Soil Fertility Research for Maize and Bean Production Systems of the Eastern Africa Highlands

Proceedings of a Working Group Meeting

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PREFACE

This volume reports the proceedings of a working group meeting on soil fertility research for maize and bean production systems of the high altitude areas of Eastern Africa. The meeting was held in Thika, Kenya 1-4 September, 1992 with the objective of improving the effectiveness of research through prioritization of research topics, improved collaboration between concerned research institutions, better focussed training and specialization, and increased availability of resources for research.

The working group meeting was organized by the CIAT Regional Programme on Beans in Eastern Africa and the CIMMYT East African Cereals Programme. Funding for the meeting and this publication was provided by the United States Agency for International Development (USAID) and the Canadian International Development Agency (CIDA).

Further information on regional research activities on bean in Africa that are part of these projects is available from:

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Coordinateur Regional, CIAT, Programme Regional pour l'Amelioration du Haricot dans la Region des Grands Lacs, B.P. 259, Butare, Rwanda.

PUBLICATIONS OF THE NETWORK ON BEAN RESEARCH IN AFRICA

Workshop Series

No. 1. Beanfly Workshop, Arusha, Tanzania, 16-20 November, 1986.

No. 2. Bean Research in Eastern Africa, Mukono, Uganda, 22-25 June, 1986.

No. 3. Soil Fertility Research for Bean Cropping Systems in Africa, Addis Ababa, Ethiopia, 5-9 September, 1988.

No. 4. Bean Varietal Improvement in Africa, Maseru, Lesotho, 30 January - 2 February, 1989.

No. 5. Troisieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Kigali, Rwanda, 18-21 Novembre, 1987.

No. 6. First SADCC/CIAT Regional Bean Research Workshop, Mbabane, Swaziland, 4-7 October, 1989.

No. 7. Second Regional Workshop on Bean Research in Eastern Africa, Nairobi, Kenya, 5-8 March, 1990.

No. 8. Atelier sur la Fixation Biologique d'Azote du Haricot en Afrique, Rubona, Rwanda, 27-29 Octobre, 1988.

No. 9. Quatrieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Bukavu, Zaire, 21-25 Novembre, 1988.

No. 10. National Research Planning for Bean Production in Uganda, Makerere University, Kampala, Uganda, 28 January - 1 February, 1991.

No. 11. Proceedings of the First Meeting of the Pan-Africa Working Group on Bean Entomology, Nairobi, Kenya, 6-9 August, 1989.

No. 12. Ninth SUA/CRSP Bean Research Workshop and Second SADCC/CIAT Regional Bean Research Workshop. Progress in Improvement of Common Beans in Eastern and Southern Africa, Sokoine University of Agriculture, Morogoro, Tanzania, 17-22 September, 1990.

No. 13. Virus Diseases of Beans and Cowpea in Africa, Kampala, Uganda, 17-21 January, 1990.

No. 14. Proceedings of the First Meeting of the SADCC/CIAT Working Group on Drought in Beans, Harare, Zimbabwe, 9-11 May, 1988.

No. 15. First Pan-Africa Working Group Meeting on Anthracnose of Beans, Ambo, Ethiopia, 17-23 February, 1991.

No. 16. Cinquieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Bujumbura, Burundi, 13-17 Novembre, 1989.

No. 17. Sixieme Seminaire Regional sur l'Amelioration du Haricot dans la Region des Grands Lacs, Kigali, Rwanda, 21-25 Janvier, 1991.

No. 18. Conference sur Lancement des Varietes, la Production et la Distribution de Semaines de Haricot dans la Region des Grands Lacs, Goma, Zaire, 2-4 Novembre, 1989.

No. 19. Recommendations of Working Groups on Cropping Systems and Soil Fertility Research for Bean Production Systems, Nairobi, Kenya, 12-14 February, 1990.

No. 20. Proceedings of the First African Bean Pathology Workshop, Kigali, Rwanda, 14-16 November, 1987.

No. 21. Soil Fertility Research for Maize and Bean Production Systems of the Eastern Africa Highlands -- Proceedings of a Working Group Meeting, hika, Kenya, 1-4 September, 1992.

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INTRODUCTION

Beans (*Phaseolus vulgaris* L.) and maize (*Zea mays*, L.) are important food crops in the medium and high altitude zones of eastern Africa and are often grown in association. Productivity of maize and beans in these systems is often constrained by soil fertility problems. In some cases, the soil fertility problems are easily managed, such as in some high potential areas where nitrogen and phosphorus deficiencies can be alleviated with fertilizer use. In other cases, the soil fertility problems are difficult to manage due to the problem's complexity, inadequate technologies or inadequate infrastructure. Research on nutrient use efficiency, including fertilizer use efficiency, is important for areas with easily manageable problems in order to improve sustainability and increase profitability. The research needs for the low potential areas are often great and complex: the problem is often poorly understood; soils may be fragile and the problem complex; input use is not profitable; and appropriate solutions are variable.

While research needs are great, resources available for this research are scarce. To improve the effectiveness of research in increasing production in a sustainable matter, available resources must be used more efficiently or the availability of resources must be increased.

The Centro Internacional de Agricultura Tropical (CIAT) and the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) organized this working group meeting to address issues of soil fertility research in the Eastern Africa Highlands. The working group consisted of bean agronomists, maize agronomists, soil scientists and socio-economists from the national research organizations of Ethiopia, Kenya, Tanzania and Uganda. Regional staff of CIAT, CIMMYT and the International Center for Research on Agroforestry (ICRAF) and staff of Tropical Soils Biology and Fertility (TSBF) also participated.

The working group sought means to improve the efficiency of resources available for research as well as to increase these resources so that research might have a greater impact on production and soil management. Problems and their probable solutions were reviewed and prioritized. Alternative research approaches, including approaches with greater farmer participation, were considered. Collaboration between the various institutions and programmes involved in soil fertility research for maize-bean systems in the highlands of eastern Africa was addressed. The need for common strategies and methods, and for specialization and training, was discussed. In order to solve problems or fill information gaps of most concern to the participants, research topics were identified and preparation of proposals initiated.

This document is a compilation of the papers presented during the working group meeting and the results of the working sessions.

FARMER PARTICIPATION IN SOIL MANAGEMENT RESEARCH IN MATUGGA VILLAGE (MPIGI DISTRICT) OF UGANDA -- AN ALTERNATIVE APPROACH

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INTRODUCTION

Human agricultural activities should basically aim at exploiting the environment efficiently. If not properly planned, these activities can lead to soil degradation. Low soil fertility imposes serious constraints on crop productivity, even on fertile soils of Uganda. Soil fertility continues to decline due to severe erosion, overgrazing, cultivation on marginal lands and exportation of nutrients without adequate replacement. Such degradation is most prevalent in the less developed countries where agriculture is mainly by small scale farmers producing mainly for subsistence amidst mounting population pressure. Conventional agricultural research has, in most cases, tended to greatly benefit the economically well-off farmers in these countries, who make up a small minority. For example, with all the resources and time put into research on inorganic nitrogen use and crop response in Africa, the average application rate for this nutrient is a meager 5kg/ha (Hauck, 1988).

But through generations of observations as well as trial and error, farmers have learnt a great deal about their soils which relate to colour, soil depth, crop performance, existing natural vegetation etc. Likewise, management of these locally different types of soils may differ in as far as trying to sustain crop production is concerned.

Therefore, if research is to adequately address farmers' needs, it has to consider their traditional knowledge as very valuable. Farmers have a role in problem identification, determination of causes, evaluation of potential solutions, and in the development and implementation of a research plan. Without their involvement, there is a greater probability that researchers will err in prioritization and selection of problems for research, in identification of causes and most likely solutions, or in deciding how and where best to conduct the research. Lightfoot *et al.*, (1987) indicated the importance of involving farmers in identifying, analyzing and solving systems problems in the Philippines. Ravnborg (1990) showed the need to involve farmers in soil management discussions in order to set priorities for research work in Tanzania. The involvement of farmers in research work have also been emphasized by Ashby (1990), Fujisaka (1989, 1990), and Tripp and Woolley (1989). All have shown that a better understanding of farmers' problems in managing their soils and production constraints has to start with serious farmer involvement.

Therefore, a starting point of research on soil management is to understand the farmers' present management practices; identify problems together with the farmers; understand causes and solutions to these problems; and set priorities for future research work to solve the problems.

Tripp and Woolley (1989) suggested a six step format in identifying factors for experimentation and Lightfoot *et al*, (1987) proposed a three step approach in identifying problems affecting farmers. This paper reports preliminary findings about a study done in Matugga village (Mpigi district, Uganda) following the format by Tripp and Woolley (1989). The objectives of the study were:

(i) to understand the predominant farming systems in the area;

(ii) to identify farmers' problems (particularly soil-related) as to lay a foundation for research towards improving the present soil management practices;

(iii) to identify relationships between the farmers perceptions, knowledge, and practices relating to soil fertility; and

(iv) to develop a research plan for future research in the area.

MATERIALS AND METHODS

The study was conducted in Matugga village, Uganda (latitude 0.44 N, longitude 35.5 E, and altitude 1200 masl)) with a total of twenty six farm units selected randomly. The selected farmers were subjected to open-ended, brief interviews for passport and soil related information (Appendix 1). Farmers were encouraged to relate the locally identified soil types to suitability of particular crops. Furthermore questions about soil management practices were asked.

The holdings were revisited to collect composite soil samples and to determine soil depth using a soil auger from each of the identified soil types in March, 1992. The pH of the top soil (water saturation method), wet soil colour (using a Munsell colour chart), and texture (by feel) were determined for all soil samples. In addition a complete analysis including organic matter (organic carbon * 1.7; Walkley and Black oxidation), available P, K and Ca (Ammonium lactate extraction, pH 3.8; Foster, 1971) was carried out for the "problem" soils, namely "Lunyu" and "Zibugo", as well as for some "Lidugavu" soils (control).

Participant farmers were subsequently invited for a series of meetings to further identify agricultural problems, map their area and draw the predominant soil catena. The identified problems were ranked according to order of importance by open voting. Farmers participated in diagramming the causes of the problems and identification of potential solutions. A research plant was prepared for experimentation to begin in September 1992.

RESULTS AND DISCUSSION

Farmers' perception of their soils and observations

Of the farmers interviewed, 69% were women and in 4% of the cases the husband and wife were jointly interviewed. The majority of the farmers interviewed (69%) indicated to be the head of the household.

The average farm size was 6.1 acres ranging from 1 to 18 acres. Regarding land ownership, 58% of the farmers questioned indicated to have no land title ("Kibanja" type of ownership, land inherited), whereas 39% held a land title ("Mailo" type of ownership). Lease of land was reported in one case only. Only 38% of the farmers had livestock ranging from 1 to 7 head of cows and 2 to 9 head of sheep or goats. On the average, there was 2.6 cows and 3.1 goats or sheep per farm having livestock.

Fifteen soil types were identified by the farmers interviewed. Table 1 lists the soil types in the Luganda vernacular with approximate translations. The criteria used by farmers for soil classification were soil color (5 types), texture (5 types), fertility status (3 types), vegetation (1 type), and consistency (1 type). On a single farm, up to five different soil types were identified. On the average there were 2.3 soil types per farm. The criteria were very similar to those found by Fujisaka (1989) who listed slope, color, fertility, texture, acidity, and friability as criteria used by farmers for soil classification in the Philippines.

The predominant soil types were "Lidugavu", "Luyinjayinja", "Limyufu", and "Lunyu" which together accounted for 67% of the fields surveyed. "Lunyu" and "Zibugo" accounted for 16% of the fields and were classified as "problem" soils associated with low soil fertility.

Table 1. Farmers' soil classification and observation of soils at Matugga.

Soil type (vernacular)	Translation	Occurrence Total	% of farms	Wet soil color	Soil depth (cm) Topsoil Range	Topsoil Mean	Subsoil Range	Topsoil pH (H_2O) Range	Mean
Lidugavu	black/ dark	13	50	dark reddish brown or very dark grey	20-55	28	31->90	5.1-6.7	6.0
Luyinjayinja	gravelly	12	46	dark reddish brown or very dark grey	8-45	24	25->90	4.2-6.4	5.3
Limyufu(yufu)	red(dish)	8	31	dark reddish brown, reddish brown, dusky red or yellowish red	15-35	24	>90	5.0-6.4	5.4
Lunyu	salty/ infertile black	7	27	dark reddish brown very dark grey or	17-35	26	40->90	4.8-5.9	5.2
Lukusikusi	brownish	5	19	dark reddish brown or reddish brown	25-53	32	>90	5.3-6.0	5.5
Lusenyusenyu	sandy	3	12	dark reddish brown	28-40	29	45-85	4.7-5.5	5.0
Zibugo	dead, kills crops	3	12	dark reddish brown	17-40	30	40->90	5.0-5.6	5.3
Gimu	fertile	2	8	dark reddish brown	25-28	26	>90	5.4-5.5	5.4
Bumba (Tosi)	clay/muddy black	2	8	very dark grey or	30-35	32	>90	4.0-4.8	4.4
Lwazi	rocky	1	4	(not determined)	30	--	>90	5.4	--
Lyakibira	forest soil	1	4	dark reddish brown	20	--	>90	5.4	--
Kikofu	dark grey	1	4	dark reddish brown	30	--	80	5.0	--
Kakumeme	black/red compact	1	4	dark reddish brown	27	--	>90	5.6	--
Ligonvu	soft	1	4	dark reddish brown	30	--	>90	5.6	--
Kiwugankofu	sandy loam, silty	1	4	very dark grey	45	--	>90	6.0	--

The typical soil catena for Matugga as described by the farmers is shown in Appendix 2. Soils on the hilltop were generally described as stony and shallow with a high infiltration rate but a low water-holding capacity. "Lunyu" soils are common on eroded sites. Other soil types frequently occurring are "Luyinjayinja" and "Kiwugankofu". Soils on the hillslope were described as being deeper than on the hilltop with better soil moisture. Generally, all soil types except the clayey "Bumba" type were found on the hillslope with the more fertile soils such as "Lidugavu" and "Gimu" being on the lower slopes (foothill). The valley soils generally have a dark top soil, a clay subsoil and are underlain with sand. The valley soils were described as difficult to till when wet.

When farmers were asked to enumerate good or bad soil characteristics they usually indicated high or low crop yield as the good or bad soil feature, respectively. Further probing ("What soil characteristics are responsible for the good or bad crop yield?") was necessary to get the farmers' perception of the characteristics related to the soil itself and not the crop. The most frequently mentioned soil characteristic was nutrient supply followed by water holding capacity (Table 2). Other important soil characteristics cited were soil depth, infiltration rate, erodibility, compaction and gravel/stones. Tables 3 and 4 list cited soil characteristics for the different soil types. (Only the soil types mentioned at least three times were taken into consideration). Apart from "Gimu" (fertile), 85% of the "Lidugavu" and 80% of the "Lukusikusi" soils, but none of the "Lunyu" and "Zibugo" soils, were classified as soils having a good nutrient supply. The latter two were most frequently considered to be soil types with a low nutrient supply

Table 2. Positive and negative soil characteristics cited on one or more soils by 26 farmers interviewed in Matugga

Soil characteristics	% of farmers Positive	Negative
Nutrient supply	69	62
Water holding capacity	27	46
Erodibility	12	23
Soil depth	23	12
Infiltration rate	15	8
Compaction	4	19
Gravel/stones	–	11

Table 3. Positive soil characteristics for major soil types mentioned by the farmers interviewed in Matugga.

Soil type	Number of times mentioned	Positive soil characteristics mentioned (Frequency (%) of mention)				
		Nutrient supply	WHC[1]	Soil depth	IR[2]	Erodibility
Lidugavu	13	85	23	23	0	8
Luyinjayinja	12	25	17	0	0	0
Limyufu	8	38	13	0	38	25
Lunyu	7	0	0	14	0	0
Lukusikusi	5	80	20	0	0	0
Lusenyusenyu	3	33	33	0	0	0
Zibugo	3	0	0	33	0	0

Table 4. Negative soil characteristics for major soil types mentioned by the farmers interviewed in Matugga.

Soil type	Number of times mentioned	Negative soil characteristics mentioned (Frequency (%) of mention)					
		Nutrient supply	WHC[1]	Soil depth	IR[2]	Erodibility	Gravel Stones
Lidugavu	13	15	8	0	8	0	0
Luyinjayinja	12	33	58	17	0	25	42
Limyufu	8	50	38	0	0	13	0
Lunyu	7	57	43	0	29	14	0
Lukusikusi	5	0	60	0	0	0	20
Lusenyusenyu	3	33	67	0	0	0	0
Zibugo	3	67	0	0	0	0	0

[1] WHC = Water-holding capacity
[2] IR = Infiltration rate

A majority of farmers indicated a low water holding capacity for "Lunyu", "Luyinjayinja", Lukusikusi" and "Lusenyusenyu". None of the soils were frequently mentioned to have a high water holding capacity.

Soil depth was not a criteria used by farmers for soil classification. It was mentioned as a positive characteristic for 23% of the Lidugavu soils and as a negative characteristic for 17% of the stony "Luyinjayinja" soils. For 42% of the "Luyinjayinja" soils the occurrence of gravel and stones was mentioned as negative feature.

The farmers easily listed the preferred crops for the different soil types. Generally all the crops were preferred on the "Lidugavu" soils which were classified as soils having a good nutrient supply (Table 5). "Lunyu" and "Zibugo" soils had the highest percentage of crops mentioned to be unadapted, whereas none of the crops were cited to be unadapted on the sandy "Lusenyusenyu" soils (Table 6).

Cooking banana was preferred on 39% of the "Lidugavu" and on 40% of the "Lukusikusi" soils but it was never preferred on "Lunyu", "Zibugo" and "Lusenyusenyu". It was cited as unadapted on 71% of the "Lunyu" and on 67% of the "Zibugo" soils. These findings underline the fact that cooking banana, the main staple food, has high priority on the more fertile soils such as "Lidugavu" and "Lukusikusi".

Cassava was a highly preferred crop on all of the soil types except "Lukusikusi", although the reason for this exception was not determined. It was cited as an unadapted crop on some of the "Luyinjayinja", "Lunyu" and "Zibugo" soils. Cassava grows relatively well on acid and highly infertile soils (Howeler, 1981). Therefore it does not have a high priority to be grown on the most fertile soils.

Maize and sweet potato were preferred crops on all the soil types except "Lunyu" and "Zibugo". All three farmers having "Zibugo" considered sweet potato as an unadapted crop for this soil type.

Beans was a preferred crop on 54% of the "Lidugavu" soil type but was never cited as a preferred crop on "Lukusikusi" and "Lusenyusenyu".

Groundnut was cited as a preferred crop only on 17 % of the "Luyinjayinja" soils but as an unadapted crop on all of the "Zibugo" soils.

Soil color was determined using the HUE 5YR Munsell color chart for 95% of the soils. The predominant soil color was dark reddish brown accounting for 70% of the soils surveyed (Table 1). Other soil colors found were very dark grey (13%), reddish brown (10%), black (3%), yellowish red and dusky red (2% each). The soil color generally corres- ponded with the soil color for which farmers named the soils. The top- soil texture of the surveyed fields was sandy clay loam, sandy loam and clay loam in 54%, 33% and 13% of the cases, respectively. All "Lukusi- kusi", 54% of the "Lidugavu", and 50% of the "Limyufu" soils were sandy clay loams whereas 59% of the "Luyinjayinja" were sandy loams. All soils were well-drained except the clayey "Bumba" soil located in the valley which had a moderate to poor drainage.

Table 5. Preferred crops on major soil types as mentioned by farmers interviewed in Matugga.

Soil type	No. of times mentioned	Preferred crop (% of times mentioned)					
		Cooking banana	Cassava	Maize	Sweet potato	Beans	Groundnut
Lidugavu	13	39	54	46	39	54	0
Luyinjayinja	12	17	50	42	25	33	17
Limyufu	8	25	63	13	25	38	0
Lunyu	7	0	57	0	0	29	0
Lukusikusi	5	40	0	20	20	0	0
Lusenyusenyu	3	0	33	67	33	0	0
Zibugo	3	0	33	0	0	33	0

Table 6. Unadapted crops on major soil types as mentioned by farmers interviewed in Matugga.

Soil type	Number of times mentioned	Unadapted crops (% of times mentioned)					
		Cooking banana	Cassava	Maize	Sweet potato	Beans	Groundnut
Lidugavu	13	15	0	0	23	0	8
Luyinjayinja	12	17	17	8	17	0	0
Limyufu	8	25	0	0	0	0	13
Lunyu	7	71	14	28	43	14	0
Lukusikusi	5	0	0	20	0	20	20
Lusenyusenyu	3	0	0	0	0	0	0
Zibugo	3	67	67	33	100	33	100

The topsoil depth ranged from 8 cm for "Luyinjayinja" to 55 cm for "Lidugavu". On the average, topsoil depth was 24 to 32 cm. The range of the subsoil depth was from 25 cm for "Luyinjayinja" to over 90 cm for the majority of the soils. However, as there was a wide range in both top and sub soil depth for each soil type identified, soil depth did not explain farmers' classification of soils.

In respect of the topographic position 83%, of the fields were located on a hillside, 10% on the hilltop and 7% in the valley. The slope of the fields on the hillsides ranged from 7% to 19%.

The pH of the top soil was generally below 6.0. Only "Lidugavu", "Luyinjayinja" and "Limyufu" occasionally reached near neutral pH values. The most acid soil was the "Bumba" valley soil having pH as low as 4.0 to 4.8.

The soil analysis of the "Lunyu" and "Zibugo" soils showed low levels for P, K and Ca (Table 7). Compared with the "Lidugavu" soil, the differences were significant. These results strongly confirm the farmers' perception of "Lunyu" and "Zibugo" being infertile soils with low crop yields.

Table 7. Mean values for pH, soil organic matter, available P, K and Ca for "Lunyu", "Zibugo" and "Lidugavu" soils at Matugga.

Soil type	pH	OM (%)	P (ppm)	K (me/100g)	Ca (me/100g)
Lunyu	5.0	2.5	7	0.20	2.50
Zibugo	5.2	3.7	14	0.41	3.84
Lidugavu	6.2	3.8	50	1.61	6.99
Mean	5.5	3.3	24	0.74	4.44
LSD ($P<0.05$)	0.89	n.s.	17.9	0.56	2.45

Recommended critical values for Ugandan soils (Foster, 1971):

- pH 5.2
- Organic matter 3%
- P 5 ppm
- K 0.34 me/100g
- Ca 1.75 me/100g

Hand hoe tillage, often combined with deep tillage, was mentioned by 92% of the farmers as their current land preparation practice (Table 8). Thus only 8% of the farmers were using a tractor- or oxen-drawn plow.

Mulching was practiced by 50% of the farmers interviewed, primarily on the banana crop. Manure use was mentioned by 27% of the farmers but only 50% of the livestock owners said they used manure. Generally the manure is applied to the banana plantations which are located near the homesteads (problem of transport). Only 4% of the farmers said they used inorganic fertilizers.

Burning and incorporation of crop residues were each cited by 12% of the farmers. Incorporation refers to the practice where the crop residues of the previous crop are left in the field and incorporated during land preparation for the following crop. Difficulty in incorporating the crop residues was the most frequently mentioned reason for burning it.

Fallow as a current management practice was indicated by 68% of the farmers. It is the main practice to restore soil fertility.

The most frequently mentioned preferred management practices were deep tillage (35%), fertilizer application (35%) and use of farmyard manure (27%). Lack of funds, labour, transport and manure were the main limitations to use of these practices.

Intercropping is practiced by 77% of the farmers on one or several fields. The banana-based systems accounted for 59% of the fields intercropped. The most frequently mentioned crops in the banana intercrop were cassava (26%), beans (21%), both cassava and beans (26%) and coffee (26%). Other intercropping systems indicated were cassava and beans (8%), cassava and maize (8%), sweet potato and beans (4%), sweet potato and groundnut (4%).

Table 8. Current and preferred management practices as mentioned by farmers interviewed in Matugga.

Management practice	Current (%)	Preferred (%)
Hand hoe tillage	92	0
Mulching	50	8
Deep tillage	46	35
Manure use	27	27
Fallow	23	19
Grass strips/pasture	15	12
Incorporation of residues	12	12
Burning of residues	12	0
Conservation bands	12	12
Ash application	8	4
Minimum tillage	8	0
Plow	8	4
Fertilizer application	4	35

No particular system of crop rotation prevailed. The following sequences of crops succeeding a fallow could be recognized (numbers in () indicate the number of fields).

(i) Fallow - intercropped cooking banana (5)

(ii) Fallow - maize (9) - cooking banana (3)/cassava (3)/groundnut (2)/vegetables (1)

(iii) Fallow - cassava (8) - cooking banana (5)/sweet potato (2)/groundnut (1)

(iv) Fallow - sweet potato (6) - cassava (3)/cooking banana (1)/groundnut (1)/beans (1)

Identification of factors for experimentation

At meetings with farmers, problems related to soils were identified and ranked as shown in Table 9. The most important problems mentioned were soil erosion, low water holding capacity and low soil fertility. The importance of these three problems corresponds with the results from the individual interviews where the same problems were also most frequently mentioned.

Particular emphasis was given to low soil fertility (LSF) and erosion. (Soil erosion is a problem in itself but also a cause for LSF). The causes of LSF as perceived by the farmers were diagrammed as shown in Appendix 3. The main causes of LSF identified by the farmers were: failure to use better soil management practices (i.e. crop rotation, use of fertilizer and/or farmyard manure, planting of leguminous crops); lack of knowledge about soil conservation methods; and nutrient losses due to leaching, burning, erosion, or removal of crop residues.

The following solutions were proposed and are listed in order of importance as perceived by the farmers:

(i) planting of grass strips and/or hedgerows as conservation bands;

(ii) use of green manure crops, especially leguminous crops (e.g. *Crotalaria* sp.);

(iii) more efficient use of farmyard manure; and

(iv) planting of nutrient efficient crops/cultivars.

Table 9. Problem identification and ranking (open vote method) by farmers in Matugga.

Rank	Problem
1	Soil erosion
2	Low water holding capacity
3	Low soil fertility
4	Weeds
5	Termites and ants
6	High percentage of sand
7	High percentage of gravel
8	Steep slope
9	Soil stickiness
10	Water infiltration
11	Poor internal drainage
12	Shallow soil
13	Poor root growth
14	Soil compaction

Grass strips/hedgerows. Grass strips are effective in erosion control and in addition provide fodder for livestock. A few farmers indicated success in using grass strips of elephant grass (*Pennisetum purpureum*) or *Paspalum* spp. Not all the farmers understood the importance of grass strips but were interested to start experimentation. The difficulty of procuring planting material was a major concern.

Planting of hedgerows using leguminous tree species such as *Calliandra, Sesbania* and *Leucaena* is effective to control erosion and improves soil fertility by nitrogen fixation and by maintenance of organic matter. In addition, it provides wood and fodder for livestock. On the other hand, the establishment and maintenance of hedgerows requires a high level of management. Nursery plants have to be provided to the farmers.

Green manure crops. On-farm trials with *Crotalaria ochroleuca* grown as green manure crop have shown that it can be easily established by farmers either in sole crop or intercropped with maize or beans. Preliminary results indicated a substantial yield increase for maize planted after a crop of *Crotalaria*.

Farmyard manure. Provided farmyard manure is available, it is cheaper than inorganic fertilizer and in addition it contributes towards the maintenance/improvement of soil organic matter. The farmers already using farmyard manure wished to know more about storage techniques, time and mode of application of farmyard manure.

Planting of nutrient efficient crops/cultivars. While research on nutrient use efficient crops and cultivars is underway, farmers were advised to take into consideration the soil fertility when the crop is chosen.

CONCLUSIONS

The need for farmer participation in identifying factors for experimentation has long been acknowledged. A variety of approaches for assessing farmers circumstances and problems exist. The method of individual interviews combined with farmers meetings for exploring farmers knowledge of their soils has been successfully applied in this study. Several conclusions can be drawn from the results obtained.

(i) Farmers have considerable knowledge about their soils. Farmers perception of specific soil characteristics exists but soil problems are rather described by crop response than by the responsible soil characteristics itself. Therefore, specific questions and further probing was necessary to get the farmers perception of the soils itself.

(ii) Farmers are generally aware of the causes of low soil fertility. In some cases the possible solutions are known but application is limited by economic constraints. Thus priority has to be given solutions with low capital requirements.

(iii) The chosen approach was a learning process for both farmers and researchers. Through discussions with individual farmers on the spot as well as at the meetings, a collaborative relationship could be established which is crucial for a fruitful work. The field visits allowed discussions of specific problems on the spot and to compare farmers perception of the soils with our own observations.

SUGGESTIONS

Based on the results of this study, several topics for future research work are suggested.

Hedgerows. In collaboration with AFRENA (Agroforestery Network for Africa), on-farm trials will be conducted to evaluate tree species such as *Sesbania, Calliandra* and *Leucaena* for adaptation on the infertile soils identified at the survey, namely on the "Lunyu" and "Zibugo" soils. Feasibility of hedgerows will be evaluated on more productive soils as well. The long term objective is the establishment of hedgerows on all farms where interest is shown.

Green manure crops. On-farm trials with green manure crops e.g. *Crotalaria* will be carried out on soils of moderately low to low fertility.

Study of nutrient fluxes. Major nutrient fluxes within and to and from representative farms will be estimated following the procedures given in Appendix 4.

As the approach followed in this study proved to be valuable a similar approach may be useful for other areas.

Further discussions with the farmers are necessary to answer certain questions which arose from the analysis of the interviews (e.g. why are beans mentioned to be unadapted on the "Lukusikusi" soils which were mostly cited to be fertile?). Combined with the nutrient flux study, a complete picture of nutrient movement to and from the farms will be established.

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APPENDIX 1: Questionnaire for soil and soil management survey in Matugga (Mpigi district)

BACKGROUND INFORMATION

Farmers name ______________________________ District _______________________

County _____________________ Interviewer __________________ Date __________________

Head of household: Y/N; Sex: M/F; Age:_____

No. of cattle _______ Goats/sheep _____

Mailo (Arable _____ A Non-arable____ A);

Leased (Arable ____ A Non-arable____ A);

Kibanja(Arable ____ A Non-arable____ A);

DRAW TRANSECT OF FARM AND/OR RECORD ADDITIONAL INFORMATION BELOW

Observed soil characteristics

Soil Name						
Soil pH						
Top soil depth						
Sub-soil depth						
Soil color						
Soil texture						
Slope						
Topographic position						
Yrs. since fallow						
Drainage						

Farmers' perceptions of the soil/land:

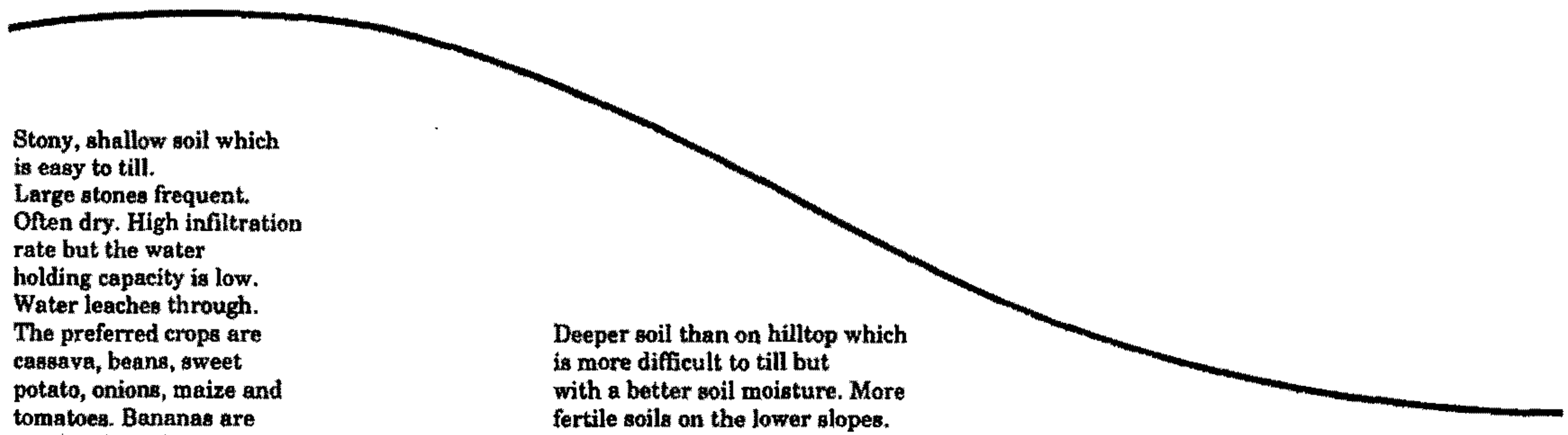
Good soil characters						
Bad soil characters						
Preferred crops						
Unadapted crops						
Current managem pract.						
Prefer managem pract.						
Recent crop sequence						

Key to soil characteristics: 1()=pH; 2()=color; 3=erodibility; 4=infilitration rate; 5=water holding capacity; 6=nutrient supply; 7=aggregate stability; 8=compaction; 9=cracking; 10=hardpan; 11=tilt; 12=stickiness;13=internal drainage; 14=external drainage; 15=organic matter; 16=P fix.; 17=%clay; 18=%silt; 19=%sand; 20=%gravel/stones; 21=root growth; 22=termites; 23=other insects; 24=vegetation; 25 = slope; 26=erodibility; 27=depth; 28=cloddiness;

Key to crops:1=maize; 2=finger millet; 3=cooking banana; 4=brewing banana; 5=sweet potato; 6=Irish potato; 7=beans; 8=g'nuts; 9=soybeans; 10=cowpeas; 11=cotton; 12=simsim; 13=sunflower; 14=trees; 15=pasture; 16=grass(cut); 17=vegetables; 18=cassava; 19=R. coffee; 20=A. coffee; 21=sorghum; 22=onions; 23=tomatoes; 24=capsicum; 25=solanum; 26=

Key to management practices: 1=plow; 2=hand hoe tillage;3=disk harrow; 4=deep tillage; 5=fertilizer use; 6=liming; 7=incorpor. of residues; 8=mulching; 9=manure use; 10=minimum tillage; 11=agrofor.; 12=green manures; 13=burning of residues; 14=ash applic; 15=herbicide use; 16=cover crop; 17=fallow;

Farmers' description of a typical soil catena at Matugga

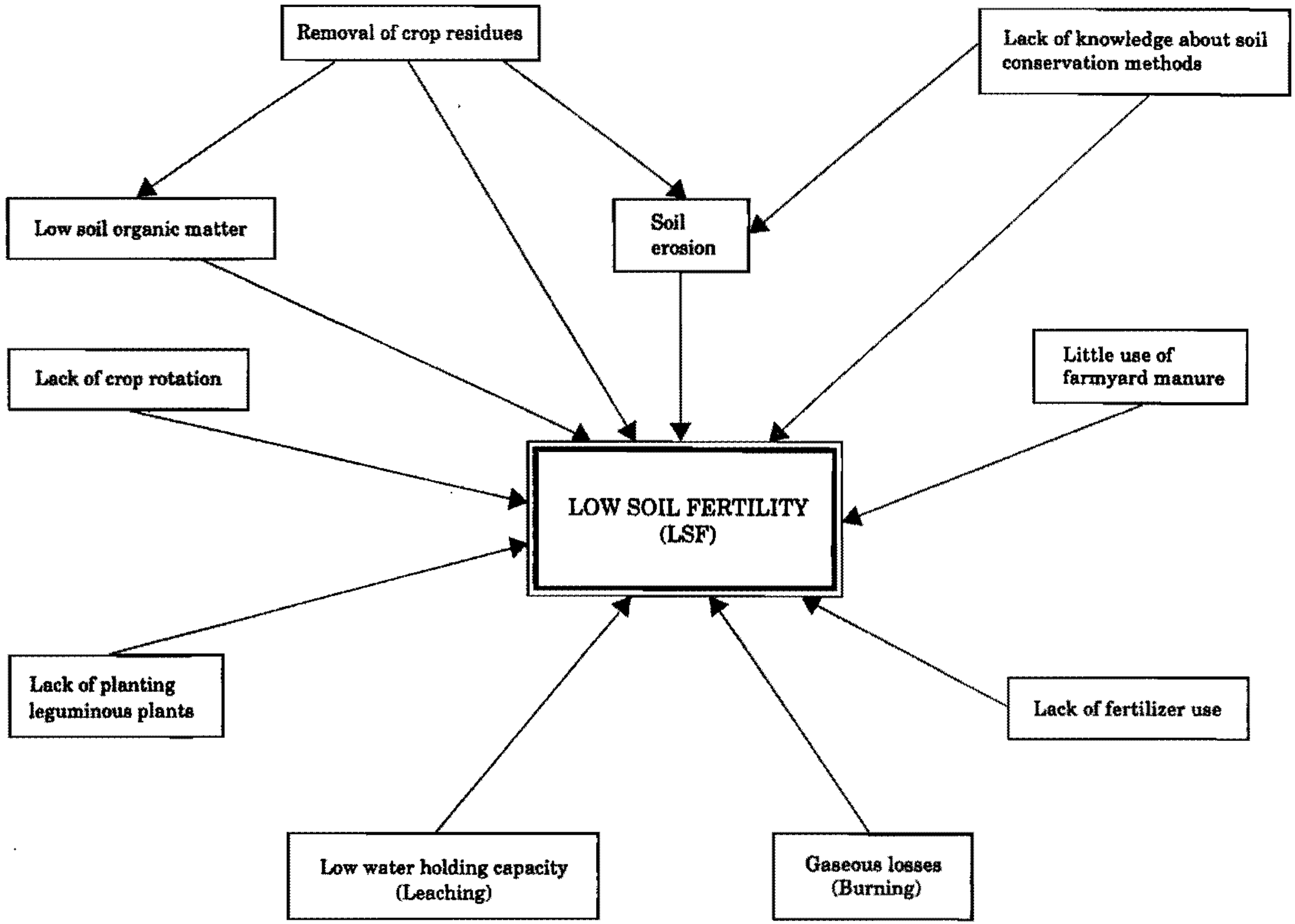


Stony, shallow soil which is easy to till. Large stones frequent. Often dry. High infiltration rate but the water holding capacity is low. Water leaches through. The preferred crops are cassava, beans, sweet potato, onions, maize and tomatoes. Bananas are poorly adapted. Soil types: Kiwugankofu, Luyinjayinja Lunyu. The latter is common on eroded sites. Estimated mean land cost is UShs. 50,000 per acre.

Deeper soil than on hilltop which is more difficult to till but with a better soil moisture. More fertile soils on the lower slopes. Preferred crops are banana, cassava, beans, maize, sweet potato and tomato. Manure is sometimes applied. Homesteads are concentrated on the lower slopes. Soil types: Limyufu, Luyinjayinja, Lidugavu, Lukusikusi. Estimated mean land cost is UShs. 100,000 per acre.

The valley soils generally have a dark top soil, a clay sub soil and are underlain with sand. Difficult to till when wet. Good fertility due to organic matter. The best grazing land. Preferred crops are cabbage, sweet potato, eggplant, dodo, yams and sugarcane. Too wet and too sandy for banana. More important than previously to get dry season production. Soil types: Bumba (Tosi), Lusenyusenyu. Estimated mean land cost is UShs. 200,000 per acre.

APPENDIX 3: Causes of low soil fertility (LSF) as perceived by farmers



APPENDIX 4: Procedures for estimating nutrient fluxes

1. Fertilizer—ask farmer the amount applied for the given season to a piece of land. Measure the land area and calculate the amount of each element applied.

2. Manure—ask the farmer to estimate the amount applied. If all applied to one field in small, frequent applications, it may be necessary to have the farmer accumulate the manure for a week and determine the dry wt. accumulated. From this, the amount for a longer period of time can be estimated.

If removal of manure is infrequent, considerable biomass and nutrient loss may occur due to decomposition, leaching and volatilization. These nutrient losses should be considered lost to the farm unless deep rooted plants are recovering some of the leached nutrients.

Samples for analysis of nutrient content should be obtained for manure which is applied to the fields un-decomposed as well as for decomposed manure, if both are applied by the farmers.

3. Rainfall—precipitation should be measured. Occasionally, the rainfall should be sampled and the nutrient content determined for a composite of the samples. In-flow of nutrients in the rainfall can then be calculated.

4. Household (H/H) refuse—this might be estimated by asking the farmers to accumulate their refuse for a period of time, maybe one week, obtaining its dry weight and sampling for nutrient content. If much variation in the content and amount of refuse is expected during a year, than data may be needed for several separate time periods.

5. Ash—similar as for H/H refuse.

6. Mulch—if bundles of grass are applied, number of bundles, their average weight and nutrient content are needed to estimate the amount of nutrients applied. More difficult to measure will be crop stover that is applied as mulch, e.g. bean plant residues. Farmers may be asked to wait with the transport of such materials to the field until the quantity has been determined.

7. Nitrogen fixation—we can not afford to measure this in each of the fields. One option is to use estimates from the literature for the various cropping associations. The other is to measure the fixation with a common variety in the main cropping associations at one location.

8. Grain, tubers, fruit and stover—the amount of material harvested from each field will be estimated. The farmers should be able to measure and record the volumes of grain and tubers harvested. Banana bunch height can be recorded by farmers and the weight estimated from the height. Stover might be put aside until the researcher can measure it. The nutrient contents of the various harvested materials will be needed (a composite sample of sub-samples from the various farms can be used to obtain one set of concentrations for each product).

9. Burning of residues—the biomass involved will be difficult to determine as the residues are burnt in small scattered piles. A simple method would be to ask the farmer to save a 3-4 representative heaps and to count the total number of heaps. The dry weight of the representative heaps can be used to estimate the total biomass burnt.

In burning, the N and S are lost, but much of the P and cations remain in the ash and are subsequently incorporated into the soil. Some of the P and cations are lost in smoke however. These loses should be estimated by burning a sample of residues for which the weight and nutrient content is known and then determining the nutrients remaining in the ash. The loss of nutrients in the smoke is likely to be affected by the heat of the fire and the strength of the updraft created.

10. Erosion losses—to accurately measure the soil and nutrient losses from whole fields would be expensive, time consuming and difficult to justify. An alternative is to use models (eg, the Universal Soil Loss Equation (USLE) or the WEPP model) to estimate these losses. USLE only estimates soil removed while WEPP estimates soil removal and deposition. The accuracy of the models can be verified by measuring the erosion losses from plots in the fields where the soil lost is collected in trenches lined with polyethylene.

11. Leaching losses—technology is not available for accurately measuring leaching losses in the field, especially on clay soils. Models based on results of studies of leaching in undisturbed profiles and on theory are likely to give better estimates of leaching losses than we can hope to measure.

12. Gaseous losses—these are difficult to measure on a whole field basis and we can probably get more reliable estimates using models.

13. Human wastes—the quantities of biomass and nutrients involved can be estimated using published estimates of per capita output. The fate of the nutrients involved may be difficult to estimate. Losses from latrines will include gaseous losses of N and leaching of N and other nutrients. Leaching be may little in cases of strata of heavy clay contents. In cases of shallow latrines, many of the nutrients will be recovered by deep rooted plants and returned to the production system, but the recycling of the nutrients will be delayed. Adequate estimates may be available in the literature to estimate the various fluxes involved.

14. Purchased and marketed produce—the farmers may be asked to record all movements of produce to and from their farms.

MEASUREMENT OF NUTRIENT FLUXES TO AND FROM FARM

Farmer's name____________________ Season ____________

Measured flows to farm

	Fertilizer	Manure (t/ha)	Rain (mm)	Ashes (t/ha)	Mulch (t/ha)	N fix.
kg N/ha	____	____	____	____	____	____
kg P/ha	____	____	____	____	____	____
kg K/ha	____	____	____	____	____	____

Food, wood, etc. purchased

	____ (kg)	____ (kg)	____ (kg)	____ (kg)	____ (kg)	____ (kg)	Total imported
kg N/ha	____	____	____	____	____	____	____
kg P/ha	____	____	____	____	____	____	____
kg K/ha	____	____	____	____	____	____	____

Nutrients removed from the farm

Food, wood, etc. sold

	____ (kg)	____ (kg)	____ (kg)	____ (kg)	____ (kg)	____ (kg)
kg N/ha	____	____	____	____	____	____
kg P/ha	____	____	____	____	____	____
kg K/ha	____	____	____	____	____	____

	Burning of residues	Erosion losses	Leaching losses	Gaseous losses	Total losses	Balances (gains - losses)
kg/ha	____	____	____	____	____	____
kg N/ha	____	____	____	____	____	____
kg P/ha	____	____	____	____	____	____
kg K/ha	____	____	____	____	____	____

MEASUREMENT OF NUTRIENT FLUXES FOR FIELDS

Farmer's name_______________ Season _______________ Soil_______________

Initial soil test vales

% Clay_____ % Silt_____ % sand_____ Soil pH (1:1 H_2O) _____ Soil pH (KCl)_____

%OM _____ % light OM _____ NO_3_____ NH_4_____ P(Olsen?)_____ Ex. K _____

Slope _____ Slope length _____ Planting date_____ Aggreg. stab._____

End of season

%OM _____ % light OM _____ NO_3_____ NH_4_____ P(Olsen?)_____ Ex. K_____

Estimated nutrient fluxes for N, P, K

Measured flows to fields

	Fertilizer	Manure (t/ha)	Rainfall (mm/season)	H/H refuse (t/ha)	Ashes (t/ha)	Mulch (t/ha)	N fix.	Total in
kg N/ha	_____	_____	_____	_____	_____	_____	_____	_____
kg P/ha	_____	_____	_____	_____	_____	_____		_____
kg K/ha	_____	_____	_____	_____	_____	_____		_____

Nutrients removed from the field

	_____ (grain/ fruit)	_____ (grain/ fruit)	_____ (grain/ fruit)	_____ stover export	_____ stover export	_____ stover export	Burning of residues
kg / ha	_____	_____	_____	_____	_____	_____	_____
kg N/ha	_____	_____	_____	_____	_____	_____	_____
kg P/ha	_____	_____	_____	_____	_____	_____	_____
kg K/ha	_____	_____	_____	_____	_____	_____	_____

	Erosion losses	Leaching losses	Gaseous losses	Total losses	Balances (gains - losses)
kg/ha	_____				
kg N/ha	_____	_____	_____	_____	_____
kg P/ha	_____	_____	_____	_____	_____
kg K/ha	_____	_____	_____	_____	_____

PRINCIPLES AND METHODS OF SOIL FERTILITY RESEARCH IN MAIZE- BASED CROPPING SYSTEMS OF THE EASTERN AFRICAN HIGHLANDS

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ABSTRACT

Overcoming the nutrient limitations in lands cropped by resource-poor smallholders requires a multidisciplinary approach that integrates the efforts of soil scientists, crop ecologists and socioeconomists. The limiting nutrient(s) to productivity and the potential crop demand for these nutrients under improved management must first be identified. Then the under-utilised availability of these resources to farmers as organic additions to soils must be weighed against alternative values and costs of those resources. A collaborative research programme has been initiated between the Tropical Soil Biology and Fertility Programme and the Kenya Agricutural Research Institute that seeks to maximise available nutrient resources of smallhold farmers in the Kenyan Highlands. These are maize based systems, often with confined cattle that are fed maize stover. Also available to these farmers are leaf litter from nitrogen-fixing trees that are currently being used as fire wood. Preliminary results indicate that incorporation of 2.5 T/ha/crop of *A. mearnzii* leaves and fine branches results in the greatest use efficiency of that resource, increasing maize yields from 1520 to 3990 kg/ha/crop. Standardised measurements of soil biological processes that may account for these differences are proposed.

INTRODUCTION

Systems-level analysis addresses whole-farm processes leading to on-farm participatory research and, hopefully, subsequent improvement of farmers lives. A difficulty in applying anthropology to agriculture is that, at some level of investigation, every farm is unique. Our abilities to develop useful criteria for the extrapolation of management recommendations becomes confounded. Soil biological processes studies involve detailed investigation of the regulators and rates of resource availability as well as the effects and, hopefully, amelioration of the individual constraints to farm productivity. However, these processes often demonstrate tremendous spatial heterogeneity and can seldom be extrapolated across a single field. Can these two contrasting scales of analysis somehow be balanced within a single research and development continuity designed to optimise the comparative strengths of each? To what extent does the information collected within one scale of information gathering account for the variation observed in the other? Is the sustainability of the natural resource base linked between these two process levels? Has the failure to recognise the importance of biological vs systems scales of processes resulted in greater confusion than solutions?

Rigorous scientific approaches by soil biologists service the scientific community as a whole without necessarily addressing the pressing environmental issues that confront resource-limited farmers in lesser developed nations. The coupling of process-level research to farming systems study presents a unique opportunity to target innovative land management practices into the programs of agricultural ministries. In order to accomplish this, a sequence of research and development activities, rather than merely a scientific program, must be initiated.

CHARACTERISTICS OF THE EASTERN AFRICAN HIGHLANDS

The Resource Information System (RIS), a geographic information system specific to Africa (IITA, 1991) was employed to identify various land areas within Eastern Africa. In Ethiopia, Kenya, Tanzania, Eastern Zaire and including other neighbouring countries, 159,000 km^2 of cropped lands occur between 1500 and 2000 metres above sea level and receive between 750 and 2000 mm annual precipitation (Table 1). These shall be referred to as the cropped, moist Eastern African Highlands which represent 68% of the total lands in the African continent meeting these conditions. Bimodal rainfall patterns are observed in 52% of the cropped, moist Eastern African Highlands.

These highlands are not contiguous, but rather occur in 4 broad areas; the Ethiopian Highlands to the north-east, the Kenyan Highlands to the east, the Mitumba Highlands west of Lake Victoria and the Tanzanian/Zambian Highlands occurring as a series of mountain ranges near southern Lake Tanganyika. Figure 1 indicates that these highland areas are not only geographically isolated, but, based on the pattern of roads, economically separate.

Several soils are cropped within the moist Eastern Highlands. Cambisols, Nitisols and Ferrisols account for 60% of the total (Table 2). Cultivated Vertisols are infrequent but note the frequency of 9 "other" miscellaneous soils each order accounting for less than 5% of the total land area but when combined accounting for 21% of the total land area. Indeed, it may be dangerous to refer to any soil order as representative of the Eastern African Highlands, although Ferrisols dominate the Tanzanian/Zambian Highlands (data not shown).

No georeferenced data base of the maize/bean cropping system is available at present, but this cropping pattern is widespread in the Kenyan, Mitangan and Tanzanian/Zambian Highlands. In these first 2 areas population densities are high, with individual holdings generally ranging between 1 and 2 ha, farm animals raised under confinement and the soil resource base rapidly degrading (Kilewe & Thomas, 1992). A generalised diagram of mass flows within a resource limited maize/cattle agricultural system is presented in Figure 2. In the Tanzanian/Zambian Highlands land availability is greater and Chitemene (slash and burn of Miombo woodlands) and Findakila (grass mound composting of *Hyparrhenia rufa*) are practiced (Araki, 1992).

IDENTIFYING AND OVERCOMING NUTRIENT CONSTRAINTS IN THE EASTERN AFRICAN HIGHLANDS

The mineral nutrition and improvement of resource-poor cropping systems within the Highlands presents a unique challenge to agricultural specialists. We propose and illustrate the integration of soil-process research and systems-level studies. In Figure 3, different research specialities are combined to identify and ameliorate the plant mineral nutrient most limiting to productivity. This is a sequential, multidisciplinary approach in which the nutrient(s) most limiting to crop productivity is identified, the potential crop demand for that nutrient established and an inventory of farmer available nutrient resources conducted. Based upon these preliminary activities, the most promising management options for these available resources are explored within an experimental programme as a means of overcoming the nutrient deficit.

Table 1. Land areas of the Eastern African Highlands identified in a stepwise fashion using a geographic information system.

stepwise parameter	parameter range	land area (km^2)
modal elevation	1500 - 2000 m	454,000
annual precipation	750 - 2000 mm/yr	399,000
landuse croplands		159,000

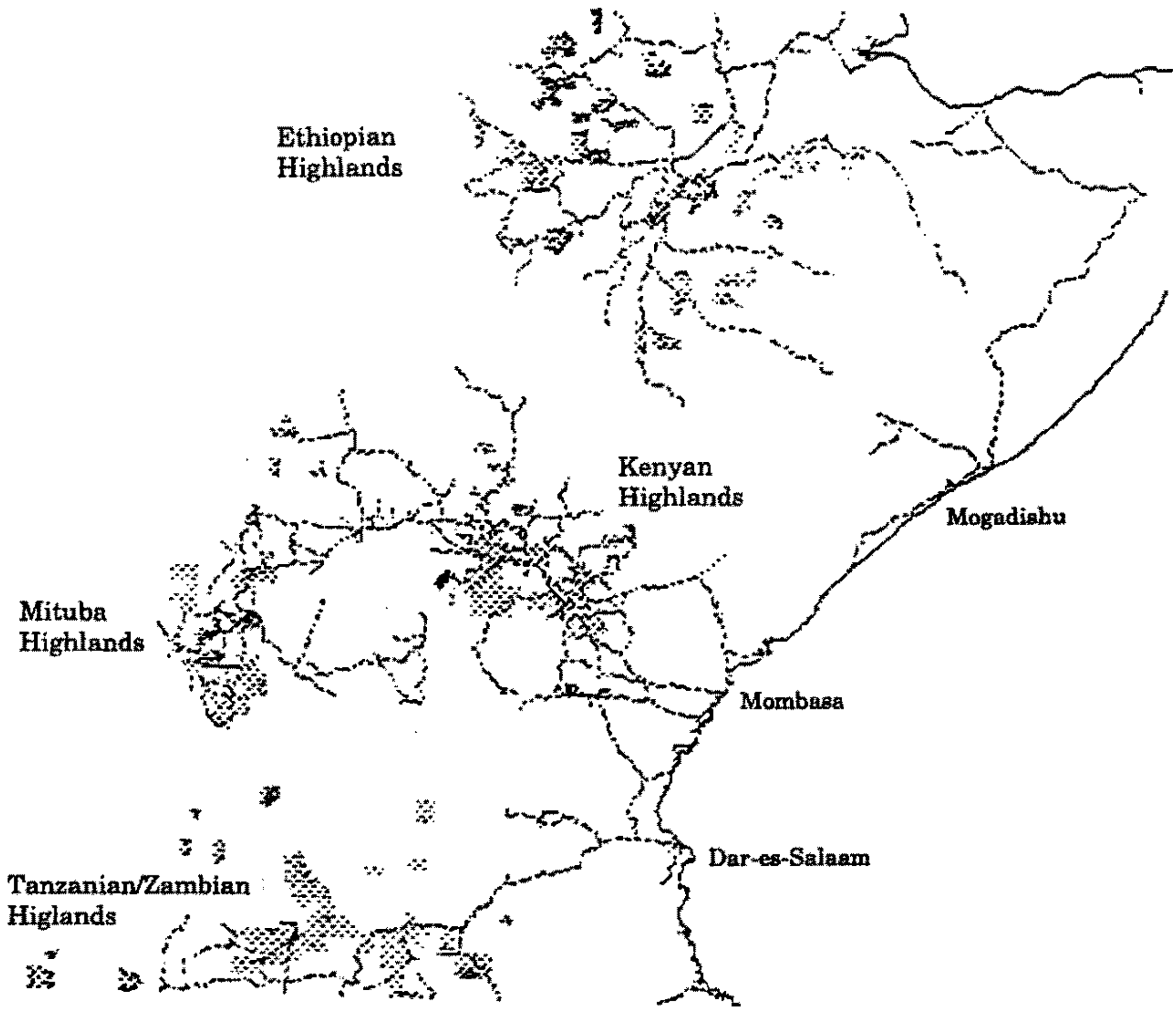

Figure 1. Moist, cropped Eastern African Highlands occupy 159.000 km² (Precipitation 750-2000 mm/yr, elevation 1500-2000 m, grey shaded area). Solid lines denote coastal boundaries and roads.

Table 2. Land areas of moist, cropped Eastern African highlands by FAO soil order[1].

FAO soil order	km^2	% of total
Vertisols	5,300	3.3
Lithisols	10,800	6.8
Acrisols	12,500	7.7
Cambisols	26,600	16.7
Nitosols	29,900	18.8
Ferrisols	39,100	24.7
other	34,800	21.9

[1] The moist, cropped Eastern African Highlands are considered to range between 1500 and 2000 m. above sea level, 750 and 2000 mm precipation annually and to presently be cultivated.

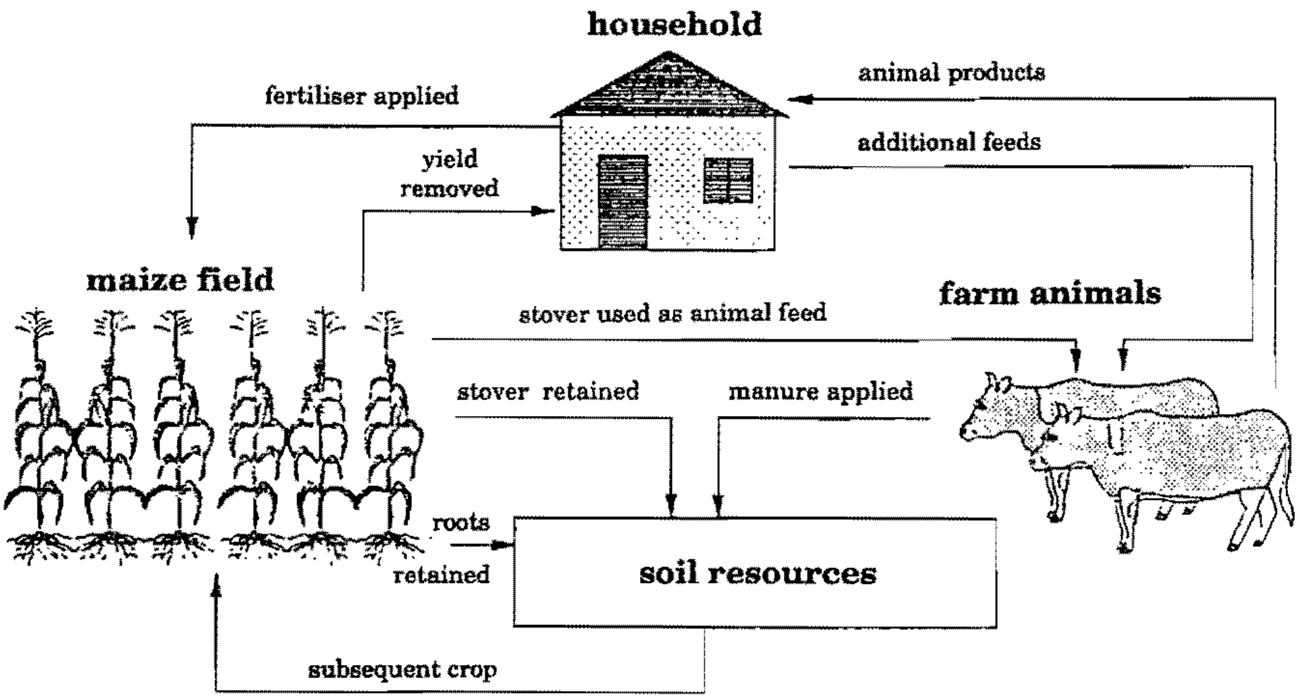

Figure 2. A key to conserving soil resources in the Kenyan Highlands is the improved use of limited farmer-available resources.

Identification of the limiting nutrient. This is accomplished in glasshouse culture using an indicator crop of local importance. Because this determination requires relatively little resources and space, it is envisaged that several soils be assessed at a single time. Alternatively, this may be conducted as a field investigation. Our experience suggests that the application of inorganic nutrients to 3-5 rows of field crops established without fertilisation in a completely randomised design is a cost and labour effective approach to obtaining this information. The relative simplicity of this experiment allows for its establishment on-farm directly into established fields if one is certain no fertilisers or other external inputs were applied. The suggested nutrient sources are listed in Table 3. It is important not to confound the effects of macronutrients. A combined nitrogen and phosphorus treatment (4) is included as these are the most frequently encountered limiting nutrients. The rates of nutrient addition in Table 1 are 50 kg ha^{-1} in treatments 2-6 and 25 kg Mg^{++} ha^{-1} in treatment 7. In phosphorous sorbing soils it is necessary to increase the rate of applied P in treatments 3 and 4. Crop response to treatment 3 is a strong but not absolute indicator of a P limiting soil due to the presence of calcium in triple super phosphate. Confounded within the design are the effects of magnesium and sulphur (7). Should this treatment be the most productive, additional investigation is required to identify the exact limiting nutrient.

Application of the limiting nutrient will result in improved plant productivity when compared to the other treatments and the complete control. If nitrogen and phosphorus are the 2 most limiting nutrients (e.g. treatment 4 results in the greatest productivity), the most limiting nutrient is identified by comparing the nitrogen (2) and phosphorus (3) treatments. If either treatments 7 or 8 result in the greatest productivity, additional experimentation is requires to identify the limiting nutrient. Other than N and P, this approach is unable to identify the limiting nutrients if two are equally limiting. For example if both K and Ca are deficient, neither treatments 5 or 6 will respond. Once identified, the limiting nutrient(s) become the focus of later mineralisation experiments. In the remainder of this section it is assumed that nitrogen is identified as the limiting nutrient.

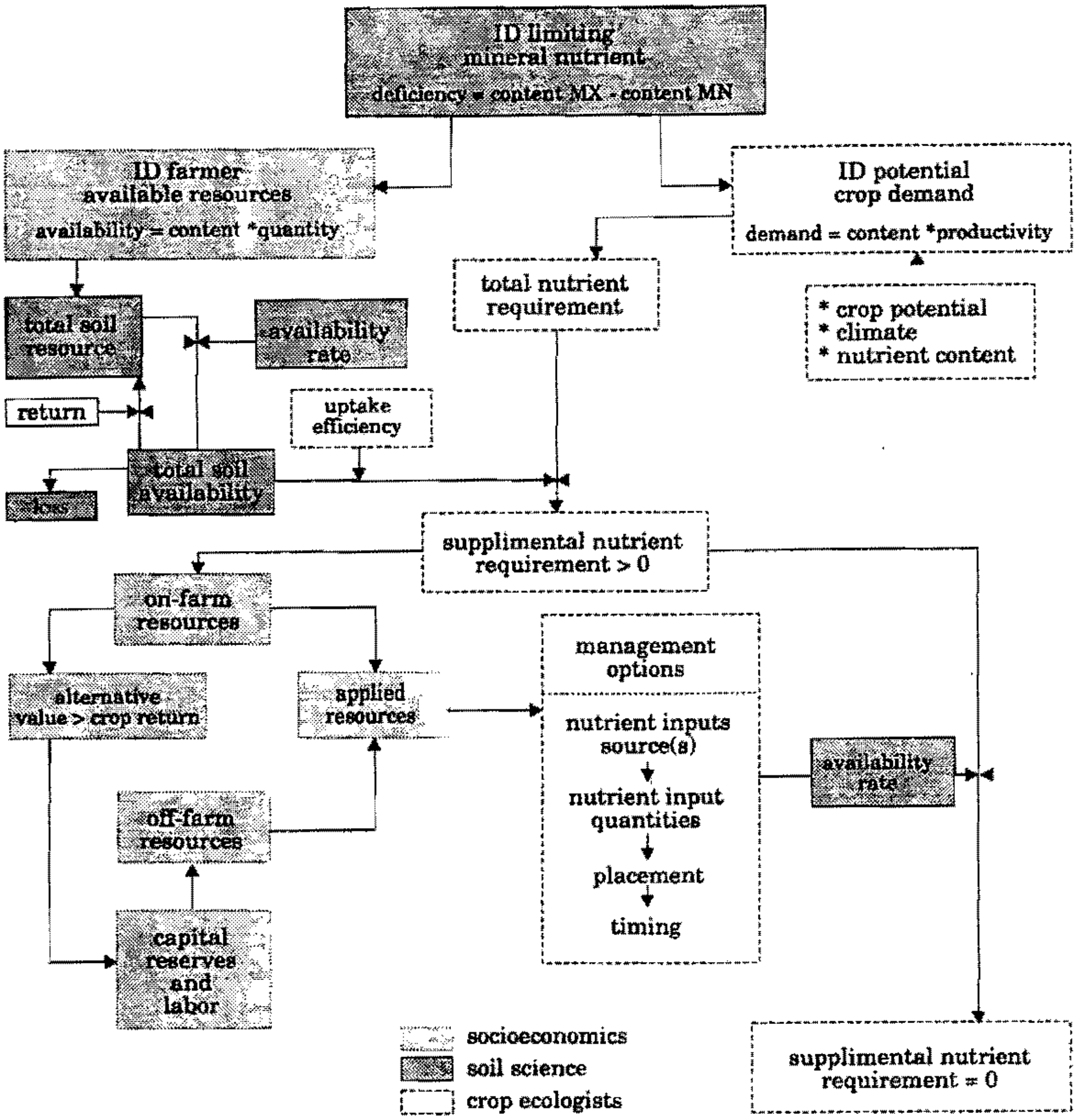

Figure 3. Flow diagram of a multidisciplinary strategy designed to identify and resolve soil fertility limitations.

Table 3. Nutrient application rates and forms useful in the identification of limiting available nutrients.

Treatment	Rate (kg ha^{-1})	Source
1. Complete control	0	n.a.[1]
2. + Nitrogen	113	as urea
3. + Phosphorus	109	as TSP
4. + Nitrogen/Phosphorus	as above[2]	as urea and TSP
5. + Potassium	95	as KCl
6. + Calcium	137	as $CaCl_2$
7. + Magnesium/Sulphur	125	as $MgSO_4$

[1] n.a. = no additions to complete control

[2] alternatively, 213 kg ha^{-1} as $(NH_4)_2HPO_4$ and 11 kg ha^{-1} as urea may be substitutes in treatment 4.

Estimation of total crop demand. The potential crop demand is a function of the desired productivity and the nutrient content at that productivity level. Desired productivity levels may be determined at the farm level as yield increases required to meet growing household requirements and realistic farm family expectations in the improvement of living standards (Woomer, 1991). Crop simulation models may also be employed as a means of determining the potential of these desired yield levels within a given cropping system, soil and climate combination. Available models include CERES Maize (Ritchie *et al.*, 1989), SUBSTOR for tropical root crops (IBSNAT, 1990), SOYGRO (Jones *et al.*, 1989), BEANGRO (IBSNAT, 1990), PNUTGRO (Boote *et al.*, 1989), and CENTURY, a generic plant/soils model originally developed for temperate grasslands (Parton *et al.*, 1987, 1989) and later validated for tropical conditions (Parton *et al.*, 1989; Woomer, 1992). There are some difficulties in the use of models as a means of estimating total crop nutrient demand. Several of the above models include routines for nitrogen, but not other mineral nutrients. Also, the effort required to collect the information required to initialise a model may be greater than that necessary to address agronomic problems in a more direct fashion.

Preliminary inventory of farmer available resources. Based upon whether or not, and which mineral nutrient(s) are limiting, an evaluation of farmer available resources is conducted. The first resource to be considered is the ability of the soil to supply nutrient resources under the current management practices. This requires that the soil content be analyzed, and the availability over the course of a cropping cycle be approximated via mineralisation studies (see Anderson and Ingram, 1989). A finer elaboration is to estimate the nutrient uptake efficiency of those available nutrients based on soil nutrient dynamics and root uptake rates (Barber, 1984). This is a crop specific proportion of total available nutrients dependant upon total fine roots and their maximum uptake abilities. Again, this feature is built into many crop simulation models (IBSNAT, 1990) but requires that sufficient site data is available to initialise the model itself. The total nutrient availability is then compared to the total crop demand, and the need and amounts of supplemental nutrients required to meet that potential crop demand calculated. If a net deficit of available nutrients exists, then a detailed inventory of on- and off-farm resources is required.

Detailed inventory of farmer available resources. Here we make an important assumption, that the available resources, other than soil, containing the limiting nutrient are not being fully exploited within the agroecosystem. Furthermore, we suggest that the resource base of that nutrient may be improved through judicious residue management strategies. This requires a detailed account of which and what amount of organic amendments are available from within the farm; the alternative (non-soil amendment) value of these additions; the availability of labour to meet the additional efforts required to utilise these resources; and the access to nutrient resources from beyond the limits of the agroecosystem, particularly fertilisers and other nutrient-rich materials. Often the availability to off-farm resources is related to farm productivity, access to markets, price stability and opportunities for off-farm employment. These are determinations that are clearly outside the normal activities of soil biologists and crop ecologists yet at the same time are only a small subset of the information routinely collected during detailed socioeconomic studies (see Shanner *et al.*, 1982). We are not seeking to understand why farmers do what they do, but rather the availability of the conditions and materials that may lead to improved crop nutrient conditions. At this juncture, farming systems experts provide crop scientists with an inventory of farmer available resources for inclusion into residue management experiments. This is an important starting point for problems on-station and subsequent on-farm research.

Optimising available resources through improved management practices. At this point agricultural scientists examine the effects of resource quality, placement and timing of applied organic amendments. By no means are the farming systems experts excluded from treatment selection. Furthermore, on-farm trials are conducted that utilise farmer resources in a manner that is intuitively promising given the availability of resources. A more powerful approach is to pre-select these promising interventions using simulation models. Again, farming systems experts must assist in the selection of user provided management options available within the model.

The key scientific output resulting from this round of the residue management experimentation is the prediction of nutrient mineralisation and plant availability based upon management practice, soil physical conditions and the chemical characteristics of the applied materials. In most cases the benefits of applied organic residues extend beyond a single cropping cycle. Therefore, it becomes necessary to document the nutrient use efficiency of the agroecosystem as a whole as a means of assessing changes within the agroecosystem resource base. We propose that the sustainability of an agroecosystem is determined by the state of the resource base over time in response to perturbations of that system and that soil biological process are an important means of assessing changes in that resource base (Swift and Woomer, 1991; Swift *et al.*, 1992).

SYNCHRONY: A GUIDING PRINCIPLE

The general SYNCHRONY principle (Ingram and Swift, 1988), simply stated, is: *The release of nutrients (N, P) from above- and below-ground litter can be synchronised with plant growth demands*. The objective of the SYNCH principle is directed toward the use of organic additions and biological processes for increasing nutrient use efficiency, of both organically and inorganically supplied nutrients, resulting in increased crop production and reduced nutrient losses.

Inherent within our approaches to SYNCHRONY research is the understanding of biological processes that affect nutrient availability under different residue management practices. Candidate management practices are then evaluated based upon their feasibility within specific agricultural systems and socioeconomic conditions. On the other hand, the initial design of experiments must not be overly constrained by traditional farmer practices as SYNCHRONY research often addresses unique approaches to farmer-available resources. The successful management options developed through SYNCHRONY approaches may not only improve an existing farming system, but alter the socioeconomic opportunities of the farmers to sufficiently change the cropping system itself.

The following set of hypotheses address the experimental phase of mineral nutrient problem solving and should be kept in mind when candidate management options are being evaluated. These hypotheses were framed by a working group at a recent Tropical Soil Biology and Fertility Programme (TSBF) workshop held in Kenya, July, 1992.

H1: System Nutrient Use Efficiency: In the long-term, the system nutrient retention will be highest when the nutrients are applied in the least available form. Similarly, long-term system nutrient retention will be functionally related to quality of organic inputs, such that there will be an optimum quality.

H2: Plant Nutrient Use Efficiency: In the short-term (e.g. current crop), the maximum yield achievable by the use of fertilizer inputs can be approached or exceeded by optimizing the time of application, placement and quality of organic nutrient sources.

H3: Lignin Carry-over: Residues high in lignin will result in lower plant uptake in the first cropping season, but will produce a greater residual effect in subsequent seasons.

H4: Tannin Time-delay: Residues high in hydrolysable tannins exhibit a delayed nutrient release pattern such that a material can be chosen to release nutrients after a pre-determined period. Similarly materials high in some tannins will not release nutrients initially, but that eventually nutrients will be released at a rapid rate.

H5: The Speed Trap: Incorporation of organic inputs, as opposed to surface application, accelerates the release of nutrients, thereby providing another option for improving nutrient availability.

H6: The Invertebrate Switch: Organic inputs can influence soil faunal composition and activity and, as a consequence altering the optimal organic input effects of litter application on nutrient use efficiency.

STANDARDIZED EXPERIMENTAL PROCEDURES

The development of improved resource management strategies requires an appreciation of the key biological processes operative within the soil system. Of particular importance are the decomposition rates of applied organic amendments, changes in the mineralisation rate of nutrients resulting from additions of plant residues, immobilisation of the nutrients by microbial biomass and the principle sources of nutrient loss. The Tropical Soil Biology and Fertility Programme has developed a suite of standardised methods of biological processes in soils (Anderson and Ingram, 1988). The use of standardised methods allows for the comparison of site characterisation and experimental results across sites. This can lead to improved interpolation of likely system improvements within a new site based upon previous results and experiences and allows for greater resolution in the use of plant/soil simulation models as a means of preselecting candidate experimental treatments (see Parton *et al.*, 1987, 1989). Some suggested measurements follow:

* **plant nutrient uptake:** this is measured over time by sampling the plants and root in-growth volumes within the nutrient uptake sample areas and then determining the plant nutrient contents. Poor recovery of roots represent a source of error for this measurement, but either whole root recovery should be attempted or the following method employed.

* **root productivity *via* in-growth bags:** two litter bags (or metal mesh bags) are placed into the soil prior to planting the plots. Upon sampling for biomass, these are removed, the roots recovered and the total root biomass estimated *via* extrapolation of the root in-growth volume. The nutrient content of these roots may also be determined.

* **soil moisture content:** this routine measurement is required to adjust fresh weight to dry weight measurements for many of the soil measurements as well as being of interest in itself. This measurement is most useful when moisture contents are compared to soil moisture tension *via* the preparation of a soil moisture release curve. Furthermore, soil moisture content may be used to calculate the total water filled pore space when total pore space (calculated from bulk and specific mineral densities) and field moisture capacity are known.

* **litter decay:** the mass loss of the high and low quality resources including roots from the previous crop is determined using litter bags. These litter bags are placed directly into the plots in a manner consistent with the particular treatment (e.g. roots always incorporated). There must be at least 5 sampling times with more frequent sampling earlier in the experiment (e.g. after 1, 2, 4, 8 and 16 weeks).

* **nutrient mineralisation:** closed soil cores are inserted to 50 cm depth along the margins of the plant nutrient uptake sampling areas and recovered at specified times during crop growth. These are inserted following the addition and incorporation of the organic materials or fertiliser. The method and times of sampling for mineralisation will vary according to the experiences at a particular site. An alternative is to cover the bottom end of a shorter core (e.g. 25 cm) with commercially available root excluding mesh, then pack the core with soil at the same bulk density as the cultivated surface soil and then insert the core into the soil to the depth of tillage (15 cm). Alternatively, potential anaerobic mineralization may be conducted in the laboratory.

* **microbial biomass C and N:** This is measured *via* chloroform fumigation/extraction of soils. This serves as a measure of the microbial immobilisation of nutrients in the various treatments. Again the timing of these measurements will be determined by the climate at the various sites. These samples are recovered adjacent to the mineralisation cores during the course of residue decomposition.

* **carbon light fraction:** this is a measure of the near term balance between organic matter additions and losses from the soil. This may be measured by floatation of soil organic residues.

* **leaching:** this can be measured or estimated from a variety of techniques and the one chosen will probably differ for different climate and soil type. Possible techniques are uncovered cores compared to the covered cores, open cores with resin covering the top and bottom of the core, or by sampling the lower horizons with time. Ssali *et al.* (1990) observed no leaching losses of N in a East African Highland Paleudult

* **losses *via* volatilisation or denitrification:** these are more difficult measurements and perhaps are a small proportion of the total losses in many systems. However, where the residues are surface applied volatilisation may be a major pathway. Likewise denitrification may be important in wetter climates.

* **soil faunal communities:** a soil sample 20 cm x 20 cm x 30 cm (depth) is excavated and the soil mesofauna collected by hand. Samples are sorted among earthworms *vs* arthropods, and arthropods separated into functional groups (plant pests, endogeics, exogeics). Population densities and dry weights are determined for all groups and these measurements compared between management options. Alternatively, the soil faunal communities may be recovered from the root in-growth and litter bags.

AN EXAMPLE OF THE APPROACH IN THE KENYAN HIGHLANDS

Limiting Nutrient. The soil mineral nutrients most limiting crop productivity were identified for a Paleudalf at the Kenya Agricultural Research Institute, Muguga Station in the glasshouse. Inoculated Clark soybean (*Glycine max*) and the non-nodulating isoline of Clark were cultivated in 4 liter pots until maturity and the shoots harvested. The use of inoculated nodulating (nitrogen-fixing) and non-nodulating isolines allows for detection of the second most limiting nutrient if the most limiting nutrient is nitrogen. Total shoot yield is presented in Figure 4. Interpretation of these results indicate that N is the most limiting plant nutrient in the absence of biological nitrogen-fixation followed by either P or K.

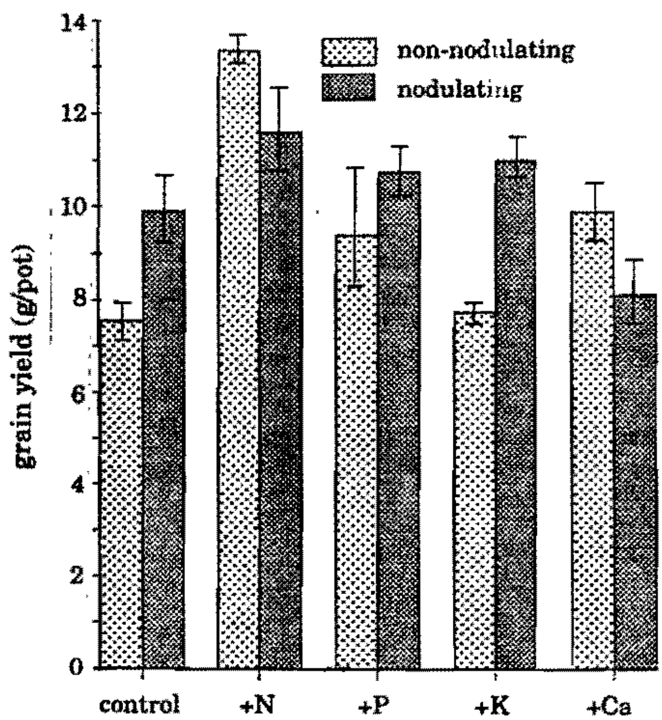

Figure 4. Glasshouse results suggest that nitrogen availability is the largest nutrient constraint to soybean (cv. Clark) productivity in a Paleudalf at Muguga, Kenya.

Potential Crop Demand. Based on the productivity of maize under rainfed conditions and improved fertility management (40 kg N/ha), the total crop demand for N is estimated as 134.2 kg/ha/crop in order to produce 3600 kg/ha/crop of air dried grain (Table 4).

Table 4. Nitrogen demand of maize cultivar H512 under improved fertility conditions at Muguga, Kenya.

Plant component	dry matter (kg/ha)	N (%)	total N (kg/ha)
grain	3600	1.79	66.2
cobs	540	0.30	1.6
stover	5030	0.72	36.2
roots (approx.)	2750	1.10	30.2
Total	**11920**	.	**134.2**

Identification and chemical characterisation of farmer available resources. The results of on-farm observation and informal survey will serve to identify the range of residues available to the farmer. Some estimates of the amounts available to farmers must be made at this time. These materials are then recovered and analyzed for N, P, C, lignin and polyphenol (as well as any other limiting nutrient identified in the previous experiment). Let us assume that maize stover and cattle manure are identified as the most promising organic residues (Table 5) and that farmers have access to and limited capital resources to purchase nitrogenous fertiliser (urea). Nutrient-rich leaf litter is also available as hillside plantings of Wattle (*Acacia mearnzii*). Note that the maize stover need not be transported as it is being produced on site by the previous crop, and that its commercial value is approximately 200 Ksh T^{-1}. As the maize stover will either be surface litter or standing dead at the time of preplant tillage, and that excessive labour is required to remove the stover from the field, then return this to the field as a surface mulch, all experimentation with maize stover will focus upon this as an incorporated resource. Alternatively, the manure is applied either before or anytime following tillage, and will be examined as an incorporated and surface applied resource.

Preliminary research into improved residue management strategies. A preliminary investigation was conducted at the Muguga station, Kenya in order to determine the placement effects of agroforestry residue on maize productivity. The overall objective was to partition the effects of surface mulched and incorporated prunings of wattle leaves and fine branches (*Acacia mearnzii*) at different application rates. This tree was earlier identified as a locally available and under-utilised nitrogen-fixing tree resource. *A. mearnzii* was surface applied and incorporated by hand hoeing to 15 cm depth at the rate of 0, 1, 2, 4, 8 T/ha in a 2-way continuous function design at Muguga, Kenya. Maize cultivar K-512 was planted with 50 cm between rows and 15 cm within rows and grown to harvest maturity (Figure 5). Maize productivity fit the quadratic function:

Table 5. Characterisation of nutrient resources available to farmers in the Kenyan highlands.

Attribute	Maize stover	Cow manure	Urea	Wattle leaf
Availability (kg ha^{-1})	4000	1500	91	2500
Nitrogen (%)	0.25	2.67	44	2.40
Carbon (%)	47.0	37.0	8	45.0
Lignin (%)	11.0	19.2	0	n.a.
Distance (km)	0	0.25	10	.5
Value (ksh T^{-1})	800	200	9600	500
Labour (hours ha^{-1})	16	8	2	16

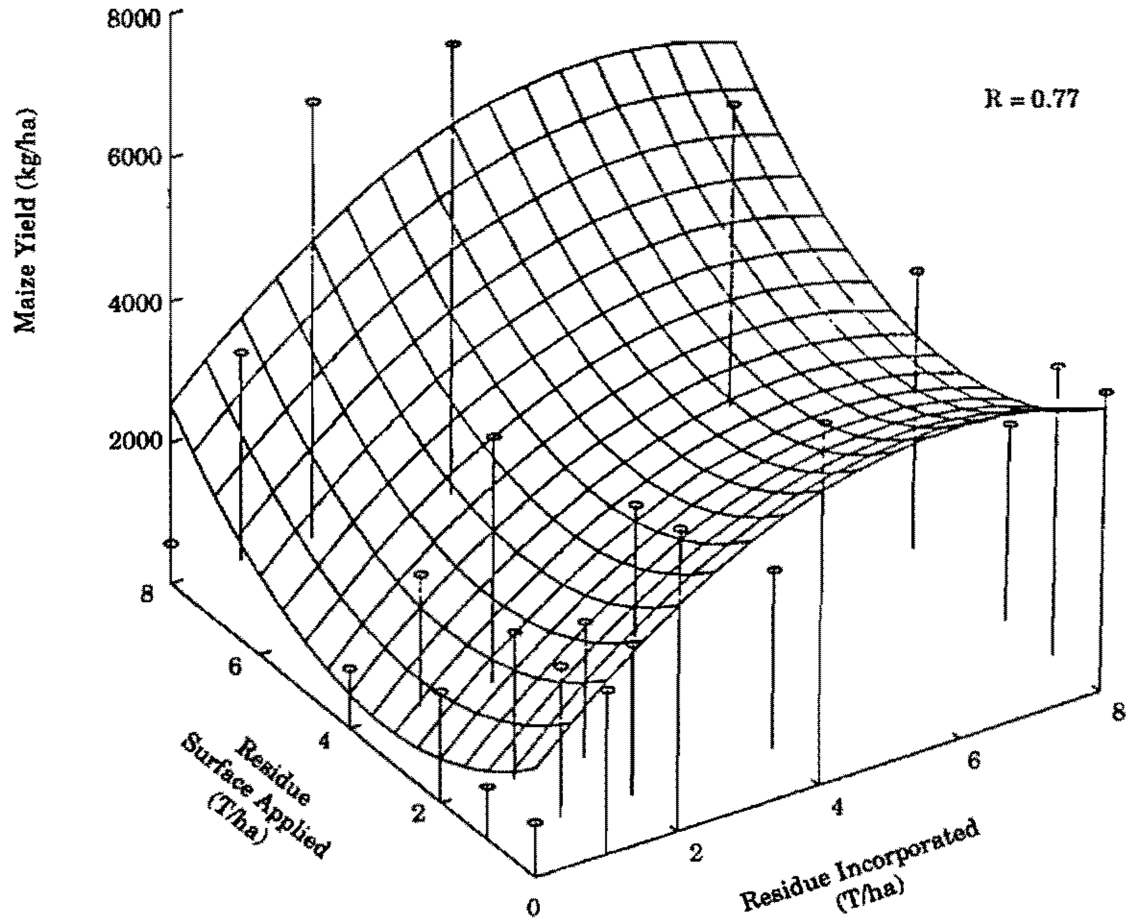

Figure 5. The response of maize yield to the amount and placement of *Acacia mearnzii* leaf and fine branch litter fit to a quadratic function.

GRAIN = 1520 - (0.65 SURF) + (0.99 INC) + (0.009 SURFACE²) - (0.008 INC²) + (0.003 SURF * INC), R^2 = 0.6[illegible]. p = 0.002

where GRAIN = oven dried grain productivity (kg/ha/crop); SURF = rate of surface applied *A. mearnzii* (kg dw/ha/crop) and INC = rate of incorporated applied *A. mearnzii* (kg dw/ha/crop).

Based upon the coefficient values and their individual coefficient probabilities (INC p = 0.008 vs SURF = 0.065), incorporation of *A. mearnzii* contributes to maize productivity to a greater extent than does surface mulching under these experimental conditions. There was no significant interaction between placements (SURF x INC P = 0.905). Another approach to the interpretation of these results is through the change in plant productivity per unit of residue applied. In this case the RETURN per unit applied is:

$$\text{RETURN} = (\text{YIELD}_R - \text{YIELD}_C) / \text{APPLICATION RATE}$$

where YIELD + YIELD are the maize yields of the residue treatment and unamended control, respectively.

The relationship between the return in yield per unit application, and the amount of litter applied for 3 litter placements (surface, incorporated and an equal mixture of the two) reinforces the observation that the greater crop response is to incorporation *vs* surface application (Figure 6). These points are smoothed using Negative Exponential Interpolation (Wilkenson, 1988), a method that forces the response surface through all observed values. These results suggest that approximately 2.5 tons incorporated into the soil offers the greatest incremental return to the organic inputs. The results in Figure 5 suggest that there is low input level that does not result in improved plant performance, followed by an increase in the return per unit applied and then a decline in return.

Current research addresses the residual effects of the *A. mearnzii* on the next season maize productivity and the effects of the rate and placement of maize stover. Future activities will evaluate the rate and placement of cattle manure. The objective of these research activities is to develop a "residue management package" for on-farm testing by mid-year 1993.

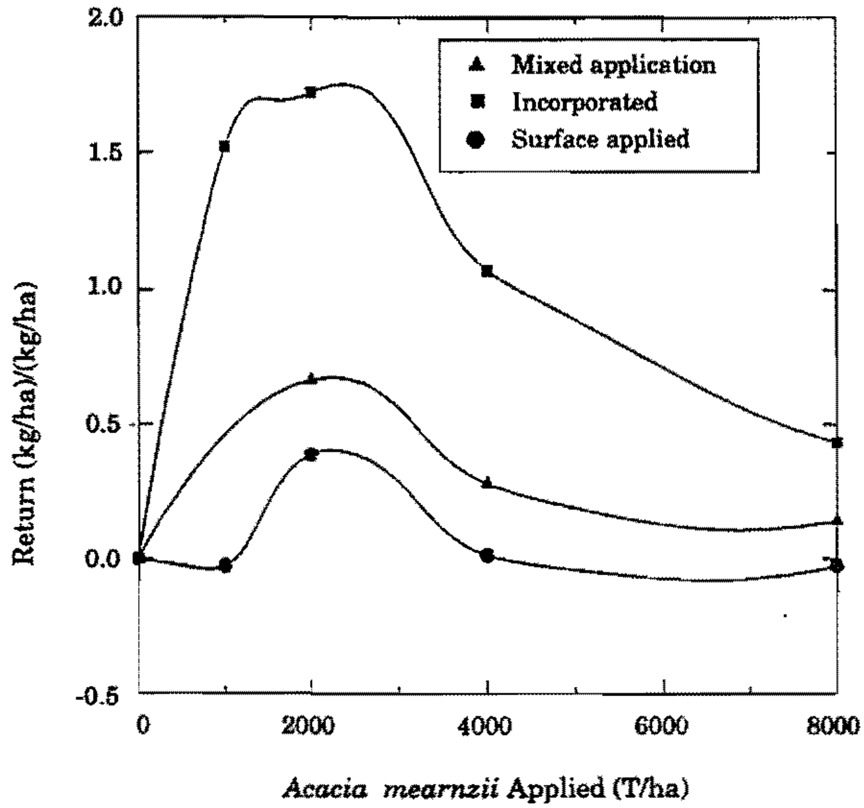

Figure 6. The effects of placement and quantity of *Acacia mearnzii* leaf litter on the incremental return of maize yield cultivated in a Kenyan Paleudalf.

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LOW INPUT ALTERNATIVES FOR IMPROVED SOIL MANAGEMENT

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INTRODUCTION

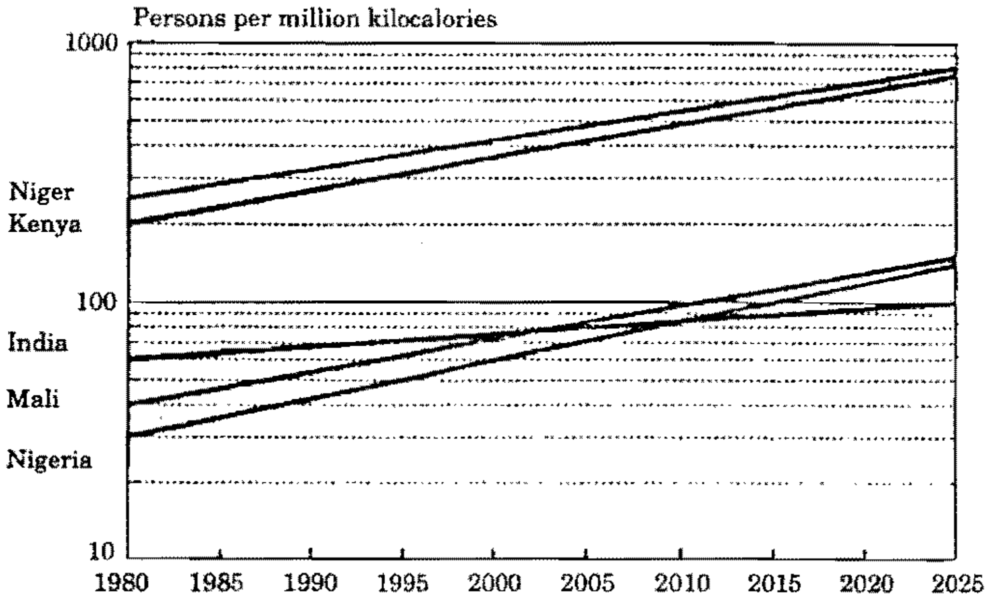
Agricultural production is the mainstay of national development in Kenya (NARP, 1986). For production to increase sufficiently so the increasing population can be fed adequately in the future, major efforts must be undertaken in the area of agricultural research. The current population growth rate for Kenya is in the order of four percent per annum (World Population Data Sheet, 1988); significantly higher than the rest of Sub-Saharan Africa which was reported by Binswanger and Pingali (1988) to average 3.2% a year during the 1980's. Agricultural production has not kept pace with this increase in population and better soil management is desperately needed to prevent future disasters. More emphasis must be placed on low input alternatives which are available to small holders and have less impact on the environment.

Binswanger and Pingali (1988) projected population growth densities of various countries through the year 2025 based on an intermediate agricultural production capacity (Figure 1). The results are frightening in that both Kenya and Sahelian Niger have a similar agroclimatic population density. This is due to the fact that both countries have large semi-arid areas of low production potential. The present agroclimatic population density of these two countries averages about 300 persons per million kilocalories which means that on a daily basis approximately 3000 kilocalories per person are currently produced. If trends are followed through 2025 as projected by Binswanger and Pingali (1988), the daily production potential at that time for Kenya and Niger will be in the order of 1250 kilocalories per person: substantially below the 3000 kilocalories needed per day by an active adult.

World maize production on a hectare basis has benefitted from technological improvements in most regions especially where irrigation is possible and hybrids are used (CIMMYT, 1990). Figure 2 illustrates the trend of maize production in four regions of the world from 1961 through 1988. South, East and Southeast Asia rely heavily on both irrigation and hybrid use to maintain an annual maize production growth rate of 4.8%. Latin America also relies on these management technologies which allow the production growth rate to be maintained at 3.0%. Although the production growth rate of West Asia and North Africa is about 2.4%, significant increases in yield have been achieved. Due to limited irrigation, hybrid use, and other technological improvements, average maize yields in Sub-Saharan Africa have not increased much over 1 Mg ha^{-1} and the present production growth rate is just over 2% per year (Figure 2; CIMMYT, 1990). Food production in Africa has failed to keep pace with the accelerated rate of increasing population (Harrison, 1987). This is the region which most desperately needs an increased emphasis on production strategies which are based on low inputs.

Maize production in Kenya was about 1.0 Mg ha^{-1} during the 1950's and increased with the introduction of hybrid use to about 1.5 Mg ha^{-1} in the early 1960's (FAO, 1990; Figure 3). Stable yields were maintained at this level until 1978 when erratic production started. This phenomenon has continued through at least 1988, the end of the reporting period. Sorghum and millet production, clumped together by FAO, was actually higher than maize production during the 1950's as more people relied on traditional crops. With the introduction of hybrid maize, the level of effort directed toward sorghum and millet production was reduced resulting in diminished yields. Current production levels of sorghum and millet are in the order of 500 kg ha^{-1} reflecting the limited level of technological improvements used and probably a shift to more marginal areas for production. Bean production has remained in the range of 500 - 900 kg ha^{-1} for some time (Jaetzold and Schmidt, 1983; Ministry of Agriculture, 1989).

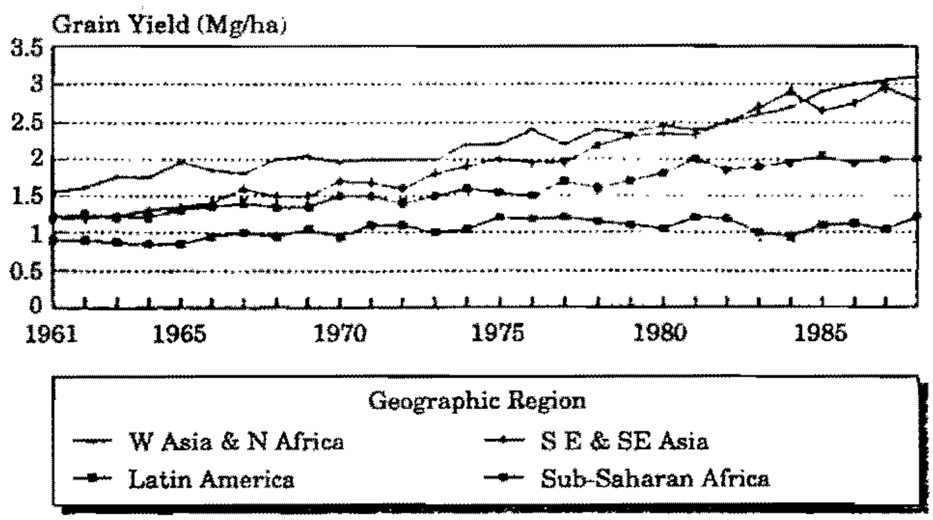
Agroclimatic Population Density



Source: Binswanger & Pingali, 1988.

Figure 1. The agricultural production potential at a medium input level as discussed by the authors.

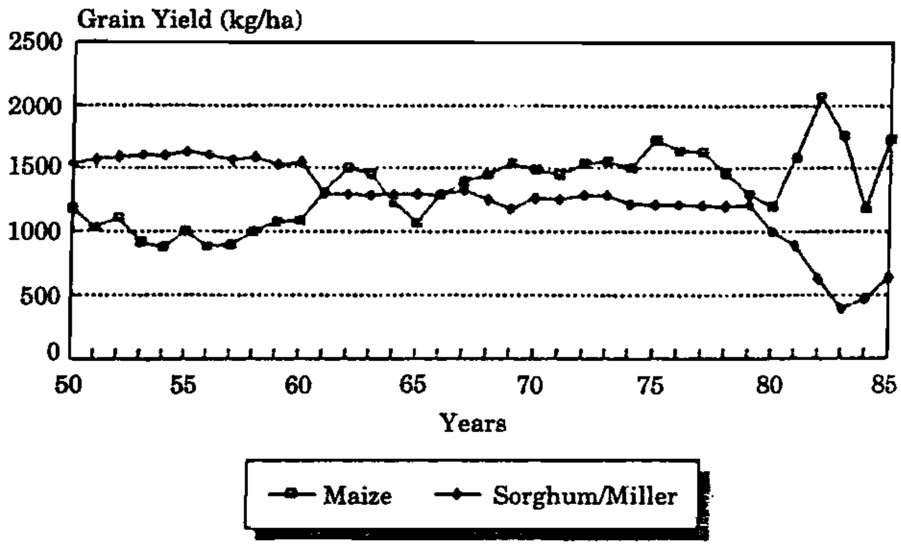
Regional Maize Production
1961-1988



Source: CIMMYT, 1990

Figure 2. World maize production per hectare by region from 1961 to 1968.

Maize and Sorghum/Millet
Kenya Production 1950-1985



Source: FAO World Crop & Livestock Statistics, 1948-1985

Figure 3. Maize and sorghum/millet production per hectare in Kenya from 1950 to 1985.

Demonstrated biological and technical yield levels are much higher for these crops. Research station yields for maize can reach 9 - 10 Mg ha^{-1} in the high potential zones and nearly 8 Mg ha^{-1} in the lower potential regions using appropriate varieties and fertilizer (Wafula and Keating, 1987; O'Neill and Keating, 1989; Njoroge et al., 1990). Sorghum varieties can yield in excess of 4 Mg ha^{-1} while sorghum hybrids yields may double that (M'Ragwa and Kanyenji, 1987; Kamau and O'Neill, 1990) and on-station bean production can approach 3 Mg ha^{-1}. Clearly, the problem is not the lack of high yielding varieties but rather technnological practices are currently not being utilized by farmers on a national basis. These high on-station production figures are the result of high input technologies which are well known by agronomists and extensionists.

Improved soil management through more efficient use of nutrients and maintenance of good soil conditions is essential for improving and sustaining the productivity of intensively cultivated lands (Kanampiu and Irungu, 1992). Maize and beans production has decreased in the central Kenyan highlands mainly due to declining soil fertility. Continuous cropping with no or sub-optimal rates of fertilizer application has led to a decline in soil fertility (CMRT, 1991) and nutritional deficiency symptoms of nitrogen and phosphorus are observed on most farms. Previous on-station and on-farm experiments have demonstrated that with the addition of a modest economical dose of 40 kg/ha N and P_2O_5, maize yields can be more than doubled (Kanampiu et al., 1991). Nevertheless, few farmers appear to apply fertilizer even after observing its effect on maize in on-farm trials. Removal of subsidies for inorganic fertilizer has led to increased prices which has resulted in a further decline in inorganic fertilizer use. It is time for a shift from research which concentrates on input intensive technologies to research which is devoted to the use of low input alternatives.

SUSTAINABLE AGRICULTURE

The process by which farmers harvest solar energy as an economic product of interest to themselves and others is made up of a series of events linked together as a system (Lal et al., 1988). Increasing population pressure has made obsolete and unacceptable systems which mine the environment for resources to their eventual degradation. Environmentally sustainable farming systems require that these systems function as a unit to "efficiently and economically harness solar energy in the form of consumable products on a continuing basis while preserving soil productivity and maintaining a high level of environmental quality" (Lal et al., 1988).

Sustainable agriculture requires that nutrients and organic matter are returned to the soil (McWilliams, 1988). The soil acts as a bank or reserve from which nutrients are removed during cropping periods and if this reserve is not replenished by nutrient additions then the bank must close and agriculture is no longer possible. Common indicators of decreasing sustainability include the depletion of soil organic matter, deficiencies of macro and micro nutrients, as well as decreased diversity of soil micro organisms (MacKay, 1989). Because of the great diversity of soil conditions within the tropics (Buol and Sanchez, 1988) adoption of sustainable technologies requires on-site experimentation for adequate verification. On-farm testing is necessary for researchers and farmers to interact in developing the technologies which will maintain a productive farming environment long into the future. Due to increasing pressure on land and declining soil fertility, low input alternatives, to sustain productivity need to be sought. These low input options include improved organic matter management, agroforestry and increased efficiency of limited fertilizer use.

SOCIO-ECONOMIC CONSIDERATIONS

Improved soil management for increased crop production is to be achieved primarily through the maintenance of the soil physical conditions (through soil erosion control) and fertility improvement (through the replenishment of the depleted soil nutrients). Mineral fertilizers have played a significant role in modern agriculture in adding nutrients to the soil and have contributed substantially to yield increases that have been achieved in many countries. Mineral fertilizer is however a non-renewable resource and as such other alternatives to complement fertilizer use have to be sought if the productivity of the land is to be maintained to meet the increasing demand for food (Ströbel and Hinga, 1987).

Socio-economic studies carried out within the maize/beans cropping systems of central Kenya indicate that more mineral fertilizer is applied to cash crops than food crops. It is also shown that the amounts of fertilizer applied to food crops are normally much lower than the recommended rates and that more farmers use fertilizer on maize than on beans (Karanja and Oduor, 1986; Minae and Nyamae, 1988; Murithi, 1990; CMRT, 1991; Kanampiu et al., 1991; Murithi and Shiluli, 1992). For example in one of the surveys (Kanampiu et al., 1991) carried out during 1991 in Embu District, maize grain yield ranged from 3,198 kg/ha to 5,365 kg/ha (Table 1). Mean grain yield was below the average potential of 4,500 kg/ha for the recommended maize variety in the region. Between 35.8 and 60.1 kg/ha of nitrogen and 14.5 to 22.1 kg/ha of P_2O_5 were removed by the maize grain. Maize stover removed another 6.5 to 17.2 kg/ha of nitrogen and 0.8 to 3.0 kg/ha P_2O_5 (Table 1). Mean nutrient removal by the grain and stover amounted to 58.8 kg/ha N and 18.7 kg/ha P_2O_5. Unless there is replenishment of these macro nutrients, continuous cropping would deplete the soil reserve of N and P and hence lead to declining soil fertility.

Of the maize stover produced, between 70 and 83% was removed at harvest as feed to tethered animals (Table 1). The current manure collecting system in which animal sheds are exposed to rain and direct sunshine leads to substantial losses of nutrients and low quality of applied manure. Since most of the manure produced by the animals is generally applied to coffee, there appears to be considerable transfer of essential plant nutrients from fields used for maize production. Continued demand for continuous cropping because of increasing population pressure necessitate more efficient nutrient recycling within the farm. Increased efforts must be made in on-farm research to better identify N and P flux and develop appropriate methods to stabilize crop production.

Table 1. Average maize grain yield, stover, nitrogen and phosphorus removed (kg/ha) from four farms at harvest prior to long rains (March) 1991.

Farm	MAIZE GRAIN			MAIZE STOVER				
	Yield	N	P_2O_5	Left on field	Removed from field	Given to Animals		
						%	N	P_2O_5
1	3198	41.9	14.6	532	2624	83	12.6	3.0
2	3381	35.8	14.7	494	1234	71	6.5	0.8
3	5365	60.1	22.1	1065	3241	75	17.2	3.0
4	3957	51.4	14.5	752	1756	70	9.8	2.0
Mean	3975	47.3	16.5	711	2214	75	11.5	2.2

Source: Kanampiu et al., 1991

At planting between 8.4 and 17.5 kg/ha N and 6.7 to 44.8 kg/ha P_2O_5 were applied as inorganic fertilizer (Table 2). Mean mineral nutrient applications for N and P_2O_5 amounted tp 13.9 and 28.6 kg/ha, respectively. Nitrogen application was far below the amount removed by the previous crop while more P_2O_5 was supplied by fertilizers than removed by the previous crop. Manure applications were between 3,040 and 7,980 kg/ha dry matter. This supplied an average of 63.9 kg/ha total N and 95.9 kg/ha total P_2O_5 (Table 2). Assuming the decay rate of manure is 20% (Pratt et al., 1973; California Fertilizer Association, 1985) the resulting average mineralized nitrogen would amount to only 12.8 kg/ha. Mean total applied mineral N would therefore be only 26.7 kg/ha resulting in a deficit of 58.8 kg/ha. Phosphorus mineralization efficiency would also be low and hence decreased amounts of available P_2O_5 applied in the manure.

Figures 4 and 5 illustrate that the national fertilizer consumption in Kenya and national fertilizer imports have been on the decline over the years. This justifies the need to look for other alternatives to chemical fertilizers for improving the fertility of the soils. The low usage of chemical fertilizers on maize and beans is normally attributed to the following problems: high price ratios

Table 2. Amount of N and P_2O_5 from fertilizer and manure (kg/ha) applied at planting for the long rains (March) 1991.

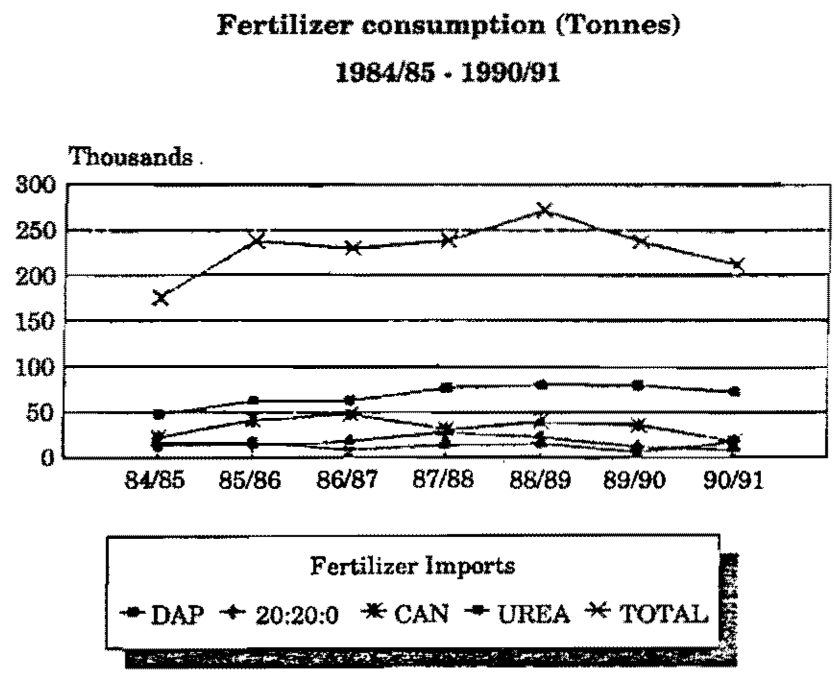
Farm	FERTILIZER		MANURE		
	Nitrogen (N)	Phosphorus (P_2O_5)	Dry Matter	Nitrogen (N)	Phosphoru s(P_2O_5)
1	8.4	21.5	3040	41.5	59.2
2	13.3	6.7	7980	84.6	137.1
3	16.2	41.3	-	-	-
4	17.5	44.8	5320	65.4	91.5
Mean	13.9	28.6	5447	63.9	95.9

Source: Kanampiu et al., 1991

for fertilizers and food crops, especially following the liberalization of the fertilizer trade starting in 1985; cash flow problems mainly due to many alternative demands of available cash (school fees, medical expenses, food, other farm inputs, etc.) and low prices for cash crops which are the principal sources of income for most farmers; lack of credit for fertilizers due to low cash crop yields and prices; poor and untimely supply of appropriate fertilizers; and lack of appreciation of the benefits of using chemical fertilizers on some crops such as beans.

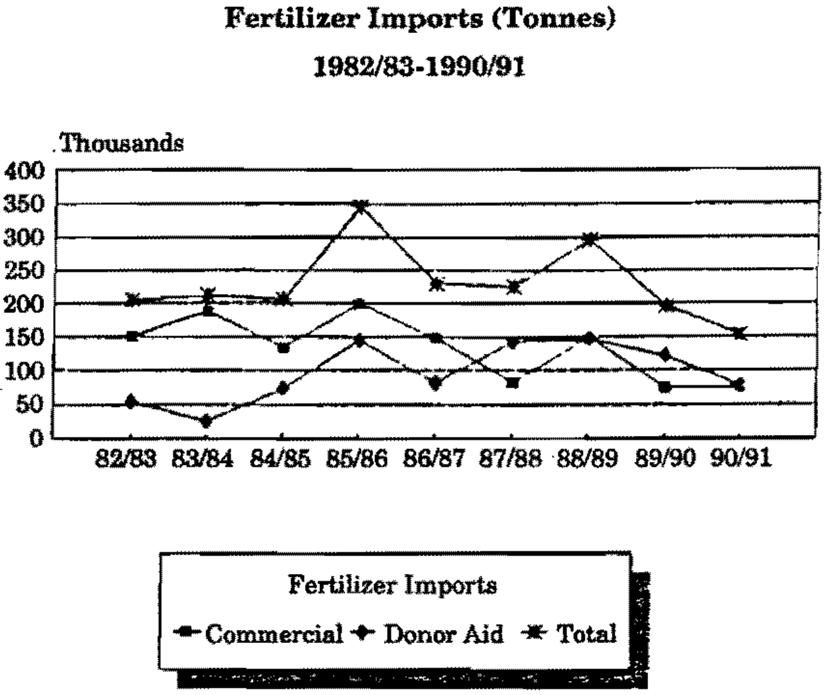
The above problems have led to continuous cropping of the land with inadequate or no replenishment of soil nutrients. There is no possibility of fallowing the land for any period of time due to small farm sizes and the need to sustain food supplies for the families on a continuous basis. In the long term, soil fertility will have to be maintained through other measures. With a view to both long and short-term considerations, the integration of mineral fertilizer use with other soil improvement measures such as agroforestry, farm yard manure application, mulching, terracing, etc. would slow down or stop soil degradation and also enhance the effectiveness of mineral fertilizer use. Emphasis on soil improvement should lie on investigating existing farming systems and developing or promoting appropriate low-input measures of maintaining soil fertility.

After many years of fertilizer promotion and their commercial availability in the Kenyan market, farmers of central Kenya are aware that mineral fertilizers can improve crop yields. If farmers are therefore not using fertilizers to the extent required, the reasons may be anything else but not wholly lack of knowledge. There is, therefore, a need to create efficiency of fertilizer use through the procurement of more appropriate types of mineral fertilizers and other soil improving techniques for use on the various crops in different agroecological zones. This should also include considering the changing socio-economic and natural environment which the farmer faces in maintaining a productive soil.



Source: Murithi and Shiluli, 1992.

Figure 4. Estimated national fertilizer consumption by type: 1984/85 - 1990/91.



Source: Murithi and Shiluli, 1992.

Figure 5. Estimated national fertilizer imports by category: 1982/83 - 1990/91.

The following issues should, therefore, be considered when developing technologies for soil management: changes in natural soil fertility status over time; changes in cropping patterns and sequences; changes in production technologies (new varieties, crop protection methods, etc.); changes in input/output prices; and changes in input/output markets.

ALTERNATIVE PRACTICES FOR LOW INPUT SOIL MANAGEMENT

Low input alternatives to improve soil fertility involve the combination of manure, mulch, rotations, intercropping etc. with input use. Reduced inputs are used with these combinations to achieve adequate production with increased use efficiency. This also is part of organic farming which involves the use of traditional farming techniques including the application of farm yard manure, compost, green manure, crop residues, rhizobium seed inoculation, soil and water conservation, and natural methods of weeds, disease and pest control (Ireri, 1990). These techniques aim at improving soil fertility as well as controlling pests and diseases in order to boost yields while at the same time avoiding environmental degradation. Organic farming is inexpensive and ensures steady, sustainable crop production. Although yields may be lower than those resulting from high input agriculture, they can be maintained indefinitely because soil fertility is improved through the use of natural products that are commonly found on the farm of small holders.

Compost: Composting is important especially to farmers with limited or no access to animals as well as farmers with inadequate supplies of animal manure. By composting, valuable plant materials that otherwise might be wasted can be utilized to improve soil productivity. Although compost is both an organic fertilizer and soil conditioner, it's primary value is the role it plays in modifying soil structure. The physical condition of the soil is improved by promoting granulation. Good physical condition makes the soil easier to work, improves drainage and maintains aeration. Compost also improves the nutrient exchange capacity of the soil as well as the cation exchange capacity and acts as a direct source of plant nutrients including nitrogen, phosphorus, and potassium. Soil buffering is improved with the use of compost which in turn helps stabilize the soil reaction or pH. Organic acids in the compost and humus also help in the chemical weathering of the mineral portion thus increasing the nutrient status of the soil. Compost use reduces or prevents soil crusting and also improves the conditions required for the activity of beneficial soil organisms such as earth worms and nitrifying bacteria.

Manure: Animal waste and plant residues including plant materials used as bedding in livestock sheds which are trampled, urinated on, and decomposed within the animal shed are referred to as manure. It can be used directly from sheds or kept to decompose further. Manure is used in the same manner as compost and has the following benefits: an additional of ammonium nitrogen; greater movement and availability of phosphorus and micronutrient due to complexation; increased moisture retention; improved soil structure with corresponding increases in infiltration rate and decreases in soil bulk density; increased buffering capacity against drastic changes in pH; an complexation of Al^{3+} thereby reducing its toxicity.

Mulching: This is a process by which the soil surface is covered with plant residue to reduce water loss through evaporation and prevent soil compaction. Mulch material is highly desired in coffee because of the reduction in soil erosion and the release of nutrients into the upper layer of the soil where coffee roots are predominate. It is commonly practised in kitchen gardens and helps to keep vegetables productive over a long period of time. Other benefits of mulch are: reduction of soil temperature and restricts diurnal variation compared to bare soil; reduction of soil erosion by wind and water; reduction of growth of weeds; improves infiltration of rain water by breaking the impact of rain drops; enhancing earthworm and termite activity; and improves soil structure and gradually reduces nutrients to the soil.

Crop rotation: Rotating crops promotes the efficient use of soil nutrients over time (Tisdale *et al.*, 1985). Other advantages of rotating crops are: more continuous vegetative cover with less erosion and water loss; improved tilth of the soil; crops vary in feeding range of roots and nutrient requirements; deep-rooted versus shallow-rooted, strong feeder versus weak feeders; and nitrogen fixers versus non-legume; and weed and insect controls are favoured; diseases are controlled by avoiding pathogen build-up in crop residues; and broader distribution of labour and diversification of income are effected.

Green Manure: A luxurious cover crop which is ploughed into the soil is known as a green manure. The following crop benefits from the rapid decomposition and nutrient release of the green manure. Nutrients are redistributed in the soil and kept available for the succeeding crop. This technology is particularly important and effective when a fast growing legume is used as the green manure. Because of their association with nitrogen fixing bacteria, leguminous plants are often used as green manure crops to improve soil fertility and increase soil organic matter (Okigbo, 1977).

Intercropping: Intercropping is a strategy to decrease risk and obtain crop production under variable environmental situations (Andrews and Kassam, 1976). This is especially true in areas of low input agriculture as experienced by small scale farmers. Acland (1971) as presented by Okigbo and Greenland (1976) reported various intercropping systems in Kenya including: bananas/coffee; bananas/maize; bananas with maize, beans, cowpeas, potatoes, sugarcane; beans/maize; millet/sorghum with maize, cowpeas, pigeonpeas, and/or bambara nuts. Additionally, coffee, bananas, mangos, coconuts, cashew, and cotton play an important role in the intercropping systems of various zones.

Willey (1981) lists areas of intercropping research which need increased efforts for maximizing yields. This is especially so in the area of agronomy and include: plant population and spatial arrangement relationships; effects of nutrient fertility and water regimes; identification of appropriate genotype combinations. Other areas of research as expressed by Steiner (1982) which deserve attention include: methodology of intercropping experimentation; fertilizer use; breeding and selection for intercropping systems; pest management;socio-economic analyses of intercropping enterprises. Sorghum/pigeonpea and millet/groundnut (Osiru and Kibira, 1981), relay cropping and intercropping (Nadar and Rodewald, 1981; Nadar and Faught, 1984), and maize with beans, cowpeas, and pigeonpeas (Nadar, 1984 b,c,d) have been systems studied in Kenya and show promise for small scale farmers on both a yield and economic basis as well as a improving nutrition.

AGROFORESTRY

Considerable interest has recently been raised in the potential of agroforestry in sustainable, low input agriculture. It may be necessary though to define agroforestry in a manner which is acceptable to all. Nair (1989a) presents 12 definitions of agroforestry which have, in the past, been promoted to categorize this old practice with a new name. The final definition which includes many aspects from the others is: "Agroforestry is a collective name for land-use systems and technologies where woody perennial (trees, shrubs, palms, bamboos, etc.) are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence" (Nair, 1989a). Agroforestry, therefore, involves more than one species, has multiple outputs, lasts longer than a year, and is more complex than monocropping systems. The deliberate mix of woody perennial with crops and/or animals is an attempt to maximize efficiency and total output in a sustainable manner of land use.

Several characteristics of trees have been suggested as desirable for low input agroforestry based agriculture. Deep rooting systems are preferred which take up nutrients normally beyond the root system of commonly cultivated crops. The nutrients are then recycled through leaf litter in a process termed "nutrient pumping" (Nair, 1984). In addition, trees contribute large quantities of organic matter through leaf litter. Crop production under *Faidherbia albida* is commonly much higher than in open fields (Nair, 1984; Poschen, 1986). Inclusion of nitrogen fixing trees in agroforestry is often mentioned as a beneficial component of low-input systems (Nair, 1989b) and is promoted for use in low input agriculture although it must be pointed out that there is a wide range in the nitrogen fixing potential of these trees.

In addition to desirable biological attributes of agroforestry systems, there are also physical qualities which improve the crop production environment. The potential of agroforestry in soil conservation has been reviewed by Wiersum (1984) and Young (1989). Rainfall erosivity is greatly reduced by ground cover and the presence of trees in a cropping system helps dissipate the energy of raindrops before they reach the soil surface (Wiersum, 1984; Young, 1989). Soil erodability is also decreased under trees because of the increased organic matter resulting from leaf litter. Reduced rainfall erosivity and soil erodability have the combined effect of reducing soil erosion with the concurrent reduction in nutrient loss, especially significant in low input agriculture.

The use of trees for wind breaks and fire wood has been very successful in parts of Niger, a country suffering from both reduced crop lands and significant deforestation (Dennison, 1988; Long and Presaud, 1988). Neem (*Azadirchta indica*) tree lines have reduced wind speeds and crop evapotranspiration which in turn improved the cropped area and resulted in increased yields of pearl millet. *Maerua crassiflora* has been used in Niger as a browse because of its prolific growth even during the dry season and its nutritious, palatable foliage (Harrison, 1987). Methodologies need to be developed for low input research which include the crop, livestock, and tree components (Sandford, 1988; Van Den Belt, 1989).

Summary of the potential beneficial effects of trees on soils.

Nature of processes	Processes	Main effect on soil	Scientific evidence
Input processes (augment additions to the soil)	Biomass production	Addition of carbon and its transformations	Available
	Nitrogen fixing	N-enrichment	Available
	Rainfall	Effect on rainfall (quantity and quality) and therefore nutrient additions through rain	Not adequately demonst rated
Output process (reducelosses from the soil)	Protection against water and wind erosion	Reduce loss of water as well as nutrients	Available
Turn-over processes	Nutrient retrieval, cycling, and release	Uptake from deeper layers and "deposition" on surface via litter	Not adequately demonst rated
		Withholding nutrients that can be lost by leaching	Not demonst rated
		Timing of nutrient release: this can be regulated by management interventions	Available
"Catalytic" processes	Physical processes	Improvement of physical properties (water-holding capacity, permeability, drainage,etc.) at the microsite as well as at macrosite (watershed)	Available
	Root growth and proliferation (enhanced)	Addition of more root biomass; growth-promoting substances; microbial associations	Partially demonst rated
	Litter quality and dynamics	Improvement of litter quality through diversity of species; better timing of quantity, and method of application of litter possible	Now being increasingly studied in alley cropping and other intercropping experiments
	Microclimatic processes	Creation of more favourable microclimate; shelterbelt and windbreak effects	Available
	(Bio) chemical/ biological processes (net effects on various processes)	Moderating effect of extreme conditions of soil acidity, alkalinity, etc.	Partially demonstrated

Source: Nair, 1989b.

CONCLUSION

There are many interacting components within the farming system with no individual entity working in complete isolation. As crop production specialists, we must be aware of these interactions and incorporate them into our research program when feasible. The major interacting elements of crop production in sub-Saharan Africa are the crops, livestock, and trees. Each one of these elements may be of primary interest to the farmer on a continuing basis or only at specific periods during the year. Sanford (1988, 1989) and Reynolds and de Leeuw (1988) identify some of the various interactions which can benefit various components of the system. In general they can include but are not restricted to: manure utilization; animal traction; nutrient recycling; leaf litter; reduced evapotranspiration by crops within wind breaks; substantial crop residue utilization by animals; tree browse for feed; green manure; shading and seed dispersal.

The potential of these interacting components must be considered for incorporation into low input systems. A systems perspective is needed because many of the alternatives deal with organic matter incorporation which is usually produced on a different farming unit. Crops, livestock, and trees all play a role as producers of the organic matter necessary for sustainable agriculture in a low input framework.

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AGRICULTURAL TECHNOLOGY EVALUATION—SOME CONSIDERATIONS

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ABSTRACT

This paper addresses considerations for agricultural technology evaluation at various levels. At the research level, considerations include the information need, the resources required to conduct the research and the probability of research success. At the field-level, agronomic feasibility and the impact of the technology on sustainability should be assessed. Expected micro-economic or farm level impact of the technology, especially the expected accpetability of the technologies and their effect on the ability of the farm to stay in business needs consideration. Concern for the environment and natural resource management means that technologies must be assessed in light of ecological sustainability at a regional level. A technology needs to be compatible with macro-economic forces and its sensitivity to changes in policies and capital availability, and its impact on labor availability needs to be considered. The probable effect of the technology on social justice, or equity, for poor consumers, poor farmers, rural poor and future generations merits consideration.

A means of integrated these considerations into a technology evaluation procedure is presented.

INTRODUCTION

Current thinking among development leaders and agricultural scientists favors the idea that many, if not most, farmers, whether small or large-scale, are interested in assessing the technological options open to them. If a practice is found to be appropriate, they are likely to adopt it. Harwood (1981) wrote "Change depends on a workable technology which transforms existing farm systems in accordance with farmers' goals". However, in a recent workshop in which the impact of on-farm research was reviewed, participants agreed that there were not many on-shelf technologies available which could be easily adapted for adoption by small-scale farmers (Low, 1992).

The probability of developing a technology which will be adopted by farmers and which will be environmentally and socially acceptable can be improved by evaluating the technology prior to experimentation. In evaluating potential technologies, several aspects of the required research and the impact of the technology at various levels should be considered (Allen *et al.*, 1991 and Lowrance *et al.*, 1988). At the research level, considerations include the information need, the resources required to conduct the research and the probability of research success. The expected agronomic potential and field-level impact of the technology should be assessed. Expected micro-economic or farm level impact of the technology, especially as it may affect the ability of the farm to stay in business needs consideration. Concern for the environment and natural resource management means that technologies must be assessed in light of ecological sustainability at a regional level. A technology needs to be compatible with macro-economic forces. The probable effect of the technology on social justice, or equity, for poor consumers, poor farmers, rural poor and future generations merits consideration.

This paper elaborates on these considerations and presents a scheme for evaluating potential technologies according to relevant criteria.

RESEARCH LEVEL CONSIDERATIONS

Information need

The need for a better understanding of the technology and the level of required information needs to be considered. For many soil and crop management technologies, basic principles are well understood and the technology may already be utilized elsewhere. When a good basis for extrapolation of information exists, little additional research may be needed. In other cases, the technology and its application to a given set of circumstances may not be well understood and more basic research may be needed. A technology which is already in use elsewhere, and which requires only adaptive research, may be a better option than one which requires much more research.

Probability of successful completion of research

Lack of continuity and inadequacy of funding, staffing and commitment can interfere with the completion of a research effort. In an analysis of the progression of technologies from on-farm research initiatives to farmer adoption for three southern Africa countries, Low (1991) found that 9% of the research initiatives failed because the research was not followed through to the production of a recommendation. The probability of successful completion of the research needs consideration. Research of long duration, high complexity, or high costs is less likely to be completed successfully than less demanding research.

Resources required for the research

Resources required in terms of cost, time, expertise and facilities need to be considered as most research programmes have a scarcity of resources. Commitment to a research topic implies that fewer resources will be available for other research topics that might be implemented.

On-going research

Opportunities for collaboration with other related research efforts deserves consideration. While collaboration with on- going research efforts can be mutually beneficial, unnecessary duplication should be avoided.

FIELD LEVEL OR AGRONOMIC CONSIDERATIONS

Agronomic feasibility

The agronomic feasibility or the probability that the technology will be superior or complimentary to currently used technologies needs to be considered. Low (1991) reported that approximately 19% of farming systems research initiatives in Southern Africa did not lead to adoption because they did not result in an improvement over the current practice or because the results were inconclusive. Results from other research, from application of the technology in other circumstances, or from experiences of farmers with related technologies can be useful in ex ante evaluation of the agronomic feasibility of a technology. Computer-run models are becoming useful tools for pre-testing technologies for given sets of circumstances. Examples include the RUSLE (USDA-ARS, 1991) and WEPP (NSERL, 1989) models for soil erosion, SCUAF (Young and Muraya, 1990) for agroforestry, and the DSSAT models for crop growth simulation (IBSNAT Project, 1989)

Sustainability or rejuvenation of productivity

A technology should contribute to the rejuvenation or sustainability of the crop production system. Improving the agronomic sustainability implies improving the buffering capacity of the field level ecosystem to maintain its long-term productivity despite changes in the prevailing environment or production systems (Lynam and Herdt, 1988). Soil organic matter level is a major aspect of buffering capacity of tropical soils.

FARM LEVEL, MICRO-ECONOMIC CONSIDERATIONS

In considering the farm-level feasibility of a new technology or a possible solution, Tripp and Woolley (1989) advise consideration of profitability, compatibility with the farming system, contribution to reducing risk, need for institutional support and ease of demonstration or testing by farmers. Long-term effects on profitability and sustainability of agricultural production and on the quality of life of the farm family must be considered. Sperling and Steiner (1991) discuss socio-economic aspects of required resources, including land, labour, management and capital, for the adoption of soil management technologies.

Profitability

The potential financial profitability of a technical change relates to its agronomic feasibility. Solutions that are not profitable in the short term are not likely to be attractive unless farmers are convinced of the long-term benefits. Solutions that researchers believe have little chance of being profitable at present or in the future probably should not be further tested, unless subsidization of the costs can be expected. Potential profitability should be assessed once sufficient information is available for an economic analysis.

Long-term effects on farm level sustainability

Short-term growth of small holder production has been demonstrated, but sustained long-term growth remains elusive (Lynam and Blackie, 1991). Farm-level sustainability is determined by a complex interaction of biological, physical and socioeconomic factors that constitute the basis of the production systems. Some technologies may be immensely productive and/or profitable in the short term, but have deleterious effects in the long term. Other technologies are superior for a given set of conditions, but are sensitive to changes in the prevailing environment and in socioeconomic circumstances. An agricultural system which fails to respond to change is unlikely to be sustainable (York, 1988). Short-term costs must be weighed against long-term benefits. Preferred technologies will make a long-term contribution to the sustainable growth of the farm enterprise.

Contribution to reducing risk

System sustainability might be viewed as the ability of a system to maintain its historical trend of total factor productivity (i.e. products of the system may change) over the long term, despite changes in prevailing environmental and socio- economic conditions. Sustainable growth implies that the trend will have an upward tendency. Stability is the capacity of the system to minimize short-term deviations from the long-term trend (Lynam and Herdt, 1988).

Risk is an important determinant of farmers' practices. Risk is associated with instability or a weak buffering capacity of the system against short-term abnormalities in environmental or socio-economic conditions. An improved technology should result in improved food or income security by improving the financial buffering capacity of the farm-level system against abnormal conditions.

Improved quality of life for the farm family

Technologies are preferred which will contribute to the improved physical, psychological and social well being of the farm family. The value of a technology which may result in contaminated water supplies, reduced diet quality, toxicity problems, or excessive physical or emotional stress is in doubt.

Resource availability

Farm-level compatibility of a technology depends on resource availability. Land, capital, labour, and management are considered here.

1. Land. Three aspects can be considered including land abundance, land tenure and dispersal of fields (Sperling and Steiner, 1992).

Alley cropping, fallowing and terracing are examples of practices which are land-intensive, i.e. their use requires that land be unavailable for the production of the primary commodity. While these technologies may result in an improved sustainable system, these may be unattractive to land-scarce farmers.

With insecure land tenure, farmers are reluctant to invest in practices to preserve or enhance soil fertility. Practices which require more than one season to produce visible effects, or which must be applied continuously for continued benefit, are likely to be unattractive to farmers lacking secure tenure. Application of mineral fertilizer and manures may give visible effects during the season of application. Other practices require two or more seasons to show visible effects, and may even show a negative effect in the short term.

Farm fragmentation or dispersal of plots implies that some plots may be distant from the homestead. Generally farmers invest more resources in plots near the homestead as the distant plots require more labour, are more difficult to manage and are often less secure (Sperling and Steiner, 1992).

2. Capital. The capital investment required for technology adoption may be in the form of a one-time investment, repeated seasonal investments, or an initial large investment followed by regular smaller seasonal investments. Three issues need to be considered concerning availability of capital: actual availability and the minimum acceptable rate of return; variability in costs of using the technology and in prices of produce; and long-term implications of technology adoption in terms of capital requirements.

Actual availability of cash for investment is often of less concern than the expected rate of return on the investment. A suggested minimum rate of return for the majority of situations may be between 50 and 100% (CIMMYT, 1988). For new practices, especially practices requiring new skills, the minimum rate of return may have to be 100% for the technology to be attractive. If the technology merely requires an adjustment in farmers' current practices, a minimum rate of return of 50% may be sufficient.

Costs of inputs and prices of commodities vary with time. In evaluating the potential of a technology, these variations need to be considered. While future prices cannot be reliably predicted in most cases, the ability of a technology to withstand price changes can be tested through sensitivity analysis. Sensitivity analysis simply implies redoing an economic analysis with alternative input and commodity prices (CIMMYT, 1988).

3. Labour and management. Labour and management issues include those concerned with overall demand, divisions of labour and responsibilities within farm families, availability of skills and the need for community involvement.

Labour is often scarce, even with small holders, especially at times of peak-labour demands. Availability of additional managerial capacity may be periodically limiting as well. Utilization of alternative technologies at least should not add to the peak demands for labour or management.

Sperling and Steiner (1992) advise consideration of who is to be responsible for the utilization of the technology. Women play major roles in agricultural production in Africa. Increased demands on the woman's time may lead to abandonment of a technology. Alternatively, if the woman is expected to contribute, but the benefits go largely to the man, problems may arise due to the conflicting interests.

Skills can be acquired but this often is costly. Inadequacy of certain required skills will make a technology less adoptable.

Some technologies cannot be successfully implemented on small plots, e.g. bench terraces and irrigation canals. Cooperation is needed of: a block of farmers who will be involved; those who control the natural resources and make decisions about their management; and those who will be affected by changes in the management of the resources.

Need for institutional support

Much of the technology used by small scale farmers evolved locally and farmers understand their use. These involve primarily the use of locally available resources. Much of the produce is consumed locally and market channels have developed for the small quantities that are marketed.

Adoption of a new technology may create new information needs, require the use of purchased inputs or result in larger quantities, or new products, to be marketed. The adequacy of the infrastructure to provide such support, or its capacity to be adequately improved, needs to be considered. Low et al. (1991) found that 19 of 53 on-farm research initiatives failed to lead to widespread adoption because of inadequate supply of inputs. They found that in seven of the 53 cases widespread adoption was not achieved because of poor research/extension communication. Negassa et al. (1992) also cite examples of poor adoption of technologies because of inadequate supply of seed, fertilizer or herbicide, and because of inadequacy of extension services. Inadequate infrastructural support is a major reason for failure to achieve widespread adoption.

Ease of demonstration of benefits

Clear demonstration of the benefits of a technology and successful testing by farmers at low cost are likely to contribute to high adoption rates. Early adoption rates are likely to be slow if obvious short term benefits are lacking, if the technology is complex, or if demonstrations or testing sites need to be large. The demonstration of benefits of fertilizer application are relatively easy, inexpensive, and require small sites and little time compared to demonstration of the benefits of soil conservation measures, measures to improve synchrony of nutrient supply with demand, or of crop rotations.

Ease of adoption

Innovations are most easily adopted if changes in basic cultural or husbandry practices are not required, e.g. adoption of a crop variety or a higher rate of N use. Practices that require a modification of husbandry are more difficult to adopt, e.g. first-time herbicide use. Most difficult to adopt would be a transformation of a farming system which would require a different mix of practices and yield a different mix of products (Bosc et al., 1991). Farmers prefer sequential adoption of practices rather than adoption of packages to improve traditional systems. Adoption of practices often require new skills or the investment in new inputs. Small farmer operations are heterogeneous and practices often need to be fine-tuned for specific conditions. Farmers also prefer to observe the effects of individual changes on their production systems. Adoption of more than one practice at a time greatly complicates the adoption process. Still, the products of the research are often practices which result in little improvement individually, but in a package the cumulative additive effects and positive interactions result in considerable improvement.

Often, adoption of a single component of a package will improve the farmers' present package, while other practices have little impact on their own. In such cases, the practices may be introduced and adopted in a sequence. For example, a package of maize production practices, including sowing of hybrid seed, high plant density, fertilizer use and pesticide use may be much more productive than the traditional package. The package requires new skills and additional capital investment. The farmer does not know the risk factors or profitability involved. Rather than adopt the whole package, the farmer is more likely to adopt the practices in sequence. The researcher must determine the sequence in which to introduce the components of a package. Which practices will stand alone in the farmers' situation? Which interactions between practices are important (Parkhurst and Francis, 1986)? Rather than attempting to introduce the complete hybrid maize production package, could the variety first be introduced on to more fertile soils under farmers' normal management practices? Adoption of the maize variety may be followed by fertilizer application on poorer soils or higher plant density.

Expected extent of adoption

Technologies which are appropriate to specific sets of conditions and farmers, i.e. location-specific, are needed. However, other technologies which are adoptable by many farmers in heterogeneous conditions are expected to have greater impact. Ease of adoption and obvious benefits to the farmer will contribute to high total adoption. A good basis for extrapolation of research results will allow fine-tuning the technology for varied sets of conditions.

ECOLOGICAL LEVEL

Effect on the regional environment

Technologies are preferred which will allow highly productive sustainable agriculture while preserving the larger ecosystem. Gains achieved through the adoption of a technology may be offset at a broader level due to environmental damage. While agricultural practices such as irrigation and use of agrichemcials have often lead to improved ecosystems, there are ample examples of negative environmental effects, including wildlife kills, contamination of water supplies, soil erosion, salinization and ground water depletion. While ecosystem management is complex, as a minimum we need to consider the potential local and regional environmental impact of the use of a technology. Will quality of life in the region be affected? Will opportunities for economic growth decline due to loss of wildlife or natural vegetation?

Impact on non-renewable resources conservation

Globally, non-renewable or slow to renew natural resources are being consumed at a high rate. As the supplies of these resources decrease, their cost and the costs of their substitutes is likely to increase. A region's economic future will be affected, positively or negatively, by the current consumption of its supply of natural resources. Regional resource supplies commonly affected by changes in technology for agricultural production include top soil and/or soil organic matter, and surface and ground water. The gains achieved from the depletion of such resources must be weighed against the future costs of their reduced supply.

MACRO-ECONOMIC LEVEL CONSIDERATIONS

The agriculture sector is a major portion of most of Africa's national economies. It is a major employer. National economies are very sensitive to fluctuations in prices of agricultural produce or levels of production. Farmer production decisions to an extent determine the diversity and quality of foods available to consumers, and farm-level technologies may significantly affect the economic and social well-being of rural communities (MacCannell, 1988).

At the same time, farm-level economics are affected by economic forces at the regional, national and international levels. Policy changes will affect the availability of inputs and the strength of the markets. The major transition occurring in many African nations from largely government-controlled economies and parastatials to free enterprise and market-driven economies will affect future farm-level economics. The changes are expected to result in freer movement of inputs and greater ease of marketing, but possibly less subsidization of agriculture. High potential production areas are likely to gain in importance relative to less favored areas.

Compatibility with macro-economic forces

While a technology may appear profitable now, its future profitability will be determined by macro-economic forces. Decline in demand for a product or decrease in supply of an input or other provision of infrastructural support, at the national or international scale, may reduce the profitability of a technology. Fluctuations in interest rates can greatly affect high input agriculture. Technologies become obsolete as they are replaced by alternatives. Demand for products change as substitutes are adopted.

Generation of employment and migration of rural population

Unemployment is a major problem in most developing countries. Growth of the industrial and service sectors is often insufficient to match the growth in the workforce. Agriculture is often the major employer.

Preferred technologies generate employment, either directly or indirectly, in rural or non-rural areas. The technologies themselves may be labour saving, but because of increased production, result in increased employment opportunities elsewhere. Some migration of rural populations may be desired when employment opportunities are adequate in other sectors of the economy.

Contribution to long-term growth

Technologies are preferred which contribute to long term economic growth at both the micro- and macro-level, benefit the total clientele, including the producers, the consumers, and those whose employment is affected by the technology.

SOCIAL JUSTICE LEVEL (EQUITY)

In evaluating the potential impact of technologies, we tend to overlook the needs of human beings who are separated from us, whether it is by distance, by socio-economic status, or by time (future generations). It is difficult to assess such impacts. There are often competing interests involved and subjective value judgements are required. Environmental soundness and economic viability need to balanced with social justice. Allen *et al.* (1991) urge that equity be considered to effect a more fair distribution of costs and benefits among all sectors of society. Three groups that might be considered in technology evaluation are poor farmers and other members of the rural community, poor consumers, and future producers and consumers.

Poor farmers and rural communities

Poor farmers are dependent on the environment and their agriculture for their livelihood. A commonly cited negative effect of the Green Revolution is that rural poor were further marginalized as they could not compete with farmers with greater availability of resources. In bad times, farmers are driven below the line of subsistence causing them to assault the environment (forests, marginal lands, etc.) for short-term gains in ways they would not do if their incomes were stable above the subsistence levels (Mellor, 1988).

Technological advancement may improve the lot of the rural poor by improving the level and stability of their agricultural production. In many cases, however, marginal areas will need to lose population in order to avoid prolongation of a continuous cycle of poverty and degradation of natural resources. People will need to emigrate to areas with greater growth potential.

Farm safety in the use of a technology should be considered. Cases of health problems related to handling of toxic chemicals are common (Cojocaru, 1992). Equipment use related accidents are common. Drudgery is often associated with farm work. Technologies generally should result in an improved situation for farm workers.

Poor consumers

Improved ability of poor consumers to meet their dietary needs is an important goal of agricultural development. This implies increasing the availability of basic commodities at lower costs. It is fortunate for the poor consumer that common benefits of increased agricultural production are increased availability and reduced prices of the commodities (York, 1988).

Future producers and consumers

With so many immediate concerns in technology evaluation, it is difficult to be concerned about future generations of producers and consumers. Often at the farm level, there already is genuine concern for future producers as these are expected to be descendants of the present producers. Still, in technology evaluation we should consider likely effects on the well-being of future generations. Environmentally-sound and sustainable production practices are likely to be favourable to future generations.

A FORMAT FOR EVALUATION OF POTENTIAL TECHNOLOGIES

Figure 1 consists of a list of considerations discussed above for technology evaluation.

Technologies may be first evaluated on a culling basis, i.e. if it is unacceptable to even one of the criteria it is rejected as a potential alternative to be adopted by farmers. Generally technologies will have some problem with several of the criteria but not be unacceptable. Therefore, the second step is to evaluate the technology in light of those particular criteria and then compare the overall strength of the technology with other potential technologies. Two examples are given below.

1. Consider the complete replacement of N and P fertilization of the maize-bean production systems in the Kitale area of Kenya with organic manures. At the research level, no problem is perceived. At the field level, the technology is of questionable agronomic feasibility. At the farm level, there are likely problems with profitability, compatibility with existing farming systems, security of land tenure and labour demand. No problems are perceived with ecological or macro-economic considerations. However, costs of production are expected to increase food costs to the detriment of the poor consumer. Therefore the technology is unacceptable at the equity level and the must be revised or rejected.

2. Consider improved weed management for enhanced nutrient cycling. The technology is acceptable at the research level but the agronomic feasibility may be questioned. At the farm level, questions arise about profitability, compatibility with existing systems, ease of demonstration of benefits, and labour and management demands. There are no apparent problems with ecological, macro-economic or equity considerations. Therefore, the technology is potentially acceptable, but the identified field- and farm-level concerns should be further considered. The targeted farming system should be in mind when re-evaluating the technology in light these field and farm level concerns. Finally, this technology must be compared to the potential of other prospective technologies.

Research level considerations	**Farm level considerations,** continued
Information need	7. Capital availability
Probability of research success	8. Sensitivity of rates of return
Resources required for research	9. Long-term capital requirements
Related on-going research	Expected extent of adoption
Field level (agronomic) considerations	**Regional (ecological) level**
Agronomic feasibility	Effect of regional environment
Package versus stepwise adoption	Natural resource conservation
Sustainability or rejuvenation	National and international (macro-economic) level
Farm level (microeconomic) considerations	Compatibility with macro-economy
Profitability	Generation of employment
Compatibility with existing F. system	Contribution to long term growth
Contribution to reducing risk	
Need for institutional support	**Social justice (equity) level**
Ease of demonstration of benefits	Farm workers
Long term effects on farm	Poor consumers
Resource requirements	Rural poor
1. Land abundanc	Future producers and consumers
2. Security of land tenure	
3. Consolidation of fields	
4. Labour/management demand	
5. Division of labour/responsibility	
6. Need for community involvement.	

Figure 1. List of considerations for the evaluation of potential technologies.

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FERTILIZER TRIAL RESULTS OF MAIZE AND MAIZE-BEAN INTERCROP TRIALS IN KENYA

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ABSTRACT

Fertilizer trial studies were conducted in all major crop producing agro-ecological zones (AEZs) of Kenya. The aim of the study was to establish reliable and current response curves for major food crops to applied nitrogen and phosphorus. The experimental sites of 0.5 ha were located in various AEZs. The experiment considered N and P_2O_5 at four levels each (0, 25, 50 and 75 kg/ha). Maize, Kenya's main food crop, was tested in pure stand and intercropped with beans.

The study shows that intercropped beans affected maize yields differently in different environments. At 60% of the trial sites, intercropped maize yields were 5 to 47% less, while at 24% of the sites maize yields were 1 to 32% more, than sole crop maize yields. At 25% of the sites, gross monetary returns were less with intercropping. Maize response to N was widespread, especially in the western parts of Kenya and around Lake Victoria. P responses were few and rather localized, especially in the upper parts of Kisii, the Molo area and at Githunguri in Central Kenya.

Crop response to applied nutrients were not found to relate well to characteristics of agro-ecological zones or to soil test levels. It was found to be feasible to predict the nitrogen and phosphorus intercrop needs from the maize sole crop response curves. Sets of equations are presented which enable the prediction of points on the intercrop response curves using the sole crop data.

INTRODUCTION

Maize is the main food crop grown and consumed in Kenya. It covers a much greater area than other food crops and is grown in all high and medium potential zones in Kenya, extending from sea level up to 3,000 metres.

In many parts of the country, maize is grown season after season on the same field, as a sole crop or intercropped with beans. Intercropping of maize and beans is a common practice in Kenya, especially with small-scale farmers who produce about 90% of the maize (Chui and Nadar, 1984). The farmers aim to get full production of the maize plus some yield from the intercropped legume. Intercropping has been shown to be more productive than monocropping (Chui and Nadar, 1984, Okigbo, 1978). The additional productivity depends upon the extent of the interspecific competition for available environmental resources (Agboola and Fayemi, 1971, Willey, 1979).

Continuous cultivation of land leads to soil fertility decline and hence yield decline (Mochoge and Mwonga, 1991, Stocking and Peake, 1986). The decline of soil fertility is mainly due to plant nutrient depletion caused by nutrient removal in harvested crops and losses to erosion and leaching (Stocking, 1986). Through use of inorganic and organic fertilizers to replenish plant nutrients, yields of maize and crops have increased steadily. In Kenya, an increase of 40-60% of maize yields through the use of N and P fertilizers has been reported (Qureshi, 1987). However, fertilizer use on maize production has not been adopted fully by all small-scale farmers, partially due to the unspecific recommendations of fertilizer use with regards to ecology, soil types and cropping systems. Other reasons include high costs of fertilizers and low knowledge of farmers on fertilizer use management. Because of these and others, the Government of Kenya started a Fertilizer Use Recommendation Project (FURP) on food crops in 1985 (FURP, 1987). Its major aims were to obtain reliable and up-to-date response curves for inorganic and organic fertilizers for major food crops in all major AEZs and soil types, and to improve the efficiency of fertilizer use through better recommendations based on soil, climatic and economic information.

The aim of this paper is to present fertilizer response results of maize and beans from FURP trial sites (1986-1991) situated between 1000 m and 3000 m above sea level. Potential for extrapolation of results based on AEZ characteristics and soil test values is discussed. The paper elaborates on the prediction of intercrop fertilizer needs from sole crop response curves.

MATERIALS AND METHODS

FURP trial sites were located to represent all major maize producing agro-ecological zones (AEZs) in Kenya between 1000 to 3000 m above sea level (Table 1). AEZs are defined on the basis of temperature and probability of sufficient rainfall for the main crops (Jaetzoid and Kutch, 1982). Each AEZ represents a certain climatic yield potential. The FURP experimental sites were therefore selected according to AEZs and soil types (Smaling and Van de Weg, 1990).In Table 1 are presented the AEZs, their seasonal rainfall probabilities (66%), mean annual temperatures, soil types and some soil properties. The soils have been classified according to the FAO Legend (FAO, 1988).

The experiment had two modules, maize sole crop and maize-bean intercrop and considered N and P effects on productivity. It was a 4^2 factorial arrangement with four levels of N at 0, 25, 50 and 75 kg/ha^{-1} and four levels of P_2O_5 at 0, 25, 50 and 75 kg/ha^{-1}. Phosphate (TSP) was applied at the time of planting maize while nitrogen (CAN) was top-dressed at emergence or four weeks after planting. Fertilizer was applied in close proximity to the maize seed or plants and the beans needed to scavenge that to benefit from the fertilizer.

In Module 1, maize was grown in pure stand at a spacing of 75 cm and 60 cm, 2 plants per hill. In Module 2, a maize-beans intercrop was grown. Beans were row-planted between maize rows. Plot size was 6 X 6 m. Weights of maize and bean grains were expressed at 12.5% moisture content. Gross returns of maize and beans were based on the prices of 1986, i.e. KSh 3 and KSh 6 for maize and beans, respectively.

The data were further analyzed to determine the feasibility of predicting intercrop needs for N and P from maize sole crop needs.

RESULTS

Mean maize and bean yields in quintals per hectare are shown for five of 43 locations in Table 2. Comparing maize sole crop with intercrop yields (Table 3), maize yield in the intercrop module from 26 of 43 trial results, i.e. 60% of the experimental sites, had decreased yields, while 10 sites (24%) had increased yields, and at seven sites (16%) intercrop maize yield did not differ from sole crop yield. The decreased yields ranged between 5 and 47% while the increased yields ranged between 1 and 32%. Decrease or increase of maize yield due to intercropping was independent of AEZ characteristics and soil types.

The gross returns (KSh) of intercropping were higher than in maize pure stand for 75% of the sites, ranging from 2 to 49% (Table 3). At other sites, gross returns were 5 to 32% less with intercropping.

The results show that maize was more responsive to N than to P in approximately 80% of the sites (FURP, 1992). Distribution of maize responses to N and P nutrients is shown in Figure 1. Maize response to applied N tended to be greatest in areas bordering Lake Victoria and the western parts of Kenya. In the upper parts of Kisii, Nakuru (Mau Summit area) and Kiambu (Githunguri), maize was more responsive to applied P. In most areas in Eastern Province and some parts of Central Province, maize responded to both N and P. Beans were most responsive to P application (Table 2), but also responded frequently to low levels of applied N (Fig. 2-11).

Responses to applied nutrients were expected to be related to AEZs in order to base fertilizer recommendations on the AEZs. However, often maize responses did not follow the AEZs well (Table 1 & 3). Still, in some zones, for example UM 4, LM 2-3 and LH 2-3, responses to N were frequent and greater than for P.

Soil test results were not found to be useful in predicting site productivity as site productivity was not significantly related to the determined levels of soil N or available soil P.

In many cases, the response curves for the maize sole crop were similar to those for intercrop maize yield (Fig. 2-11). This resulted in a good relation of sole crop maize response curves to intercropping response curves when these were expressed in gross returns (Figures 12-21). N and P response by cropping system interactions were not found to be statistically significant for these five locations. Simple equations for predicting points of response curves for intercrop N (equations i - iv) and P needs (v - viii) from sole crop response curves are:

(i) for 0 kg N/ha, $MB_i = 1835 + 0.98 * M_{sc}$, $R^2 = 0.79$

(ii) for 0 kg N/ha, $MB_i = 2286 + 1.01 * M_{sc}$, $R^2 = 0.86$

(iii) for 0 kg N/ha, $MB_i = 2227 + 1.02 * M_{sc}$, $R^2 = 0.86$

(iv) for 0 kg N/ha, $MB_i = 3566 + 0.93 * M_{sc}$, $R^2 = 0.85$

(v) for 0 kg P/ha, $MB_i = 2823 + 0.93 * M_{sc}$, $R^2 = 0.85$

(vi) for 0 kg P/ha, $MB_i = 288 + 1.10 * M_{sc}$, $R^2 = 0.94$

(vii) for 0 kg P/ha, $MB_i = 2998 + 0.92 * M_{sc}$, $R^2 = 0.69$

(viii) for 0 kg P/ha, $MB_i = 4983 + 0.82 * M_{sc}$, $R^2 = 0.62$

where MB_i and MB_{sc} are gross returns to intercropping and maize sole cropping, respectively.

DISCUSSIONS AND CONCLUSIONS

In this study, intercropped beans affected maize yields differently as 60% of the sites had decreased maize yields while at 24% of the sites, maize yield was higher with intercropping. This intercropping influence was independent of soil types and agro-ecological zones. Willey (1979) concluded that any yield additions due to intercropping will depend on improved efficiency in utilizing available resources, probably because of the species tapping different niches. Nadar (1984) found plant spacing to be a contributing factor. Seasonal variability in rainfall accounted for much variation in intercrop yields (Nadar et al, 1983).

Gross returns were higher with intercropping in 75% of the cases. These results are in agreement with results reported elsewhere (Chui and Nader, 1984, Francis, 1982 and Gardiner and Craker, 1979).

Maize responded significantly to N more frequently than to P fertilizer application. P responsive areas were few and scattered over the country. Intercropping did not much affect the occurrence of responses (Figures 2 to 9). Response to N occurred in soil with nitrogen and organic

Table 1. **Basic Ecological and Soil data Information from experimental sites.**

Site	AEZ	RAINFALL (Season 1) (66% probability)	TEMPERATURE (mean °C)	SOIL TYPE (FAO-UNESCO, 1986)	Soil Properties C%	N%	C/N	P ppm	pH NKcl 1:2.5
Githunguri	UM 1/LH 1	920	16.9	humic Nitisol	2.4	0.3	8.0	2.8	5.08
Otamba	UM 1	820	20.1	mollic Nitisol	3.01	0.24	15.0	12.3	4.97
Chepkumia	UM 1	850	19.8	humic Acrisol	3.56	0.38	7.4	16.5	5.08
Sosiot	UM 1	820	17.1	humic Nitisol	3.25	0.37	8.8	16.8	4.30
Kakamega WARS	UM 1	850	20.7	mollic Nitisol	2.31	0.22	10.7	7.0	4.78
Vihiga Maragoli	UM 1	800	20.4	humic Ferralsol	1.73	0.23	7.5	12.2	4.80
Kerugoya	UM 2	840	19.2	humic Nitisol	1.44	0.15	9.9	8.6	4.75
Embu ARS	UM 2	610	19.5	humic Nitisol	2.01	0.23	9.0	7.2	5.28
Kaguru	UM 2	620	18.0	humic Nitisol	0.97	0.31	7.9	6.6	5.35
Kamakoiwa	UM 2	650	19.4	rhodic Ferralsol	1.30	0.20	11.1	4.0	4.73
Nairobi NARL	UM 4	409	18.0	humic Nitisol	2.47	0.18	14.0	12.0	4.10
Chebunyo	UM 4	440	16.8	vertic planosol	1.87	0.25	8.2	29.0	6.65
Kitale NARC	UM 4	880	18.2	humic Ferralsol	1.87	0.13	15.1	20.0	4.65
Tongaren	UM 4	600	19.0	ferric Acrisol	1.62	0.13	14.4	23.0	4.55
Turbo	UM 4	750	19.9	chromic Acrisol	1.22	0.12	10.4	27.3	4.55
Alupe ARSS	LM 1	840	22.2	orthic Acrisol	1.78	0.20	9.3	17.3	4.65
Oyugis Ober	LM 2	620	20.9	luvic Phaeozem	1.72	0.20	8.8	20.5	4.78
Ukwala	LM 2	680	22.7	orthhic Acrisol	0.57	0.13	4.5	9.3	4.38
Homa Bay FTC	LM 3	500	22.5	haplic Phaeozem	1.60	0.22	7.4	15.7	6.23
Siaya Obambo	LM 3	630	22.7	chromic Luvisol	1.41	0.17	8.5	54.3	5.43
Buburi	LM 3	580	22.4	ferric Acrisol	1.47	0.21	7.1	17.3	4.58
Kampi Ya Mawe	LM 5	180	22.5	orthic Ferralsol	1.40	0.18	6.5	12.8	5.88
Kiamokama	LH 1	800	19.2	mollic Nitisol	2.41	0.24	8.0	12.3	4.38
Kapenguria	LH 2	810	16.3	humic Cambisol	5.0	0.55	9.1	13.0	5.23
Bugar	LH 2-3	700	14.5	humic Nitisol	1.81	0.22	8.2	15.3	4.50
Baraton	LH 2	670	17.4	humic Nitisol	3.2	0.29	11.2	10.5	4.43
Ol Ngarua	LH 3	350	16.2	ferric Luvisol	2.1	0.28	7.6	24.8	5.18
Eldoret Moi TTC	LH 3	650	15.5	ferric Cambisol	1.28	0.15	8.5	49.0	4.45
Mau Summit	UH 2	680	13.7	mollic Andosol	2.50	0.26	9.6	13.0	4.50
Ol Joro Orok	UH 3	520	13.8	luvic Phaeozem	2.75	0.30	9.2	63.3	5.40

Table 2. Yields of pure maize (I) intercrop maize (II) and intercrop beans (III) in Q/ha (1Q = 100kg).

SITES	OTAMBA			MAU SUMMIT			KAGURU			VIHIGA MARAGOLI			OL JORO OROK		
TREATMENTS	I	II	III	I	II	III	I	II	III	I	II	III	I	II	III
P0-N0	42.6	32.4	7.0	38.7	24.4	1.6	26.6	24.4	1.7	39.2	39.7	3.6	68.9	67.7	6.0
P0-N25	46.2	39.8	7.5	38.3	25.2	1.9	34.4	23.7	2.0	51.9	43.6	4.8	72.5	56.3	6.0
P0-N50	49.4	47.7	7.3	46.5	28.7	1.9	33.2	36.4	2.0	47.5	40.2	6.0	69.5	63.6	5.9
P0-N75	55.9	58.8	6.3	36.1	25.7	2.2	28.5	37.0	1.5	52.9	53.5	7.9	67.9	69.1	5.6
P25-N0	43.7	38.0	7.3	49.9	37.8	1.9	19.7	24.0	2.7	44.9	39.3	3.5	68.3	68.6	4.9
P25-N25	48.7	46.9	8.8	38.7	45.2	3.0	28.2	26.7	3.1	45.4	45.7	4.9	68.9	66.9	5.8
P25-N50	53.7	48.8	8.9	55.1	42.9	2.5	27.0	35.9	2.9	47.6	49.9	4.4	68.9	67.0	4.8
P25-N75	58.6	60.2	8.2	48.1	40.8	1.6	36.4	37.6	3.7	47.9	52.3	4.4	67.0	63.3	5.7
P50-N0	39.0	54.1	9.2	52.6	42.9	2.2	16.8	24.6	3.7	45.9	45.6	4.6	72.1	65.2	5.0
P50-N25	48.0	33.5	9.5	46.1	41.9	1.6	30.6	29.7	2.4	51.2	50.8	3.2	68.9	66.5	7.2
P50-N50	53.3	39.6	8.1	53.8	45.8	1.9	31.8	36.5	3.1	46.5	45.3	4.8	66.0	70.0	5.2
P50-N75	51.9	49.4	8.3	46.5	48.8	1.6	38.9	44.2	2.0	52.2	55.2	5.4	66.2	65.9	7.9
P75-N0	49.0	42.2	8.5	55.0	55.2	2.5	19.8	20.3	2.0	41.6	43.4	4.8	68.7	60.7	4.7
P75-N25	46.6	46.0	9.6	55.0	47.3	2.5	23.9	29.6	4.3	48.5	47.0	5.6	68.3	66.6	6.8
P75-N50	55.5	58.2	8.9	59.2	48.9	2.2	34.1	30.9	3.6	51.3	53.0	5.4	71.0	65.3	5.8
P75-N75	63.0	58.2	9.4	52.3	49.9	2.2	39.6	40.8	3.1	45.8	53.7	4.7	70.9	66.0	5.1
CV	39	45	39	33	31	24	36	31	44	41	39	32	15	11	23
F-Values															
N	47.3	8.2	0	0	0.3	0.5	39.6	67.0	0	1.2	4.3	7.8	0.4	0.5	0.8
P	0.1	0.5	6.8	14.7	57.3	1.1	0.1	0.2	21.6	0	1.1	0.4	0	0.1	0
N*P	0.9	1.8	0.1	0.1	0.3	1.3	9.9	0.7	0.1	0.1	0	7.2	0.2	0.3	0.3

Table 3. Mean yields of maize and beans, nutrient responses and gross returns.

Site	Sole crop maize	Intercrop maize	Intercrop beans	Gross returns (Ksh) Sole crop, maize	Maize + beans
Otamba	50.1(N)	46.8(N)	8.3(P)	15110	19064
Oyugis Ober	32.0(N)	24.7(N,P)	2.6(P)	9606	8976
Kakamega WARS	61.1(N)	58.3(P,N)	4.0	18330	20896
Sosiot	45.9(P,N)	36.4(P)	3.9	13770	13260
Chebunyo	74.9	39.8(N)	5.7	22486	1538
Ol Ngarua	77.0(N)	69.7(N)	8.2(P)	23115	258
Mau Summit	48.2(P)	40.7(P)	2.1	14275	12635
Bugar	57.9(N)	55.0(N)	2.8(N,P)	17377	18229
Rongo	32.2(N,P)	19.9(N)	5.2(P)	9680	9122
Homa Bay	52.6(N)	57.9(N)	5.2(N,P)	15780	20490
Buburi	23.9(P)	25.1(P)	3.4(P)	7440	9395
Mumias	19.0(N,P)	19.8(N,P)	4.8(P)	5650	8820
Chepkumia	47.7(N)	50.7(N)	6.8	14325	1930
Kaguru	34.1(N)	44.9(N)	3.0	10237	15272
Turbo	54.5(N)	55.0(N)	6.3	16356	20341
Vihiga-Margoli 47.5	47.4(N)	4.9(N,P)	14250	17160	
Githunguri	16.5(P)	16.5(P)	1.7(N,P)	5111	5970
Embu ARS	-	45.1(N,P)	2.5(N,P)	13745	1507
Eldoret Moi TTC	-	48.0	3.5	14478	16563

matter contents ranging from 0.12 to 0.38% N and 0.97 to 3.56% OC. Shukla (1972) reported responses to N to be negligible if total soil N was more than 0.32%, but in this study significant responses were observed at 0.38% N.

Field trials are expensive and time consuming. Therefore, a basis is needed to extrapolate the available research results to larger areas than the immediate vicinity of trial sites. The FURP was formulated partly for this purpose (Smaling, 1989). The results of this study did not fully follow AEZs (Table 4), although N responses were frequent in a few zones i.e UM 4, LM 2-3 and LH 2-3. Nevertheless, environmental variability within an AEZ make extrapolation of research results difficult.

Individual soil properties were not found to be related to responses. Total nitrogen is an unreliable indicator of productivity as it is not a reliable predictor of N availability for crop use. Plants take up nitrogen in NH_4^+ and NO_3^- forms which have to be released through mineralization. Rate of N release is not uniform in all soils due to the nature of organic substrates, soil pH and other soil properties (Mochoge, 1990). Instead of using total nitrogen some researchers are now using mineral-N in soils for extrapolation purposes (Ris *et al.*, 1981).

Table 4. Main agro-ecological zone (AEZs) and maize responses to N and P

Site	AEZ	Main Response	Site	AEZ	Main Response
Githunguri	$UM_1/L4_1$	P	Alupe ARSS	LM_1	N(P)
Otamba	UM_1	N	Oyugis Ober	LM_2	N
Chepkumia	UM_1	N	Ukwala	LM_3	N(P)
Sosiot	UM_1	PN	Homa Bay FTC	LM_3	N
Kakamega WARS	UM_1	N(P)	Siaya Obambo	LM_3	N
Vihiga Marag.	UM_1	N	Buburi	LM_3	P(N)
Kerugoya	UM_2	K(NP)	Kampi Ya Mawe	LM_5	NP
Embu ARS	UM_2	PN	Kiamokama	LH_1	P
Kaguru FTC	UM_2	N	Kapenguria	LH_2	-
Kamakoiwa	UM_3	N	Bugar	$LH_{2\text{-}3}$	N
Nairobi NARL	UM_4	N(P)	Baraton	LH_2	N
Chebunyo	UM_4	N	01 Ngarua	LH_3	N
Kitale NARC	UM_4	N(P)	Eldoret M.TTC	LH_3	N
Tongaren	UM_4	N(P)	Mau Sammit	UH_2	P
Turbo	UM_4	N	01 Joro Orok	UH_3	-

Approaches which consider two or more soil properties such as QUEFTS (Quantitative Evaluation of the Fertility of Tropical Soils) (Janssen *et al.*, 1986), or crop growth simulation models may provide better basis for extrapolation.

The ability to predict response curves for intercropping from sole crop curves offers the opportunity for improving efficiency of fertilizer use for intercropping. The proportions of maize and beans in an intercrop varies with time and space. In Kenya, maize is generally the preferred crop and is planted at near full density while intercrop beans are planted at relatively low densities. In much of Uganda, the opposite is true in that farmers plant beans at near sole crop densities with low intercrop maize densities. Farmers in Kenya have been observed to vary the relative proportions of the two crops with seasons. Determination of response curves for the range of relative crop proportions in maize-bean intercropping for the many AEZs would be a mammoth task. Ability to estimate intercrop response curves from available sole crop data provides an opportunity for improving fertilizer use efficiency without much additional experimentation.
However, research is needed to establish the relationships between sole crop and intercrop response curves for the various planting patterns.

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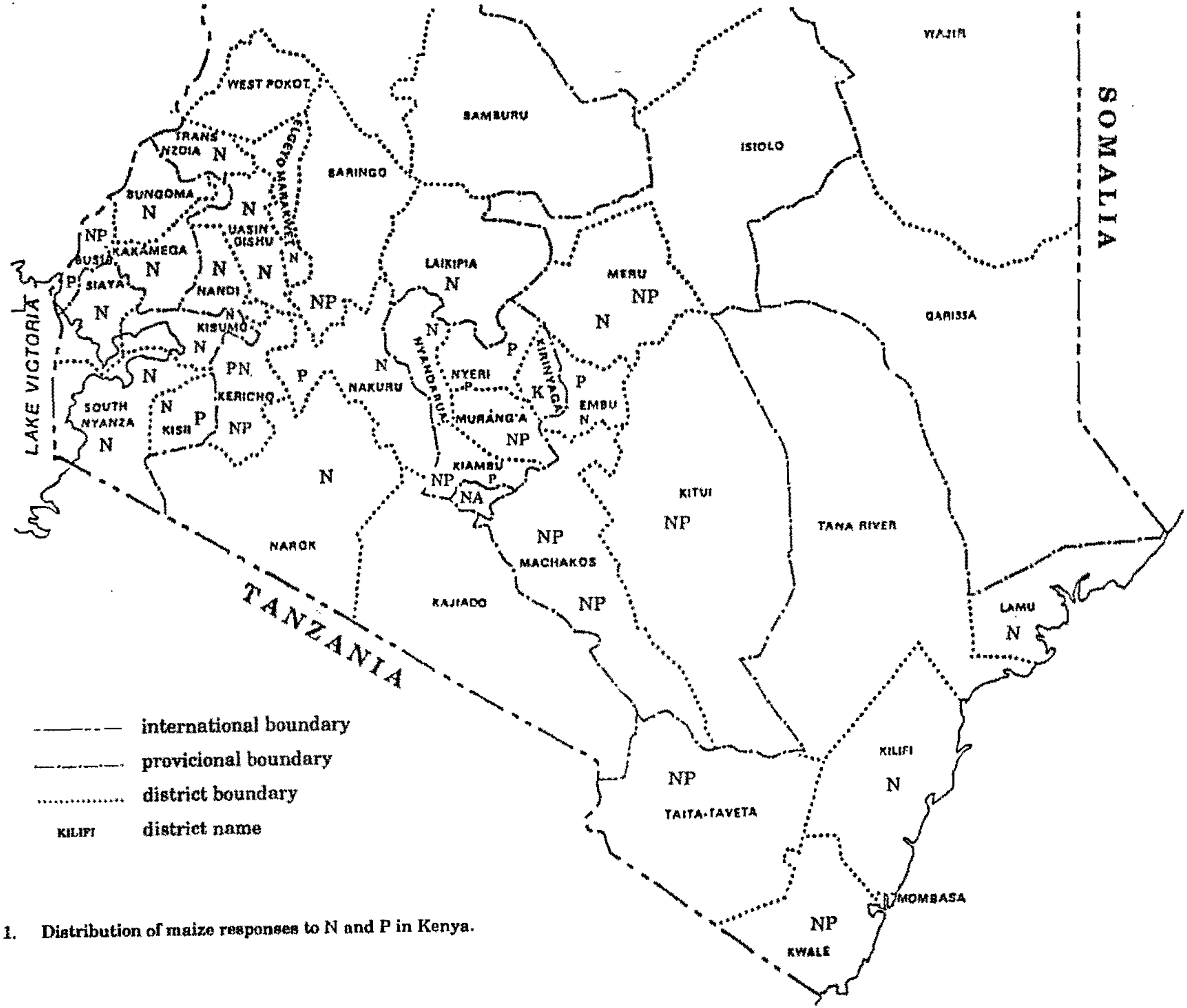

Figure 1. Distribution of maize responses to N and P in Kenya.

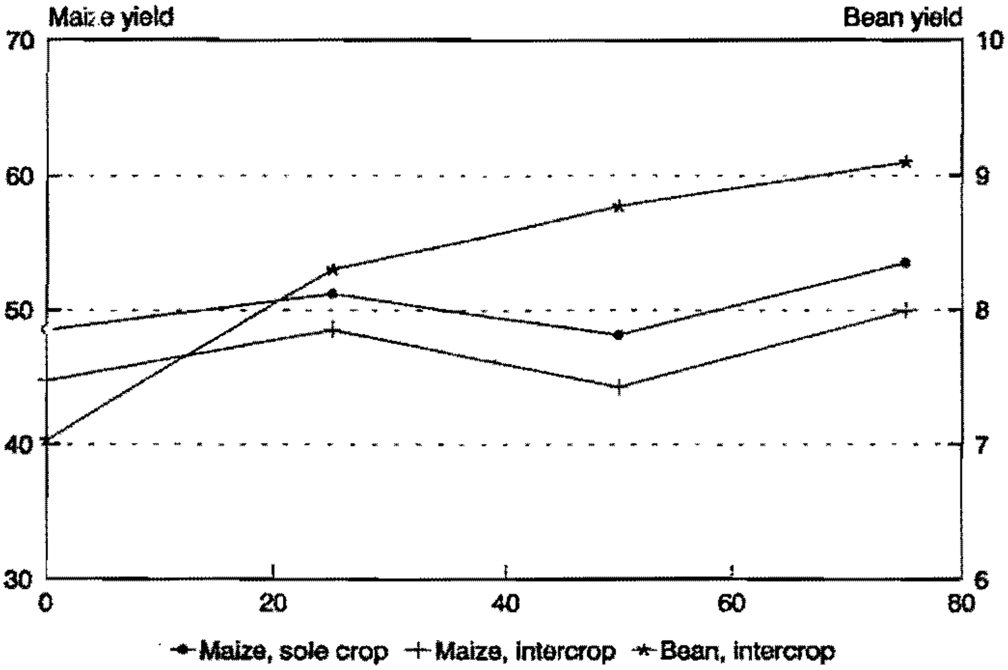

Figure 2. Response curves to applied P at Otambo.

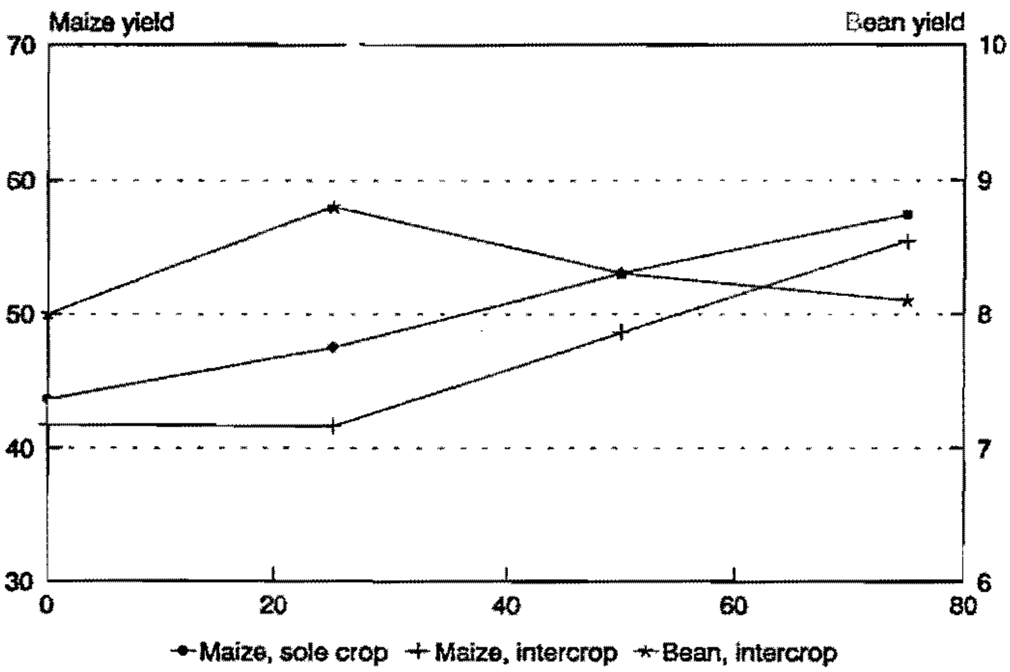

Figure 3. Response curves to applied N at Otambo.

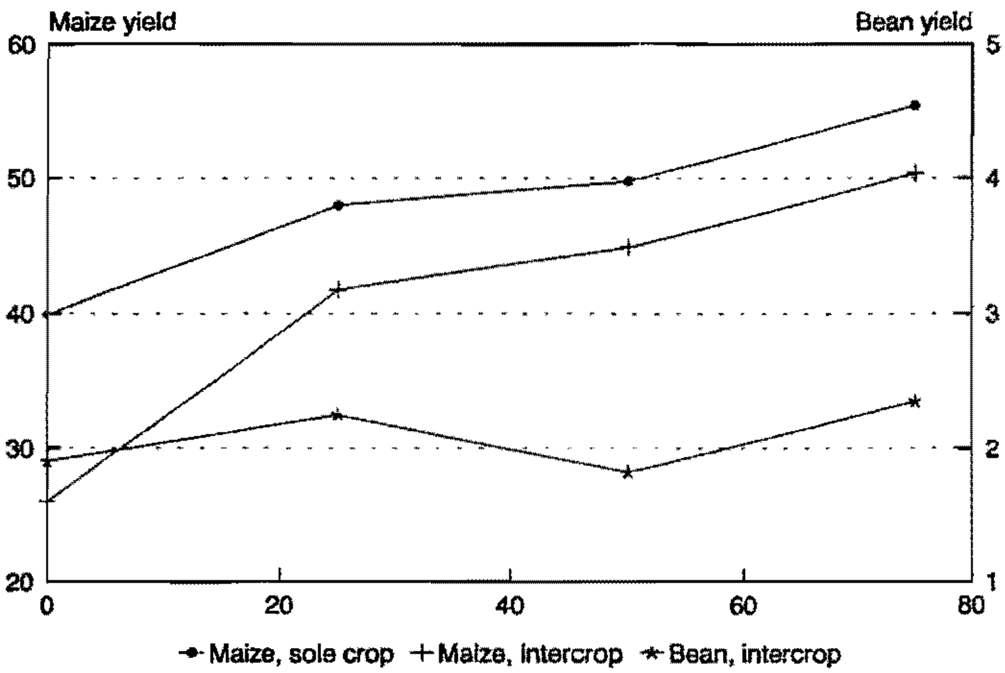

Figure 4. Response curves to applied P at Mau Summit.

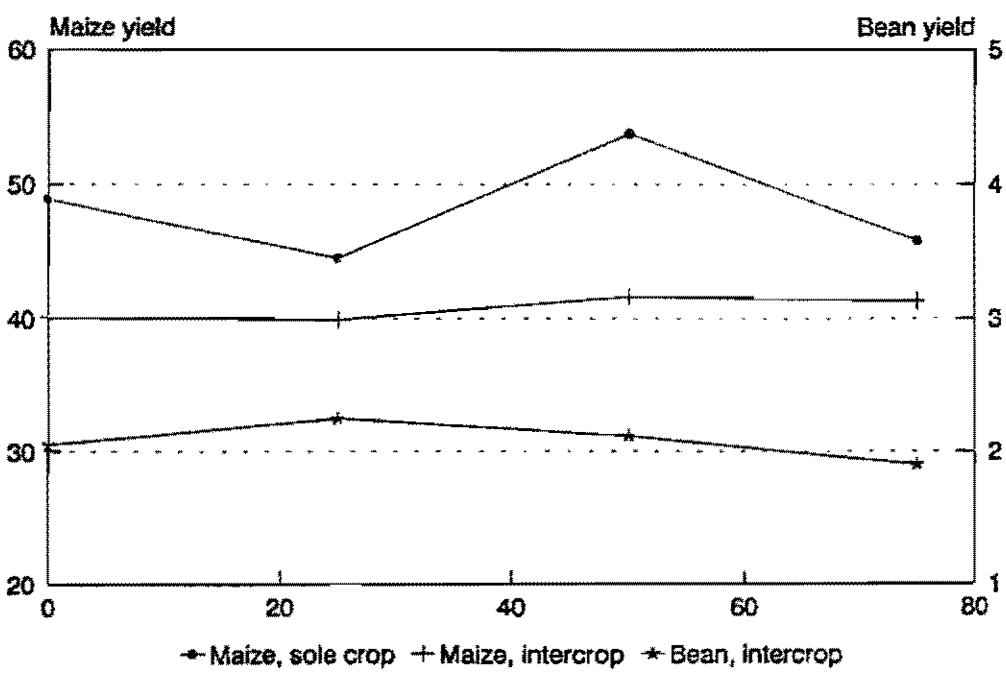

Figure 5. Response curves to applied N at Mau Summit.

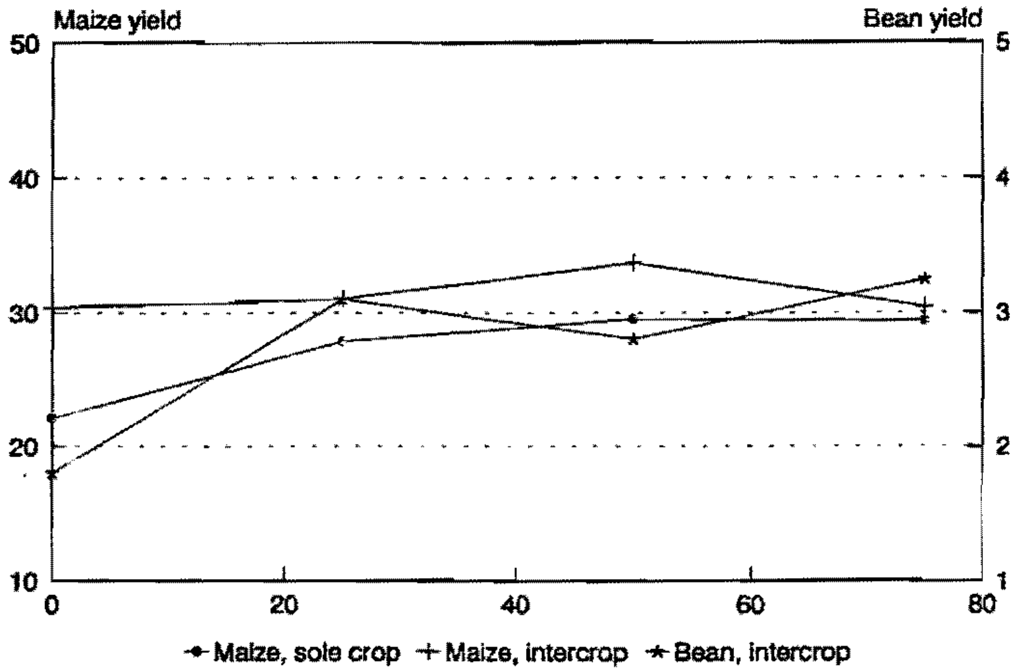

Figure 6. Response curves to P at Kaguru (Q/ha).

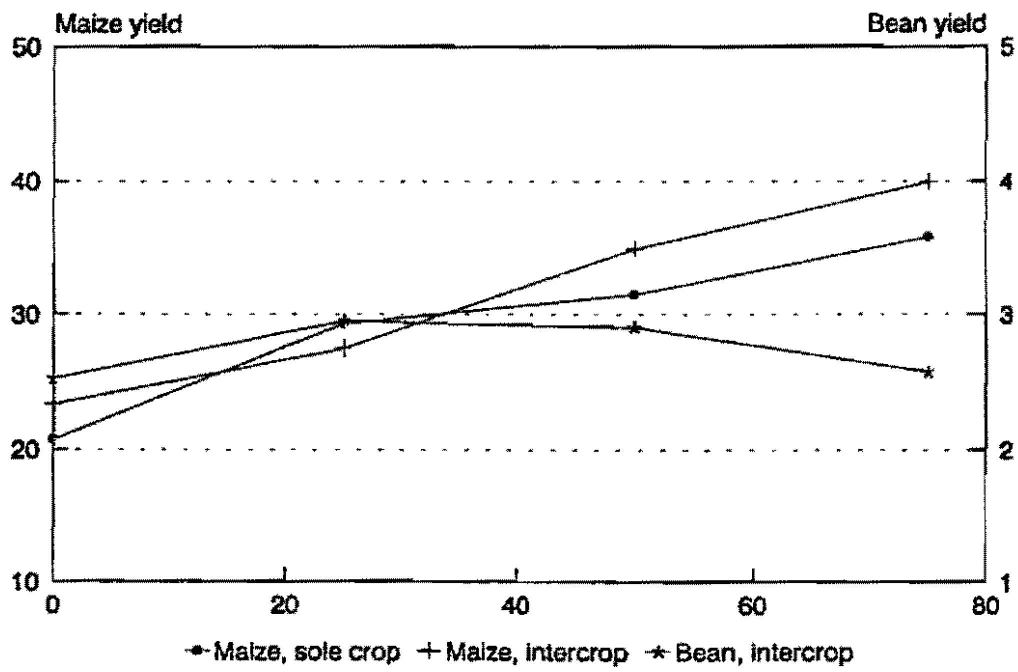

Figure 7. Response to applied N at Kaguru (Q/ha).

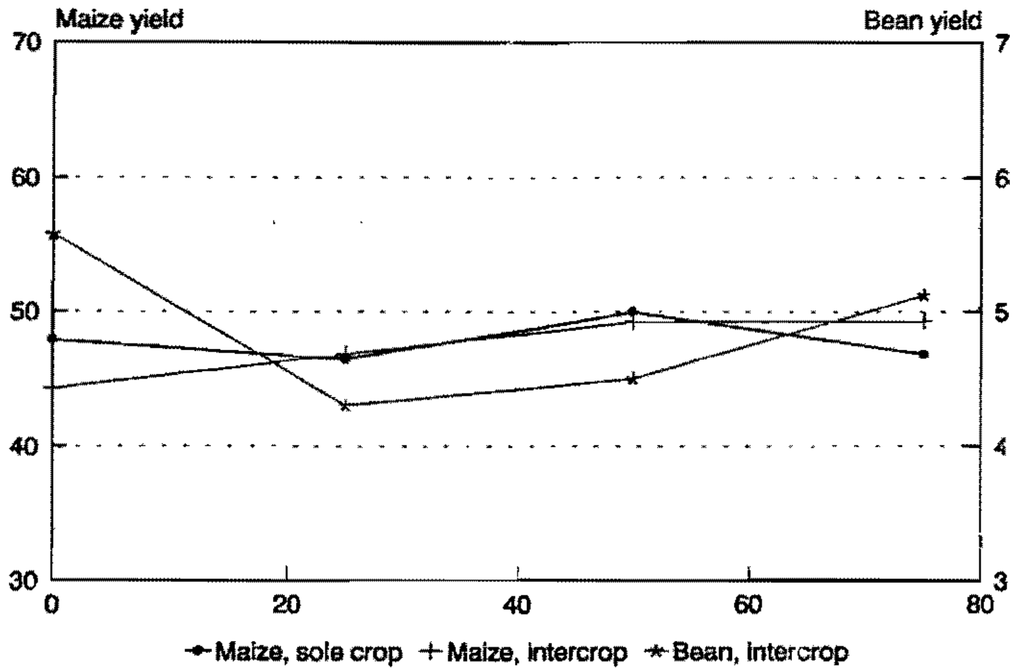

Figure 8. Response curves to applied P at Vihiga-Maragoli.

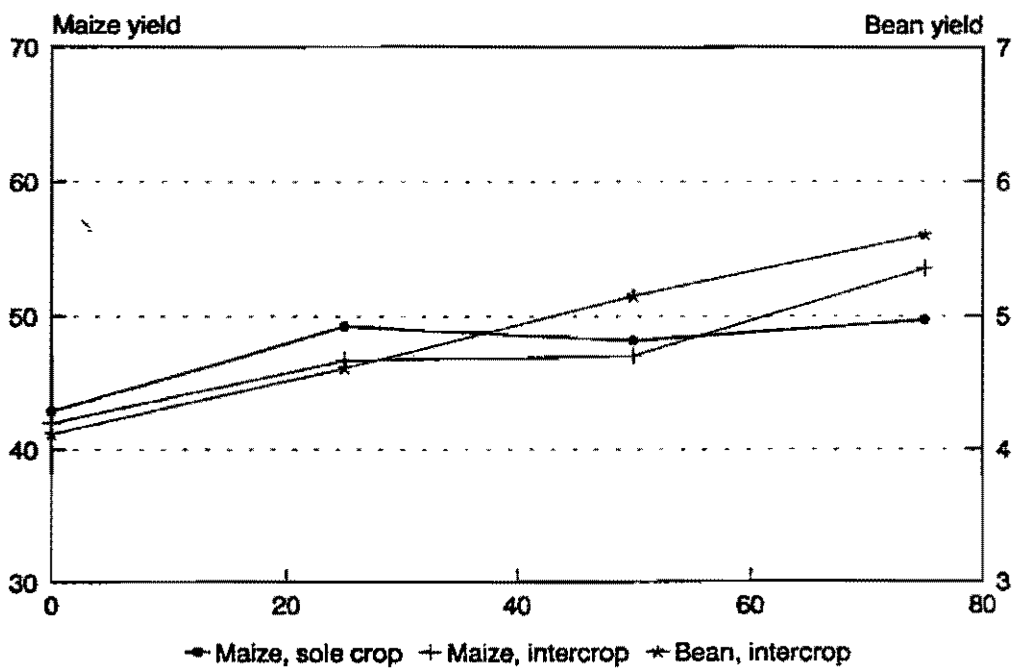

Figure 9. Response curves to applied N at Vihiga-Maragoli.

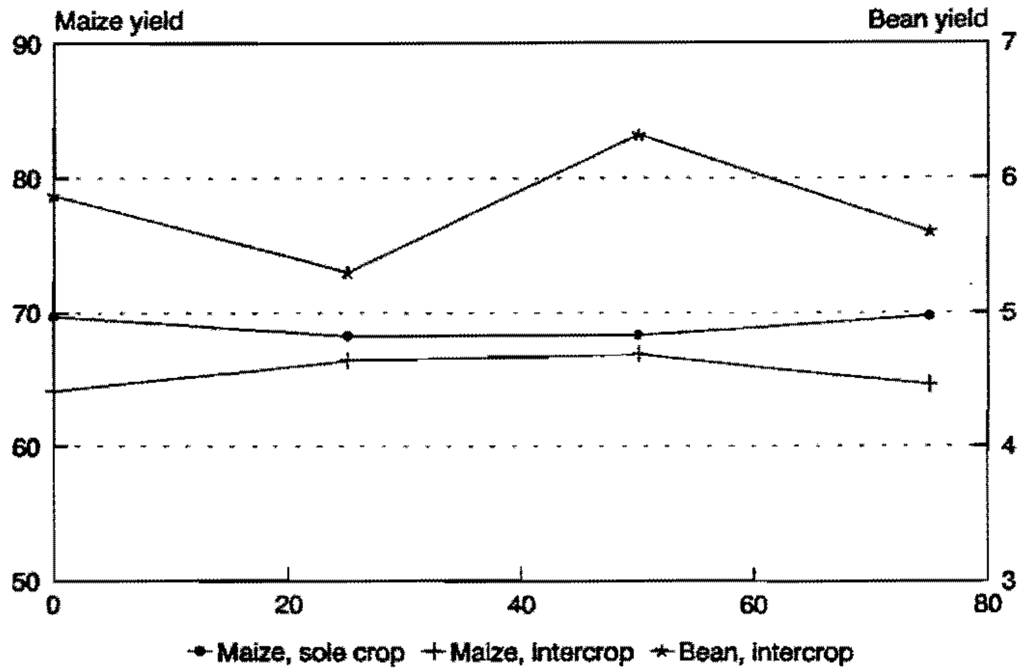

Figure 10. Response curves to applied P at Ol Joro Orok.

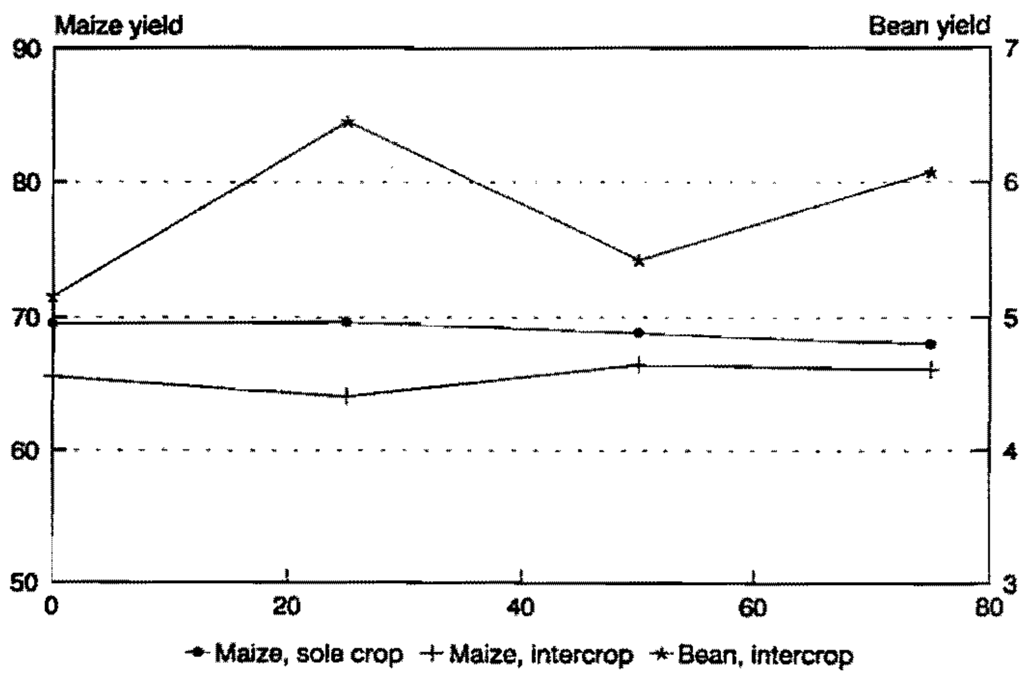

Figure 11. Response curves to applied N at Ol Joro Orok.

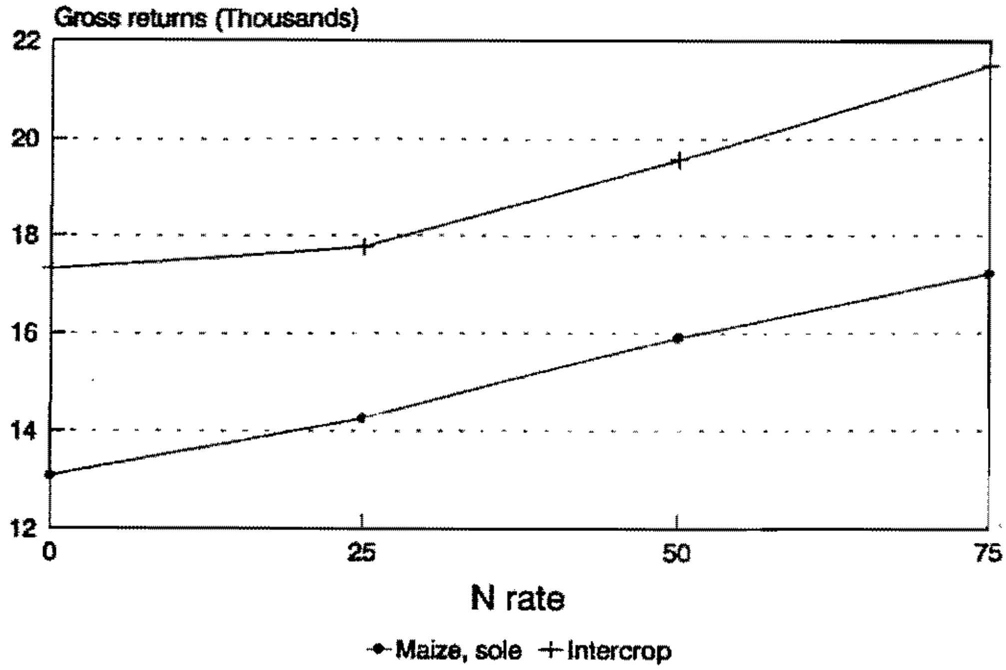

Figure 12. Gross returns (KSh) to maize and maize-bean intercropping in response to applied N in Otamba.

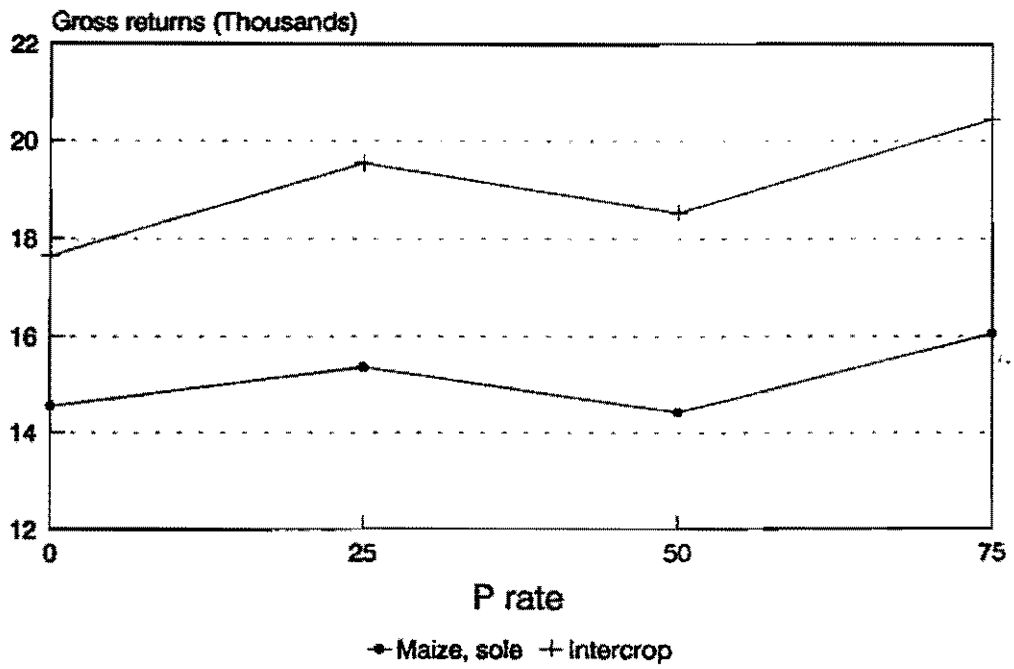

Figure 13. Gross returns (KSh) to maize and maize-bean intercrop in response to applied P in Otamba.

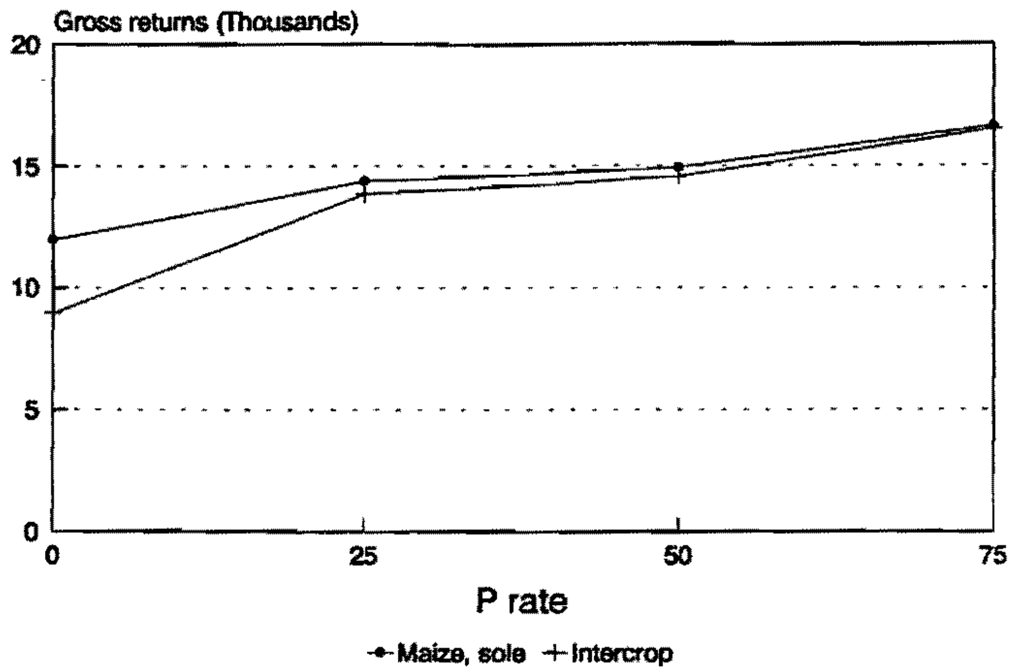

Figure 14. Gross returns (KSh) to maize and maize-bean intercrop in response to applied P at Mau Summit.

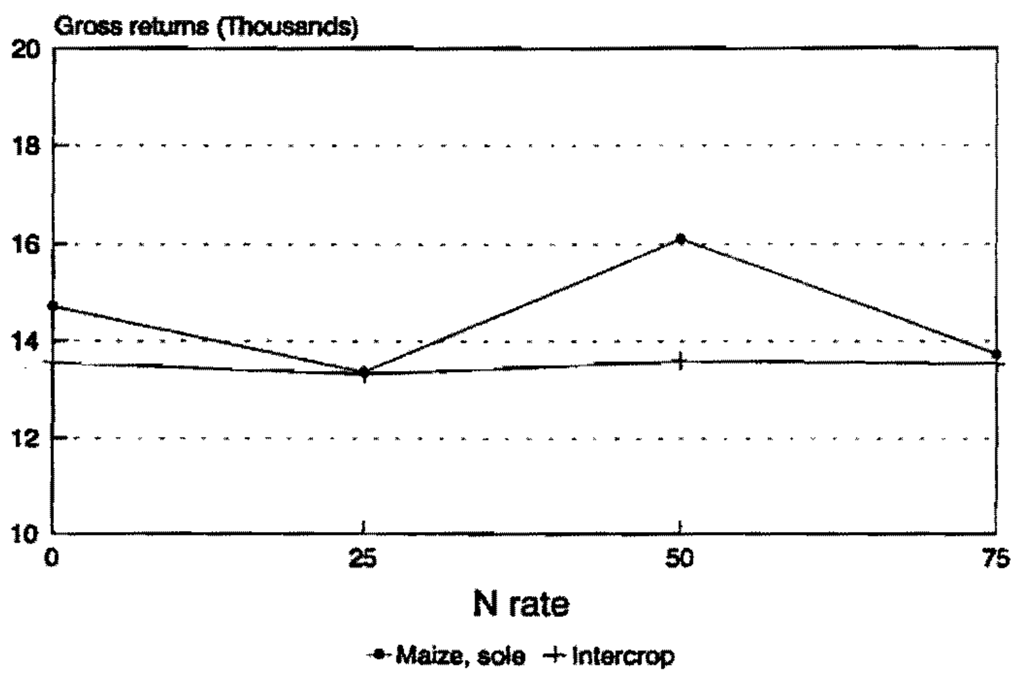

Figure 15. Gross returns (KSh) to maize and maize-bean intercropping in response to applied N at Mau Summit.

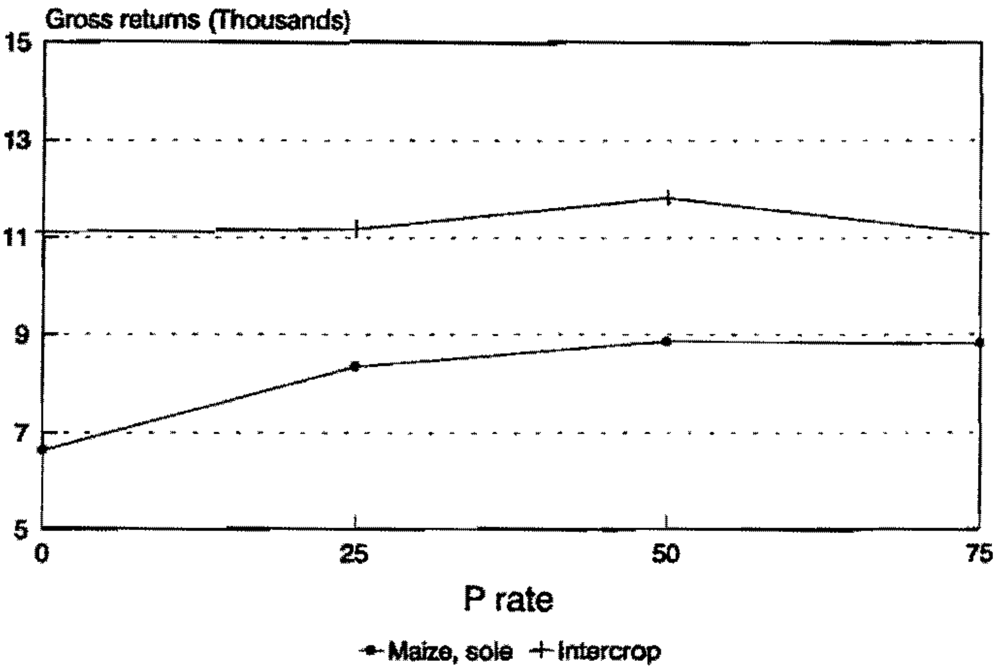

Figure 16. Gross returns (KSh) to maize and maize-bean intercrop in response to P at Kaguru.

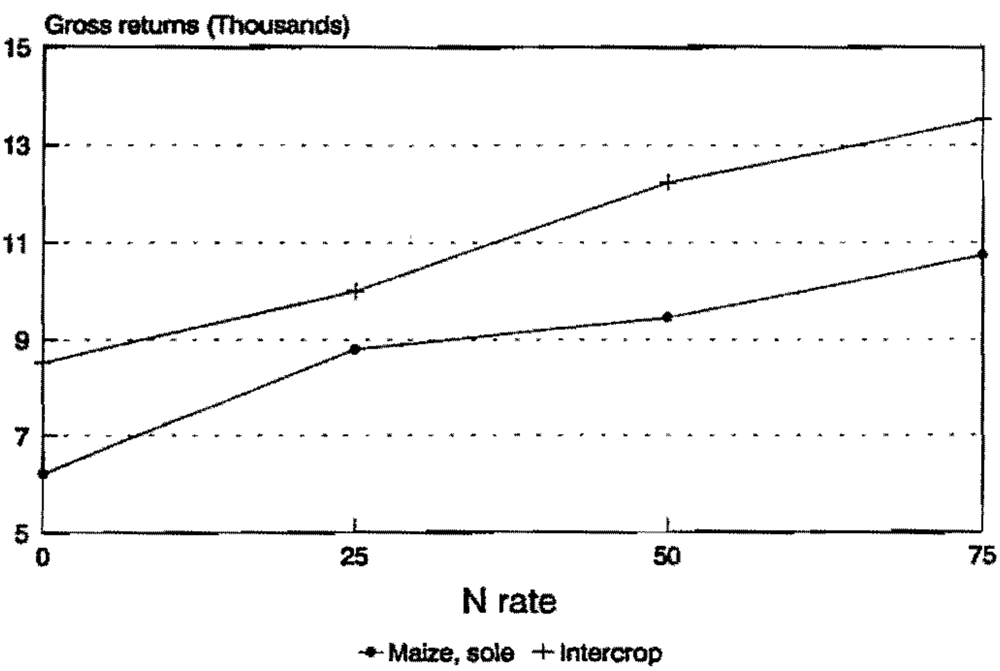

Figure 17. Gross returns (KSh) to maize and maize-bean intercrop in response to N at Kaguru.

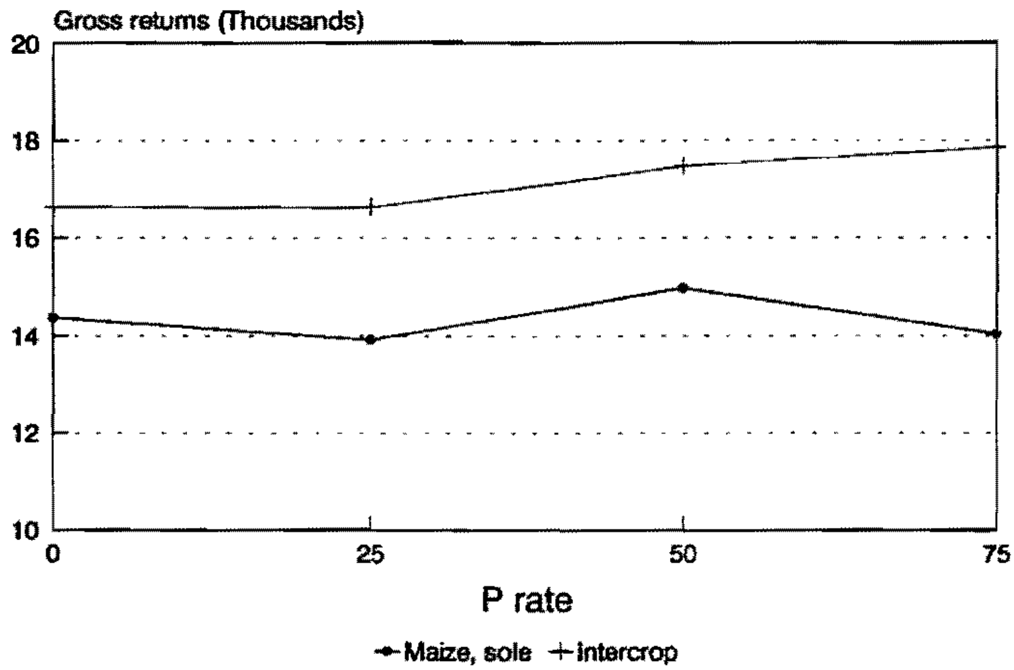

Figure 18. Gross returns (KSh) to maize and maize-bean intercrop in response to P at Vihiga-Maragoli.

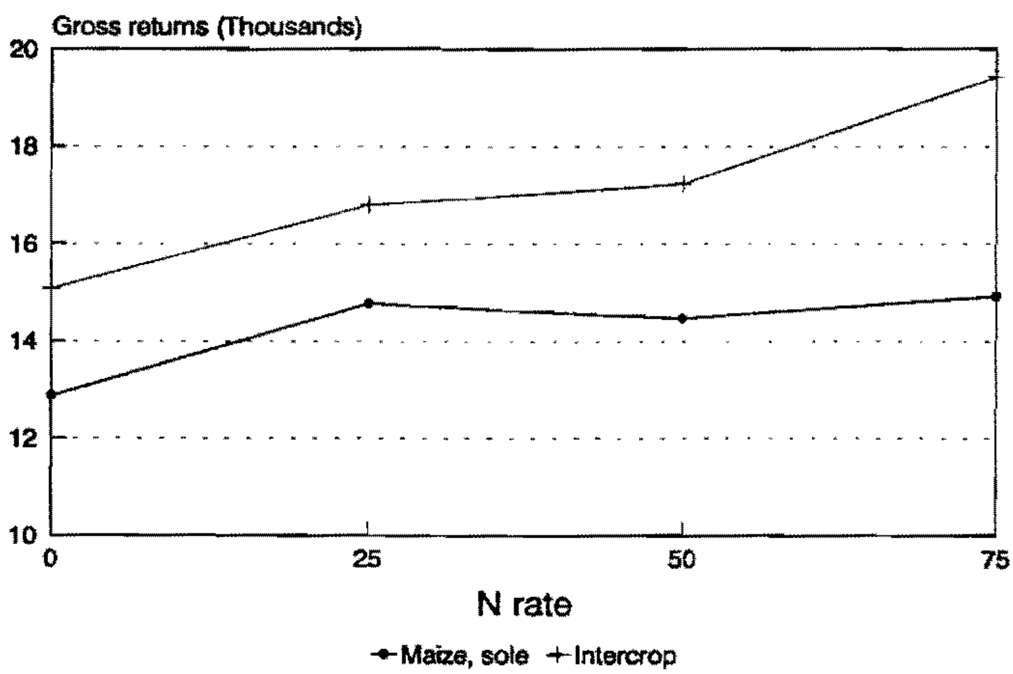

Figure 19. Gross returns (KSh) to maize and maize-bean intercropping in response to N at Vihiga-Maragoli

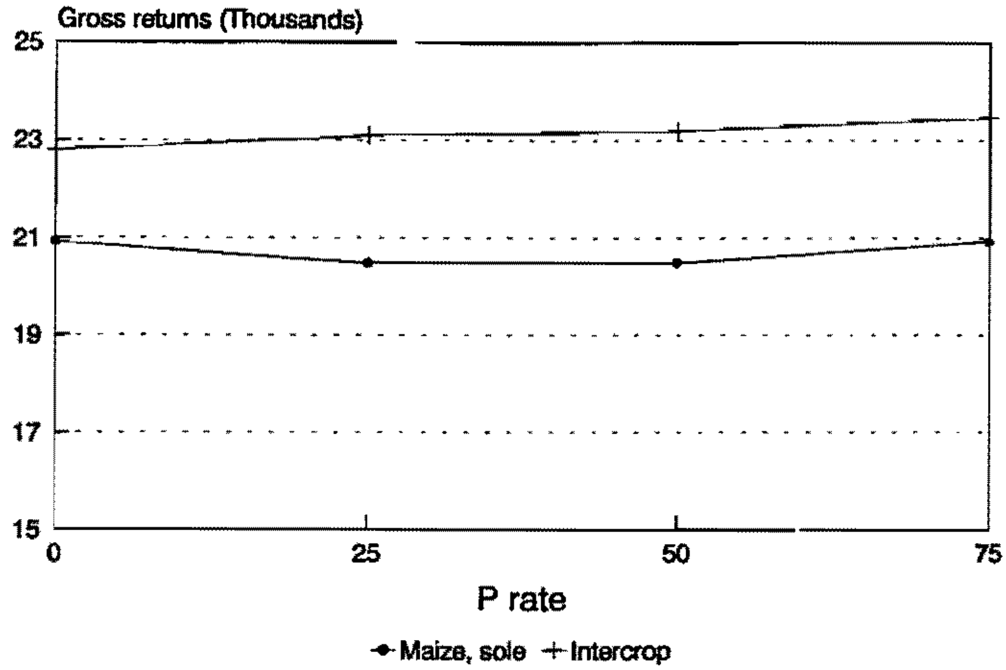

Figure 20. Gross returns (KSh) to maize and maize-bean intercrop in response to P at Ol Joro Orok.

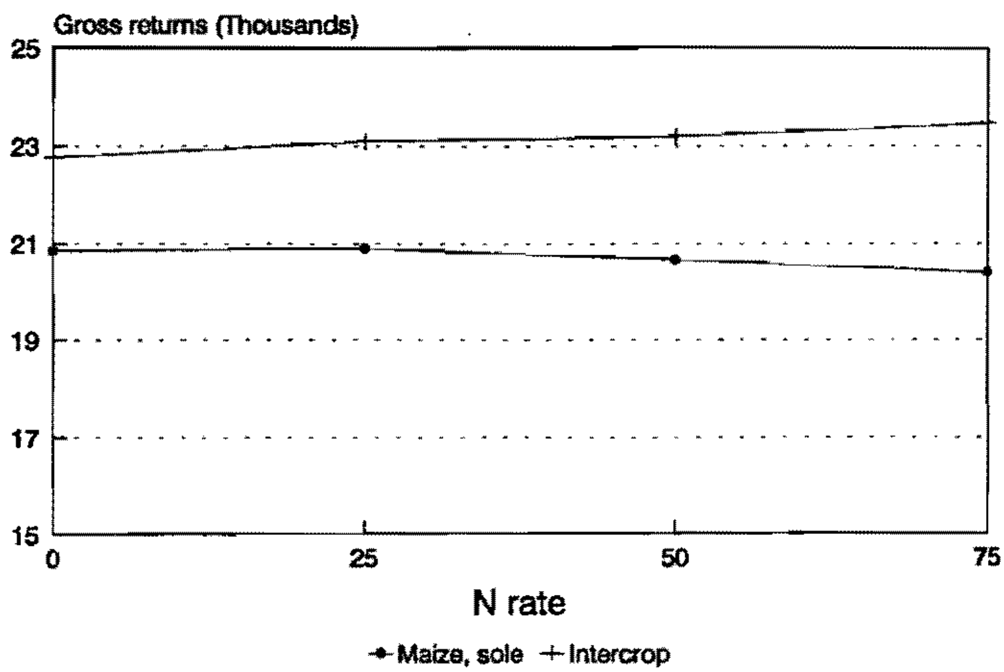

Figure 21. Gross returns (KSh) to maize and maize-bean intercrop in response to N at Ol Joro Orok.

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RESEARCH FOR SUSTAINABLE AGRICULTURAL PRODUCTION SYSTEMS IN HIGH ALTITUDE ZONES OF EASTERN AFRICA

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ABSTRACT

Demands for food and fiber are increasing at a faster rate than supply in the medium and high altitude zones of Eastern Africa, while the productivity of the land is apparently declining. In many cases, productivity is constrained primarily by insufficient nutrient supply. To meet future demands for food, the land's productivity will need to be maintained, or rejuvenated, and managed for greater productivity. Sustainable agricultural systems which allow for increased production need to be developed and implemented. This paper explores a number of issues relevant to research for sustainable agriculture in Eastern Africa and proposes an alternative research approach.

The need and place for both high-input and low-input production systems is explored. Roles of alternative research methodologies, including commodity and disciplinary, farmer participatory, agro-ecological and eco-regional methodologies are discussed. The challenge of improving agricultural production in a sustainable manner for a wide range of micro-environments is addressed. Promotion of technologies, especially when packages of practices or novel systems are needed, is discussed.

A research approach is proposed which is based on intensive farmer participatory research in carefully selected farming communities. The communities serve as benchmark research "sites" of larger agro-ecological zones, with consideration of socio-economic factors. Various research methodologies are applied at the various stages of the research process.

INTRODUCTION

Demand for food is increasing at a faster rate than supply in the medium and high altitude zones of eastern Africa, while the productivity of the land is apparently declining. Anthropogenic pressures are increasing due to a population growth rate of 3.1% for Sub-Saharan Africa (World Bank, 1989) and due to increasing demands for an improved distribution of income. Agricultural production has decreased in some parts of the Region (Jain, 1988). Throughout most of the eastern Africa, the farming system/input levels might be classed as low or moderate traditional such that arable land requirements for subsistence exceed 0.5 hectare per capita (Buringh, 1989).

In many cases, productivity is constrained primarily by insufficient nutrient supply. At the same time, estimated rates of net nutrient depletion are high, exceeding 40 kg/yr of N and K, and 15 kg/yr of P, per hectare of arable land in Kenya and Ethiopia (Stoorvogel and Smaling, 1990). Lower, but still high rates, are estimated for Tanzania and Uganda. Rate of fertilizer use is low throughout this area and probably near the average of five kilograms of fertilizer per hectare of arable land used in Sub-Saharan Africa in 1983 (Plucknett, 1991). In places fertilizer use is declining because of insufficient profitability, inconsistent crop response, and/or failure to sustain high crop yields with continued fertilizer use (Brossier, 1991). Much of the negative nutrient balance is due to loss of nutrients because of soil erosion and leaching with detrimental effects on the regional environment.

To meet future demands for food, the land's productivity will need to be maintained, or rejuvenated, and managed for greater productivity. Sustainable agricultural systems which allow for increased production need to be developed and implemented.

SUSTAINABLE AGRICULTURE

Definitions of sustainability are numerous but the following elements are commonly suggested (Okigbo, 1989):

- adequate economic returns to farmers;
- maintenance of natural resources and productivity indefinitely;
- minimal adverse environmental impacts and preferably enhancement of the environment;
- optimal production with efficient use, and maybe minimal use of non-renewable internal and external resources;
- satisfaction of human needs for food, fiber and income;
- provision for the social and psychological needs of farm families and communities; and
- economical viability of the farm enterprise, in that it earns a fair return on farm investments.

Sustainability is needed at the levels of field, farm, region (ecology), and macro-economy (Lowrance *et al.*, 1986).

i) It is needed at the field level for continued productivity of the land. Factors threatening sustainability at this level include soil erosion, degradation of soil structure, soil organic matter loss, nutrient losses, depletion or contamination of water supplies, salinization, pest build-ups, and limited bio-diversity.

ii) Farm-level sustainability is needed for economic viability of the production system. It may be threatened by unsustainable field-level systems, incompatibility of enterprises, low profitability, high risk, insufficient supply of required resources, infrastructural inadequacies, and unhealthy living and working conditions.

iii) Sustainability at the ecological or regional level is needed for the health of the society and community, the environment and the resource base. Pollution, resource depletion, inadequate supply of food and fiber may threaten sustainability at this level. Sustainable agriculture should contribute to the economic well-being of the region by creating or reducing employment opportunities as needed and by stimulating economic activity.

iv) Macro-economic sustainability is controlled by factors such as fiscal policies and interest rates which affect the viability of national agricultural systems. Some production systems are more likely than others to be sensitive to macro-economic fluctuations.

SUSTAINABLE AGRICULTURE AND RESEARCH IN EASTERN AFRICA

In order to meet future food and fiber needs in eastern Africa, production will need to increase. Currently, both high potential (or favorable) lands, marginal lands (due to unfavorable climate, poor soils, or maybe the socio-economic status of the farmers) and those areas of intermediate potential are farmed. The question arises as to where to invest available research resources. Some say that there are adequate technologies on-the-shelf for the high potential areas and relatively little investment in research is needed. Therefore, they argue emphasis should be placed on the more problematic areas. Another side argues that the greatest returns to research will be achieved in the high potential areas, and that efficiency of input use and avoidance of pollution need the attention of researchers. This side argues that the marginal lands are often too fragile to sufficiently intensify the agriculture in a sustainable manner, and the returns to research will be relatively small (Plucknett, 1991). More production is needed from the high potential areas to alleviate the pressure on the more fragile areas which may be irreparably damaged with improper intensification.

The Green Revolution approach has not been successful in eastern Africa, but ample evidence indicates that a moderately high input approach is technically feasible in favourable parts of the eastern Africa highlands. Global 2000 has successfully assisted farmers in the Arusha-Kilimanjaro and the Southern Highland areas of Tanzania to achieve very good responses of maize to applied inputs. Researchers and farmers in Kenya (e.g. the Kitale area) and in Uganda (e.g. the Mbale area) have been successful with a moderately high-input approach. Inadequate infrastructure for transport, provision of inputs and markets is a major hinderance to further intensification in many areas (Bosc et al, 1991). Facilities for absorbing the increased risk associated with such systems are often lacking, including credit and crop insurance facilities. Distances of production areas from the source of the inputs and to the markets are often great resulting in less profit for the producer. The demand for the produce, especially for production areas which are far from population centers, is often variable adding to the risk of production.

Those areas where intensification is not much hindered and the infrastructure is adequate might be high-priority areas for research (Jain, 1988). Research to increase yield may be needed, but often much of the needed information is already available. More research is needed on input-use efficiency, stability of production and prevention of pollution of ground and surface water. Work to maintain bio-diversity in the system is likely to be important in order to avoid creating an essentially mono-culture production system which will be especially susceptible to breakdown of genetic resistances to pests, but also provide an environment where minor pests can develop to be major pests. Maintenance of soil organic matter for its role in stabilizing production is a major concern.

Most of the arable lands of Eastern Africa probably are not currently suited for high-input agriculture, either because the land is marginal for production due to soil or climate related factors, the soil is fragile (due to easy erodibility, low fertility, sensitive to soil structure changes, etc.), or because the socio-economic conditions are inappropriate. In such areas, moderate and sustainable increases in output may be the objective, probably through combining use of low-input alternatives with regenerative agriculture. Okigbo (1991) suggests that the development of such systems may involve a combination of elements of traditional systems and their component technologies that maximize on use of locally available biological inputs, with affordable external inputs. Increased efficiency in the use of locally available renewable resources may be an important goal. Improved soil and water conservation, management of organic materials, enhanced nutrient cycling with reduced nutrient losses, biodiversity for improved resource-use efficiency and stability, improved pest management, and improved compatibility of crop and livestock production systems are likely features of such systems.

Agricultural research has achieved much in developing varieties and yield increasing and protection practices which are potentially useful to improved, sustainable systems, but it should also be pointed out that some achievements in increased productivity came with increased threat to sustainability. Adoption of new technologies has in many cases led to fragile monoculture production systems with little biodiversity, high pest levels, serious nutrient losses and pollution problems.

Research must continue to play a major role in sustainable agriculture. However, the effectiveness of research must be improved.

Conventional approaches to agricultural research

Agricultural research in eastern Africa, and in most places of the globe, is generally commodity or discipline oriented and aimed at variety development, testing for response to the use of inputs, and studies of narrowly defined components of systems. The effects of two or three components and their interactions are typically studied in factorial trials. Most research is on sole crop systems and seldom are the interactions of more than two species evaluated in intercropping trials. The degree of farmer involvement or consideration of farmer's circumstances varies considerably but has probably increased recently through farming systems research and on-farm research. Still farmer participation in research is very minor.

Conventional agricultural research approaches have been successful in improving our knowledge about crop production systems, solving production problems, and developing technologies for increasing productivity through the use of inputs. The approach has contributed primarily to the development of high input systems. It is well suited to study of the input-output aspects of such systems and will play a major role in development of high input sustainable systems (Lockertz, 1988).

It is useful for example in the study of nutrient-use efficiency in narrowly defined boundaries, but another approach may be needed to reach a high level of nutrient use management in which the interactions between the management of the crops and soils with soil macro- and micro-organisms are managed to improve the synchrony of nutrient supply and demand. In low input systems, we may envision the management of considerable biodiversity, including numerous crops, weeds, soil fauna, etc.. Again, the interactions between the numerous components may be important to maintaining sustainability while achieving increased production, but the study becomes complex.

Agricultural research will probably need to be more inter-disciplinary, more eco-system-oriented, and to have more farmer participation to achieve the development of improved, sustainable systems which are acceptable to farmers. Many opportunities of the future for sustainable agriculture are likely to be found at the interfaces of disciplines (Francis *et al.*, 1988, Jain, 1988) through inter-disciplinary research, for example, with weed scientists and entomologists collaborating in high quality research to control and insect pests or agronomists and soil micro-biologists collaborating to achieve improved symbiosis between crops and soil micro-organisms.

A merger of agronomy and ecology, i.e. an agroecological approach, may be necessary to adequately understand the dynamics of systems and to define their critical components (Altieri and Anderson, 1986). Once those critical components are defined, McCalla (1991) suggests that the investigation of these critical components and their interactions will most likely be addressed through the application of traditional approaches to breeding, agronomy, economics, etc.. Others suggest that agro-ecology will have a major role in the study of components and their interactions (Gliessman, 1987, Hendrix, 1987,).

Greater farmer involvement in identification of researchable questions, selection of potential solutions, evaluation on farm, and validation of results will give a more efficient research process, but will also lead to creative combinations of farmer wisdom and technical expertise (Francis *et al.*, 1988).

Farmer participatory research

Farmers can contribute to most stages of the research process. Their indigenous knowledge and understanding of the technical and socio-economic conditions of their situation can be useful at all stages of the research process. Over centuries, farmers developed production systems which are often difficult to improve upon given their circumstances and resource availability, and an objective of achievement of short term benefits. Many farmers are ready investigators of alternative technologies and conduct simple trials on their farms.

Farmer participation can be valuable in better understanding the farmers' situation through: learning and analyzing the technical and socio-economic aspects of their living and agricultural production environment; diagnosis of production problems and opportunities; understanding management practices and how these vary with soil types; and learning the history of changes which have occurred. They can contribute to the prioritization of problems and identification of likely solutions. Farmer evaluations of technologies are essential to successful adoption and the research process can be improved by early involvement of farmers in the evaluation process.

Farmer participation in research on low-input alternatives is likely to be more important than with high-input alternatives. The low-input systems are generally more complex due to greater biodiversity of livestock, crop, weed and insect species, soil microbial life, etc.. Low-input alternatives are likely to be more influenced by socio-economic factors. Efficiency of use of locally available and regenerative resources is important, and farmer knowledge of the availability, present uses and restrictions on use of such resources can be valuable in investigating alternative practices. Often a technology to be tested may be one which was "discovered" on a farmers' field but in need of further evaluation or modification to apply it in another environment. As low-input alternatives are often likely to be location-specific, research requirements to adequately serve all of the varied agro-ecosystems will be very high, and it is probable that farmers will continue to be major players in the development of their production systems.

The farmers' role in farming systems research and on-farm research has generally been of minor importance, and often limited to providing information during the diagnostic phase and providing fields on which to conduct on-farm trials. The work has often been done extensively to test technologies on many farms, with some input from farmers in trial management and assessment. A successful approach to development of improved low-input sustainable systems will require a more intensive approach with research, extension and representative farmers working together in-long term collaboration at a small number of sites. The expectation is that all parties will gain a deep understanding of the dynamics of the systems, while with experience the collaboration will become more effective. Opportunities to involve other disciplines will develop. The participating farmers will be key to the promotion of the new systems by demonstrating these on their own farms to visitors from elsewhere.

Not all farmers are potentially valuable collaborators in research. Researchers experienced in working with farmers have undoubtedly encountered disappointments due to farmer disinterest or their failure to make a useful contribution. Selection of participating farmers is important as some are not suitable for collaboration, either because of lack of interest, mental or physical deficiencies, or limited abilities in observation, analysis or articulation. Observation of a farmer's household and fields may give clues of his/her potential in participatory research: a good collaborator may be one who tries different enterprises, but who manages them well. A good collaborator should be of a typical socio-economic status, observant and capable of articulating observations and opinions. An important role for agricultural anthropologists is to further develop procedures for farmer participation in research: to better utilize indigenous knowledge and farmers' skills; to better select collaborating farmers; and to better understand farmers' research process and how to improve their capacities in improving their production systems. In any case, the skills as collaborators in research may need time to develop through experience.

Research for niche farming

With small-scale farming there generally is much variation within and amongst farms. Farming in response to the various soils, or other conditions, on a farm has been called niche farming, precision farming, square-foot farming and prescriptive farming. The farmer attempts to maximize resource use and productivity of the farm by managing each of the soils specifically. Niche farming often has not been feasible with large-scale farming because of insufficient flexibility in equipment use. In many developing countries, farmers are advised to follow blanket recommendations for their management practices. However, small-scale, low-input farmers do already consider the variation in their land and farm it accordingly.

Large-scale niche farming is expected to be commercially feasible within a few years. The equipment is becoming available which enable the use of computer-guided equipment to operate at variable rates, including planters, fertilizer and pesticide applicators, and tillage equipment which is variable for residue incorporation. Such equipment is guided by either ground (beacons) or satellite (global positioning systems) based systems and computer software with detailed maps of the field showing variation in soils, weed infestation, etc..

Research on niche farming is needed. On both large- and small-scale high input farms, farmers need to optimize use of resources on their various soils. Site specific information is needed. Simplified land classification systems, such as the Fertility Capability Classification system (Boul et al, 1975), need to be confirmed for Eastern Africa soils and applied. Research for niche farming may imply the need to develop numerous alternatives from which farmers can select (Sperling and Steiner, 1991).

Development of novel systems

A common approach to agricultural research is to make step-by-step improvements on farmers' production systems. Novel systems are less easily adopted than are single practice modifications.

However, research on novel systems may be justified for both high- and low-input sustainable agriculture.

In the USA, strip intercropping with crop rotation is showing promise as an alternative to simple rotations of sole-crops (Francis *et al.*, 1986). Typically, the advantage of mixed or row intercropping lessens as levels of productivity increase. Strip intercropping may be an alternative to small-scale farmers who are using moderately high levels of inputs as it may ease the input application, increase the efficiency of input use and profit, and possibly increase productivity. Similarly, novel rotations, relay intercropping, agroforestry or inclusion of new crops may present opportunities for novel systems.

In low input systems, typically numerous crops are produced with a variety of management practices. In some cases a novel system may be a modification of a production system already in use by farmers elsewhere, but under slightly different conditions. A novel approach may involve the management of certain weed species to accomplish more than weed suppression, but to provide a suitable habitat for beneficial insects or to enhance nutrient cycling. In Tanzania and Zaire, farmers have been observed to manage certain weeds as green manure crops to compliment the current crop. In Uganda on the western slopes of Mt. Elgon, grassy weeds appear to play an important role in stabilizing the soil, protecting it from erosion and improving permeability. Low input novel systems may be needed to increase the favorable activity of soil microbial activity and improve the soil microbe-crop symbiosis.

Utility of on-the-shelf technologies

Much progress as been achieved by research in developing technologies, but in many cases the rate of adoption is low, i.e. the technologies are still on the shelf. Most of these technologies were developed for moderately high-input systems, and many are probably appropriate where the use of higher levels of inputs is economically feasible. With small-scale, low-input systems, however, such on-the-shelf technologies frequently are not superior to technologies which have evolved in traditional systems, or are inappropriate for other reasons and generally have had little impact (Altieri and Anderson, 1986).

Complexity of systems and information needs

It is frequently said that improved sustainable, low-input agricultural systems need to be more information intensive than conventional high-input systems (Lynam and Herdt, 1988 and Lockeretz, 1988). The sustainable low-input systems are viewed as complex ecosystems with many interspecific interactions and their interactions with the environment. Information needs for research are undoubtedly great, however, the information needs to manage these systems may not be so great once they are developed and established. They are expected to be more stable and better buffered than simpler, high-input systems and therefore should require less attention and fewer therapeutic actions of the farmer.

Research for high-input systems, on the other hand, may require less information but the manager must be relatively better informed overall, though the information requirements will differ from that of the low-input manager. The high-input manager needs to be well informed of the various products available and to use them in a sustainable matter. In high-input systems of limited diversity, the manager is probably working with a relatively fragile system and must be prepared for frequent instances of opposing nature with therapeutic treatment.

Computer-run models are becoming increasingly important in the application of information on crops and soils to understanding the dynamics of systems, for pre-testing technologies, and for extrapolation of results. The maize model of the DSSAT (IBSNAT, 1989) crop growth simulation models has been used successfully in Kenya (Wafula and Cornor, 1992), and BEANGRO is being evaluated for eastern Africa. WEPP (NSERL, 1989) and RUSLE (Renard et al, 1991) appear to be useful in evaluating soil erosion problems and potential solutions. EPIC is useful in the evaluation of agricultural sustainability and has been used successfully to measure crop fertilizer requirements, nutrient transport in runoff, soil and fertilizer phosphorus dynamics and the effect of low-input legume-based crop rotations (Jones et al, 1991). ADSS (TropSoils, 1991) and other expert systems are useful decision making tools for farmers and technical advisors. While the utility of many of these models for eastern Africa is currently limited due to inadequacy of information for many of the production environments, researchers as well as managers of larger farms in eastern Africa and extension staff should be considering their use.

Technology promotion

Ease of demonstration and adoption are two important criteria for technology evaluation. Promotion of the use of chemical inputs, new varieties, or alternative planting methods is relatively easy, especially when there is a significant yield increase. The use of method and result demonstrations conducted through the extension service can be effective.

The promotion of some alternatives aimed at improving sustainability, especially with low input systems, is likely to be more difficult. The impact may not be obvious in the short term, and several aspects of the system may be affected without a major impact on any one aspect. Result demonstrations may not be effective as the results are not very obvious and they may have to run for several to many seasons to demonstrate their full benefits. Alternative approaches to result demonstrations may be needed. Farmers are likely to need considerable faith in the researchers and extensionists, and in the basic principles of the technology, in order to try such a technology and to continue using it. More effective than result demonstrations may be the use of show-case villages where farmers who participated in the research apply the results on their own farms and eagerly discuss it with visiting farmers.

Eco-regional research

Research for agricultural sustainability requires an improved understanding and information on farming systems, agroclimatic constraints, and the dynamics of each (Lynam and Blackie, 1991). However the information base on African agriculture is very weak with a lack of detailed information on soils, climate, and socio-economic characters of farming systems. A strategy for the development of improved and sustainable agricultural production systems requires planning based on stratification of environments at macro-levels (primarily rainfall and temperature) and micro-levels (soils differences, farmer and consumer preferences, socio-economic variables), and then developing technologies and designing alternative management systems within each stratum (Okigbo, 1991). Such a strategy will rely on well-structured, geo-referenced, relational databases with the capacity to analyze the data using geographic information systems (GIS) software, statistical packages, and increasingly sophisticated crop, disease, and biological and edaphic processes models (Lynam and Blackie, 1991, Plucknett, 1991). The eco-regional approach should aid in focusing on critical problems and allocating resources more efficiently but it will not reduce the need for high quality efforts of more traditional agricultural scientists (McCalla, 1991).

PUTTING IT TOGETHER -- A RESEARCH APPROACH

An approach to sustainable agricultural research in eastern Africa may have to combine a number of approaches including the commodity and disciplinary approaches, inter-disciplinary approaches, intensive farmer participation, and agro-ecological and eco-regional research (Fig. 1).

Stage 1. Regional stratification and benchmark site selection

This strategy for the development of improved and sustainable systems requires planning based on stratification of environments and then developing technologies and designing alternative management systems within each stratum. Stratification will be first by rainfall and temperature, and secondly by soil differences, farmer and consumer preferences, socio-economic variables. The major production zones will be delineated and communities to serve as benchmark sites will be identified.

Eco-regional research approaches using available data and models are expected to become increasingly useful at this stage, though the more sophisticated technologies are generally not yet well enough developed to be very useful in macro- and micro-level stratification in Eastern Africa. However, available information is often adequate to identify benchmark sites which are representative of larger production areas in terms of climate, soils, crop preferences, socio-economic variables, etc..

Stage 2. Farming system description

The physical, biological, and socio-economic aspects of the various niches and their systems will be studied and described. Eco-regional research will be important at this stage, esp. for the use of models to study the dynamics of soil organic matter, nutrient fluxes, crop-climate interactions, etc.. An inter-disciplinary approach is important at this time to adequately study the various components of the systems and their interactions. Where researchers are in situations with few disciplines represented, the researchers involved will need to work with an inter-disciplinary perspective to adequately consider all important aspects of the systems. An agroecology approach will be useful to adequately study the production systems and their interactions with the micro- and macro- environment. Farmer involvement at this stage is important as their indigenous knowledge and understanding of the technical and socio-economic aspects of their situation can be useful at this stage as well as in later stages of the research process.

Stage 3. Identification of problems and potential solutions

Problems will be diagnosed and potential solutions identified and evaluated, and a plan for technology evaluation developed. Niches within the zone are expected to be many due to differences in climate, soils and socio-economic status. The research will attempt to develop several alternative solutions to the various problems as indicated by the niche requirements with the intent of offering farmers a choice of alternatives.

Eco-regional research will contribute through the use of models to pre-test technologies for a range of environmental and socio-economic conditions. Inter-disciplinary research will be important because of the probability of overlooking important opportunities with a commodity or discipline approach. Agroecology will be important for adequate consideration of the systems and to pre-determine the impact of proposed solutions on the micro- and macro-level systems. Farmer participation is needed for their potential contributions to the prioritization of problems and identification of likely solutions.

Stage 4. Development and testing of alternative technologies

A range of technologies will be identified or developed and validated for improved, sustainable production systems. Disciplinary and commodity approaches with both on-station and on-farm research, and probably with a good deal of farmer involvement, will plan a major role at this stage. Some of the research may be best addressed with an agro-ecological approach. Inter-disciplinary research efforts are likely to be needed for some topics. The farmers' role will continue to be important as their evaluations of technologies are essential to successful adoption.

Stage 5. Extrapolation of results and promotion of technologies

Once technologies have been developed, their promotion must begin. Promotion of technologies will be aided by eco-regional research tools to improve extrapolation of results to other micro- and macro-environments. On both large- and small-scale high input farms, farmers need to optimize use of resources on their various soils. Site specific information will be needed.

Technology promotion and farmer adoption may be a major problem if the technologies are complex or if the short-term benefits are not obvious. However, packages of practices and novel systems of production may be needed to achieve satisfactory increases in production in a sustainable matter. Participating farmers are likely to have an important role in promotion by demonstrating the technologies on their farms, discussing these with visiting farmers, and assisting in making necessary adaptations for different environments, i.e. their villages will become something of show cases of the application of new technologies.

The research process will be on-going. As farming systems are improved, more maintenance research and research to make further improvements will be needed. Therefore, steps 3 & 4 will need to be revisited regularly and updated.

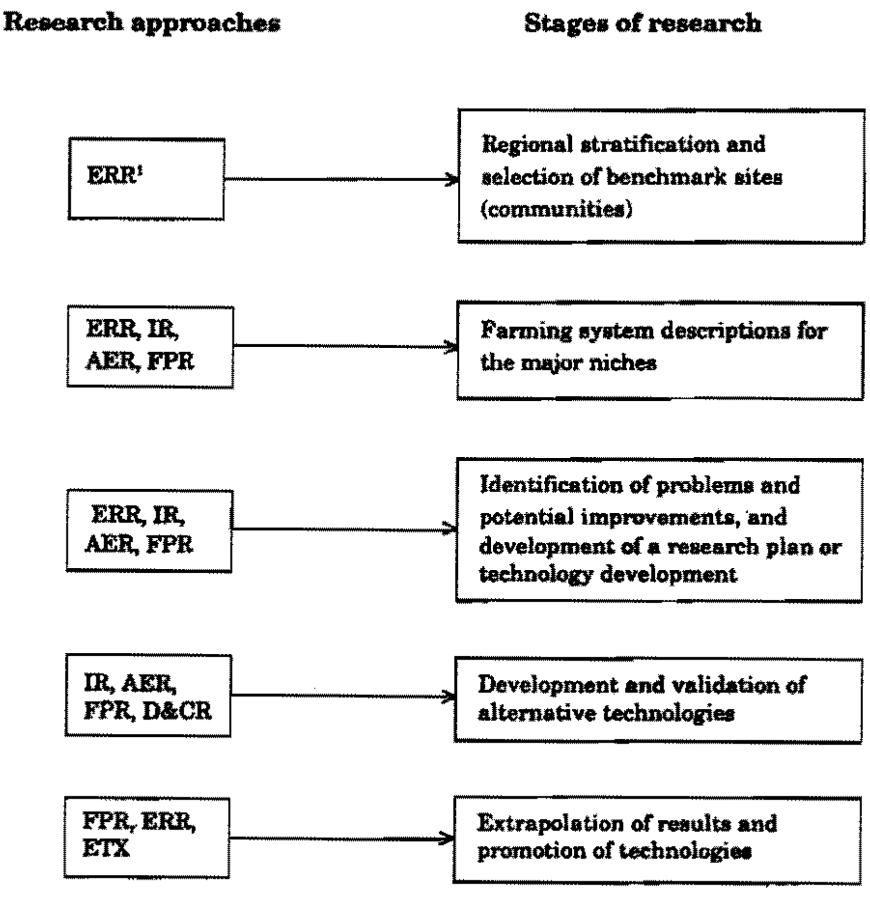

Figure 1. A flow chart for sustainable agricultural research.

AER, D&CR, ERR, EXT, FPR and IR refer to agroecology research, disciplinary and commodity research, eco-regional research, extension, farmer participatory research and inter-disciplinary research, respectively.

SUMMARY

The steps in implementing this research process may be as follows (Figure 1).

1. Production zones will be delineated and communities to serve as benchmark sites will be identified. Eco-regional research approaches will be employed using available data and models.

2. The physical, biological, and socio-economic aspects of the various niches and their systems will be studied and described. Eco-regional (use of models to study system dynamics), inter-disciplinary, agro-ecological, and farmer participatory approaches will be employed.

3. Problems will be diagnosed and potential solutions identified and evaluated. A plan for technology evaluation will be developed. Eco-regional (use of models to pre-test technologies), inter-disciplinary, agroecology, and farmer participatory approaches will be employed.

4. A range of technologies will be identified or developed and validated for improved, sustainable production systems. Disciplinary and commodity, inter-disciplinary, agroecology, and participatory research approaches will be employed.

5. Promotion of technologies will be aided by farmer participatory research and extension and by eco-regional research to improve extrapolation of results.

6. The process will be on-going. As farming systems are improved, more maintenance research and research to make further improvements will be needed. Therefore, steps 3 & 4 will need to be revisited regularly and updated.

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WHAT BEYOND SUSTAINABILITY?

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ABSTRACT

Improved sustainability of tropical agroecosystems must not be viewed by scientists and decision-makers as an end in itself, but as a means of improving the quality of human lives while protecting the environment. For many years, agricultural development was guided by the principals of economic viability and technical feasibility. More recently, environmental soundness and social acceptability have been identified as equally important criteria. Suddenly, the impact of all criteria have been grouped into the catch all of "sustainability". Meanwhile, individual research objectives continue to be addressed within single disciplines, or occasionally by teams representing a few disciplines. Perhaps, the definition of sustainability needs to be better elaborated through an interdisciplinary approach directed toward the maintenance of the agroecological resource base. The resource base consists of renewable and non-renewable requirements for plant productivity, labour and capital. These resources interact with farming systems through a series of cropping cycles. Because the farmer seeks to recover part of the resource base as yield, changes in the sizes of individual components of resource pools are an inevitable consequence of land management. However, the sizes of the individual components of the resource are partially interchange-able. For example, capital and labour may be combined as a variable input and substituted for plant nutrients removed as yield or lost to leaching and erosion. Of the many mineral nutrients required for plant growth, only carbon, nitrogen and sulphur are biogeologically recycled, with readily available and manageable atmospheric reserves. All other plant nutrients are subject to long-term sedimentary processes, and are concentrated and recycled over geological time. This disparity in nutrient recycling processes must be considered within the context of developing sustainable agroecosystems receiving little or no external inputs. A key component to the development of more sustainable agroecosystems is the reduction of loss from the non-renewable resource base, primarily soils. While it can be argued that soils are a renewable resource, and that soils lost from an location often accumulate at another, it must be remembered that soil formation also occurs over geological time, and that soils lost from a single storm event can result in losses equivalent to the amount formed over centuries. Increased removal of the resource base as yield per unit land area is an important means of addressing the food requirements of increasing populations. Meanwhile, the improved sustainability of agroecosystem supplied with little or no external inputs approach a yield potential proportionately lower than these population increases. The solution to this dilemma lie in the resource base itself. Cash generating agriculture must be promoted as a means to increase capital, and in turn used to resupply renewable resources and better reward labour. Human resources must also be more effectively applied to limit the losses of non-renewable resources; particularly soil degradation due to erosional processes. The development of high value/low volume agricultural products is an important means to reduce the international export of plant nutrients from lesser to more developed economies. Soil conservation and the development and promotion of high value/low volume export commodities must remain important national priorities as a means of reducing plant nutrient losses that otherwise must be replaced with costly, imported fertilisers. Improved sustainability of the resource base at the farm-level is not the solution but only the first step to improving human lives in developing nations of East Africa.

INTRODUCTION

Given the present state of affairs, the attainment of sustainable development in Africa is an attractive ideal. Population increases, coupled with the diminished availability of unexploited lands with agricultural potential have resulted in a decline in per capita food production. The threat of continued desertification and the extent of soil erosion and fertility decline has led to the rethinking of agricultural development strategies. At this assembly, a series of presentations will take place where sustainability is used as a rationale for continued research objectives. Once again, we will be told that research and development activities will likely result in improved sustainability of agroecosystems, but additional, longer-term research efforts will be necessary in order to guarantee that, indeed, sustainability has been achieved. Too often, sustainability is referred to in the title and throughout a paper, yet remains undefined within the text. Less often, a serious attempt will be made to define sustainability in a new and revealing context without regard for the confusion resultant from constant redefinition. Sustainability reins in the universities and institutes from the most to the least developed nations and rings from lips of deans and donors, scientists and public servants, schoolchildren and graduate students and someday will be taught to young, innocent minds on the knees of grandfathers. It seems everyone is talking about sustainability issues except for the silent majority most affected. I have never heard a farmer say this word; perhaps they are too busy.

SUSTAINABILITY DEFINED

In all fairness, the recognition of the need for agricultural sustainability has developed from the good intentions of a great many sectors. The World Commission of Environment and Development (WCED, 1987) defined sustainable development as meeting "the needs and aspirations of the present without compromising the ability of future generations to meet their own needs".

Agricultural sustainability may be viewed as having evolved from the public awareness that agricultural systems must meet the food needs of present as well as future generations and to represent a refinement of agricultural development policies that consider the needs and potentials of small-scale farmers to contribute to national and international food production (Brady, 1990). This awareness was in marked contrast to previous paradigms manifest in the "Green Revolution" of the 1960's and 1970's, marked by large-scale international efforts to develop increased food production in the tropics through modification of technologies in the developed countries during previous decades (see Harwood, 1990). Harwood (1990) defined the framework for sustainability as "an agriculture that can evolve indefinitely toward greater human utility, greater efficiency of resource use and a balance with the environment that is favourable both to humans and to most other species".

Okigbo (1991) stated that "A sustainable agricultural production system is defined as one which maintains an acceptable and increasing level of productivity, that satisfies prevailing needs and is continuously adapted to meet the future needs for increasing the carrying capacity of the resource base.." The above definitions are holistic, and reflect the awareness that agricul-tural development must address more than immediate food needs and current world markets. A great many farmers are resource poor, and are likely to remain so; agricultural development "solutions" that fail to address the present and future needs of smallholders in the tropics are in fact missing a large segment of target populations.

Others have taken a more agroecological approach to sustainability issues directed toward the identification of environmental parameters useful in sustainability assessment. Conway (1985) defined sustainability as the ability of a system to maintain productivity in spite of larger disturbances such as repeated stress or a major perturbation..." Similarly, Young (1989) recognized sustainability as the maintenance of production over time, without degradation of the resource base on which that production is dependent. Recently, Swift 1992 (personal communication) has examined the feasibility of identifying specific soil parameters that may serve as indicators of the soil resource base. These indicators include organic matter fractions, rations of those fractions, indicator groups of soil fauna, and N-mineralisation capacity.

These definitions of sustainability obviously span a great deal of spacial and temporal boundaries as well as reflect the wide range of disciplines that have implicit interest in the subject. When regarded in this light, the diverse and occasionally contradictory definitions of sustainability become less confusing, allowing me to (apologetically) contribute one of my own. "Agroecosystems can never be entirely sustainable due to the inevitability of resource removal as yield, however, components of the homeostasis associated with natural ecosystems can be promoted within managed ecosystems resulting in reduced depletion of non-renewable and greater resilience of renewable resources." More simply stated, something need not be completely sustainable to provide long-term benefit to humankind in a more sustainable fashion. It is the purpose of this paper to justify this definition, and to demonstrate that improved sustainability at the cropping system level is but a first step to meeting the needs of present and future generations.

BEFORE SUSTAINABILITY

The emergence of sustainability as an agricultural philosophy is the culmination of a series of previous developments in agriculture and international aid. successful traditional agricultural systems in Africa serviced local communities, with few components of yield removed from the immediate vicinity. In part, these systems were displaced by colonial plantations designed to develop export products intended for European markets. Immediately following World War II, western agriculture underwent drastic transformation. Improved crop varieties in conjunction with broad based use of petroleum fuelled farm vehicles and fertilisers, followed by the widespread availability of pesticides (Edwards, 1988) led to what may be termed "conventional high energy input agriculture". Agriculturalists were focused upon the optimalisation of short-term gains.

International agricultural development during the 1960's and 1970's sought to horizontally transfer these developments from developed to developing countries (Okigbo, 1990). In what is termed "the Green Revolution", research was conducted to develop improved larger-scale farm technologies, develop infrastructural capabilities to import or produce agricultural supplies, and create progressive rural structures (Harwood, 1990). It was in this spirit that the first of the International Agricultural Research Institutes were conceived and implemented. Particular successes of this approach was the transfer of wheat and rice production technologies, particularly in Asia (Plucknett, 1990). The Green Revolution sought, and to some extent succeeded in the transformation of tropical rural communities from small-scale, non-market to larger-scale market economies as a means to improve the qualities of human lives. The economic imperative of sustainable systems can be traced to this objective of the Green Revolution.

Despite the obvious successes of Green Revolution approaches, it became apparent that an important component was lacking; the input of the farmers themselves. Many technologies developed for the benefit of small farmers tended to "remain on the shelf" rather than receive rapid acceptance. As a means of correcting this deficiency an additional approach was included within many programs, that

Table 1. Comparison of ecological characteristics between conventional and innovative systems (after Stinner and Blair, 1990).

Conventional	Innovative-Sustainable	
Fossil fuel energy	high	low
Labour/management	low	high
Fertiliser	inorganic	organic
Tillage	low(?)	low
Crop diversity	low	high
Pests	unstable	stable
	chemical control	biocontrol
Nutrient cycling	open/pulsed	more closed
Animal integration	low	high
Decomposition importance	low	high

of "farming systems research and development" (see Shanner *et al.*, 1982). The basic premise of this approach is that agricultural research and development activities should be inspired through direct interaction with the farmers themselves, and the impact and merit of these activities be assessed on-farm by trained teams including anthropologists and socioeconomists. This awareness has led to the inclusion of equity considerations within the objectives of sustainable development.

Meanwhile, agricultural developments in western countries began to compromise the principles upon which the Green Revolution was based. Extensive use of fertilisers and pesticides began to threaten ground water quality and non-target plant and animal communities. Outbreaks of pesticide-resistant strains of pests occurred. Despite massive application rates, many farm yields began to decline. Increases in the cost of petroleum resulted in non-profitability of many conventional approaches. A renewed appreciation of many of the agricultural practices that preceded conventional petroleum-based agriculture emerged, including the benefits of crop rotation and the maintenance of biodiversity. Integrated pest management practices evolved. "Regenerative" agriculture reemerged(Rodale, 1990). Ecologists became involved with agriculture. This led to the inclusion of ecological principles in sustainability issues.

IS THIS SUSTAINABLE ??

A small family farm exists near Meru, Kenya, on the lower slopes of Mount Kenya. It is a beautiful place. Their home is made of locally available resources, namely sticks, clay and thatch. They produce and market coffee to the local cooperative and grow bananas, cassava, maize and a tremendous diversity of other crops on their shamba for use within their household. Yields are low, but as reliable as the bimodal rains, and are likely to continue at the same levels into the future. They do not consume any petroleum products within the farming system except for occasional use of kerosene lighting. Nor do they apply fertilisers, as the soil is moderately fertile being derived from volcanic ash. They do not apply pesticides. They own a cow, feeding the animal maize stover, mixing the manure and straw with the leaves of *Grenvilla robusta* and then placing this indigenously produced fertiliser at the base of their coffee plants. A row of *Tephrosia vogelii* is found along a property boundary to repel moles from the cassava field. The household does not pollute except for the deposition of human excrement in continuously relocated latrines. This family obtains water from a nearby stream and cooks food on wood fires fuelled by a woodlot located on their property. In most ways, this farming system has achieved the ecological characteristics associated with innovative, sustainable agriculture (Table 1) identified by Stinner and Blair (1990).

The husband speaks English well, but is unfamiliar with the term sustainable, and would justifiably resent the realisation that he and his family have successfully achieved someone else's ecological ideal. His life expectancy is less than 60 years. When a family member becomes ill they are unable to pay for proper medical attention. The family is in debt from past loans to cover school fees yet his children are unlikely to ever attend college despite their intellectual abilities or ambitions. The sons will either remain on the farm, subdividing it to the extent where a greater proportion of land is required for base sustenance, or they will migrate to urban areas unprepared for any but the most menial, underpaid employment. Envy this family for their hard work ethic and caring family environment, but never envy their attainment of an outsider's definition of holistic sustainability, to do so is to not understand their aspirations.

ECOSYSTEM COMPONENTS

All ecosystems may be viewed as consisting of 3 principle components, the plant, herbivore/carnivore, and detritus/decomposition sub-systems (Swift *et al.*, 1979). In terrestrial ecosystems, plants assimilate atmospheric CO_2 through photosynthesis and these assimilates serve as the energy source for the other sub-systems (Fig.1). Many animals feed on plant tissues and are in turn predated upon by carnivores. Herbivores regularly deposit mixtures of partially digested plant materials and microorganisms onto the soil surface. Eventually, both plants and animals die, their tissues forming detritus and providing substrate to comminutive soil fauna and decomposing organisms, primarily fungi and bacterial. The decomposition sub-system recycles and mineralises plant nutrients, that are in turn assimilated by plants following uptake by plant roots. In this way, each sub-system is dependant upon the others.

In mature, natural ecosystems, net community productivity tends to be low in proportion to the standing biomass and total system organic matter. Nutrient cycles are closed, with little nutrients lost or gained from the system. Detritus is efficiently decomposed and recycled by all segments of the ecosystem. This is due, in large part to the heterogeneity of rooting structures, a component of plant biodiversity, and to the complexity of food webs. The entropy of such a system is low, similarly, the resource base may be viewed as well integrated. Little is gained or lost. Can agricultural ecosystems behave in this fashion, given the necessity of the continuous removal of a portion of the resource base as yield? Can it not be argued that mature natural ecosystems subsist while managed ecosystems exploit?

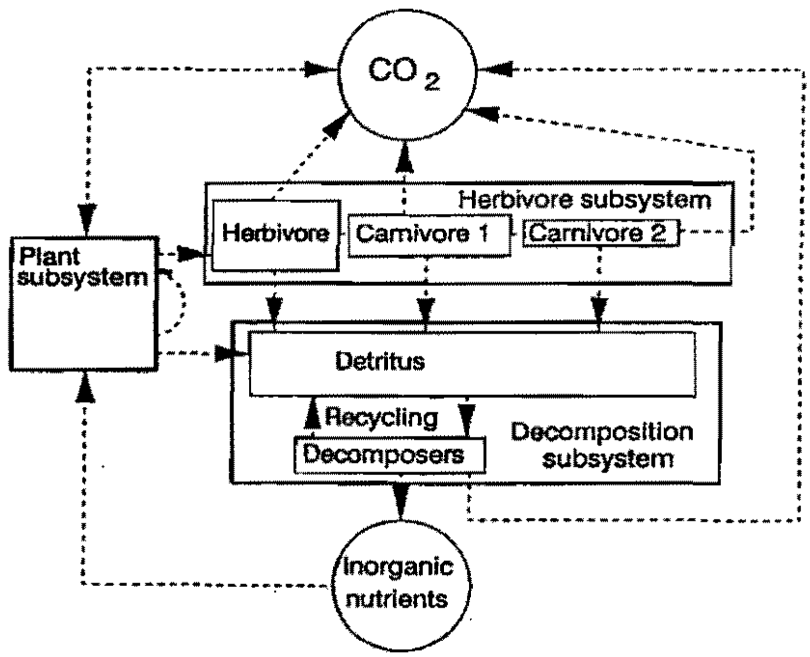

Figure 1. A generalised conceptual model of ecosystem dynamics. An ecosystem consists of 3 components; the plant, herbivore/carnivore and decomposition sub-systems (after Swift *et al.*, 1979).

RESOURCE INTEGRATION WITHIN MANAGED ECOSYSTEMS

Resource integration in mature natural ecosystems is regulated by the homeostatic feedback among all ecosystem components. The resource base of a farming system is regulated by the management practices and the farmer's allocation of capital. The farm resource base may be viewed as passing through the farming system during a series of cropping cycles (Figure 2). This resource base, consisting of capital, labour, renewable and non-renewable resources, is altered during each cropping cycle, yet the farmer is able to modify the sizes of individual resources through the allocation of variable inputs resulting from a combination of labour and capital. Non-renewable resources, such as bulk soil as a rooting environment, are best protected through conservation measures. Renewable resources, such as soil nitrogen, can be managed through choice of crops (e.g. the choice of a legume/cereal intercrop and rotation) or through direct application of fertilisers or organic materials originating from outside of the farming system. When placed into this context, the regenerative agriculture of Rodale (1990) is the purposeful management of the renewable resources lost or exported. Something need not be entirely sustainable to behave in a more sustainable fashion.

This conceptual model (Figure 2) is presented to remind the reader that productive gain, and not the maintenance of the resource base is the immediate objective of farmers. Reallocation of the individual farm resources is the means through which this yield is obtained. Sensible reallocation of resources over time results in sustained productivity. There are some problems with this conceptual model, due to over-simplicity. Soil lost through erosion is considered a non-renewable resource. But that soil must go somewhere, and when it enters an adjacent farming system, it becomes (technically at least) a renewable resource. Another difficulty is that this model assumes that all available farm income is generated from the farm itself, when in reality, there are many off-farm activities. Please, do not fail to see the agroforest for the trees, the point remains that within any farming system some resources will be irreversibly lost over time due to the perturbations required to manage the system and to the removal of yield from the boundaries of the system. The marketing of yield is necessary to the farm family as the means of obtaining that which they do not produce themselves. It is the intention of the farmer from the very onset to market farm resources. How can farm activities be viewed as sustainable within the same context as the closed integration of resources occurring within a natural ecosystem?

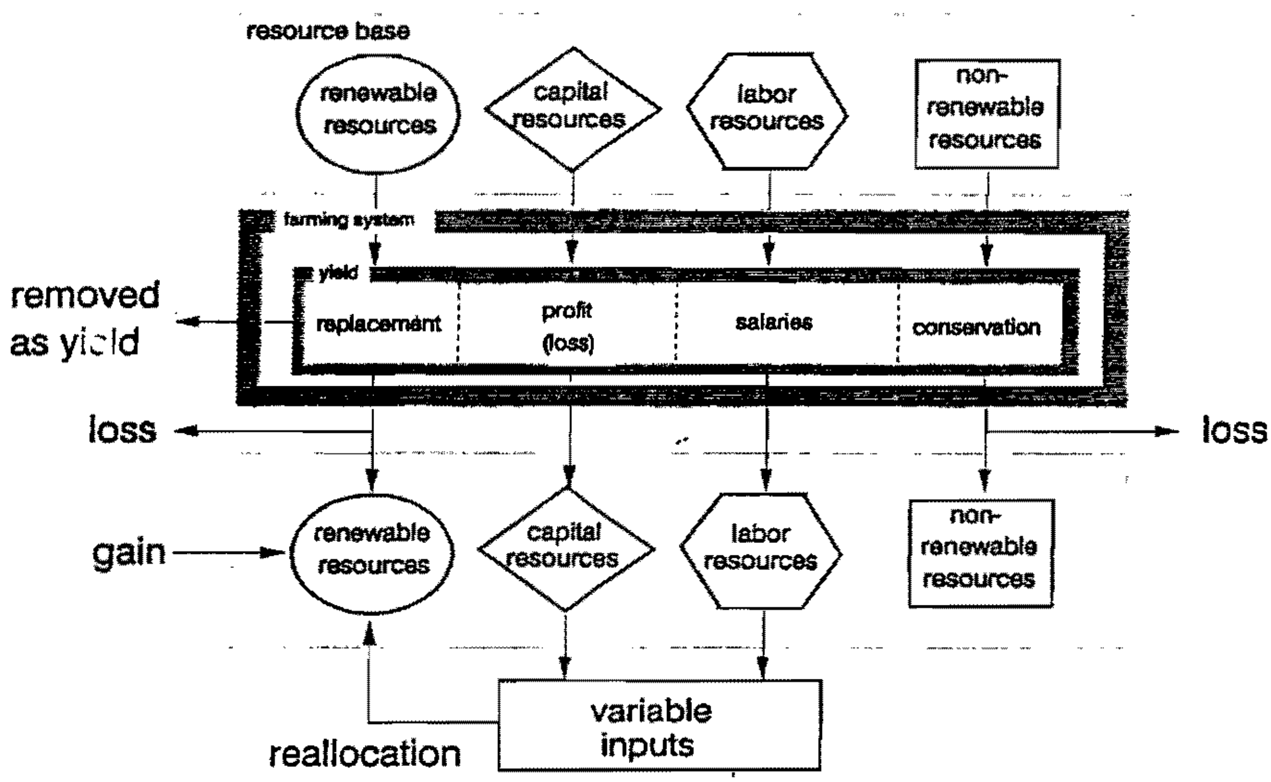

Figure 2. The resource base of an agroecosystem passes through the farming system during a series of cropping cycles. These resources can be partially substituted for one another.

AGRICULTURAL DEVELOPMENT AND THE INTEGRATION OF RESOURCES

Definitions of sustainable development usually include reference to the integration of the agricultural resource base. During a recent meeting of the Tropical Soil Biology and Fertility Programme, Professor Richard Harwood of Michigan State University speculatively plotted the degree of integration of resources (from open to closed) with the stage of agricultural development. I have modified this concept by plotting specific agricultural developments and practices (figure 3) in a similar fashion. This theoretic plot indicates that the nature of agricultural developments interact with the integration of the natural resource base in an oscillating fashion.

Initial agricultural interventions, such as removing less useful plant species from plant communities, or the selective placement of animal or human wastes had little impact on the integration of the resource base, nor did the agricultural practices of early civilizations that developed along flood plains. However, during the course of human dominance over the natural environment, destructive practices such as slash and burn agriculture, and the cultivation of steep hill sides were initiated. Even the decline of entire civilizations in central Asia has been linked to the development of irrigation projects using slightly saline water, and the subsequent large-scale salinization of agricultural soils. Other early civilizations continue to prosper, due in large part to the integration of the natural resource base associated with the production of the principal cereal grains. An example is the permanence of rice production in South East Asia and China, and the continuance of those civilizations into the present. The wisdom developed by traditional cultures in the maintenance of the soil resource base became synonymous with their success.

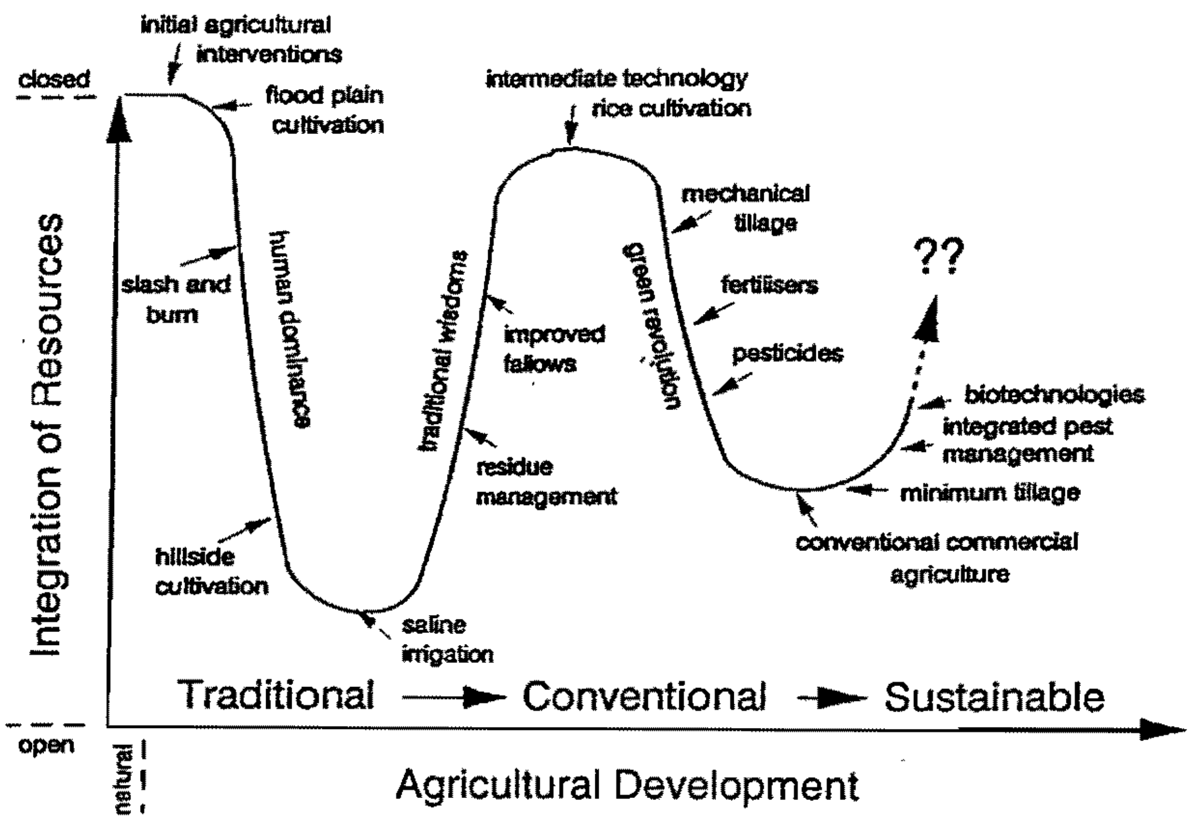

Figure 3. A theoretical relationship between the integration of the agroecological resource base and agricultural development suggests an oscillating pattern of disintegration and reintegration of resources driving developments (after R. R. Harwood).

The relationship between high energy input systems (fossil fuels) conventional agriculture and the degree of integration of the resource base was discussed earlier. The development of mechanical tillage, fertilisers and pesticides all served to optimise immediate yield potential, but to produce many longer-term detrimental effects upon the environment. This may be viewed as the partial disintegration of the natural resource base established from previous natural ecosystems.

The awareness of this partial disintegration is responsible for the development or return to regenerative agricultural practices (Rodale, 1990). Examples of the practices include minimum and zero tillage schemes, integrated pest management strategies and the improvement of agricultural biotechnologies such as the increased use of microsymbiont and biocontrol agent inoculants. Hopefully, this trend will continue until most cropping systems are viewed as sufficiently reintegrated and sustainable.

ECONOMY AND EQUITY, SEPARATE OR EQUAL?

Economics relies on placing monetary value upon materials and activities, and recording the dynamics that follow. As such, it is quantifiable and statistics may be generated that characterise individuals within a geographical context. Equity is more nebulous. It may be either viewed as the rights of individuals to self determination as long as their activities do not interfere with those of others, or the right of every individual to achieve their full intellectual or productive potential. These statements may be inappropriate in East Africa, where equity is more closely associated with a farmers availability to procure medicine when ill, or to be able to purchase a wheelbarrow, bicycle or a radio, or to pay school fees with the assurance that their children will receive the sort of education that will prepare them for the future.

In East Africa, societal equity and home economy are intimately linked. The farmers in Meru market their coffee as dried cherries to the local cooperative for KSh.5/= per kilo (about US$ 0.17). During good years, a mixed farming system of about 1.5 ha will produce approximately 400 kg/year. The farmers yearly income from coffee would be Ksh.2000/= (US$ 68). This coffee is purchased and marketed by the national coffee board, and then sold to international brokers who operate on behalf on individual businesses that distribute and market coffee to consumers in developed countries through local retailers. Select Kenyan coffee is sold at speciality shops in Hawaii, very likely its furthest market destination, for up to US$ 8.80/kg.

If the quality of human lives were assessed along the market chain of coffee from Meru producer to western consumer, it is likely that only the farmer is the one who has never visited a dentist, or will never own a motor vehicle or will never see the ocean. In market economies, the equity of the human condition, in it's most practical sense, is inseparable from domestic economics, and will remain so into the foreseeable future.

WHAT BEYOND SUSTAINABILITY?

Some might suggest that the attainment of sustainable agroecosystems in it's fullest holistic sense is so flexible and lofty an ambition that no alternative development philosophy will become dominant. Others will remind us that the series of sequential development philosophies; optimalisation of return, Green Revolution, farming systems approaches and now sustainability of the resource base has had little impact on the actual lives of African farmers or the viability of the continent and that the exact details of the next developmental fad are less important than whether or not the enthusiasm generated is sufficient to raise public awareness and attract donors. Still others will quietly confide that some interpretations of sustainability are synonymous with the admission that there is little that can be done for the rural poor of the tropics other than to encourage them not to so readily destroy their environments.

Within low external input agricultural systems, farmers necessarily reduce the resource base through removal of yield. The arguments presented in this paper suggest that in many cases the ecological basis of sustainable development is flawed concept, and when viewed in the proper context, sustainable agriculture is not qualitatively different than previous or existing agricultural efforts. Rather, the priorities that a farmer bases his choice on the allocation of his labour and capital must be altered in a fashion that anticipates longer term consequences of his present management practices. The human dominance upon the planet has reached sufficient proportion that this has become necessary. The feedback between the stage of agricultural development and the extent of resource integration is pushing us in this direction, or else our civilisation will fail. But even if all of the farmers in East Africa were as ecologically sound as the coffee growers in Meru, Kenya, there will still be some very important developments before the quality of their lives approach its full potential.

* Countries within the region must embrace political and economic cooperation, access to markets and transportation must be more freely granted to all states throughout the region.

* Consumers in developed countries must be forced to pay higher prices for agriculture products that can only, or best, be produced in the tropics. These products include coffee, tea, sugar and cocoa. Furthermore, the farmers themselves, rather than the national commodity bureaus, must directly benefit from these increased price. One means of accomplishing this is for tropical countries to process the raw agricultural products into finished consumable. Similarly, high value/low volume crops must be identified and promoted as a means of reducing nutrient depletion of soils.

* The East African labour force must be mobilised more effectively. It seems that the most hard working farmers live no better than those who are often idle. This is due to the controlled low prices that result from policies that artificially restrain food prices. Cottage industries should be promoted to allow for greater off-farm income generation. This will also serve to reduce rural migration to urban areas.

What beyond sustainability? Prosperity!

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DISCUSSION ON PAPERS PRESENTED

Questions to M. Fischler and M. A. Ugen

M.E.T. Mmbaga (Question)

Certainly farmyard manure can improve soil fertility. However, I do not agree with Martin that it is cheap. FYM is bulky and needs to be transported and spread in the field. How are you going to make it cheaper for the farmer?

M. Fischler (Response)

FYM as a material is free. I do not know about fertilizer prices in Tanzania but I assume it is not cheap for the farmers. On the other hand, I agree that transport to the field and application of FYM is not cheap. But the question is: Is it cheaper (or not) than inorganic fertilizer? Are cost studies necessary?
N.B: Could oxen with trailers be used to transport FYM?

S.D. Baguma (Question)

From your list of potential solutions, which are potentially feasible and appropriate solutions given the circumstances of the farmers?

M. Fischler (Response)

We already carried out trials with crotalaria at other sites. First results have shown an increase in maize yield. Thus, we intend to start on-farm crotalaria trials on the poor soils identified by farmers at Matugga. We have seen that crotalaria is easy to establish, and as increases in maize yield become apparent, it is readily tried by farmers. In on-farm trials, treatments are:

Maize sole)
Beans sole)
Maize & Crotalaria) replicated twice
Beans & Crotalaria)
Crotalaria sole)

The next season, the whole area is planted with maize to see the residual effect of crotalaria.

D.O. Sigunga (Question)

Did you determine soil colour using the Munsell color chart with wet or dry soil.

M.A. Ugen (Response)

We used wet soil.

M.C. Shiluli (Comment)

Reading through the paper, I see that the solutions suggested would have been arrived at by only talking to farmers instead of doing soil analyses and diagnostic interviews.

M.A. Ugen/M. Fischler (Response)

The purpose of the soil analyses was to determine the cause of the low productivity of these problem soils ("Zibuga" and "Lunyo") and to compare this with the farmers' perceptions. Also, the process is a continuous one for future research work which therefore needs alot of information. There has existed a large "gap" between farmers, extension agents and researchers which needs to be narrowed. This is expected to take some time.

C.S. Wortmann (Comment)

I wish to reply to some of the comments. First, the diagnostic process is continuing, i.e. through nutrient flux studies, nutritional screening trials, field observations, etc. Second, it should be remembered that this participatory approach is only beginning in Mattuga and communications with farmers are at a relatively shallow depth. The expectation is that with time, farmers' articulation of problems and reasons for their practices will improve and the value of their role in collaboration will increase.

Questions to P. Woomer

D.O. Sigunga (Question)

With respect to the use of maize stover to improve maize production, when do you apply the stover in order to benefit the current maize crop?

P. Woomer (Response)

Our research programme at Muguga is not examining this aspect at present as we feel this avenue does not lead to many realistic management options. For example, what if our research results suggest that maize stover from the previous crop should be applied 6 weeks into growth of the subsequent crop? Can we then recommend that on-farm trials remove stover from the field, store this material for some months and then return stover to the same fields from which they originate? I think not. In general, maize stover is most conveniently chopped into large pieces, and incorporated during hand hoeing.

B.O. Mochoge (Question)

Have you tried with different sizes of incorporated materials to find their effectiveness in mineralization - immobilization aspects and hence net release of nutrients to the soil?

P. Woomer (Response)

Unfortunately not. In labor-intensive low external input cropping systems, farmers are reluctant to cut residue materials into small sizes. In green manure or agroforestry systems, the size of applied organic residue is generally dictated by the leaf or leaflet size of the green manure or tree component. While I suspect that there is a strong influence of size on decomposition rates, we do not forsee this as a potential management option. At present we are examining the influence of placement and quantity of hand chopped maize stover on the subsequent maize crop in the Kenyan highlands.

Questions to M.K. O'Neill, F.K. Kanampiu and F.M. Murithi

A. Belay (Question)

Agroforestry is an alternative approach for sustainable agriculture but tenure systems (i.e. land tenure, tree tenure) could be a problem. In cases where land is not owned by farmers, farmers may be reluctant to invest. Do you have any experience or information on this?

F.K. Kanampiu (Response)

Certainly, tenure plays an important role in the adoption of agroforestry. We, in Kenya, are lucky because of land demarcation and ownership. Small-scale farmers in Kenya own their land so they know that they can invest in long-term technologies. This is not the case in many other places. The socio-economic unit at ICRAF is investigating land/tree tenure issues and how agroforestry technologies can be incorporated in cases of less secure land ownership.

A. Nyaki (Question)

How much scientific data has been generated from the Kenya Institute of Organic Farming to support organic farming as an alternative?

F.K. Kanampiu (Response)

Most of the practices they (KIOF) promoted are very popular with the farmers. Use of organic manures are an important part. However, amounts of N, P, K, etc. are not quantified. In pest control, active ingredients which control pests are not well documented. For example, though tobacco extracts are used to control pests, we don't know the product or active ingredient involved. Concentrations are also not quantified.

D.O. Sigunga (Comment)

Population movement to marginal land is caused largely by low production per unit land area, and by talking about low input alternatives (p.1 your text) knowing that to raise the yield the nutrient availability must be raised commensurately is to advocate for farming production level that enhances soil degrading factors and processes.

F.K. Kanapiu (Response)

Migration of population from high to low potential areas has led to continuous cropping in low potential areas. This has resulted in decreased soil fertility. Since inorganic fertilizer use is not very feasible in these areas, low cost input alternatives need to be sought to improve soil fertility. The topic, therefore, does not suggest low nutrient inputs in already low fertile soils but rather low cost input alternatives..

B.O. Mochoge (Question)

Are the figures shown on fertilizers based on pure nutrients or fertilizers *per se*?

F.K. Kanampiu (Response)

They are based on fertilizer *per se*.

S.D. Baguma (Comment)

I suggest that to avoid confusion with the table on rates of all types of fertilizers, it would have been better if you indicated for each crop the type of fertilizer applied.

F.K. Kanampiu (Response)

I agree the original paper of Shiluli and Murithi (1992) covers each type of fertilizer for each crop. Table 1 just summarizes the amount of fertilizer used in each crop. The means were meant to show that fertilizer rates (no matter the source) are lower than the recommendations.

M.A. Ugen (Question)

Can you give us more information on bean response to chemical fertilizers in the 4 AEZs? Generally, there is a lack of appreciation for use of chemical fertilizers on beans yet in UM1 the rate of application is up to 250 kg fertilizer/ha!

F.K. Kanampiu (Response)

Lack of appreciation on the use of fertilizer on beans is indicated by low proportions of farmers using the fertilizer on the crop. There are, however, a few who use the fertilizers on beans. The responses for each region have not been determined from the surveys conducted.

M.A. Ugen (Question)

Following the lack of appreciation of fertilizer use on beans by farmers in the 4 regions, has there been more response of bean to inoculation with Rhizobia? If so, what proportion of the farmers in the 4 AEZs are practicing inoculation of beans?

F.K. Kanumpiu (Response) Not many farmers are known to be inoculating beans currently.

Questions to C.S. Wortmann

P. Woomer (Question)

I am concerned about your willingness to reject a candidate technology based upon conflict with only one of your criteria rather than develop an overall balance between benefits and consequences. For instance using your criteria we could reject the transition from subsistence/small market to export production based on the impact on poor consumers.

C.S. Wortmann (Response)

That's right. If the shift is to result in substantial increase in food costs it should probably be rejected. Of course if the exportation somehow enables increased food availability without a substantial food price increase either through importation of food or importation of agricultural inputs which enable higher production, then it satisfactorily meets the equity requirements.

A. Belay (Question)

Technologies which are of immediate benefit are mostly adopted by the farmer even though they could have gradual degrading effects on the environment. However, technologies which give benefit after years, e.g. agroforestry, may not be easily adopted because it is not easy to convince the farmer about the long-term positive effects. How can we convince farmers of these long-term effects, whether they be negative or positive?

C.S. Wortmann (Response)

I suspect that with many technologies which do not show positive short-term impact, promotion must be by means other than demonstrations, i.e. by using results from other places and the underlying concepts to convince farmers. Similarly with detrimental long-term impacts, the specialists need to identify areas where problems are, or are likely to occur, and then convince farmers to make the needed changes. The researchers must be ready to offer an alternative option. Also, if the farmer believes in the specialist, he or she is more likely to adopt a recommendation whose impact is not obvious in the short term.

Questions to B. O. Mochoge

M. Shiluli (Comment)

FURP results should be subjected to economic evaluation which utilizes realistic costs and benefits in order to develop recommendations for farmers.

B.O. Mochoge (Response)

This is in progress.

S.D. Baguma (Question)

Why didn't you use net benefit other than gross returns and then proceed to marginal rate of return?

B.O. Mochoge (Response)

This is in progress.

K. Kena (Question)

1. In most cases I see the CV is relatively high! Why? 2. When expressing the economic analysis results wouldn't it be better to express in PI and VCR?

B.O. Mochoge (Response)

1. The high CV reflects experimental management. This could also be due to variability of soil fertility and rainfall.

D.O. Sigunga (Question)

There appears to be inconsistent results especially in terms of responses to N and P. Could this be due to variation in the number of plants harvested?

B.O. Mochoge (Response)

Variation in plants harvested was accounted for with a compensation approach, but only in badly affected areas.

M. Fischler (Question)

Why were N and P application rates so low? It is not surprising that up to 75 kg/ha there is a linear increase in yield. On this base no recommendations are possible.

B.O. Mochoge (Response)

The rates were based on previous research data.

C.S. Wortmann (Comment)

The data set from your trials over many sites and years is a valuable resource. I hope that more will be done to establish a basis for extrapolation of the results to other soil/climate combinations. There is an opportunity to test alternative soil classification systems, such as the fertility capability classification system, or to test alternative crop growth models, such as those of DSSAT, as bases for extrapolation of results.

B.O. Mochoge (Response)

I am with you.

J. Lynam (Question)

Given the problems of extrapolation based on AEZs or soil tests, what does FURP now do in improving the basis for extrapolation and making better fertilizer recommendations?

B.O. Mochoge (Response)

Improved soil sampling and analysis for different nutrients is to be done in the next phase when verification trials are planned in many of the current sites. Further soil analyses to generate more data is in progress. Probably this will help in data extrapolations.

D.O. Sigunga (Question)

Given the tremendous variations in soils and climate and the few experimental sites per district (e.g. 3 sites in Embu), do you consider the results from those few sites adequate for extrapolation to the rest of the district?

B.O. Mochoge (Response)

Selection of sites was based on AEZs and not administrative boundaries. AEZs overlap district boundaries.

PRIORITY SETTING AND IDENTIFICATION OF RESEARCH TOPICS

TABLE 1. PROBLEM IDENTIFICATION AND PRIORITIZATION

Problem Identified	Widespread distr.	Severity	Total	Final ranking
N deficiency	1	2	2	1
P deficiency	2	3	5	2
Poor biological N fixation	5	6	11	6
Toxicities (cation)	6	4	10	5
Soil erosion	3	5	8	4
Low potential cultivars	7	8	15	7
Micronutrient deficiency	10	7	17	8
Soil moisture deficits	4	1	5	3
K deficiency	9	9	18	10
Inappropriate fertilizer use	8	10	18	9

N-DEFICIENCY

EVIDENCE

1. Symptoms observed
2. Experimental results
3. Soil and tissue testing
4. Soil survey results.

ADDITIONAL EVIDENCE REQUIRED

1. Improved soil survey reports i.e. better information on distribution of problem.

POTENTIAL SOLUTIONS

1. Efficient fertilizer use
2. Efficient N-use cultivars
3. Control of soil erosion
4. Proper crop residue management
5. Proper management of FYM
6. Breed or identify bean (legume) varieties for improved N-fixation.
7. Identify superior strains of Rhizobia
8. Proper weed management
9. Improve plant nutrition for enhanced BNF
10. Improve extrapolation of research results
11. Improve synchrony of nutrient supply with demand
12. Improve credit facilities
13. Improve extrapolation for research results to varied environments
14. Improve recommendations for the maize-bean intercropping system
15. Hedgerows or alley cropping
16. Leguminous green manure crop

P-DEFICIENCY

EVIDENCE AVAILABLE

1. Symptoms observed
2. Experimental results
3. Soil and tissue testing
4. Soil survey reports

ADDITIONAL EVIDENCE REQUIRED

1. Improved soil survey reports, i.e. to know distribution of problem.

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Liming (increase pH - reduce fixation) (H)
2. More efficient fertilizer use - sources and rates (H)
3. Control of soil erosion
4. Proper crop residue management (H)
5. Cultivars/species for improved mycorrhizal activities
6. Use of rock phosphate
7. Proper management of FYM (H)
8. Breeding of P-use efficient cultivars.
9. Deep tillage/improve soil structure
10. Control of root pests
11. Foliar application of mono-ammonium phosphate.
12. Improved weed management
13. Improved extrapolation of fertilizer results.

SOIL MOISTURE DEFICITS

AVAILABLE EVIDENCE

1. Wide spread observable symptoms
2. From radio/TV news broadcast
3. Low rainfall amounts - meteorology records
4. Experimental data information

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Hedge row intercropping/alley cropping with compatible multipurpose tree species and crop species for:
   - (i) reduced water run-off;
   - (ii) mulch; (L)
   - (iii) improved fix-N; and
   - (iv) improved regulation of the micro-climate. (M)

2. Minimum/conservation tillage: (M)

   (i) reduced disturbance of the soil structure;
   (ii) improved organic material management; (H)
   (iii) reduced soil erosion;
   (iv) improved micro-climate; and
   (v) reduced evaporation rate.

3. Response farming to vary planting time, plant densities, fertilizer rates, etc. in response to the early season rains. (H-M)
4. Better weed management. (L)
5. Screening of bean cultivars for tolerance to low moisture availability. (M)

SOIL EROSION

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Grass strips--on-farm species evaluation for erosion control and for alternative uses (H)
2. Conservation tillage and residue management OFR adaptive research (H)
3. Cover crops -- on-farm species evaluation (H)
4. Hedgerows -- on farm species evaluation (H)
5. Crops/cultivars with early ground cover (M)
6. Small catchments -- on farm adaptive research (M)
7. Terraces (L)
8. Improved pasture management (L)
9. Destocking
10. Include scattered trees in crops (L)

TOXICITIES

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Liming (H)
2. Tolerant varieties (M-H)
3. Addition of organic matter (M)

POOR N_2 FIXATION

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Inoculation (H)
2. Optimum environmental/soil conditions, e.g. amendment of soil pH (M)
3. Screening/breeding for efficient N-fixing bean cultivars (H)

4. Identify parameters that relate N_2 fixation and grain yield (L)
5. Screening for Rhizobium strains that associate well with the bean varieties (L)
6. Study the interaction between mycorrhizal fungi and Rhizobium strains in N-fixation (L)

LOW POTENTIAL CULTIVARS

EVIDENCE

1. Poor performance relative to breeders' varieties.
2. Farmers' willingness to accept new varieties.

ADDITIONAL EVIDENCE REQUIRED

1. Niche specific information needed.

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Increase genetic variability through collections, introductions, and breeding.
2. Strengthen breeding programs by providing more resources for breeding work.
3. Identify the environmental factors contributing to GXE and stratify agro-ecological zones according to those environmental factors.
4. Develop improved and efficient seed systems.
5. Select or breed for nutrient use efficiency and improved biological N fixation.

MICRO-NUTRIENT DEFICIENCY

EVIDENCE AVAILABLE

1. Plant symptoms and trial results.

ADDITIONAL EVIDENCE REQUIRED

1. Verification -- problem's existence and distribution.

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Improved soil/foliar application of nutrients, i.e. better timing and use of chelates (H)
2. Improved SOM management to avoid negative interactions (H)
3. Caution in application of other nutrients (L)
4. Seed coating with nutrients, e.g. molybdenum on bean seeds (L)
5. Production of seeds under conditions of adequate micronutrient supply (L)
6. Soil pH management (L)

INAPPROPRIATE FERTILIZER USE

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Less labour intensive methods of fertilizer application, less labour intensive (L)
2. Better timing of fertilizer application -- adaptive on farm research (M)
3. Better placement of fertilizers -- adaptive on farm research (M)
4. Low cost fertilizer application equipment (L)
5. Improved extrapolation of research results (strategic research) (H)
6. Fertilizer response studies (H)
7. Relate intercrop to sole crop fertilizer needs -- strategic research (M-H)

POTASSIUM DEFICIENCY

POTENTIAL SOLUTIONS AND THEIR IMPORTANCE AS RESEARCH TOPICS (High, Medium, Low) AS DETERMINED BY RESPONSIBLE WORKING GROUP

1. Erosion control studies (L)
2. Fertilizer use trials (H)
3. Improved SOM management (L)
4. Improved crop residue management (M)
5. Improved soil moisture management (L)

RESEARCH TOPICS SELECTED FOR COLLABORATIVE PROJECTS BY WORKING GROUP MEMBERS

1. Study of hedgerow management and effects on the nutrition of the maize bean intercrops.
2. Research on improving the efficiency of use of farm yard manure by developing management practices for reducing nutrient losses before and after applying to the field, and for improving the compatibility of use with crop residues.
3. Study of factors which affect performance and persistence of Rhizobial strain and which cause strain by environment interactions.
4. Research on conservation tillage for soil and water conservation.
5. Research on technologies for improved fertilizer use efficiency and for improved extrapolation of research results.

RECOMMENDATIONS OF SMALL WORKING GROUPS

TRAINING AND SPECIALIZATION NEEDS

Short courses for mid-career specialized training

1. Application of computer models
2. Methodologies for N_{15} studies
3. Interpretation of results of studies of complex systems, i.e. intercrops
4. Methodology approaches
5. Methodologies for systems research with an agro-ecology approach

MSc and PhD research areas

1. Study of extrapolation of fertilizer use research results--evaluation of various bases for extrapolation, including soil classification systems, soil properties, and models.
2. Studies of mineralization of different types of organic materials as it relates to nutrient use efficiency and soil organic matter
3. Management of agroforestry hedgerow systems in relation to nutrient use efficiency and soil organic matter
4. Efficiency of use of applied nitrogen and phosphorus fertilizers in maize-bean production systems

IMPROVED COLLABORATION IN RESEARCH

Specialization

1. Greater use of existing experts within the Region, rather than bringing scientists from outside the region to address specific problems.
2. Improved matching of available specialists with needs.
3. Short-term scientific visits and monitoring tours.
4. Improved access to research facilities.

Analytical facilities for soils and plant tissue analyses

1. Standardization of available methods through better information exchange between the laboratories in the Region.
2. Quality control through routine comparison of results with other laboratories and through participation in international laboratory testing programs.
3. Training of laboratory technicians to ensure they understand and use the methods of analysis well.

Research facilities and equipment

1. Ensuring equipment and chemicals match with research needs.
2. Repairs for existing laboratory equipment.

Monitoring and evaluation

1. Joint and regular monitoring and evaluation of projects.
2. Travelling workshops.

Information exchange

1. Financial support in publication and journal membership.
2. Annual workshops on research for maize-beans production systems.
3. Providing information on maize and beans research to scientists – updating of the concerned IARCs' mailing lists.
4. Newsletter on maize and bean research activities.

Improved collaboration between IARCs in the Region

1. Collaborate in giving technical support to research projects.
2. Find opportunities to further collaborate in systems research.
3. Continue collaboration in training.
4. Continue collaboration in administration.
5. Facilitate technical support across research sites, especially for less visited sites.

IMPROVED MOTIVATION TO CONDUCT RESEARCH

1. Respect of promotion/demotion procedures.
2. Increased efforts to generate funds for research
   - national agriculture research funds
   - revolving funds
3. Improved control of research funds.
   - limited funds from the Ministry
   - funds solicited by researchers
4. Provision of professional allowances
5. Provision of publication incentive
6. Provision of top-up allowances/per diem.
7. Maintenance of training funds
   - workshops and seminars
   - short and long term training
8. Improved accountability.
9. Provision of adequate working facilities.

RECOMMENDATIONS ON POLICIES AFFECTING SOIL FERTILITY RESEARCH AND MANAGEMENT

1. Provision of credit for fertilizers, especially to small-scale farmers.
2. Timely provision of fertilizers--reduce bureaucratic constraints on important and distribution mechanisms.
3. Intensify training of farmers on benefits of soil fertility enhancing strategies.
4. Investigate alternative extension approaches for improved effectiveness.
5. Provide relevant technical information and promote use of organic manures to complement inorganic fertilizers.
6. Pricing policies for fertilizers should adequately consider the benefits of using fertilizers.
7. Training on soil fertility management should focus on local needs.
8. Provide incentives to reduce the high turn-over of qualified personnel from research institutes.
9. Progressively reduce role of government in output/input markets to allow market forces to operate more effectively. Government should aim at market regulation and meeting strategic needs.
10. Support long-term research on soil fertility management.

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