatory trial is being implemented in the main maize growing areas of the central highlands of Kenya to address the above problem. The trial is farmer-researcher managed with a general expected output of offering small-scale resource poor farmers feasible soil management techniques for combating soil nutrient depletion. Results for the two seasons reported here indicate that the general maize performance may be improved by combining fast decomposing plant biomass (e.g. *Tithonia diversifolia*) and half the recommended rate of nitrogen fertilizer.

Key words: biomass transfer, nitrogen replenishment, N leaching, maize yield

Introduction

One of the challenges facing Kenya today is the production of adequate food to feed the rapidly growing population and in particular, the inhabitants of the densely populated highlands of central Kenya with over 500 persons km^{-2} (Government of Kenya, 1994). The soils in this area are deep, well drained, weathered humic nitisols with moderate to high inherent fertility (Jaetzold and schmidt, 1983). Over time, the soil fertility has declined due to continuous cropping with little nutrient replenishment (Ikombo, 1984) and crop yield decline has been a major problem facing smallholder farmers in the area. Though high yielding maize varieties have been developed with yield potentials of 7-12 Mg ha^{-1}, maize yields at the farm level hardly exceed 1.5 Mg ha^{-1} (Wokabi, 1994). The use of inorganic fertilizers is generally low, less than 20 kg N and 10 kg P ha^{-1} (Muriithi *et al.*, 1994). The amount is inadequate to meet the crop nutritional requirements for optimum crop yields at the farm level. Due to the high cost of inorganic fertilizers and low prices of farm produce, over 80% of the farmers use farmyard manure (FYM) to improve soil fertility and crop productivity (Maize Data Base Project, 1993). The usefulness of FYM is limited mainly due to its variability and often-low nutrient contents and also the large quantities (5–10 Mg ha^{-1}) needed to supply adequate nutrients (Kihanda, 1996; Nzuma *et al.*, 1998).

Surveys carried out in the area indicate that farmers are fully aware of the declining soil fertility (as expressed by declining crop yields), but in most cases they do not have readily available resources to replenish it (Muriithi *et al.*, 1994). Research work by Mugendi *et al.* (1999); Mutuo *et al.* (1998) and Nziguheba *et al.* (1998) reported positive results from use of tithonia, calliandra and leucaena biomass for soil fertility improvement. These biomass are therefore supplementary components in soil fertility improvement and needs to be evaluated on-farm by farmers and other stakeholders in agricultural production processes. The information reported herein is from a participatory on-farm trial conducted in the predominantly maize growing zones (UM2– UM3) of Meru South District. The aim of the evaluation is to provide a menu (demonstration) on integrated soil fertility management strategies for increased agricultural production by smallholder farmers in Central highlands of Kenya. This project sought to i) integrate nutrient management practices that will arrest the current nutrient depletion and increase food production, and ii) encourage farmers to adopt improved nutrient management practices.

Materials and Methods

Experimental site

The study was carried in Meru South District. According to Jaetzold *et al.* (1983), the area is in upper midlands 2 and 3 (UM2-UM3). Coffee and dairy are the main Land Use Systems (LUS) with an altitude of approximately 1500 m above sea level, annual mean temperature of about 20^0 C and annual rainfall of about 1200 mm. The rainfall is bimodal, falling in two seasons, the long rains (LR) lasting from March through June and short rains (SR) from October through December. About 65% of the rains come during the long rainy season. The main food crop is maize.

Experimental layout

The experiment was established in March 2000 on a farm with poor and impoverished soils and laid out as a randomized complete block design (RCBD) with 3 replicates. The plot sizes were 6 m x 4.5 m. The test crop, maize, (*Zea mays* L, var. H513) was planted at a spacing of 0.75 m and 0.25 m inter- and intra-row, respectively. Three (3) seeds were sown and thinned at four weeks later to 2 plants per hole to give an approximate population of 53,300 plants ha^{-1}. Nine external soil fertility amendment inputs (Table 41.1) were applied to give an equivalent of 60 kg N ha^{-1}. The tenth was an absolute control (no external input) representing farmers on the lower end of resource endowment.

Organic materials were applied and incorporated into the soil to a depth of 15 cm during land preparation just before the onset of the rains. Nutrients compositions of the applied organic inputs are represented in Table 41.2. The inorganic source of N and P was the compound fertilizer (23:23:0) that was applied during maize sowing. All the agronomic procedures for maize production were appropriately followed after planting. The plots were hand weeded twice, four weeks after planting and at maize flowering. Stalk borers were controlled by use of borericide (Buldock dust) four weeks after the crop emergence. During the first season a general P deficiency was noted, thus a uniform top dressing for P, as TSP, was carried out in the second season.

Table 41.1: Experimental treatments indicating the different soil applied fertility amendment inputs at Chuka, Kenya

Treatment. No.	Treatment
1	Cattle manure
2	*Tithonia diversifolia*
3	*Calliandra calothyrsus*
4	*Leucaena leucocephala*
5	Cattle manure + 30 kg N and 30 kg P ha^{-1}
6	Tithonia + 30 kg N and 30 kg P ha^{-1}
7	Calliandra +30 kg N and 30 kg P ha^{-1}
8	Leucaena + 30 kg N and 30 kg P ha^{-1}
9	60 kg N and 60 kg P ha^{-1}
10	Absolute control (no inputs)

Table 41.2: Nutrient composition (%) of organic materials inputs applied in the Soil at Chuka, during season 1 and 2

Treatment	N	P	Ca	Mg	K	Ash
Cattle manure	1.4	0.2	1.0	0.4	1.8	46.1
Tithonia	3.0	0.2	2.2	0.6	2.9	13.2
Calliandra	3.3	0.2	0.9	0.4	1.1	5.8
Leucaena	3.8	0.2	1.4	0.4	1.8	8.7

Sampling and analyses

Maize was harvested at maturity from a net area of 21.0 m^2. This was after leaving out one row on each side of the plot and the first and the last plants of each row in order to minimize the edge effect. At the end of the second season soil samples were taken with an Alderman auger. The soils were sampled from three different depths: 0-30, 30-100 and 100-150 cm. One sub-sample of each soil sample was dried at 105^0 C for 48 hours in order to determine gravimetric water content.

For determination of ammonium and nitrate, about 20 g of field moist soil was extracted with 100 ml 2 *M* KCl by shaking for one hour at 150 reciprocation per minute and subsequent gravity filtering with prewashed whatman paper. Soil water content was determined on the stored field moist soil at the time of extraction in order to calculate the dry weight of extracted soil. Ammonium in the extract was determined by a calorimetric method (Anderson and Ingram, 1993) and nitrate was determined by cadmium reduction (ICRAF, 1995). Biophysical data was statistically analyzed using Genstat program (1995).

Results and Discussions

Maize grain yield

The average maize grain yield across the treatments was 0.9 Mg ha^{-1} (Table 41.3) during the first season. Application of recommended inorganic fertilizer (60 kg N and P ha^{-1}) gave the highest maize grain yield with an average of 1.6 Mg ha^{-1}. Average maize grain yield from calliandra was lowest (0.2 Mg ha^{-1}) and was worse than the control. The maize yields in this season (long rains) were not significantly different. The average maize grain yield was against the expected grain yield of greater than 6 Mg ha^{-1} (*Var.* H513) for the area. The low maize grain yield in calliandra treatment could be attributed to the lower rate of decomposition and mineralization due to the high polyphenol and lignin content of calliandra, which could have resulted to net immobilization of nutrients. The low soil moisture content resulting from the low rainfall (126 mm received in the first 20 days of the season) during this season could have exacerbated the situation. The higher maize grain yield with the inorganic fertilizer could be due to the readily available N compared to the N from organic inputs which must first decompose and mineralize before the N is available to the plant. Rains that stopped very early in the season could have meant that the organics did not have sufficient water (moisture) to decompose and mineralize and even if they did, water was not available for the mineralized nutrients to be taken up by the plants.

Table 41.3: Maize yields under different soil fertility amendment inputs in Chuka during season 1 and 2

Treatment	1st season Grain wt (Mg ha^{-1})	2nd season Grain wt (Mg ha^{-1})
Cattle manure	0.7	5.0
Tithonia	0.8	5.9
Calliandra	0.2	4.0
Leucaena	0.9	5.1
Cattle manure + 30 kg N & P ha^{-1}	1.4	5.7
Tithonia + 30 kg N & P ha^{-1}	1.5	6.2
Calliandra + 30 kg N & P ha^{-1}	1.1	4.7
Leucaena + 30 kg N & P ha^{-1}	1.0	5.1
60 kg N & P ha^{-1}	1.6	5.4
Control	0.3	3.1
Mean	0.9	5.0
SED	0.7	1.2

The average maize grain yield across all the treatments during the second season was 5.0 Mg ha^{-1}. During this season tithonia with 30 kg N and P ha^{-1}gave the highest maize grain yield of 6.2 Mg ha^{-1}. The control had the lowest maize grain yield (3.1 Mg ha^{-1}). The maize grain yields in the second season were significantly different ($P<0.05$) between the treatments. The better performance of tithonia during this season could be attributed to the faster release of N and P from the leaf biomass (Gachengo *et al*., 1999). The integration of tithonia and mineral fertilizer had higher maize grain yields than the recommended rate of mineral fertilizer; this could have been as a result of the provision of additional benefits (besides N and P) by the tithonia (organic).

The integration of organic and inorganic nutrient sources of N gave higher maize grain yields as compared to the sole application of organic materials in both seasons. These results concur with results by Gachengo (1996), Kihanda (1996), Mutuo *et al* (1998), Nziguheba *et al.* (1998) and Mugendi *et al.* (1999) on the integration of organic and inorganic soil fertility inputs. Integration of inorganic and organic nutrient inputs can be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients (Donovan and Casey, 1998). Kapkiyai *et al.* (1998) reported that combination of organic and inorganic nutrient sources has been shown to result into synergy and improved synchronization of nutrient release and uptake by plants (leading to higher yields).

The low maize grain yields in the first season could be associated with the very low precipitation (average 126 mm) with most of it being recorded within the first three weeks of the season. This low precipitation could have reduced the availability of nutrients to the maize plants. However, the second season was characterized by high precipitation (average 698 mm) occurring throughout the season and this could have led to the higher maize grain yield.

Residual Mineral N

Leucaena with 30 kg N and P ha^{-1} had the highest (97.7 kg N ha^{-1}) residual mineral N while recommended level of inorganic fertilizer had the lowest (51.4 kg N ha^{-1}) residual mineral N at 0-30 cm depth. There was a significant difference ($P<0.05$) of mineral residual N between treatments at the end of the second season (Table 41.4). All treatments were higher in residual mineral N than the control with the exception of the recommended level of inorganic fertilizer. This trend could be attributed to the beneficial ability of the soil incorporated biomass to release N gradually (especially in the present scenario where they were soil incorporated when dry) unlike inorganic fertilizers which release N drastically after application making them have a low residual effect. No significant differences were observed for ammonium between the treatments at 0-30 cm depth but significant differences were observed in the other depths. Nitrate concentration was significantly different ($P<0.05$) between the treatments as well as depth. Lower levels of ammonia-N were noted in comparison with nitrate-N in all the treatments. This could be as a result of the rapid conversion of ammonia to nitrate following mineralization of inputs in the soil.

Table 41.4: Treatment effects on soil residual mineral N (kg ha^{-1}) at various soil depths at Chuka at the end of the second season

Treatment	0-30 cm	30-100 cm	100-150 cm
Cattle manure	77.7	143.4	38.2
Tithonia	67.8	282.8	94.2
Calliandra	64.1	-	-
Leucaena	77.5	104.4	43.2
Cattle manure + 30 kg N & P ha^{-1}	64.7	70.6	44.1
Tithonia + 30 kg N & P ha^{-1}	77.7	131.9	84.2
Calliandra + 30 kg N & P ha^{-1}	87.1	-	-
Leucaena + 30 kg N & P ha^{-1}	97.7	207.2	87
60 kg N & P ha^{-1}	51.4	56.4	49.8
Control	51.7	161.5	95.8
Mean	70.8	144.8	67.1
SED	10.6	28.5	15.6

The average concentration of mineral N was highest (144.8 kg N ha^{-1}) in the 30-100 cm soil depth and lowest (67.1 kg N ha^{-1}) in the 100-150 cm soil depth. Mineral N concentration was lower in the 100-150 cm depth in all the treatments. Cattle manure had the least concentration (38.2 kg N ha^{-1}) in the 100-150 cm depth (Table 41.4) while the recommended level of fertilizer had the least concentration in both the 0-30 cm and 30-100 cm depth with 51.4 kg N ha^{-1} and 70.6 kg N ha^{-1} respectively. The mineral N in the 100-150 cm soil depth is below the rooting zone of maize plants and may not be available to the maize plants (Mugendi *et al.*, 2000). It may also not be readily transformed (denitrified or assimilated) because of the limited microbial population and available C at this depth (Paramasivam *et al.*, 1999). This mineral N is therefore prone to leaching into ground water therefore careful management of soil fertility inputs like timely application and split fertilizer application that have been reported to reduce N leaching should be encouraged (Paramasivam *et al.*, 2001).

A bulge in nitrate occurred at 30-100 cm in all the treatments. This concurs with Kindu *et al.* (1997) who reported a bulge in nitrate at 0.3 to

1.5 m soil depth in the maize land use system in Western Kenya. The bulge (accumulation) in nitrate at this depth could be attributed to greater N mineralization compared to plant uptake of top soil N immediately after the onset of the rainy season, subsequent nitrate leaching and then adsorption of nitrate on positively charged soil surfaces. Hartemink *et al.* (1996), also working in the land use systems of western Kenya reported that about 60% of nitrate at 1 to 2 m depth was sorbed on soil surfaces; this sorption of nitrate is known to delay its downward movement resulting in nitrate accumulation in the subsoil (Wong *et al.*, 1987).

Farmers' perception

Two farmers' field days were held during the two seasons. The farmers were impressed with what they saw in the field and they were willing to experiment with these technologies especially with tithonia, which grows locally along the boundaries and roadsides.

Conclusion

The high maize grain yields in the second season demonstrate the positive impact of these technologies in the area. Tithonia with half recommended rate of inorganic fertilizer gave impressive yields and hence the farmers are encouraged to adopt it on their farms to improve their food security. The bulge in nitrate at 30-100 cm depth indicates that there is nitrogen leaching in the soil and this calls for action.

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References

Anderson, J.M. and Ingram, J.S.L. (1993) Tropical Soil Biology and Fertility: A Handbook of Methods. CAB International, Wallingford, UK.

Donovan, G. and Casey (1998) Soil fertility management in Sub- Saharan Africa. World Bank. Technical Paper. 408 Pp

Gachengo, C. (1996) Phosphorus release and availability on addition of organic materials to Phosphorus fixing soils. MPhil thesis, Moi University, Eldoret, Kenya.

Gachengo, C.N., Palm, C.A., Jama, B. and Otieno, C. (1999) Tithonia and senna green Manures and inorganic fertilizers as phosphorus sources for maize in Western Kenya. *Agrof. Syst.* 44:21-26.

Genstat (1995) Genstat Release 3.2 for Windows 95. Lawes Agricultural Trust, Rothamstead Experimental Station, UK.

Government of Kenya (1994) The 1989 Kenya National Census results. Ministry of Home Affairs, Nairobi, Kenya.

Hartemink, A.E., Buresh, R.J., Bashir, J. and Janssen, B.H. (1996) Soil nitrate and water dynamics in sesbania fallow, weed fallow, and maize. *Soil Sci. Soc. Am. J.* 60: 568-574.

ICRAF (1995) Laboratory Methods for Soil and Plant Analysis: Version 1.1 Nairobi.

Ikombo, B.M. (1984) Effects of farmyard manure and fertilizers on maize in semi-arid areas of Eastern Kenya. *East. Afr. Agric. for. J.* 44:266-274.

Jaetzold, R. and Schemidt, H. (1983) Farm management handbook of Kenya. Natural conditions and farm information. Vol.11/ C. East Kenya. Ministry of Agriculture, Kenya.

Kapkiyai, J.J., Karanja, N.K., Woomer, P., and Qureshi, J.N. (1998) Soil organic carbon fractions in a long-term experiment and the potential for their use as a diagnostic assays in highland farming systems of central Kenya. *African Crop Science Journal* 6: 19-28.

Kihanda, F.M. (1996) The role of farmyard manure in improving maize production in the sub-humid highlands of central Kenya. PhD Thesis. The University of Reading. UK.

Kindu, M., Buresh, R.J. and Bashir, J. (1997) Root and inorganic nitrogen distributions in sesbania fallow, natural fallow and maize fields. *Plant and Soil* 188: 319-327.

Maize data base project (1993) Preliminary results for the Embu area presented in workshop held in Nairobi, Kenya, September 23-24, 1993.

Mugendi, D.N., Nair, P.K.R., Mugwe, J.N., O'Neill, M.K. and Woomer, P.L. (1999) Calliandra and Leucaena alley cropped with maize. Part 1: Soil fertility changes and maize production in the sub humid highlands of Kenya. *Agrof. Syst.* 46: 39-50.

Mugendi, D.N., Kanyi, M.K., Mugwe, J.N., Kung'u, J.B. and Wamicha, W. (2000) Mineral N movement and management in the Agroforestry systems in the central highlands of Kenya. Paper submitted to the 18th conference of the Soil Science Society of East Africa at Mombasa Kenya.

Muriithi, F.M., Thijssen, H.J.C., Mugendi, D.N., Mwangi, J.N., O'Neill, M.K. and Nyaata, O.Z. (1994) Report of a survey on agroforestry technologies used for fodder production and soil fertility improvement in Meru district, Kenya. National Agroforestry Research Project, Regional Research Centre, Embu, Kenya

Mutuo, P.K., Mukalama, J.P. and Agunda, J. (1998) On-farm testing of organic and inorganic phosphorous source on maize in Western Kenya. In: The Biology and Fertility of Tropical Soils: TSBF Report, pp22.

Nziguheba, G. and Mutuo, P.K. (1998) Integration of Tithonia diversifolia and inorganic fertilizer for maize Production. In: The Biology and Fertility of Tropical Soils: TSBF Report, pp 23.

Nzuma, J.K., Murwira, H.K. and Mpepereki, S. (1998) Cattle manure management options for reduction nutrient losses. Farmer perceptions and solutions in Mangwada, Zimbabwe. In: Soil Fertility Research for maize based system in Malawi and Zimbabwe. CIMMYT, Soil Fertility Network.

Paramasivam, S., Alva, A.K., Prakash, O. and Cui, S.L. (1999) Denitrification in the vadose zone and in surficial groundwater of a sandy entisol with citrus production. *Plant Soil* 208: 307-319.

Paramasivam, S., Alva, A.K., Fares, A. and Sanjwan, K.S. (2001) Estimation of Nitrate Leaching in an Entisol under Optimum Citrus Production. *Soil Sci. Soc Am. J.* 65: 914-921.

Wokabi, S.M. (1994) Quantified land evaluation for maize yield gap analysis at three sites in the Eastern slopes of Mt. Kenya. International Institute for Aerospace Survey and Earth Science (ITC), The Netherlands.

Wong, M.T.F., Wild, A., and Juo, A.S.R. (1987) Retarded leaching of nitrate measured in Monolith lysimeters in southeast Nigeria. *J. Soil Sci.* 38: 511-518.

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Impact of Adopting Soil Conservation Practices on Wheat Yield in Lesotho

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Abstract

This study assesses the impact of adopting soil conservation practices on wheat yield in Lesotho. The study uses input-output data collected from 50 smallholder farmers in Mafeteng and Maseru districts, the major wheat growing areas in the country. A system of equations was used to estimate factors affecting adoption of soil conservation measures, and impact of soil conservation measures on wheat yield. For each farmer's wheat field, based on the soil conservation practices adopted by the farmer, two soil conservation variables related to farmer's soils erosion control methods were constructed. Two Tobit models and a modified Cobb-Douglas production function were used to model adoption, and impact of, soil conservation measures respectively. The adoption of two soil conservation measures was modeled as function of household's demographic characteristics and availability of extension services. The yield equation was modeled as a function of inputs used in production and soil conservation efforts. The results indicate that soil conservation efforts were superior to inorganic fertilizer application in terms of increasing wheat yield. Increase in soil conservation efforts, coupled with low inorganic fertilizer use has a potential of increasing wheat production among smallholder farmers in the area.

Key words: Adoption, Impact, Improved Wheat Varieties, Lesotho, Soil Conservation

Introduction

Information on the causes and effects of soil erosion on Lesotho's agricultural productivity is quite limited, despite considerable erosion being visible in many parts of the country. It is evident that soil loss and land degradation have escalated in recent years with a consequence of decreasing agricultural productivity in the country. Coupled with Lesotho's topographical and climatic variation, soil erosion is severe in most parts of the country. Only 13% of land is arable for growing crops and in recent years, soil erosion has reduced this to 9% (LMRG, 1996). Because of high human population in the lowlands, even with a moderate livestock population, extensive overgrazing, soil erosion and rapid deterioration of water and soil resources occur at an alarming rate. Everywhere, the plateau and hill slopes are marked by signs of heavy erosion by water and wind, leaving behind bare bedrock, laterite hard pans and stony soils lacking in organic matter.

According to the Kingdom of Lesotho's report to the United Nation conference on environment and development (1980), about 54% of cropland and 28% of those in the mountains are subject to severe sheet erosion (KoL, 1980). Further, about 40% of the cultivated area should ideally be under fodder or pasture. Soils are low in organic matter; yields are low and decreasing, and cultivated area is diminishing. About 50-60% of rangelands show severe soil erosion and degradation. Significantly, in quantitative terms, soil losses per year amount to 15 million tonnes from croplands and 23 million from rangelands, and 1 million tonnes from gully erosion (LMRG, 1996).

To increase agricultural productivity, soil conservation is of paramount importance to farmers involved in crop production. Replenishment of soil fertility by artificial fertilizer would be very expensive. Even then, the use of inorganic fertilizers does not compensate for the loss of soil organic matter. This study assesses the potential impact of adopting soil conservation practices on wheat yield.

The focus is on conservation measures advocated by the extension department of the ministry of agriculture co-operatives and land reclamation. These farming practices include contour farming, crop residue management for the improvement of infiltration and planting of cover crops like fodder to increase land productivity. Structural methods include cut-off drains or diversion to cater for excessive run-off, terracing within cropland for reduction of steepness and length of slope, waterways to improve water disposal from the terraces and cut-off drains, and gully treatment by vegetative methods and the construction of silt traps to retard water flow (especially on the catchments area) (MoA, 1988).

A system of equations is used to estimate factors affecting adoption of short-term and long-term soil conservation measures and impact of adopted soil conservation measure on wheat yield. This study deviate from the past studies that assess the impact of soil conservation measures on crop yield in two folds. First, the methodology allows using the whole samples. Past studies that used systems of equations to estimate adoption, and the impact of soil conservation measure, dropped out non-adopters in the yield equation to take into account the sample selection bias. Second, the model takes into account the zero values in the explanatory variables by using the Battese's modified Cobb-Douglas hence BMCD production function. The basic assumption is that farmers who did not use some of the inputs should have different level of yield (thus intercept) from those farmers who used the corresponding inputs. This is important when estimating a system of equations that involve adopters and non-adopters. The modified production function incorporates both intercept and divergent shifts in the model.

Literature Review

Feder, Just and Zilberman (1985) define adoption as the degree of use of a new technology in long run equilibrium when a farmer has full information about the new technology and its potential. Therefore, adoption at the farm level describes the realization of farmer's decision to apply a new technology in the production process. On the other hand, aggregate adoption is defined as the process of spread or diffusion of a new technology within the region. Therefore, a distinction exists between adoption at the individual farm level and aggregate adoption within the targeted region. Adoption at the farm level is often quantified or represented by a binary variable (adoption = 1, non-adoption = 0). In the case of a divisible technology, a continuous variable describing the intensity of adoption (e.g., hectares devoted to a new technology or number of livestock under a new treatment) or extent of adoption (e.g., share of land devoted to a new technology) are used. Other researchers suggest other variables which include the earliness of adoption; the time the technology was first used by the farmer; the thoroughness of adoption; the number of technical components adopted by farmer from the recommended package and an index of innovativeness which aggregate the adoption dimensions mentioned above. In most cases, the adoption response depends on the problem at hand, study objective, available data, and sometimes the available computer package (Feder, Just and Zilberman, 1985).

A particular technology is adopted when the anticipated utility from it exceeds that of non-adoption (Rahm and Huffman, 1984). Since utility is not observable, change in utility can be inferred from farmers' decision of adopting or not adopting a technology (incidence of adoption) or adopting some continuous choice over a predefined interval (Kazianga and Masters, 2001). When assessing the incidence of adoption implies using Probit models (Maddala, 1992). To consider intensity or extent of adoption involves using Tobit models as in Baidu-Forson (1995). Sometimes, a two stage procedure is used to model adoption when it is observed that adoption of one innovation leads to adoption of another complementary farming techniques (Nkonya, *et al.*, 1997; Kaliba, *et al.*, 1999).

Assessing adoption of soil conservation measures, involves defining the soil conservation variable or index, which varies from researcher to researcher. The tendency is to choose one specific soil conservation measure as an indicator of adoption. For example, see Shively (1999) on adoption and impact of contour hedgerows in the Philippines for the case of Probit model, and Kazianga and Masters (2001) on adoption and impact of field bunds and micro-catchments in Burkina Faso for the case of Tobit Model. The difficulty arise when there are several soil conservation measures or a package of soil conservation innovations. Nowak (1987) used the ratio of adopted practices related to total numbers available in the package to define the soil conservation variable for each farmer. This approach is simple because it involves just observing soil conservation practices adopted by the farmer. Kastens and Dhuyvetter (1999) used the ratio of total farm costs relative to the costs of adopted soil conservation measures. This procedure evaluates all inputs used in production at market prices and requires proper record keeping. This study adopted the former approach due to its simplicity and unavailability of price data on all input used in production.

From the literature, factors influencing adoption of new agricultural innovation can be divided into three major categories: farm and farmers' associated attributes, attributes associated with the technology (Adesina *et al.*, 1992) and the farming objective (CIMMYT, 1988; Ockwell, 1991). In the first category, factors discussed in the literature include human capital represented by the level of education of the farmer (Rahm and Huffman, 1985; Goodwin and Schroder, 1994), the risk and risk management strategies (Saha and Love, 1994), the institutional support system, such as marketing facilities, research and extension services, transportation etc (Feder, Just and Zilberman, 1985), availability of production factors and factor endowment such as farm size, number of livestock owned (Rahm and Huffman, 1984), and the level of off-farm income and income sources (Kimhi, 1994). The second and third categories depend on the type of technology and are important when farmers have access to different types of technical innovation e.g., different type of crop varieties with differences in production characteristics and performance, or when dealing with heterogeneous farmers with different farming objectives e.g., small and larger farmers, subsistence and market oriented farmers. Therefore, the influence of each exogenous variable on adoption responses is unique and specific to the study area. These characteristics make adoption studies site specific and often incomparable.

Two techniques are commonly used to study the impact of soil conservation practices on crop productivity. The first approach is the crop modeling system, which uses several ecosystem factors to evaluate the dynamics of crops and soils processes that include soil conservation measures. The technique requires a lot of data and experience in system modeling (Cox, Hammer and Robertson, 2001). The second approach uses abstract models such as a production function based on relatively few variables to relate production to soil conservation activities (Kazianga and Masters, 2001). This technique concentrates on modeling the response of crop growth relative to several exogenous variables that ensure the survival and growth of the crop. The commonly used production functions are the Cobb-Douglas and the translog. The unrestricted translog production function is sometimes preferred because it is general and flexible and allows analysis of interaction of variables (Byiringiro and Reardon, 1996). The Cobb-Douglas is a special case of a translog function, when the interaction terms have zero coefficients (Gujarti, 1995). Unlike the Cobb-Douglas, the translog function does not always generate elasticities of substitution of one, and the isoquant and marginal products derived from the translog depend on the coefficients on the interaction terms. However, under low-input agriculture, most smallholder farmers produce on the increasing side of the production function, and the translog production function may not represent an actual data generating process. Whereas the translog functions are superior when the objective is to calculate the optimal mix of inputs, Cobb-Douglas function often behaves better when the objective is tracing the production frontier under low input agriculture (Shively, 1998).

Empirical Model and Estimation Procedure

To rationalize the model, consider a farmer who chose to adopt some or all soil conservation measures as advocated by the Extension Department in Leshoto. The farmer has two choices: to adopt innovations from short-term soil conservation package (i.e., contour ploughing, crop residue management and cover crops); and /or from long term soil conservation package (i.e., structural methods that include cut-off drains, terracing, gully treatment, and slit traps). Let Ai_j represent percent of innovations adopted from any package (extent of adoption) such that Ai_j=0 for non-adopter, and (0<Ai_j100) for adopters. Also, a binary variable dij (incidence of adoption) can be created such that dij=0 for non-adopter, and di_j=1 for adopter. Formally, this relationship can be presented as follows:

$$\sum_{j=1}^{2} A^*_{ij} = \mathrm{B}_j^T Z_{ij} + \varepsilon_{ij}\ , \quad \sum_{j=1}^{2} d^*_{ij} = \theta_j^T X_{ij} + \nu_{ij}\ , \tag{1}$$

$$d_{ij} = \begin{cases} 1 & if \quad d^*_{ij} > 0 \\ 0 & if \quad d^*_{ij} = 0 \end{cases},$$

$$A_{ij} = d_{ij} A^*_{ij} \qquad\qquad (i = 1, 2, \ldots\ldots, T;\ j = 1, 2).$$

In the equations, A^*_{ij} is the latent variable representing extent of adoption and is generated by the classical linear regression, d^*_{ij} is the latent variable representing incidence of adoption and is generated by the classical Probit regression,$_j$ and θ_j are parameters of the models, superscript T is the transpose function, matrices Z_{ij} and X_{ij} contains variables associated with adoption such that matrix X is contained in matrix Z, and e_{ij} and v_{ij} are random errors. The basic assumption is that the farmer takes a two-step decision process. First, the farmer decides either to adopt or not to adopt any soil conservation innovation. Second, if the farmer decides to adopt, a decision is also made on the number of innovations from the advocated technical innovations from the package. The system represents simultaneous double-bounded Tobit equations, were the lower limit is zero and the upper limit is 100. In the system (j=1) represent extent of adopting short-term soil conservation measures, and (j=2) represent the extent of adopting long-term soil conservation measures. As shown by Shonkwiler and Yen (1999), the unconditional mean of A_{ij} in Equation (1) can be also represented as:

$$A_{ij} = \Phi(\theta_j^T X_{ij})(\beta_j^T Z_{ij}) + \delta_{ij}\varphi(\theta_j^T X_{ij}) + \eta_{ij}, \qquad (\eta_{ij} \sim N(0, \sigma_{u_j})), \tag{2}$$

Such that :

$$E(A_{ij} \mid Z_{ij}, X_{ij}) = \Phi(\theta_j^T X_{ij})(\beta_j^T Z_{ij}) + \delta_{ij}\varphi(\theta_j^T X_{ij}),$$

were $\Phi(.)$ and $\varphi(.)$are cumulative distribution function and univariate standard normal probability density function, E(.) is the expectation operator and η_{ij} is the identically normally distributed error term. Notice that in the adoption equations, previous decision to adopt some of the long-term soil conservation measures may induce a farmer to adopt specific measures from the short-term soil conservation package and vise versa.

To evaluate the impact of adopting soil conservation measures on wheat yield, consider a Cobb-Douglas production function that relates agricultural input and soil conservation measures to yield. The function accounts for the fact that expected yield depend on inputs used in production and current or past decisions to adopt soil conservation measures. If Yi represents the yield observed on plot i, the corresponding Cobb-Douglas production function is:

$$Y_i = \alpha_0 M_i A_{i1}^{\alpha_{21}} A_{i2}^{\alpha_{22}} \mu, \qquad \mu \sim N(0, \sigma_\mu). \tag{3}$$

In Equation (3), α 's are parameters to be estimated, M is the matrix of production inputs used to produce wheat on plot i, and other variables are as explained before. Using information contained in Equations (1) to (3), the adoption and yield equations can be formulated as follows:

$$\begin{aligned} A_{i1} &= \Phi(\theta_1^T X_i)[\beta_{10} + \beta_2 A_{i1} + \beta_{11} z_1 + \beta_{21} z_2 + \beta_{31} z_3 + \beta_{41} z_4 + \beta_{51} z_5 + \beta_{61} z_6 + \beta_{71} z_7] + \delta_1 \varphi(\theta_i^T X_i) + \eta_{i1} \quad (4) \\ A_{i2} &= \Phi(\theta_2^T X_i)[\beta_{20} + \beta_1 A_{i2} + \beta_{12} z_1 + \beta_{22} z_2 + \beta_{32} z_3 + \beta_{42} z_4 + \beta_{52} z_5 + \beta_{62} z_6 + \beta_{72} z_7] + \delta_2 \varphi(\theta_i^T X_i) + \eta_{i2} \\ LY_1 &= \alpha_0 + \alpha_1 LnL_i + \alpha_2 LnF_i + \alpha_3 LnA_{i1} + \alpha_4 LnA_{i2} + \alpha H_i + (\alpha_0 - \lambda) DF_i + \mu_i \end{aligned}$$

In the adoption equations, z_1 is sex of the household head (z_1=1, if respondent is male; z_2=0, otherwise), z_2 is age of respondent in years, z_3 is education of the respondent in years, z_4 is the number of adults in the households, and z_5 is the estimated monthly income of the respondent in Lesotho's Maluti. Other variables were defined as: z_6 the experience of the farmer measured as years in growing wheat, and z_7 is a variable representing availability of extension services to the farmer. The last but one item, φ(.), is known as the correction factor, and η_{ij} are random errors. The extension service variable was constructed as in Kaliba *et al.* (2000).

In the yield equation, Ln is the natural logarithm function, Y_i is yield for plot in bags/acre (one bag is 90 kg), L_i is labor used in production in mandays equivalents (family and hired labor was combined together because few farmers used hired labor). Other variables are: F the quantity of NPK (3:2:1) fertilizer used per plot in 25kg bags; A_{i1} and A_{i2} are extent of adopting short and long terms soil conservation measures; Hi the dummy variable representing hybrid wheat varieties (H=1 if used hybrid seeds, H=0 otherwise); and D_Fk is dummy variable introduced to capture the influence of non use of fertilizer as suggested by Battese (1997), and ìi is the identically normally distributed error term. The dummy variable is such that: D_Fk=1 if the farmer did not use any fertilizer, D_Fk=0 if the farmers reported the use of fertilizer. However, the zeros (non-use of fertilizer) in the fertilizer variable (F_i) are replaced by ones for the model to be identified. The important assumption of the MCD model is that farmers who did not use any fertilizer have different intercept from those who used fertilizer. This assumption is true if the parameter λ is statistically different from zero. The use of manure and other organic fertilizer are very limited as animals usually stay away from the cropland.

The inclusion of adoption variables as independent variables introduces endogeneity and contemporaneous correlation problem in the model (i.e., cov(η_{ij}, μ_i) ~ 0). Zero observations in the fertilizer variable imply that users and non-users have different intercepts. In order to increase the efficiency of the estimated parameters and to correct for correlation between errors, Equation 4 was estimated in a two-step procedure. First, the estimates of θ_j were obtained using maximum likelihood probit (Maddala, 1992) where the dependent variables were the binary outcome of d_{ij}=1 and d_{ij}=0 for each j but without including corresponding A_{ji} as independent variable in each adoption equation. Second, the results were used to estimate $\Phi(\theta_j X_{ij})$ and $(\theta_j X_{ij})$ in Equation (2). The estimated of β, α and δ in Equation (4) were estimated using nonlinear seemingly unrelated regression (SHAZAM, 1997) as suggested by (Shonkwiler and Yen, 1999). Table 42.1 list the variables included in the model, expected signs and reasons.

Source of data

This study uses cross-sectional data collected through a survey using a structured questionnaire. The survey covered a sample of 50 smallholder farmers selected randomly from Maseru (25) and Mafeteng (25) districts. The districts are the main wheat growing regions and are easily accessible from the National University of Lesotho. The sample size took into consideration the budget constraint. The data collected were on inputs used in production, wheat varieties grown and the demographic characteristics of the respondent. Soil conservation measures for each farm field were determined by observation. A soil conservation variable was then developed based on the number of soil conservation practices adopted by the farmer out of the soil conservation package as advocated by extension agents working within the area. The major respondent was the household head.

Results and Discussion

Summary statistics of the variables

Table 42.2 presents summary statistics of the variables used in the model. On average, every respondent farmed nearly five acres of wheat with a standard deviation of about 4.91. The total harvest was roughly 33 bags of wheat per plot (6.6 bags/acre). The respondents used about 9.5 man-days equivalent (about 77.5 hours) to complete all field activities involving wheat production. This included family and hired labor. About 6 bags of NPK fertilizer were applied in the five acres plot. About 48% of respondents were growing hybrid varieties and about 16% of respondents did not use inorganic fertilizer in their wheat field. On average, the farmers adopted four measures of soil conservation out of the package with nine recommendations (see also Table 42.3). Whereas few respondents have no formal education, about 38% of respondents indicated that an extension agent to discuss wheat production has never visited them. On average, a respondent had attended a two-day formal training on wheat production. These formal training included seminars, workshops and attending field days organized by the extension services department, or any other non-governmental organization involved in agricultural development.

Table 42.1: Exogenous variables included in the model, expected signs and justification

Variable	Expected sign	Justification
Adoption Equations		
Sex	+	Male headed households have more resources and are more likely to adopt new innovations than female headed households
Age	+	Older farmers have more resource than younger farmer and are more likely to adopt new innovations
Education	+	Educated farmers are best farmers as they know the benefits of soil conservation
Number of adults in households	+	Availability of adult labor increase the ability to adhere to all important agronomic practices
Income	+	High income avails necessary inputs for better farming methods such as soil conservation
Experience in farming	+	Farmer's experience increase the likelihood of understanding the benefits of soil conservation
Extension services	+	Extension services increase productive performance
Yield Equation		
Labor (mandays equivalent)	+	Availability of labor improve crop management
Quantity of fertilizer	+	Fertilizers increase soil nutrient and crop growth
Soil conservation measures	+	Conservation improves soil structure and texture and thus yields
Hybrids	+	Hybrid are high yielding than local varieties

Table 42.2: Summary statistics of variables used in the regression analysis

Variable	Unit	Mean/ Percent	STD Deviation
Total production per plot	Bags/kg	32.62	26.36
Size of the plot	Acres	4.91	3.51
Total Labor used per plot	Man days	9.68	7.03
Fertilizers (NPK:3:2:1)	25 kg bag	6.28	4.74
Age of household head	Years	39.96	5.59
Experience of the farmers	Years	15.78	6.89
Education of household head	Years	4.75	10.56
Monthly income	Maluti	670.76	890.54
Training in wheat production	Days	2.34	4.79
Extent of short-term soil conservation measures adopted	%	0.40	0.18
Extent of long-term soil conservation measures adopted	%	0.40	0.18
Sex of household head: (male)	%	76.00	
Farmers growing hybrid varieties	%	48.00	
Extension visits: Always	%	30.00	
Sometime	%	32.00	
None	%	38.00	

Table 42.3: Percentage of farmers adopting soil conservation practices

Soil conservation variables	%
Long-term Soil Conservation Measures	
Terraces	11
Silt traps	4
Water ways	15
Sandbags	2
Short-term Soil Conservation Measures	
Crop rotation	24
Inter-planting	2
Fallowing	16
Contour ploughing	12
Vegetation cover	13

Table 42.3 indicates the types of soil conservation variables adopted by different respondents in their wheat fields. From this table, the most common measure adopted by the farmers is crop rotation, (24% of respondents). Other popular soil conservation measures were fallowing (16%), construction of waterways (15%), vegetable cover (13%) and contour farming (12%). Sandbag construction and interplanting were the least common among the respondents. However, all respondents have adopted at least one soil conservation measure in their wheat fields.

Regression Results

Table 42.4 presents the results on factors affecting extent of adopting short-term soil conservation measures. During the analysis, the lower limit for the Tobit mode was set at 0 and the upper limit 100. The likelihood ratio statistics for the null hypothesis that all parameters in the model are zero was rejected at 1% probability level, meaning that variables included in the model explain some of the variation in extent of adopting short-term soil conservation measures. Positive and negative signs on the exogenous variable indicate that the variable's marginal effect on short-term soil conservation measures were positive (increasing extent of adoption) or negative (decreasing extent of adoption).

Table 42.4: Factors affecting adoption of short-term soil conservation measures

Variable name	Estimated coefficient	Asymptotic T-Ratio
Constant	-0.2478	-0.6992
Long-term soil conservation measures index	1.4123	2.2450**
Sex of household head (Male=1,0 otherwise)	-0.1081	-0.8986
Age of household head in years	0.0418	1.0119
Education of household head in years	0.1078	2.1568**
Number of adults in the households (> 18 years)	-0.0303	-2.3481**
Household monthly income in maruti	-0.0750	-2.2271**
Experience of growing wheat in years	0.0012	-0.4000
Availability of extension services variable	-0.0116	-1.1016
Correction factor (δ_1)	1.5487	2.6655**
R-square (%)	59.4**	
Log of Likelihood ratio test	88.0313**	

Double and single asterisks denote statistically significance at 5% and 10% level

The statistically significant variables and variables with positive influence were adoption of long-term soil conservation measures, education of household head, and the correction factor. Sex, age, and experience of the household head and availability of extension services have no influence on the extent of adopting short-term soil conservation measures as anticipated. Other statistically significant variables but with unexpected negative influence were number of adults in the households and household monthly income.

The results of Tobit models that examine factors affecting the adoption of long-term soil conservation measures are presented in Table 42.5.

Again, positive and negative signs on the exogenous variables indicate that higher values of the variables will increase or decrease adoption of long-term soil conservation measures. The likelihood ratio test statistics was significant at 1% probability level. The statistically significant variables included extent of adopted short-term soil conservation measures, number of adults in the households and household monthly income.

Table 42.5: Factors affecting adoption of Long-term soil conservation measures

Variable names	Estimated coefficient	Asymptotic T-Ratio
Constant	-0.3619	-1.1753
Short-term soil conservation measures index	1.1739	2.2780**
Sex of household head (Male=1,0 otherwise)	0.1144	1.0930
Age of household head in years	-0.0413	-1.1921
Education of household head in years	-0.0976	-2.0435**
Number of adults in the households (> 18 years)	0.0296	2.7527**
Household monthly income in Lesotho Maruti	0.0573	1.7968*
Experience of growing wheat in years	0.0018	-0.0660
Availability of extension services variable	0.0103	1.1280
Correction factor (δ^2)	0.7465	1.6193
R-square	44.62	
Log of Likelihood ratio test statistic	94.25**	

Double and single asterisks denote statistically significance at 5% and 10% level

Table 42.6: Multiple Regression Results on Wheat Production per Plot

Variable	Estimated coefficients	Asymptotic T-Ratio
Constant	1.9285	4.7994
Log of total labor (mandays)	0.0308	0.2023
Log of quantity of fertilizer (25 NPK bags)	0.0887	2.2553**
Log of short-term soil conservation variable	0.0892	2.1995**
Log of long-term soil conservation variable	0.1141	1.9452*
If used Hybrid (yes=1, No=0)	0.1256	0.8537
Dummy for quantity of fertilizer (Dk)	-1.4995	-3.4716**
R-squares (%)	77.5600	
F-statistics (zero slopes)	85.11**	

Double and single asterisks denote statistically significance at 5% and 10% level

The results of both models suggest the followings. First, a decision to adopt long-term soil conservation measures has a great influence on the adoption of short-term soil conservation measure and vise versa. However, once adopted, long-term soil conservation measures stay in the field and will always acts as benchmark for adopting short-term soil conservation measures. Extension efforts that promote soil conservation should therefore be directed more to long-term soil conservation measures in order to stimulate the adoption of short-term soil conservation measures. Second, the signs on the estimated parameters indicate that the two technologies are considered to be substitute to each other rather than complimentary. For example, households with more available labor (number of adults) will tend to focus more on adopting long-term soil conservation measures than both technologies. Relatively educated farmers will tend to adopt short-term rather that long-term soil conservation measures. Demonstration plots that show the benefit of adopting both technologies is highly recommended. Third, the indication that availability of extension services has no influence on adoption, surpass all logic. Nevertheless, this may be a sign of weak extension services in the country, meaning that the current extension services delivery system is too weak to influence any technological adoption

For the yield equation, the estimated coefficient of determination (R^2) was about 78%, indicating that the model explains at least 78% of the variation in wheat production as reported by sample respondents. The likelihood ratio test of the null hypothesis that all variables included in the model have zero slopes was rejected at 1% level of significance. All signs were as expected. Statistically significant variables were quantity of fertilizer, and both adoption of short-term and long-term soil conservation measures. The dummy variable for non-use of fertilizer was statistically significant and negative as expected, indicating that the yields of farmers not using fertilizers was more likely to be less than those of farmers using fertilizer.

Because the variables used in the model are in the logarithm form, the estimated coefficients for continuous variables are elasticities and for dummy variables, the coefficients are intercept shifters. Therefore, the average marginal product (AMP) of an input is the product of the estimated elasticity times the output-input ratio (i.e., AMP=ÄY/ÄX=áY/X). At the sample mean, the calculated marginal product of labor was 0.021, implying that increase in labor by one unit will increase yield by 0.02 bags/acre (0.3%). The marginal products of the fertilizer and short-term and long-term soil conservation efforts were respectively 0.024, 1.18 and 1.80, implying that a unit increase in the use of fertilizer, therefore, increases yields by 0.024bag/acre (0.3%). Adoption of additional one unit of short-term or long-term soil conservation measure, however, has a much greater impact, increasing yield by 1.18bags/acre (17.9%) and 1.8bags/acre (27.3%) respectively.

Conclusion and Policy Implication

The need to address the problem of soil erosion in Lesotho is widely known. The solution to this problem lies in reducing the negative impact of soil erosion on crop yields through soil conservation measures and improved land management practices. As indicated by the regression results, wheat farmers stand to gain more through increased soil conservation efforts than use of inorganic fertilizers alone. Given the limited availability of land, increase in acreage is not a viable solution. Agricultural intensification through adopting soil conservation measures may be best option for most farmers.

A thing to note is the limited influence of extension services on adoption of soil conservation measures. Extension services are important in enhancing the adoption of any new farming practices. Adequately trained, well-supported extension services can effectively induce the adoption of soil conservation practices. Field trials and demonstrations successfully create awareness on returns associated with soil conservation measures to farmers. It is therefore imperative that extension services need to be strengthened in order to enhance the adoption of soil conservation measures. Moreover, farmers will adopt the practices that give high returns. Farm management studies aimed at establishing soil conservation mixes that optimize returns to the farmers are highly recommended.

References

Adesina, A. and M.M. Zinnah (1992) *Adoption, diffusion, and economic impacts of modern mangrove rice varieties in Western Africa: further results from Guinea and Sierra Leone.* In: Towards a New Paradigm for Farming System Research/Extension. Working Paper for the 12th Annual FSR Symposium 1992. Michigan State University, 1992: 443-466.

Anderson, D. and Grove, R. (1987) *Conservation in Africa, People, Policies and Practices*, Cambridge University Press: Great Britain.

Battese, G.E. (1997) A note on the Estimation of Cobb-Douglas Production Functions when Some Explanatory Variables have Zero Values, *Journal of Agricultural Economics* 48: 250-252.

Byiringiro, F. and T. Reardon (1996) Farm Productivity in Rwanda: Effects of farm size, erosion, and soil conservation investments. *Agricultural economics* 15:127-136.

CIMMYT (1993) *The adoption of agricultural technologies: a guide for survey design*. International Wheat and Improvement Center, Londres: Mexico.

Cox, H.W., Hammer, G.L., and Robertson, M.J. (2001) *Opportunities for crop modeling in barley*. Proceedings of the 10th Australian Barley Technical Symposium. The Regional Institute Ltd:Australia.

Feder, G., Just, R.E., and Zilberman, D. (1985) Adoption of agricultural innovations in developing countries: a survey. *Economic Development and Cultural Change* 33 (1985): 255-297.

Goodwin, B.K. and Schroeder, T.C. (1994) Human capital, producer education, and adoption of forward-pricing methods. *American Journal of Agricultural Economics* 76: 936-947.

Greene, W.H. (1997) *Econometric Analysis*, Prentice, Hall, Upper Saddle River: New Jersey.

Gujarati, D.N. (1995) *Basic Econometrics.* McGraw-Hill International,Singapore.

Hall, B.H. (1994) Time Series Processor User's Guide. TSP International: Palo Alto, CA.

Kaliba, A.R.M., Verkuijl, H.J.M. and Mwangi, W. (2000) Adoption of Maize Production Technologies in the Intermediate and Lowlands of Tanzania. *Journal of Agricultural and Applied Economics* 32(1): 35-47.

Kazianga, H. and Masters, W. (2002) Investing in Soils. Field bands and Micro-catchments in Burkina Faso. *Environmental and Development Economics*, 7(3):571-592.

Kimhi, A. (1994) Quasi maximum likelihood estimation of multivariate models: farm couples' labor participation. *American Journal of Agricultural Economics* 74(4): 828-835.

Kingdom of Lesotho (KoL). (1980) *National Papers on Environment and Development in Lesotho*.Government of Lesotho for the United Nation's Conference on Environment and Development, Maseru: Lesotho.

Kastens, T.L. and Dhuyvetter, K.C. (1999) *Management Factors: What is Important? Prices,Yield,Costs, or Technology Adoption?* Staff paper, Agricultural Economics Department, Kansas State University: Manhattan, Kansas.

Lesotho Mountain Research Group (LMRG). (1996) *Towards an Integrated perspective on Land Degradation in the Mountains of Lesotho.* A report on the Inaugural Meeting held at Malealea Lodge, Ministry of Environment, Maseru, Lesotho.

Maddala, G.S., 1992. *Introduction to Econometrics*. Macmillan Publishing Company: New York

Ministry of Agriculture (MOA). (1988) Soil Conservation Handbook for Lesotho, Conservation Division: Maseru: Lesotho.

Nkonya, E., Schroeder, T. and Norman, D. (1997) Factors affecting adoption of improved maize seed and fertilizer in northern Tanzania, *Journal of Agricultural Economics* 48:1-12.

Nowak, P.J. (1987) The Adoption of Agricultural Conservation Techniques: Economic and Diffusion Explanations. *Rural Sociology* 52(2): 208-210.

Ockwell, A.P. (1991) Characteristics of improved technologies that affect their adoption in semi-arid tropics of eastern Kenya. *Journal of Farming System Research and Extension* 2:6-18.

Rahm, M.R., and Huffman, W.E. (1984) The adoption of reduced tillage: the role of human capital and other variables. *American Journal of Agricultural Economics*. 66: 405-413.

Saha, A., Love, H.A. and Schwart, R. (1994) Adoption of emerging technologies under output uncertainty. *American. Journal of Agricultural Economics* 76: 836-846.

Shively, G.E. (1998) *Modeling Impacts of Soil Conservation on Productivity and Yield Variability: Evidence from a Heteroskedastic Switching Regression*. Selected paper at Annual meeting of the American Agricultural Economics Association, 2-5 August 1998, Salt Lake City, Utah.

White, H. (1980) A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskedasticity. *Econometrica* 48:721-746.