PROCEEDINGS OF A WORKSHOP ON

SOIL FERTILITY RESEARCH FOR BEAN CROPPING SYSTEMS IN AFRICA

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Organizing Committee: R. Kirkby, O.T. Edje,
W. Graf, C. Wortmann

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P R E F A C E

This volume is the third in a publications series that documents the findings of researchers on bean (Phaseolus vulgaris) in Africa. These proceedings form part of the activities of the pan-African bean research network, which serves to stimulate, focus and co-ordinate research efforts on this crop.

The network is organized by the Centro Internacional de Agricultura Tropical (CIAT) through three interdependent regional projects, for the Great Lakes region of Central Africa, for Eastern Africa and, in conjunction with SADCC, for the Southern Africa region.

Publications in this series include the proceedings of workshops held to assess the status, future needs and methodological issues of research in selected topics that constrain production or productivity of this crop in Africa. Publications in this series currently comprise:

No. 1 Bean Fly 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.

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Further information on regional research activities on beans in Africa is available from:

Regional Co-ordinator, SADCC/CIAT Regional Programme on Beans in Southern Africa, P.O. Box 2704, Arusha, Tanzania.

Regional Co-ordinator, CIAT Regional Programme on Beans in Eastern Africa, P.O. Box 67, Debre Zeit, Ethiopia.

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

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Opening Address

Dr. Seme Debela

General Manager, Institute of Agricultural Research Ethiopia

It is a pleasant experience for me to be given the opportunity to make an opening address on the occasion of this workshop on soil fertility research for bean cropping systems in Africa. I thank the workshop organizers for providing me with this unique privilege.

It is only fitting to start my brief address by welcoming each and every one of you to Ethiopia. You are now in the capital city of one of the ancient nations in the world. With an area of 1.25 million sq. km, Ethiopia is a relatively large country by African standards. Its current population is estimated at over 47 million and is growing at an annual rate of 2.9%. This makes it the third largest country in Africa, after Nigeria and Egypt.

Population growth has a major impact on land utilization and land degradation. Population pressure leads to the exhaustion of fertile agricultural lands and the progressive utilization of enviromentally sensitive marginal areas. Thus, in the Ethiopian context, enviromental degradation as a result of deforestation, overgrazing, salinization, alkalization and cultivation of marginal lands already are, or are rapidly becoming, serious problems closely associated with population growth.

Agricultural activities are basically aimed at efficiently and effectively exploiting the environment. Plant breeders' main aims are related to the development of genotypes that are efficient in extracting water and nutrients from the soil. Such activities naturally and eventually lead to soil exhaustion, unless soil fertility improvement schemes are conciously and deliberately planned into the agricultural development process. Such plans can be based on biological and non-biological means, or on a convenient combination of both.

For resource-poor countries like Ethiopia, a non-biological approach to soil fertility is not an ideal solution, although we are well aware that we may have very little choice, at least in the short term. The use of artificial fertilizers, despite their great advantages, has major implications for us. As all our chemical fertilizers are imported, the task of providing the farming community with all its fertilizer needs is beyond our national capacity. It is believed that, on the average, the annual rate of chemical fertilizer application is between 20-30 kg/ha.

The other major implication associated with fertilizer is its impact on the natural envirőment. Unrestricted chemical fertilizer application has been reported to lead to pollution of underground water and the reduction of essential biological activities in surface waters. Such phenomen are more of a problem in developed countries; however, it is a problem that must be noted. In fact, in the Ethiopian context, state farms are an advanced agricultural scheme and their use of modern agro-chemicals, including chemical fertilizers, is reaching a stage where close monitoring may be needed.

Thus, the search for an alternative system of maintaining and even improving soil fertility becomes an important subject. I am glad to note that this workshop deals with this important topic. Traditional schemes such as the use of animal manure and green manuring as well as the more modern concept of agro-forestry are to be discussed during the course of this workshop. Our traditional farmers can not afford to practice green manuring schemes. In fact, the idea is not palatable in economic terms even on our state farms. Crop rotation, with an appropriate selection of legume crops, is preferred, although our state farms have not fully developed such schemes on the grounds that they don't have suitable legume varieties to adequately fit their productivity level in terms of economics. This, of course, is a challenge to our breeders.

It is in this context that scientific workshops like the one we are opening this morning become relevant. Scientific information and experiences gained in such workshops can become effective tools to advance agricultural development efforts. Regional and international cooperation in such efforts increases our critical mass not only in scientific manpower but also in technical facilities. Because of the mutual benefit associated with such cooperations, the Institute of Agricultural Research as well as the Ethiopian government are totally commited to such cooperative efforts.

Over the past several years, the IAR has been doing its best to increase its contact and improve its working relationship with international agricultural research centres like CIAT. In fact, at this time we have close relations with nine of the thirteen centres under the CGIAR system. Four of the centres have staff stationed in Ethiopia, and CIAT was among the first to take this constructive step. The fact that this workshop is being held in our capital city testifies to our good relations with CIAT.

We are well aware that the benefits accruing from our relations with the International Agricultural Research Centres very much depend upon our national capacity to use the IARC's potentials effectively. This calls for a strong national research system with clearly defined scientific and technological targets endowed with the necessary manpower, support facilities and finance. Despite all good intentions, the IARC's cannot substitute for the NARS; however,they can play a crucial role in strengthening it. It is with this recognition that we in the IAR have been trying hard to strengthen our national programme, while working closely with the IARC'S.

I am tempted to say a lot more than this in order to introduce you to our objectives, goals and research programmes in the IAR. In the interst of time, however, I will restrain myself from going any further, especially aware of the fact that there are several IAR staff members amongst you who can brief you on as many details as you care to know. Your workshop coordinator, Dr. Kirkby, is also on hand and can be relied upon to adequately keep you informed. If you still need to know more, you are welcome to call upon me during the course of your stay in Ethiopia. Finally, I would like to again thank Dr. Kirkby for inviting me to make this inaugurual address. I wish you workshop participants success in your deliberations and a pleasant stay in the country.

Background and Objectives of the Workshop

Roger A. Kirkby

CIAT Programme on Beans in Eastern Africa

Production of beans and other food crops in Africa are failing to keep up with population growth. We are in the midst of a vicious spiral in which crop yields are declining as a result of soil fertility decline in some of the most densely inhabited regions, while the productivity of labour is too low to provide good incentives for farmers to intensify. Easy solutions are not apparent: after 30 years of applied research in Africa on inorganic fertilizers, the average rate of nitrogen application to cropland is only 5 kg/ha (Hauck, 1988), concentrated mostly in the four countries of Kenya, Nigeria, Zambia and Zimbabwe.

This workshop brings together soil scientists and bean agronomists from eleven countries of Eastern and Southern Africa, as well as the agronomy staff of the three regional bean programmes. Our objectives are to document and assess current knowledge of soil fertility research as applied to systems in which beans are important, and to identify needs and priorities for future research.

Our first session reviews farmers' traditional methods for soil fertility maintenance and will address the question of how well these methods are still meeting the needs of the present generation and of the future. The second session is devoted to diagnosis of soil fertility: techniques for carrying out diagnostic studies, and some results from their application. The third session reviews nutrient requirements of the bean crop. Session Four, Five and Six examine past and potential contributions to the improvement of soil fertility by means of fertilizers, cropping systems and organic matter. Contributors are invited to be stimulating and not necessarily comprehensive. Each session will include remarks by an invited discussant, and working groups on selected themes will meet later in the week. One component of soil fertility research, biological nitrogen fixation, is not being treated specifically here because its importance to bean breeders and microbiologists led to their meeting last year in Rwanda.

We realize that beans are of secondary importance in many farming systems; perhaps only in the Great Lakes region can we really say that cropping systems are based on beans. CIAT for this reason has long followed a low-input strategy to bean improvement. Any consideration on soil fertility needs to take into account the other crops grown, and our ultimate objective is to stimulate research by national programmes that is well focussed upon the development of sustainable systems managed by small farmers. A systems perspective is especially important for scientists who find themselves organized by crop commodity or by discipline. We are therefore particularly pleased to have participation also by the International Council for Research in Agroforestry (ICRAF).

Reference

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Traditional Forms of Soil Fertility Maintenance

O.T. Edje, J.M.R. Semoka and K.L. Haule

SADCC/CIAT Regional Programme on Beans in Southern Africa, Sokoine University of Agriculture, Tanzania and National Soils and Fertilizer Use Research Programme, Tanzania

Introduction

Traditionally, farmers in the tropics were organic farmers (Singh, 1975) that is, they used neither chemical fertilizers nor pesticides. Instead, they used a system of bush fallow or shifting cultivation. In this system, man developed a stable agro-ecological system in which he, crops, fruit trees, trees, and animals lived in harmony. Trees such as *Acacia albida*, and *Gliricida sepium* were selectively retained as a soil fertility restoration technique. Fuelwood; fruits; medicine from herbs, shrubs, and trees; building materials; animal products and honey were obtained at no cost while maintaining the fertility and the productivity of the soil.

With increasing population pressure on the static or shrinking land resource, the ratio of the fallow to the cultivation period declined, and so did the fertility and the productivity of the land. The era of cheap fertilizer and pesticides also led to the decline in the use of the bush fallow method. Forests were cleared on a large scale to open more land for cultivation. Mechanization and mono-cropping, which discouraged intercropping with trees, became the norm. Urban areas were opened without provision for fuelwood needs for its dwellers. All these led to deforestation and consequently: desertification, increased erosion, floods and droughts as well as silting of streams, rivers and lakes; and increased salinity. These attendant problems have made most of the soils in Africa more vulnerable, more fragile and less fertile. Some of the indigenous methods of maintaining soil fertility through regenerative agriculture are fast becoming history.

In this paper we review some of the traditional methods of maintaining soil fertility in bean based cropping systems. Because of the complexity and perhaps the location specificity of some of these methods, it has not been possible to describe and discuss every system. We have included variants of the commoner methods.

Visoso

Visoso, also known as shifting cultivation, is a land-use system characteristic of areas with low human population density and abundant large trees. Hartman (1981) reported that about 300 million farmers practived shifting cultivation and related bush fallow as a means of restoring soil fertility (Hauck, 1971 and Clements, 1933).

In this system, land was cleared with simple tools such as a cutlass, axe or hoe; useful trees were let standing and other trees and shrubs were pruned down to stumps for fast regeneration. The debris was burnt and seeds planted on the flat or lightly tilled mounds for three to five years. Crops were planted in mixed stand as a strategy for increasing crop yields, diversity and stability on a subsistence scale (Gomez and Gomez, 1983). As yields declined and weeds became a problem, especially in the forest zones (Nye and Greenland, 1960), the farmer rotated his land by moving to another location; the whole slash-burn-plant process was repeated until yields declined rapidly and weeds became rampant again. And so a short cropping period of 3-5 years alternated with a long period of fallow for 15 or more years. During this fallow period, soil fertility was restored through forest shrub and grassland vegetation (Ruthenberg, 1976).

Chitemene

The term, *Chitemene* is a Bemba word derived from the verb "to cut". *Chitemene* land-use system is a modification of an intensive form of shifting cultivation which is found mostly in northern Zambia, southern Sudan and southern Zaire. The system depends on the lopped and burnt *Brachystegia* (miombo) woodland for the maintenance of soil fertility (Allan, 1965; Haug, 1981; Vedeld, 1981).

There are five types of *chitemene*: Large scale, small scale, block *chitemene*, *mwiniluga* system and *isoka* system. The classification is based on the following characteristics:

-- Ratio between cleared and cultivated land,
-- Shape and size of cleared and cultivated land,
-- Ration between cropping and fallow period,
-- Crop sequence,
-- Staple crop.

In the large scale *chitemene* the ratio of cleared to cultivated land is between 1:5 to 1:10. The small-scale *chitemene* has a ratio of 1:10 to 1:20. Both systems have circular shape. The shape of block *chitemene* is square. The cropping period of large-scale *chitemene* is longer than that of the small scale and the block. The large-scale *chitemene* has a shorter fallow period than the others. The *isoka* system is a combination of the large-scale *chitemene* and cattle-rearing. However, the *mwinlunga* is a transition to semi-permanent cultivation (Haug, 1981). In this section only the large scale *chitemene* will be discussed.

Large Scale Chitemene

In the first year, fields are selected. The choice is guided by the biomass and age of the trees as well as that of tall grass *mpumpo*. Then the trees are lopped or cut and piled up in the centre of the cleared area to about 1 m high. The area that is cleared or lopped is about 6.5-10 times the cultivated one. In early November, the pile is burnt. Planting is confined to the burnt area where the ash layer is rich in nutrients, especially phosphorus, calcium and potassium. In early December, finger millet is broadcast over the burnt area. Other crops such as maize, sorghum, pumpkin (along the edge of the field), cassava or bulrush millet may be planted.

In the second year, groundnuts or finger millet may be planted. In year 3, ridges are made over grass and beans planted in January/February. In the following year (year 4), beans are planted in November and harvested in January. Beans may be planted in February/March and harvested in May/June. In the fifth year, the year 4 pattern is repeated for another 2-3 years. In some cases, beans may be planted for 5 years before the field abandoned (Vedeld, 1981).

While the *chitemene* land-use system has been used to maintain soil fertility, it has rather low carrying capacity of 2-4 persons/sq km (Haug, 1981).

The effect of *chitemene* on soil chemical and physical properties are similar to those reported by Abebe (1981) on *guie* in Ethiopia, namely, increase in phosphorus and bases from mineralization, increase in soil pH and improvement in the soil structure. The clearing process also reduces weed population. Consequently the *chitemene* system has been reported to give higher crop yields than hoe cultivation (Table 1). Trials have also shown that the increase in seed yield were due to a combination of ash and heat and not only ash as fertilizer (Table 2).

Some of the disadvantages of the system include the low carrying capacity (2-4 persons/sq km), the destruction of trees and the attendant problems of deterioration of the fragile ecosystem, the low rate of tree regeneration (22-25 years), the high ratio of cleared to cultivated land and the danger of falling from trees during lopping.

One possible alternative is the use of fast growing legume trees (e.g. *Leucaena*). The trees can be lopped or cut, and left *in situ*. Instead of burning, as is the case with *chitemene*, the branches can be allowed to rot or left to the action of termites as is practised by the Dinkas of Sudan. The *Leucaena* could be planted in wide alleys and lopped periodically. Other trees that could be investigated for inclusion in an alley cropping system or a variant of it are those indigenous ones recently identified by Mr. S. Lungu (P. Comm., 1987) at Misamfu Regional Research Station, Kasama. These are: *Acacia polysantha, Acacia sieberana, Bauhinia petersiana, Cassia obtrusifolia, Cassia petersiana, Cassia singuena, Crotalaria* sp., *Entada abyssinica, Sesbania macrantha and Tephrosia vogeli.*

Ngoro (Matengo Pit)

Ngoro is the traditional land use system of the Wamatengos in

Mbinga District, Ruvuma Region, Tanzania (Allan, 1965; Stenhouse, 1944; and Kapinga, 1977).

The Wamatengos occupy the highlands between the Ungoni Plateau and Lake Nyasa in Mbinga District. They cultivate small highland areas ranging from 1280-1950 metres above sea level with rainfall of 991-1194 mm and population density of 30-100 inhabitants per sq km (Ludwig, 1968; Stenhouse, 1944). At one time, they occupied broader lands. When the Germans first visited the area in 1890 (Allan, 1965), the Wamatengos were already practicing this unique land-use system. However, the arrival of the Wangonis (of Zulu-Swazi origin) and constant raiding by slave traders drove them into caves, which could be defended or into the most inaccessible mountain-tops.

The Wangonis raided the Wamatengos for foodstuffs and women (they had no cattle). The women were protected in the caves and on the mountain tops. Foodstuffs were made readily available to the raiders in the most accessible and fertile valley bottoms. As long as foodstuffs lasted at the valley bottoms, the crops in less accessible mountain-tops were left alone. Thus the Wamatengos cultivated twice as much land as was needed; half was expected to be lost to the raiders and the other half was for their own use.

The drain on the scanty soil resources was therefore severe. The problem of how to maintain soil fertility and prevent erosion had to be tackled. Condemned to increasing land shortage with no option but to cultivate the steepest slopes or starve and with no cattle to provide manure, the Wamatengos evolved an admirable system of agriculture which included crop rotatin, maintenance of soil fertility by composting grass, weeds and crop residue; and systematic use of grass fallows.

One of the authors of this paper (O.T. Edje) visited Messrs. Pirimin Nduna (Lipumba village, altitude 1208 masl) and Joachim Kinunda (Kigonsera village, altitude 1150 masl) in Ruvuma Region on 27 April, 1988, and had an opportunity to see the *ngoro* system of land-use and its preparation.

Briefly, men prepare land by clearing the grass in February and March. This is known as *kukyesa*. The grass is allowed to dry and thereafter is collected and laid down in rows forming a grid all over the land intended for cultivation. One set of rows is across the slope, running roughly along the contour; and the other set of rows runs up and down the slope at right angles to the first. This process is known as *kubonga*.

The next stage is *kujali* wherein the grass is covered with topsoil which is exhumed from the square area bounded by the grass grid. These holes are referred to as *ingolu*. Sometimes, the *ngoro* is called *ingolu* (pot holes?). After the grass has been covered completely, seeds (beans, peas, maize or wheat) are sown usually in pure stand. The seeds are covered with sub-soil (*kuku*). Weeds are thrown into the *ingolu* where they form compost with accumulating silt. At the end of the season, crop residues are also placed in the pits. The old "soilbeds" are split and new beds formed over the old pits using the composted grass. New pits occupy the place where old beds intersected, and maize is planted in October/November.

The rotation followed is maize/bean (or peas). This simple rotation is followed until fertility declines and the land is fallowed to natural grass. Fallow periods range from 8-10 years (Stenhouse, 1944). This *ngoro* land-use system is also effective in soil erosion control as an overflow from one *ingolu* is trapped by the next. Table 3 shows the dimensions and plant density of two farms which were observed (by O.T. Edje) on 27 April, 1988.

The soil fertility improvement of the *ngoro* land-use system was illustrated from a trial that was conducted at a regional research centre in Tanzania for a six-year period (1950-1955). The trial was on a rich and stable volcanic loam of moderate slope, with an average rainfall of 925 mm. The Ngoro land-use system was compared with flat cultivation, constructed bench terraces, formed bench terraces, narrow-based contour banks and ridges (Allan, 1965). The test crop was maize. The *ngoro* system gave the best results over the period of the trial. In 1951 (a very wet year) the yields from the *ngoro* system were much more superior to those of ridging and flat cultivation (Table 4).

Maingu and Nzao (1987) working on the effect of cultivation systems at Morogoro on the growth and development and seed yield of *Phaseolus* beans reported that the *ngoro* system significantly out performed conventional systems in seed yield and other agronomic attributes.

It is likely that the *ngoro* land-use system will continue. This is suggested from the fact that Wamatengos, who have recently migrated from Mbinga to other districts of Ruvuma (where the *ngoro* system was not practised), have begun to practise the system in their new homes. However, three farmers (though a rather small sample) in Lipumba and Kigonsera villages said that *ngoro* was a back-breaking land-use system. As a matter of fact Mr. Nduna of Lipumba village said that he had too much grass for *ngoro* cultivation (because the size of the bank over the grass is a function of the volume of dried grasses, the more dried grass, the more volume of soil exhumed from the pit to cover the grass). Consequently, he burnt some and made ridges over others. According to Stenhouse (1944) and Pike (1938) some of the Wamatengos, with the advent of British rule, migrated to more fertile land and were less inclined to practise to the *ngoro* method. The younger Wamatengos who had migrated were adopting "lazier methods of cultivation."

Mambwe Land-use System of Northern Zambia

The *mambwe* land-use system also known as *fundikila* is practiced east of Mbala and along the border with Tanzania. This land-use system is an extension of the large scale *chitemene* following the destruction of the forest as a source of nutrients for crops. The *mambwe* system is essentially one of composting grass in mounds similar to the *fipa* land-use system in south west Tanzania (Lunan, 1950) and the *tumba* system in Sumbawanga, Tanzania (Smithson and Edje, 1988).

Grass, mostly *Hyparrhenia*, is cut in February/March and piled in heaps, buried and allowed to rot as compost in mounds. Usually the size of the mound is a function of the amount of biomass available for composting. Because large quantities of biomass from tall grass and bushwood would require considerable amount of soil and labour for composting, part of the bulky biomass is piled in circles and burnt.

The diameters of the mounds range from 1.5-2.0 m and the distance between one mound and the next is 63 cm (Edje, 1987). Haug (1981) reported that the mounds ranged from 1.8-2.4 m in diameter.

After the mounds have been constructed, beans are sown in (March). Mounds that are made late in the season are not planted until November/December when they will be flattened and planted to maize. At the onset of the rains (November/December) the mounds are flattened and the compost is spread. Weeds are also removed at this time and worked into the compost mixture. Maize, finger millet or sorghum may be planted on these relatively fertile soils. In the third year, mounds are re-made and beans, millet, groundnuts or maize are planted. The mounds are not leveled again until the fourth year when maize or finger millet may be planted. A crop of maize or sorghum maize be harvested in the fifth year before the land is allowed to fallow for 4-10 years (Allan, 1965), although Mansfield (1973) stated that 15-20 years were needed for the soil to recover fertility. Trapnell (1953) reported that the land is considered ready for recultivation when weeds from the previous cultivation have disappeared and *Hyparrhenia filipendula* has become dominant.

Schultz (1976) reported that, based on the frequency and the area cultivated, maize was planted most (100%) in the system followed by beans (92%). Cassava was planted the least (62%) (Table 5). Haug (1981) reported that the critical human population density of the *mambwe* system was 20-40 persons/sq km as compared to 2-4 persons/sq km.

As stated earlier, the predominant source of plant material for the *mambwe* compost is *Hyparrhenia filipendula*. It is tufted perennial grass commonly found in the savannahs of Africa and is low in plant nutrients (Gohl, 1975). Therefore, large quantities need to be composted in advance to allow for decomposition and release of nutrients during the growth period of the crop. One possible substitute might be fast-growing, nitrogen-fixing and easy to eradicate pasture legume crop (e.g. *Crotalaria zanziberica*) which is richer in plant food than the grass as compost material.

The practice might work as follows: Seeds of fast growing, nitrogen-fixing, easy-to-eradicate pasture legumes are broadcast in November/December and worked slightly into the soil with a hoe. The emerging seedlings are allowed to grow until February/March when they are buried in mounds to compost and beans planted on the mounds. Since the composting of grass in mounds is already popular with farmers, the use of a legume instead of the former should not pose much problem except for the provision of seeds and plant establishment.

The *mambwe* system is similar to ridge cultivation in parts of Malawi. Here weeds are allowed to grow following the onset of rains in October/November. The weeds are buried in ridges in January/February and beans or sweet potato (*Ipomea batatas*) are planted on them.

Edje (1983) compared the agronomic effectiveness of weed compost and Leucaena prunings on maize and bean yield. The predominate weed in the field for the trial was *Rotboellia exaltata*. Fresh and dry weights of weeds in the field at decomposting were 4744 and 2037 kg/ha, respectively. Mean weed height was 45 cm. He reported higher, but non-significant maize seed yield from plots that were planted to weed compost as compared to control. Leucaena pruning of 15 tonnes/ha had comparable yields with 52 kg/ka N and 17.5 kg P_2O_5. In the same trial there was significant response of maize to compost from Leucaena prunings. Similar results have been reported by Kang, Sipkens, Wilson and Nangju (1981) using Leucaena prunings and by Temu (1986) from compost of *Crotalaria zanziberica*.

Mounds of the Wafipas

The mounds of the Wafipas of southwest Tanzania are similar to those of the *mambwe* land-use system. The Wafipas (who are pastoralists) occupy an area with an average altitude of 1000-1950 msal, with a mean annual rainfall of 787-1194 mm and a population density of 10-100 persons/sq km (Ruttenberg, 1980; Lunan, 1950). The land of the Wafipas is covered with tall grass (presumably Hyparrhenia) and scattered trees. In each dry season, the tall grass is burnt to provide fresh grass and also to control ticks. Although they are pastoralists, they do not add manure to their soil but rely on compost as a source of plant food for their crops.

The land-use system of the Wafipas consists of a rotation system that begins with mounds followed by flat cultivation, rough mounds, flat cultivation and finally ridging.

The land preparation begins in February/April when the grass is cut and placed in small heaps. Sod is cut with hoe and piled in neat circular mounds over the grass. Mounds are about 1 m in diameter, 60-65 cm tall with the distances from one mound to another, 45-60 cm. A man can make about 100 mounds a day.

The customary crop on the mound is beans (Lunan, 1950). Women plant 10-15 seeds on top of each mound. Other crops such as potato (*Ipomea batatas?*) or cassava may also be planted. Weeding begins in October/November and the mounds are broken and spread in the field. Maize or finger millet may be planted on the land. After harvest of maize or finger millet in June/July, small rough mounds are made, covering heaps of weed and crop residue. The mounds are left until January for decomposition when they are broken down and spread and the field planted to finger millet. The finger millet is harvested in the following June, and the field is left in flat condition. The following December, the land is ridged and planted to maize interplanted with beans, groundnuts or bambara nuts. This rotation may be repeated several times until the soil is exhausted and the field is reverted to fallow of grass and weeds.

In areas where there are trees, during the first round of mound preparation, the branches (in case of large trees) or the entire tree (small trees) are cut, heaped around the base of the tree and burned. Unlike the *chitemene* system, the ashes are not spread and there is no burning of trees outside the cultivated area to accumulate ashes.

According to Luman (1950) the mound cultivation of the Wafipas is conducive to erosion control since the mounds are made in March/April when the season's rainfall is over. Erosion can also be controlled by joining the mounds to form ridges. This system also increases soil fertility because weeds are composted to humus instead of being burnt yearly.

Tumba Land-use System

This is another mound cultivation system found in southern Tanzania. Like the mound cultivation system of the Wafipas, the grass is cut and arranged in circular heaps about March/April. This is generally done on fairly heavy soils. Soil between the grass heaps is piled neatly over the dried grass. Mound dimensions are 114 cm (diameter), 43 cm (height) and 176 cm (distance between crests of adjacent mounds). However, unlike the Wafipas who plant beans and other crops on the mounds shortly after preparation, the Tumba mounds are left to decompose until November/December of the same year when they are flattened and planted to maize in pure stand or maize/bean association (Smithson and Edje, 1988). In areas with tall grasses and small trees, the bulky biomass is gathered in a circle and surrounded by a ring ridge (3.7 m in diameter) and burnt. The ash from the burnt grass and trees may be spread in November/December when the mounds are being flattened, or crops such as cucurbits may be planted over the ash.

By composting organic matter, soil fertility is enhanced. Since these soils are relatively heavy, the decomposition of organic matter could also improve soil aeration, water holding capacity and root development of otherwise relatively unproductive land in a manner similar to that of *guie* in Ethiopia (Abebe, 1981).

Guie

Guie, or soil burning, is a traditional system of soil management for crop improvement in the central highlands of Ethiopia. In this system, unlike in shifting cultivation where dried organic matter (stems, branches, brush, grasses, etc) is burnt, the soil itself is burnt. This system according to Abebe (1981) is used by smallholder farmers when cultivating fallow land with heavy clay soil and a hydromorphic horizon.

Guie soils covering about 540,000 ha are found between 2000-3000 masl with an annual rainfall of 1100-1500 mm and annual mean temperature of 14.5^{o}C. According to Murphy (1959) quoted by Abebe (1981) the soils are fertile but are hydromorphic. Consequently, they have low productivity because of internal drainage, poor aeration and infiltration; and hence low yield. The practice of *guie* was initiated in antiquity in the hope of improving the productivity of such soils.

During the short rains of February-April, fallow land that has been grazed is ploughed repeatedly in a criss-cross direction. Soils to which sod is attached are collected into heaps with the sod towards the centre on which loose soil is heaped and packed on the outside. According to Abebe (1981), there are about 850-1630 (mean 1230) heaps per hectare and each heap is about 80 cm in diameter and 60 cm high. The heap is lighted by introducing a burning cattle manure into the centre of the heap which then burns slowly for 10-15 days, The centre of the heap has the highest heat intensity (650^{o}C) and is burnt completely while the outer layers are less ashed. The burning process creates distinct layers that are demarcated by colour differences (Wehrmann and Legesse, 1965).

After cooling, the soil in the heap is spread with shovel and ploughed so as to mix the burnt soil with the rest of the soil in the field. Barley or wheat is planted in June. Farmers can obtain two to three crops before the field is abandoned and allowed to fallow for 10-15 years after which *guie* is repeated. Usually the highest yield is obtained in the first year; yield begins to decline in subsequent years.

Tables 6 and 7 show the effects of *guie* on some physical and chemical properties of soil. Of interest is the change in soil pH of 5.85 in unburnt soil to pH 7.10 in burnt soil. Zake and Nkwiine (1981) reported that ash raised soil pH to the level where liming was not recommended. The ash also contributed several bases (Table 8). Also there was a five-fold increase in available phosphorus. Zake and Nkwiine (1981) have reported similar results. The increase in P is attributed to mineralisation of organic phosphorus during burning (Wehrmann and

Legesse, 1965). The process of burning causes a false change in texture due to fusion of the clay and silt fractions into particles of sand size. This increases aeration and permeability in the burnt soil (Table 6). However, the process also causes a drastic reduction in organic matter which is likely to have adverse effects in the long run.

Mafuku in Zaire

Mafuku is a land-use system in which dried grass placed in mounds is burnt in order to improve soil fertility. The mounds are joined by ridging, and crops such as cassava and beans are planted. Briefly the land preparation is as follows. The dried grass is cut at the base using a hand hoe. The cut grass and any adhering soils are placed in mounds about one metre high in rectangles of variable sizes. The soil between the mounds is loosened by hoe and placed over the dry grass. More soil is placed on the vegetation until it is firm but with adequate space for slow burning. Thereafter, the mound (grass and soil combination) is lighted. The mound may burn from 2-7 days. Any unburnt grass is gathered, placed on the heap and burnt again. The resulting ash and soil mixture is left until the beginning of the rainy season. After the first two or three showers, the mounds are joined through ridging to form a continuous ridge. In areas where ridging is not practised, the mound is left and cassava is planted directly. However, in places where farmers grow crops on ridges, cassava is planted throughout the ridge. But since farmers know that the site of the mound is more fertile, crops such as maize, beans or tomato are intercrops on the mound site.

When one of the authors (O.T. Edje) visited the Zaire National Cassava Programme (PRONAM) at M'Vuazi in 1986, he observed that cassava growing on the mounds had higher vigour and was greener. The factors contributing to the higher observed vigour are not quite understood but could be attributed to increase in soil fertility and physical characteristics (Abebe, 1981; Wehrmann and Woldeyohannes, 1965; Zake and Nkwiine 1981; Haug, 1981; Nye and Greenland, 1960; Landu and Brockman 1983).

A system similar to *mafuku* is also used in Malawi for the production of tobacco seedlings (and after transplanting of tobacco seedlings, beans and other early maturing crops may be sown on the seedbeds). However, unlike in *mafuku* where the grass is buried and ignited, maize stover is piled on seedbeds and ignited. Briefly, the system of tobacco seedbed preparation is as follows: A suitable nursery site is chosen. One important criterion is proximity to reliable water source for the tobacco seedlings. The smallholder farmers who plant dark-fired tobacco normally choose their nursery sites close to *dambo* (hydromorphic soil) margins in order to ensure the supply of water. However, *dambo* soils are generally heavy because of their clay content.

Once the site has been chosen, the soil is dug up in

August/September. Beds, (1-12m) are constructed with paths about 0.5 m between them. About 8-9 beds are needed to raise seedlings for one hectare of tobacco field. The tobacco seedbed is prepared to very fine tilth because of the small size of tobacco seeds. Thereafter, maize stover is piled on the bed to about one metre high. The maize stover is ignited and allowed to burn gently for effective soil sterilization. The ash is then scraped off the bed. Tobacco seeds are placed in a watering can containing water, and sowing is done by watering the seeds on the beds. No fertilizer is used.

It has been observed that seedlings produced by smallholder farmers using this method are much more vigorous, grow faster, and have higher quality than seedlings from seedbeds sterilized with ethylene dibromide (EDB) or methyl bromide. Large-scale tobacco farmers who use chemicals for soil sterilization of tobacco seedbeds use an N-P-K (6-7.8-5) compound fertilizer. Smallholder farmers who sterilize their seedbeds with maize stover do not use fertilizer.

The higher vigour, quality and faster growth observed on small holder tobacco nurseries near *dambos* sterilized with maize stover could be explained on the basis of trials conducted by Abebe (1981) and Zake and Nkwiine (1981). They reported increase in the availability of phosphorus following burning. Abebe (1981) reported increase in aeration, permeability and yield following *guie*. The aeration and permeability were attributed to increase in sand fraction and decrease in clay fractions.

After tobacco transplanting, some farmers have been observed weeding the seedbed to remove remaining seedlings in order to plant beans or any other early maturing crop.

Farmers are being discouraged from the use of maize stover for soil sterilization because of the adverse effects of burning as explained by Abebe (1981). The use of ethylene dibromide (by injector guns) or methyl bromide (by special plastic sheets) has been introduced on tobacco estates (hired-labour managed and tenant farmer system). However, the adoption rate of chemical use by the smallholder farmer has been rather slow, presumably because of increased cost of production arising from the purchase of chemicals and application facilities. Since most smallholder farmers rely on water from very shallow wells (really holes) on *dambo* margins and heavy soils for seedling production, they are likely to continue to use maize stover for soil sterilization. The observation that better seedlings were produced on *dambo* margin maize-stover-sterilized soil rather than on chemically sterilized soils should not be ignored.

Termite Mounds

Termites or white ants are amongst the most destructive insect pests that feed vigorously on cellulose either in its natural state as dead and dying trees, herbs, grasses, etc. or on manufactured articles (Harris, 1940). According to Harris (1941), there are 77 species in East Africa where they do untold damage.

In spite of the damage that they cause, they break down organic matter for crop use and also move soil, thus increasing aeration and water infiltration. This unique attribute of termites to breakdown organic matter has been recognized by the Dinkas of Sudan in a modified *chitemene* land-use system. In this system, trees are lopped and the branches with the leaves are stacked to about 60 cm high. Instead of burning the stack, as is the case with the *chitemene* system, the pile of wood and leaves is left to the action of termites. The activity of termite is quite rapid; by the end of the dry season, the wood, branches and leaves have been reduced to a surface mulch of dust and the land is ready for planting. According to Allan (1965) poor soil on which grass cannot grow can be restored to fertility in a few months.

Nyamapfene (1986) in his review paper on the nature and use of termite mounds reported that farmers in Zimbabwe realize termite mounds as an agronomic resource. They generally plant crops which require good water supply and high nutrient levels, particularly of Ca and K almost exclusively on ant hills. Because of the high fertility status of termite mounds, their planting densities are much higher than on surrounding soils. Also, because of high moisture content, farmers plant maize on termite mounds as an insurance against drought.

It has been observed in Malawi (Central Region) that some farmers dig soil from termite mounds and apply it in band form. Thereafter, small ridges are made over the band and maize or tobacco is planted. Where the quantity of soil from terminte mounds is small, the soil is applied in "dollop" form close to the base of the crop. The agronomic importance of termite mounds may explain why some peasant farmers are reluctant to destroy their termite mounds.

Agroforestry

Agroforestry is a land-use system that integrates the production of woody perennials (trees and/or shrubs) with agricultural crops (food, fodders, fibre crops etc) with or without livestock simultaneously, sequentially, zonally or in a relay on the same unit of land. The aim of this land-use system is to maximise the multipurpose production of the socio-economic needs of the farmer from a limited resource base with low levels of technology in a sustainable manner from a unit of farmland (King and Chandler, 1978; Bene, Beall and Cote, 1979; Wiersum, 1981; King 1979; Meydell, 1979; Wilson, 1981; Edje, 1982).

In this land-use system, trees such as *Acacia albida, Acacia bateri. Macrothylum* spp. and *Gliricidia sepium* are selectively retained (Wilson 1981). This system recycles nutrients, fixes nitrogen, reduces soil erosion, intercepts fog drip, lowers soil surface temperature and provides organic mulch and humus (Myers, 1980, and Douglas, 1972). The trees also provide animal feed, shade for livestock, fuelwood, medicine, etc. (Chavunduka, 1981).

Agroforestry is an old land-use system but a new technical field with elements of logical extension and application from shifting cultivation. In present day agroforestry, wild species are being replaced by their domesticated relatives to fulfill the socio-economic needs of the farmer. Nevertheless the potential of *Acacia albida*, an indigenous tree in Malawi (Edwards, 1982) deserves special mention.

Acacia albida, also known as "miracle tree", winter thorn or *nsangu* is a legume (Binns, 1972). It is medium to large in size (up to 30 m) and a deciduous tree but loses its leaves during the wet season. It has a wide altitudinal range from 270-2500 masl. The agricultural value of *Acacia albida* stems from the fall and decomposition of its leaves fall at the beginning of the rainy season, releasing nutrients to the soil at the time of planting.

Edwards (1982) in reviewing the importance of this tree, stated that it was indigenous to Malawi and had high agroforestry potential because it was deep-rooted and an efficient nutrient pump. Since it sheds its leaves during the rainy season, it does not shade crops growning under it. He reported that the tree has been known to increase organic matter and organic nitrogen by up to 200% and 600%, respectively (Table 9). In Ethiopia, cereal yields have been reported to increase by 35-55% when grown under the tree (Poschen, 1986). Soils under the tree also tend to have higher water-retaining capacity. The tree ameliorates micro-climate through moderate shade during the dry season and light shade from the bare branches which reduces the extremes of maximum and minimum soil temperatures. Consequently, yields of crops, non-legumes in particular, have been reported to be higher under a light canopy of *Acacia albida*.

In Salima District (Malawi), where farmers are already aware of the importance of *Acacia albida* in maintaining soil fertility, the tree is not felled when opening a new field. Because of this the Wood Energy Programme in Malawi included it in their nursery of tree seedlings for farmers in Salima District and had difficulty in meeting farmers' request for the seedlings (J.H. Cassey, 1982, pers. comm.).

Relay Intercropping Systems

The relay intercropping system is a multiple cropping system where two or more crops are grown on the same piece of land within a growing season. This land-use system is common in areas with bimodal or prolonged rainfall, for example, in parts of Southern Region (Blantyre, Cholo) and Northern Region (Nchenachena and Misuku Hills) of Malawi, the southern highlands of Tanzania (Rukwa, Ruvuma, and Iringa Regions) and in Northern Province of Zambia.

As the name of the system implies, one crop, say maize, is planted at the beginning of the season (October/November). A second crop (beans, peas or wheat) is planted when the maize has attained physiological maturity. In other words, the land is passed on (relay) from maize to beans, peas or even maize (Kiambu District, Kenya).

Briefly, the system as practiced in Malawi is as follows: Ridges about 90-100 cm apart are made and planted to maize in October/November. In March/April when maize is at physiological maturity, the senescing lower leaves (4-5) are stripped off the plant and laid on the furrow. In some cases the leaves above the cob (3-4) may also be removed and buried. The leaves together with weeds are then covered with soil from the ridge. The field thereafter looks flat except for mounds of soil around the maize hills. Then beans, peas or wheat are planted at random on the flat. The maize plants may remain standing in the field until full flowering or early pod filling of the beans before the maize is harvested. After maize harvest, the stover may be removed leaving the appearance of a bean monoculture (Spurling, 1973).

Although there are no quantitative estimates of the agronomic effectiveness of this system, farmers in parts of Malawi recognise the manurial effects of buried maize leaves on bean yield.

In areas where termites are a problem and relay intercropping is practiced, farmers have been known to delay weeding. The weeds are then laid on the furrow as a diversionary tactic away from the maize plants. Organic matter is broken down before the lower (and sometimes top) leaves of the maize are buried to provide nutrition for the relay bean, pea or wheat crop.

A possible alternative to reliance on maize leaves for soil fertility maintenance in a maize/bean relay system is the inclusion of a fast-growing, nitrogen-fixing, easy-to-establish and eradicate forage legume. The forage legume can be planted (broadcast) following the second weeding of maize. The objective would be to enrich the resulting compost, especially, with nitrogen. Another possibility is to bury the maize leaves before all their nitrogen is translocated into the maize stover. This would be especially effective on farms where the crop residue is not returned in the form of farm yard manure (bedding for livestock) or buried through soil incorporation.

Coffee-banana-bean Cropping System of the Wahayas of Bukoba

Coffee is one of the most important crops in Tanzania. In 1981/82, 95% of the total area of 220,336 ha was found on small holder farms interplanted with banana. The coffee-banana field is known as *kibanja* in Kagera Region (Tibaijuka, 1983). The *kibanja* is also interplanted with other crops such as beans; the second most important food crop after banana.

The coffee-banana-bean cropping system occurs in an area with rainfall of 2000 mm (at Bukoba) on soils that have been described as leached, light, non-retentive and empty of nutrients. The soils are so poor that under arable conditions without manure they are used only for one crop of bambara nuts followed by fallow of 7-10 years (Allan, 1965). However, the Wahaya of Bukoba were able to maintain islands of fertility in their *kibanja* through the use of cattle manure (when available), banana peelings, and mulch from banana stems and grasses.

Removal of Maize Tassels

It has been observed in parts of northern Malawi that farmers who grow maize on poor soils with little or no fertilizer application generally remove tassels presumably to reduce competition for photosynthate and divert nutrients to the cob. The effects of tassel and leaf removal on maize yield has been conflicting. Tassel removal has been reported to increase seed yield (Hunter *et al.*, 1969 and Edje, 1984). However, Wigham and Wooley (1974) reported that detasselling reduced seed yield. Grogan (1956) concluded that detasselling increased seed because of lack of competition between developing tassels and cobs for photosynthate. Van Lanen, Tanner and Pfeiffer (1946) reported that the maize tassel contained 18.3% protein, 6.9% fat and 4.5% ash and that the total protein content in the tassel was two or more times higher than in the seed. The removal of this strong sink at an appropriate stage of its development could be one means of conserving and diverting nutrients to maize cobs.

Besides being a strong sink, the tassels, which die shortly after pollen shedding but remain on the plant have been reported as obstructions to light penetration. A single tassel may cast as much shadow as 114-153 sq cm, resulting in 19.4% maize seed reduction (Duncan, Williams and Looms, 1976).

Storage of Nutrients in Weeds

Storage of nutrients in weeds is also a method farmers use for the maintenance of soil fertility. Some farmers in Arusha Region (Tanzania) have been observed to allow weeds, especially *Nicandra physalodes* to grow to about 60-75 cm tall. They are then weeded and worked into the soil with a hoe; 7-10 days after weed incorporation, beans are planted. The farmer who was observed using this method stated that it was a traditional system of growing beans without the application of inorganic fertilizer.

Briefly, the description of the system is as follows: Land is ploughed or dug up with a hoe in November/December. Maize may be planted in associaton with beans on a portion of the field and beans as a pure stand on the other. Maize planting is done in February-March, depending on the rainfall, and beans planted between rows of maize after the first weeding of maize. The weeds are spread on the field as green manure and not heaped on bunds or a central location to rot. In late March or early April, the land for the pure beans is weeded. At this time the weeds which have stored some of the available nutrient, especially from nitrogen flush (Birch, 1964), are cultivated. After a day or two they are cut with a hoe and buried while they are still succulent for ease of decomposition. Beans are then planted 7-10 days after weed incorporation. Fairhead (1987) reported that farmers in the Kagara zone of North Kivu in Zaire used a similar practice as a means of maintaining soil fertility for bean production.

Other Methods

Other traditional methods of soil fertility maintenance include nitrogen fixation (Agboola and Fayemi, 1972) and the use of compound gardens where household waste, mulch, chicken manure, etc. decompose and form an excellent source of nutrients, especially for multipurpose bean cultivars where both leaves and green pods are used for relish (Allan, 1965). Such compound gardens are so popular in some countries that a check-list of crops, including fruit trees, is sometimes as high as 12-15. Alley cropping (Kang, Wilson and Lawson, 1984), contour, crop rotation, etc. are among some of the variants of traditional methods in use for soil fertility maintenance.

Conclusion

In this paper, we have described some of the traditional forms of soil fertility maintenance for bean-based cropping system or for systems in which beans were a part. It is evident from the literature that, traditionally, farmers who produced beans and other crops depended on standing trees and bush vegetation as a storehouse of nutrient for the restoration of soil fertility and productivity. In addition to providing nutrients through ash and burning, the vegetation also provided cover for the fragile tropical soils.

Perhaps the oldest form was shifting cultivation (*visoso*) and its variant, the *Chitemene*. While nutrients were restored almost effortlessly and "cost free" through fallow, these systems were inefficient, destructive, to some extent dangerous (men falling off trees) and had low human carrying capacity. With a reduction in fallow period the *mambwe* or mound cultivation system evolved whereby green manure was composted. The era of cheap inorganic fertilizer discouraged the dependence on regenerative agriculture. However, the oil crisis in the mid 1970s and the high attendant cost of agro-chemicals shifted emphasis to agroforestry, an alternative to shifting cultivation. We are now back to one variant of the traditional forms of soil fertility maintenance with some modification to adapt it to present day circumstances.

It is hoped that the various traditional forms described (not an exhaustive list) will contribute to the present interest by natural and social scientists to document, adapt and adopt indigenous knowledge of the means of enhancing soil fertility and productivity.

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Table 1. Finger Millet yields as affected by fertilizer on *chitemene* and hoed seedbeds

Treatments	S/A	SS	KCI	K_2SO_4	Lime	FYM
Unfertilized *chitemene*	1547	1345	1393	1603	1158	1330
Unfertilized hoed	485	373	493	373	434	538
Fertilized *chitemene*	1849	1505	797	1902	1360	586
Fertilized hoed	1091	844	762	355	463	389

Table 2. Effect of *chitemene*, burning and ash on finger millet yield

System	Seed yield (kg/ha)
Chitemene	1177
Burning alone	944
Ash alone	579
Control	268

Table 3. *Ngoro* pit width, length, depth and plant density of two farms in Ruvuma Region (1988)

Pit length	146 cm
Pit dept	27 cm
Planted area (down slope)	78 sq cm
Planted area (across slope)	78 sq cm
Plants/sq m (planted area)	33

Table 4. Maize yields (as % of highest) in *ngoro* and other cultivation systems (1951)

Cultivation system	Yield (%)
Ngoro	100
Flat cultivation	49
Constructed bench terraces	44
Ridges	43
Narrow-based contour banks	27
Formed bench terraces	22

Table 5. Relative cropping frequency and hectarage (%) in *mambwe* system.

Crop	%
Maize	100
Beans	92
Groundnuts	77
Finger Millet	69
Cassava	62

Table 6. Effects of *guie* on soil properties

Soil properties	Unburnt soil	Burnt soil
Soil pH	5.8	7.10
Available P (me/100g soil)	3.81	18.45
Total carbonates (%)	0.00	2.00
Organic carbon (%)	2.85	0.31
Percent sand	34.00	78.00
Percent silt	33.00	18.00
Percent clay	33.00	4.00
Apparent textural class	Clay loam	Loamy sand

Table 7. Effect of *guie* on soil chemical composition

Analysis and layer	Total N %	Available P ppm	Total bases
Top soil			
0-5 cm	0.19	0.5	25.9
Heated	0.24	24.0	27.4
Carbonized	0.08	45.0	20.7
Transition	0.05	64.0	15.6
Ashed	0.02	75.0	13.1
Below heap			
5-10 cm	0.16	3.0	29.5
Below heap			
10-15 cm	0.14	3.5	28.5

Table 8. Analytical results of soil, $CaCO_3$ and ash

P and Bases	Soil	$CaCO_3$	Ash
Truog's P (ppm)	11.6	42.5	98.4
Total bases	5.4	38.05	17.71

Table 9. Increase in total organic matter and organic nitrogen in soil under *Acacia albida* trees

		% increase	
Country	District	Organic matter	Organic nitrogen
Malawi	Salima	113	125
Niger	?	269	231
Senegal	Bambey	192	194
Sudan	Jebel Marra	200	600

Effects of the Traditional Cropping System on Soil Fertility in South Kivu, Zaire

Lunze Lubanga

Institut National de l'Etude et la Recherche Agronomiques, Mulungu, Zaire

Introduction

South Kivu in the highlands of East Zaire has a high and increasing population density of 232 inhabitants per sq km, and up to 500 per sq km in some areas. Soils are volcanic over basaltic subsoils. Potential productivity is high due to low absorption capacity, good saturation, low apparent soil density and, most importantly, substantial reserves of alterable minerals (Mulungulu, 1986).

Despite these favourable conditions, the overall level of agricultural production in the region and yields from major subsistence crops are often low and will continue to decline. Production of legumes are expected to fall by 20% to 35% and that of root crops by 45% within the next 25 years. This prospect is due principally to the high population density resulting in permanent cultivation without fallowing (or only short fallows), thus aggravating the already serious soil erosion by water due to geomorphology.

Land Utilization

Farms in this region are small (average 0.6 ha per family) and consist mainly of extensive banana groves intercropped with subsistence and commercial crops and pastures. The main subsistence crops in descending order of importance are banana, bean, cassava, maize (about 0.3 ha each), sweet potato (0.15 ha) and sorghum (0.3 ha). Potato, which is becoming important, is cultivated by a few farmers (Schoepf, 1982). Only 12% of farmers raise livestock (average 1.9 cows and 2.5 sheep per farm), so little manure is produced. In villages surrounding the Mulungu research station, bean is cultivated for subsistence by about 25% of farmers as a sole crop, 56% alternate it with maize or sorghum, whilst 19% utilize both systems, depending on the season (Schoepf, 1982). Intercropping with banana is also practised.

The system of crop rotation may be summarized as follows: sweet potatoes as a first crop, followed by several legume-cereal cycles and then a cassava crop before the land is left to fallow. This traditional rotation (Hecq and Lefebvre, 1961a) may be regarded as rational provided it is not abused. However, due to population pressure, the cropping cycle is becoming longer and the fallow period shorter, and fertility decline is inevitable.

Maintaining and Improving Soil Fertility

Banana, being of great importance to farmers, is grown on the most productive land, usually on gentle slopes in the immediate vicinity of the house. This crop receives almost all the manure available as household refuse and by-products.

For other subsistence crops, fallowing formerly constituted the sole means of regenerating soil fertility. The current practice involves only working residues from the previous harvest into the soil. This practice, as the bean yields following three seasons reveal, has little effect when the crop residues utilized are obtained from the same field (Table 1).

Table 1. Bean yields from plots treated for three seasons with various types of crop residues.

Type of residue	Yields kg/ha
None	599
Composting	680
Mulching	660
Working in	612

Although no treatment was statistically superior to the control from which all residues were removed, plots treated with compost and mulch produced yields 14% and 10% higher, suggesting that fertility decline might have been slower if these methods were employed.

In an on-going study, the long term effect of recycling crop residues is being evaluated. Observations on plots cultivated continuously for periods ranging between 0 and 11 years indicate that apparent density of soil at 10-20 cm depth increased from 0.79 g/cm^3 to 1.01 g/cm^3 with a gradually deterioration of soil structure. The high OM level (6.8% carbon) following a long fallow period decreased significantly after the first year of cultivation. The high initial C:N ratio (14) appeared to diminish, but stabilized after the fifth year. In a pot trial, the productivity of this soil in terms of total dry matter of sorghum decreased dramatically after the first 2-3 years and stabilized after 5 years (Table 2). In a related field trial, soil fertility under permanent maize cultivation decreased even more rapidly after a one-year fallow period (Table 3).

Table 2. Effect of continuous cropping upon total dry matter yield of sorghum, in a pot trial.

Years of cropping	DM yield (mean of 3 cuts, g/pot)
0	4.49
1	5.21
2	4.07
5	2.65
9	2.51

Table 3. Effect of fallow treatments upon maize yields over three successive years, in a field trial.

Previous cropping treatment	Maize yield (kg/ha		
	Year 1	Year 2	Year 3
Natural fallow	2650	2090	2040
Mimosa invisa	3200	2160	1890
Setaria sphacelata	2700	2180	1390

Source: Hecq and Lefebvre, 1961b

Conclusion

The current system of soil management in this area cannot sustain the ever-increasing demands of a rapidly expanding population. While a radical alternative to this system is needed, mineral fertilizer unfortunately remains a luxury beyond the reach of the small farmer.

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INERA. Rapports Annuels 1980-1987

Summary of Discussion on Traditional Systems

Rapporteur: J. Muthamia

The reported practice of soil burning (*guie*) affects texture and physical properties of the soil. Clay particles are changed to ceramic but aeration is improved. Soil N, P, OM and microbes are lost, but some nutrients may become more available. In order to evaluate the balance of short term beneficial effects and the longer term negative effects, more needs to be known about the limitations to production in this system. Is low availability or imbalance among nutrients a problem?

Chitemene can also be looked upon as a destructive system, not to be encouraged. Yet it is reported to increase yields four-fold.

In each situation more than one possible strategy can be identified. Crop rotation or fertilizer use may or may not be acceptable alternatives to these traditional practices. Ways of looking at traditional systems should be acceptable to the people.

The Distribution and Properties of Major Soils in Bean- growing Areas of Africa

S.K. Mughogho

Bunda College of Agriculture, University of Malawi

Introduction

The soil resources of the African continent constitute a very wide-ranging subject. In this paper, the discussion is directed primarily to the subject of soils in relation to bean production. Efforts to improve soils for bean production should be based on the inherent soil characteristics (Lowole, 1985). These soil characteristics should indicate the natural potentials or limitations of the soils.

A soil survey is a field investigation which is supported by laboratory data, as a result of which a soil map is made showing the geographical distribution of different kinds of soils. Soil surveyors will, therefore, attempt to provide information that will serve the needs of all potential users of the land over several decades (Buol *et al.*, 1973). This soil survey information normally describes, defines, classifies and interprets for use the different soil types. Lowole (1985) pointed out that the aims of a soil survey are as follows:

1. Identify the different kinds of soil in the area surveyed by means of investigations,
2. Show where each kind of soil identified occurs within the area surveyed (This is the main purpose of the soil map),
3. Give an idea of the relative and absolute size of areas covered by different soils,
4. Indicate the agricultural potentials of the different kinds of soils mapped and thereby indicate which of the soils mapped need inputs or other improvements to render them productive.

The amount of information needed by the soil fertility specialist is normally only a fraction of the data that has been gathered by the soil surveyor, and this is because the soil fertility specialist considers and concentrates only on the properties of the so-called "plow layer" and/or the subsurface immediately below the plow layer which the soil surveyor considers of little importance when classifying the soil (Buol *et al.*, 1973; Lowole, 1985).

Major Soils

The Soil Taxonomy (Soil Survey Staff, 1975) has been used in this text. Where necessary, the FAO Legend and local classification system have used for clarification.

Figure 1 and Table 1 give the general idea of the distribution of the soils in the bean-growing areas of Africa. Though the soils of tropical Africa have always been termed "not fertile," there are many of these infertile soils which, once they are well managed, will produce crop yields as high as those produced in temperate regions.

Inceptisols/Entisols

Inceptisols, which are estimated at 70 million hectares (Table 1), are the soils that have no developed features diagnostic for other orders, but they have features in addition to the ochric epipedon. In Ethiopia, for example, Ustalfs are found in association with Tropepts in the west, while in the south-west the predominant soils are Tropaquepts which occur together with Tropaquets. The occurence of Andepts in Africa is limited to a small but locally important bean-producing area, namely Ethiopia, Kenya, Uganda, Tanzania, Rwanda, Burundi and eastern Zaire (Sanchez and Uehara, 1980). These areas are under intensive production inspite of the large quantities of P fixed by Al and by allophane (Soil Survey Staff, 1975). Torriorthents are found in the north-east of Uganda in association with Aridisols; whereas in the more humid south-west, Andepts are found in association with the Ultisols.

Alfisols

Alfisols are estimated to be 550 million hectares in Africa (Table 1). These soils have an ochric epidedon, arqillic horizon and moderate to high base saturation. Ustalfs tend to form belts between the Aridisols of the warm arid regions and the Ultisols, Oxisols, and Inceptisols of warm humid regions (Soil Survey Staff, 1975). Ultic types of Ustalfs have 75% base saturation (by sum of cations) in all parts of the arquillic horizon (Buol *et al.*, 1973). These may fix great quantities of P.

Alfisols are found in the middle latitudes of Africa and on the eastern part all the way from Ethiopia to the Republic of South Africa (Figure 1). They are located in the transitional areas between the Aridisols of the desert and the Ultisols and Oxisols of the humid climates. The main areas in the bean-growing region where Alfisols are found are the ustalfs in western Ethiopia, southern Kenya and Somalia, northern Tanzania and the southern portion of Malawi and Zambia. These soils have a great potential for bean production.

Utisols

The Ultisols are soils that contain an appreciable amount of translocated silicate clays. Base saturation in most Ultisols decreases with depth because the vegetation has recycled the bases (Soil Survey Staff, 1975). The low fertility and low base saturation limit the potential of Ultisols. In Ultisols, the organic matter in the top horizon contains most of the nutrients, and if this supply is depleted, the soils become unproductive. The productivity of these soils is dependent on nutrient recycling by deep-rooted plants for maintenance of fertility in the surface layers.

There are only about 100 million hectares of Ultisols in Africa (Table 1), and these soils are concentrated in the region surrounding Lake Victoria in Uganda, Kenya, Tanzania and eastern Zaire (Figure 1). They usually produce good crops for the first few years until the nutrient reserve is depleted. Intensive cultivation may result in erosion, exposing the sesquioxide-rich B horizon which is also an arquillic horizon. This horizon has very high clay content and very high phosphorus fixation. Sanchez (1976) has reported some work in Brazil where it was found that an Ultisol fixed more phosphorus per unit of iron oxide content than did the Oxisols. He associated this effect with the less crystalline oxide forms in the Ultisols in contrast to more crystalline forms in the Oxisols.

Oxisols

Oxisols are found mostly on gentle slopes on surfaces of great age, and are composed of quartz, kaolinite, free oxides and organic matter (Soil Survey Staff, 1975). Without amendments, Oxisols have low productivity for cultivated plants. Due to the extreme weathering, very low nutrient reserves and low exchange capacity of Oxisols, most of the nutrients of these soils in the natural ecosystem are within the living or dead plant or animal tissues. Buol *et al.*, (1973) pointed out that these soils have unique uses and management requirements, limitations and possibilities because of their very low nutrient reserves and extremely low native fertility. This is associated with their high degree of weathering, very low active acidity and low exchangeable aluminium, high permeability and low erodibility. These Oxisols are very extensive with an estimated 550 million hectares (Table 1). They are found mostly in central Tanzania and Zambia where one finds Ustox and in much of Zaire where Orthox is found (Figure 1).

Soil Acidity

Kamprath (1984) used the base saturation of a soil as a criterion for classifying acid soils at the great group level for Inceptisols and Oxisols, and as a criterion of the Ultisols (Table 2). As for the great group Eutrorthox, only the base saturation of a subsurface horizon is used for classification. It should be realised that if the subsurface horizon is acid, that is a very good indication that the surface soil is acid in its natural state. When the acid has been limed, it is assumed that with continued cultivation, it will again be acid with time.

Figure 1: Soil map of Africa, distribution of orders and principal suborders

A ALFISOLS
A 2e Udalfs with Troporthents
A 3a Ustalfs with Tropepts
A 3b Ustalfs with Troporthents
A 3d Ustalfs with Ustolls
A 3j Plinthustalfs with Ustorthents
A 4b Xeralfs with Xeronthents

D ARIDISOLS
D 1a Aridisols with Orthents
D 1b Aridisols with Psamments

E ENTISOLS
E 2c Torriorthents with Aridisols
E 3a Psamments with Aridisols
E 3d Psamments with Ustalfs
E 3f Psamments (shifting sands)

I INCEPTISOLS
I 2c Haplaquepts with Humaquepts
I 2f Tropaquepts with Hydraquepts
I 2h Tropaquepts with Tropaquets

O OXISOLS
O 1b Orthox with Tropudults
O 2b Ustox with Tropustults
O 2c Ustox with Ustalfs

U ULTISOLS
U 3h Tropudults
U 3k Tropudults with Tropudalfs
U 4e Tropustults with Ustalfs

Source: Buringh, 1979.

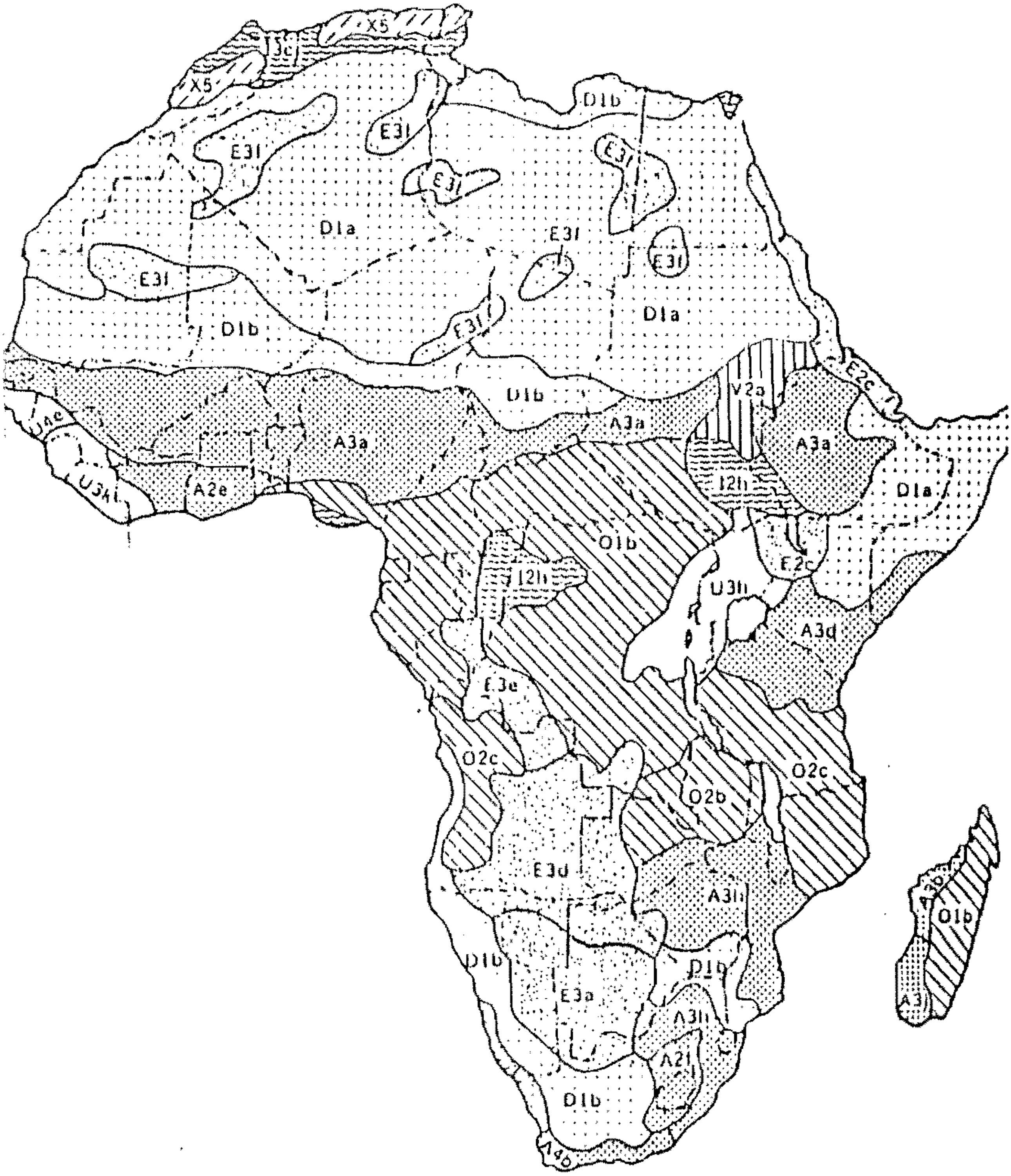

X5
X5
3c
E3l
D1a
D1b
A3a
A2e
U34
V2a
I2h
O1b
E2c
U3h
A3d
E3e
O2c
O2b
E3d
A3h
E3a
A2l
A4b
A3l

Table 1: Approximate extent of major soil suborders in the tropics (million ha)

ORDER	SUBORDER	AFRICA	AMERICA	ASIA	TOTAL AREA	PERCENT
● Oxisols	orthox	370	380	0	750	15.0
	ustox	180	170	0	750	7.5
		550	550		1500	22.5
Aridisols	all	850	50	10	900	18.4
● Alfisols	ustalfs	525	135	100	760	15.4
	udalfs	25	15	0	40	0.8
		550	150	100	800	16.2
● Ultisols	aquults	0	40	0	40	1.0
	ustults	15	35	50	100	2.2
	udults	85	125	200	410	8.2
		100	200	250	550	11.4
Inceptisols	aquepts	70	145	70	285	6.0
	tropepts	0	75	40	115	2.3
		70	220	110	400	8.3
Entisols	Psamments	300	90	0	390	8.0
	Aquents	0	10	0	0	0.2
		300	100	0	390	8.2
Vertisols	usterts	40	0	60	100	2.0
Mollisols	all	0	50	0	50	1.0
Mountain	areas	0	350	250	600	12.2
Total		2450	1670	780	4900	100.0

Source: Sanchez, 1976

Table 2: Soils in Tropical Regions that are Inherently Acid or Low in Bases

Acid soils	Low CEC and low bases
Ultisols	Acrustox
Haplorthos	Acrorthox
Haplustox	Acrohumox
Dystropepts	
Dystrandepts	
Ultic paleustalfs	
Ultic haplustalfs	
Ultic hapludalfs	

Source: Kamprath, 1984

Ultisols in their natural state will be acid and will need to be limed for intensive agriculture. Similarly, the great groups with prefixes *dystr* and *hapl* can be acid, ranging from 0 to 35 or 50 to 60% (Kamprath, 1984). Although the surface horizons of the Alfisol order have high base saturation, the ultic subgroups have a low base saturation (<75%) and therefore can have acidity problems (Buol *et al.*, 1973; Kamprath, 1984). The great group *Acr* identifies soils that are highly weathered and have a very low cation exchange capacity and are also low in exchangeable bases (Kamprath, 1984).

Hydrogen Toxicity

In most mineral soils, the direct effects of the hydrogen ion (hydrogen toxicity) on the uptake of other ions and plant growth are difficult to identify because when the pH level is harmful, aluminium, manganese and perhaps other elements may be at harmful concentrations (Islam , 1980). It is, therefore, difficult to separate the direct effects of H^+ from the indirect effects associated with the solubility and availability of various elements affecting plant growth. In organic soils, the exchangeable cation status is also difficult to describe since different cations are complexed to various degrees by organic matter (Kamprath and Foy, 1971) Trivalent cations such as Al and Fe are retained more strongly than are divalent Ca and Mg cations. It is interesting to find an appreciable amount of Ca (or Mg) in acid organic soils even though the pH may be fairly low. This is because Ca and Mg are only weakly complexed such that a greater proportion of these cations is extracted as compared with Al and Fe which may be strongly complexed.

In some acid soils of tropical Africa, aluminium may be the dominant cation associated with soil acidity. The reason is that the hydrogen ions produced by organic matter decomposition are unstable in mineral soils because they react with layer silicate clays, releasing exchangeable aluminium and siliceous acid (Coleman and Thomas, 1967). Coleman and Thomas pointed out that a useful measure of soil acidity is to calculate the percentage of aluminium saturation of the effective cation exchange acidity. The percent Al is calculated by dividing the exchangeable Al (plus H if present) extracted by normal unbuffered KCl by the sum of exchangeable Al and exchangeable bases (Coleman and Thomas, 1967; Bhumbla and McLean, 1965). A neutral unbuffered salt solution will extract only cations that are held on the active exchange sites at the particular pH of the soil, and the exchangeable acidity that is extracted from soils with neutral unbuffered salt is mostly Al^{3+} (Bhumbla and McLean, 1965). Table 3 gives an example of the relative amounts of exchangeable Al and basic cations (Ca and Mg) in an acid Ultisol at different pH values. At pH 5 and below, over half of the exchangeable cations are Al, while at pH 5.9, the basic cations constitute 94% of the exchangeable cations.

Table 3: Relative content of exchangeable bases and Al in an acid mineral soil at different pH values

Soil pH	Exchangeable		$\frac{\text{Bases}}{\text{Bases + Al}} \times 100$
	Bases	Al	
4.5	0.20	0.91	18
4.9	0.55	0.60	48
5.4	0.90	0.34	73
5.6	1.20	0.17	87
5.9	1.00	0.10	94

Barnhisel and Bertsch (1982) pointed out that there is no clear demarcation between the Al that is exchanged from a soil which is in equilibrium with an unbuffered salt solution and that which is concommitantly released from other nonexchangeable sources. They further pointed out that the Al in solution following extraction can be "truly" exchangeable; it can be that released from clay mineral structures; it can be that released from hydroxy polymeric interlayers; or it can be that released from discrete noncrystaline Al phases. Singh and Uriyo (1978) used the barium chloride-treithanolamine method in determining soil acidity, but this extractant removes both exchangeable and non-exchangeable Al.

Manganese Toxicity

Manganese is found in a number of chemical forms in soils, including dissolved, exchangeable, reducible (preciptated as sparingly soluble hydrous oxides), organically bound and residual manganese. Divalent Mn in the soil solution is the most available form to plants. Exchangeable Mn in equilibrium with dissolved Mn is also an important form readily available to plants.

Manganese is normally very soluble at pH values of lower than 5.5 (Black, 1967). If this element occurs in large quantities in an acid soil, manganese toxicity will occur. Soils that have a large sesquioxide content often contain high amounts of Mn (Kamprath, 1984). The solubility of Mn increases with decreasing pH or increases with reduction when the Mn^{4+} are converted to Mn^{2+} (Sanchez, 1976). There are certain acid soils that may be low in aluminium but high in exchangeable Mn. In the five soils that Ssali (1981) worked with, Karicho soil, an Orthoxic palehumult, had the greatest part of its exchange complex occupied by exchangeable Mn of 1.9 meq/100g compared with only 0.2 meq/100g for exchangeable Ca and 0.2 meq/100g for exchangeable Al. The Meru soil, atypic palehumult, contained both the exchangeable Al and exchangeable Mn in large quantities with values of 4.4 meq/100g and 2.32 meq/100g respectively compared with only 0.2 meq/100g for Ca. In acid mineral soils which are high in exchangeable Mn, liming should be aimed only at reducing the solubility of Mn. Unlike Al, Mn is a plant nutrient, and as such the aim should not be to eliminate soluble Mn but to keep it within a range between toxicity and deficiency. Dobereiner (1966), working with beans in Brazil, found that even though Al on the acid soils was low, the crop still responded to lime, and this was attributed to the alleviation of Mn toxicities.

Phosphorus

Phosphorus Availability

The origins of soil phosphorus are many, the most important of which is apatite. The phosphorus content of a particular soil will, therefore, depend on several factors amongst which are the degree of weathering of the soil, the parent material and the biological population and activities. For many of the soils in tropical Africa, most of the P is concentrated in the surface layers of the soil because of the biological recycling of the P from subsurface horizons (Enwezor and Moore, 1966). Although the measurement of total phosphorus may be a useful indicator of probable P deficiency, it is less useful than other measurements. In most of the soils in Africa, the levels of total P may be as low as 200 ppm (Enwezor and Moore, 1966). Beyond the fact of decreasing total phosphorus with increasing intensity of weathering is the recognition of a higher proportion of organic and occluded forms of phosphorus in these highly weathered soils Mughogho, 1975; Uriyo and Kesseba, 1975).

In an experiment where Uriyo and Kesseba (1975) determined the phosphorus fraction in 17 Tanzania soils, they found that most of the inorganic-P fractions decreased with depth. Where soils were young or calcareous, or where the parent materials were rich in phosphorus-bearing minerals, Ca-P was the dominant inorganic-phosphorus fraction. On the other hand, where soils were highly weathered, Al-P and Fe-P were the dominant fractions. In most of these highly weathered soils, aluminium phosphate increases as calcium phosphate is decreasing with declining pH; iron phosphate increases as the soil becomes ferruginous in character (Olson and Engeltad, 1972).

Organic phosphorus of the 13 soils studied by Uriyo and Kesseba (1975) was found to decrease with depth, except in a few profiles where the maximum tended to occur in the second horizon. However, the distribution of organic phosphorus in the profiles is considered to be a function of climate, vegetation and parent material. The percent of organic phosphorus (of total) ranged from as low as 27% in a Spodosol to as high as 90% in Mollisol in the top 5 to 10 cm of the profile.

The study by Uriyo and Kesseba (1975) showed that Oxisols, which occur in large areas in the country, have low levels of organic P ranging from 40 to 150 ppm P. These soils are freely drained, but due to their low base saturation they do not support good plant growth and, consequently, remain relatively low in organic phosphorus. Ultisols, Alfisols and Vertisols, on the other hand, show fairly moderate organic-phosphorus content. Mollisols, Spodosols and Inceptisols found in northern Tanzania, with an average rainfall of 1400-2000 mm, had high organic matter and high organic phosphorus contents.

Sanchez (1976) summed up and concluded that Oxisols, Ultisols and Alfisols are generally low in phosphorus. Andepts, on the other hand, are generally high in total phosphorus. In Tanzania, of the highly weathered soils, one Tropaquept had 800 ppm total phosphorus whereas the other Tropaquept had only 200 ppm total P. This could mean that the two Tropaquepts were formed from two different parent materials.

Normally, organic phosphorus accounts for 20-50% of the total top-soil phosphorus (Mughogho, 1975; Sanchez, 1976; Uriyo and Kesseba, 1975). Maida (1973) similarly found that the organic-P constituted a greater amount of the total P of the topsoil which ranged from 35% in an Oxisol to a high of 67% in an alluvial soil and 61% in the Lilongwe Ustalf. Friend and Birch (1960) estimated the organic fraction to be about 86% of the total soil phosphorus as measured by the ignition of the soil at 550^{o}C in East Africa. They obtained a negative correlation between responses to applied phosphorus and organic phosphorus contents. This may lead one to doubt whether the ignition method at 550^{o}C and extraction of the phosphorus by N sulfuric acid really estimates the organic fraction.

Organic phosphorus mineralisation is very difficult to quantify because the released $H_2PO^-_4$ may be quickly absorbed (fixed) into inorganic forms.

Inorganic Phosphorus Fractions

The distribution of the various forms of phosphorus in a soil is very important to the soil fertility specialist. The solid inorganic forms of phosphorus are usually divided into three active fractions and two inactive forms. The active forms mainly comprise Ca-P, Al-P and Fe-P, whereas the relatively inactive P fractions comprise occluded phosphorus which consists of Fe-P and Al-P compounds surrounded by an inert coat of another material that prevents the reaction of these phosphates with the soil solution; and the reductant-soluble forms that are covered by a coat that may partially or totally dissolve under aerobic conditions (Sanchez, 1976).

In highly weathered soils, most of the inorganic phosphorus is in the occluded and reductant-soluble form because of the formation of iron and aluminium coatings. Except for one soil (Alfisol) where Ca-P was very high, most of the highly weathered Oxisols and Ultisols in Tanzania were very high in occluded and reductant-soluble forms of P (Uriyo and Kesseba, 1973). It is interesting, though, to note that in the three Oxisols under study, there was no reductant-soluble P observed in all horizons, but instead most of the inorganic P was found in the iron-bound and occluded forms. The results by Maida (1973) showed that for all five Malawi soils under study, the active phosphates were distributed in such a way that Fe-P > Al-P > Ca-P. Even in an alluvial soil in Salima which had a pH of 6.4 (H_2O), the Ca-P was still much less than the Al-P and/or Fe-P.

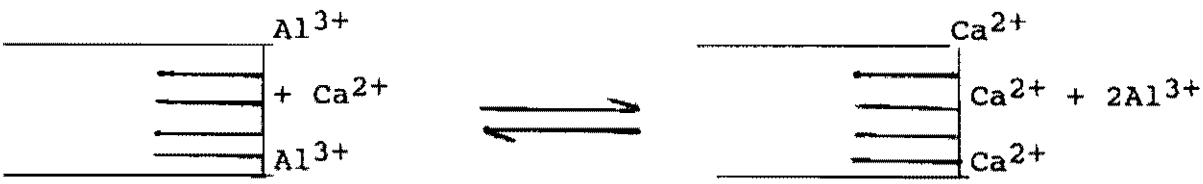
Phosphorus Fixation

The terms sorption and adsorption are also used to express the phosphorus fixation concept. Sanchez and Uehara (1980) have given a very good summary of the general areas where phosphorus fixation are expected. In general terms, acid soils that fix large quantities of P are invariably medium to fine-textured soils high in oxides and hydroxides of Al and Fe. In most soil survey reports, soil P fixation is not a classification criterion. In spite of these facts, there are several broad soil groups that are notoriously high in P fixation capacity: the Andept, suborder, Oxisols and Utisols, the orders and certain rhodic and oxic Alfisols and Inceptisols. Any soils classified into these categories that have a sandy surface texture are excluded.

In acid soils, aluminium and iron are the most abundant cations and will react with phosphorus to form relatively insoluble aluminium and iron phosphates. In calcareous soils, on the other hand, the phosphate ions are precipitated by calcium and magnesium as relatively insoluble compounds. In acid soils, the P that is fixed into slightly soluble forms is by two processes, namely by precipitation and sorption reactions with Fe and Al compounds and crystalline X-ray amorphous colloids of low silica-sesquioxide ratios present in acid soils (Sanchez and Uehara, 1980).

Exchangeable Al first gets displaced into soil solution by the basic cations and then gets hydolyzed after which the hydroxyl Al reacts with phosphate anions forming Al phosphate precipitates.

Cation exchange:



Hydrolysis:

$$Al^{3+} + 2H_2O \rightleftharpoons Al(OH)^{+}_2 + 2H^{+}$$

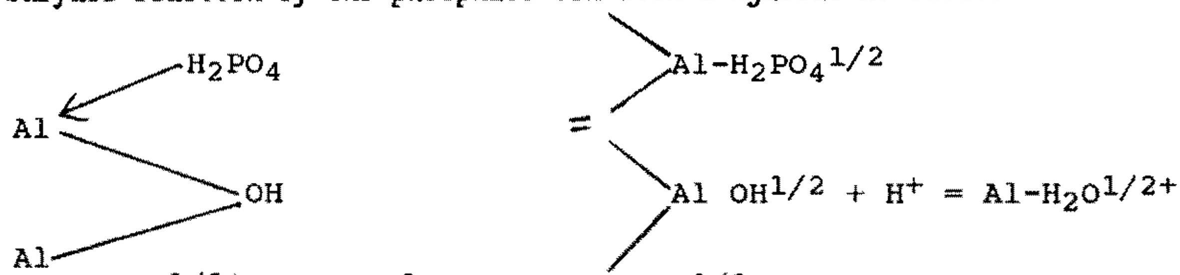
Precipitation:

$$Al(OH)_2 + H_2PO_4 \rightleftharpoons Al(OH)_2H_2PO_4 \quad (K_{sp} = 10^{-29})$$

Hsu (1965) believes that this reaction proceeded more rapidly because of surface adsorption of phosphate on the amorphous aluminium hydroxides and iron oxides already present in the soil.

Phosphorus may be adsorbed on hydrous Al oxide surfaces. As the phosphate concentration and adsorption increase, more hydroxyl groups will be involved. At adsorption maxima, the phosphate is replaced by hydroxyl groups, (Mokwunye *et al.*, 1986).

Surface reaction of the phosphate ion with a hydrous Al oxide:



$Al - H_2O^{1/2+} + H_2PO_4^{1-} = Al - H_2PO_4^{1/2-} + H_2O$

The phosphorus fixation is affected by soil mineralogy (Mukwunye , 1986; Sanchez and Uehara, 1980). As already mentioned, most of the acid soils of tropical Africa fall in three groups on the basis of their mineralogy, and these make the soils variable in fixing phosphorus. There are the Alfisols, Oxisols and Inceptisols that are fine-textured, oxidic, base-rich and typical of the East African highlands. There are the Alfisols and Altisols that coarse-textured kaolinitic can occur in different positions in a soil catena in different locations. The third group includes the stongly acidic, highly leached and weathered Oxisols and Ultisols.

The influence of clay mineralogy is illustrated in Figure 2 which shows characteristics of four soils from Malawi in relation to phosphorus adsorption (Mughogho, 1975). It is quite clear that the four soils differ not only in the amount of P adsorbed, but also in the slopes of the adsorption isotherms. It was observed that adsorption maxima were positively correlated with the citrate-bicarbonate-dith-ionite (CBD) extractable $Fe_2=_3$ percent, NaOH - Al_2O_3 percent and active Al_2O_3 (ug/g). It was negatively correlated with active SiO_2/Al_2O_3. Active Al_2O_3 and SiO_2 were extracted with 0.5 M $CaCl_2$. As shown in Table 4, the adsoption maxima varied from a low of 187 ppm for an ustalf at Bunda to a high of 898 ppm P for the Mulanje ustox.

Table 4: Some adsorption data for four Malawi soils

Soil	Adsorption maxima	Sorbed P at 0.2 ppm solution P
	ppm	
Mulanje-ustox	898	375
Bvumbwe-eutrorthox	778	205
Dedza-ustalf	460	115
Bunda-ustalf	187	27

Source: Mughogho, 1975

These results confirm what has been reported by Sanchex and Uehara,(1980) that in more highly weathered soils, more phosphorus will be fixed. In kaolinitic soils, aluminium phosphates will be the dominant forms, but in older soils iron phosphates predominate. Even in newly fertilised fields, P will first be fixed by Al; then it will be transformed into Fe-P and/or occluded and reductant-soluble P with age.

In soils with similar clay mineralogy, normally P fixation will increase with increasing clay content.

Andepts in the East Africa region are expected to fix more phosphorus because of their high contents of X-ray amorphous colloids. In fact, texture is often meaningless in Andepts because of their high contents of amorphous materials (Sanchez and Uehara, 1980).

Exchangeable Al is very important in the precipitation of phosphorus, and this reaction takes place within hours of equilibriating the soil with a phosphorus solution. Increased fertiliser use may reduce soil pH, and the hydrogen ions may exchange with Al increasing the Al concentration. For example, sulphate of ammonia may have its ammonium oxidise into NO^{-}_{3} as follows:

$$(NH_4)_2SO_4 + 4O_2 \rightleftharpoons 2NO^{-}_{3} + SO^{-}_{4} + 4H^{+} + 2H_2O.$$

For every mole of NH^{+}_{4} ion that oxidises into NO^{-}_{3} two moles of hydrogen are released.

Research Needs

There has been an imbalance of research priorities in most African countries where beans are grown. Very few funds have been allocated to soil and agronomic research. Emphasis has been on breeding new cultivars. When one extrapolates research findings into farmers' fields, it is found that matching experimental yields, and thus crop requirements, to soil conditions is still in its infancy. In other words, there is still the problem of knowing the soil conditions and how we can manipulate them for improved bean production. The problem is accentuated by the fact that beans are of secondary importance in many African countries and are just "another crop". The main crop is normally a non-legume suchas maize, cassava or banana. Fertilizers, where they are applied, are usually for the non-legume crop.

Soil acidity is known to be one of the limiting factors to growing beans in most bean-growing areas in Africa, but little is known about how to manage the pH problem,. One reason is that we do not include Al in determining the cations or cation balance. The problem is aggravated by unavailability of liming materials. The research, therefore, should be oriented towards an evaluation of indigenous fertiliser materials such as phosphate rock which can be both a liming material and a P source, and the study of the lime-phosphorus interactions in acid soils.

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Appendix 1

APPROXIMATE EQUIVALENTS

SOIL TAXONOMY	FAO LEGEND
1. ALFISOLS	
Aqualfs	Gleyish Luvisols
Udalfs	Orthic Luvisols, Nitosols
Ustalfs	Luvisols
Xeralfs	Orthic, Chronic Luvisols
2. ARIDISOLS	
Argids	Luvic Xerosols, Yermosols
Orthids	Xerosols, Yermosols
3. ENTISOLS	
Aquents	Gleysols
Fluvents	Fluvisols
Orthents	Regosols
Psamments	Regosols (Sandy)
4. INCEPTISOLS	
Andepts	Andosols
Aquents	Cambisols
Tropepts	Cambisols
Umbrepts	Humic Cambisols
5. OXISOLS	
Aquox	Ferralsols (Hydromorphic)
Humox	Humic Ferralsols
Orthox	Orthic and Rhodic Ferralsols
Ustox	Orthic and Rhodic Ferralsols
6. ULTISOLS	
Aquults	Gleyic Acrisols
Humults	Humic Acrisols and Nitosols
Udults	Orthic Acrisols and Nitosols
Ustults	Acrisols - Monsoon
Xerults	Acrisols

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Diagnosis of Soil Fertility Constraints in Bean Based Cropping Systems: Review of Research Results

S.K. Mughogho and C.S. Wortmann

Bunda College of Agriculture, University of Malawi, Malawi and C.I.A.T. Regional Programme on Beans in Eastern Africa

Introduction

The major soil groups found in the bean-growing areas in Africa are Alfisols, Ultisols, Oxisols and Inceptisols. These tend to be acidic, low in exchangeable basic nutrients, high in exchangeable aluminium and/or manganese and high in phosphorus fixation rates. These characteristics frequently result in nutritional disorders which constrain bean productivity and biological nitrogen fixation. This paper discusses these soil characteristics and associated nutritional disorders and reviews results of research conducted in Africa regarding the extent and severity of soil fertility constraints to bean production.

Soil Fertility Factors Affecting Bean Growth and Nitrogen Fixation

Soil

In acid soils, plant growth is more likely to be affected by factors related to low soil pH such as aluminium and/or manganese toxicity, or calcium or magnesium deficiency than by acidity *per se*. The effects of low soil pH on legume nutrition may be resolved into direct effects which deal with hydrogen ion concentration or indirect effects which involve the association with other elements (Andrew, 1962). Soil acidity also has an important influence on the ecology of *Rhizobia* (Holding and Lowe, 1971).

Hydrogen Ion Concentration

Although poor plant growth on acid soils is generally associated with a low pH, the effects of soil pH are complex it is difficult to separate the direct hydrogen ion effects from indirect effects. Hydrogen ions *per se* have little effect on the host legume plant, but may have more effect on *Rhizobium* species. Still, if soil pH is low but that there is an adequate supply of calcium, the rhizobia will survive and proliferate in the rhizosphere (Islam et al., 1980; Vincent, 1965). Dobereiner (1966) showed that *Phaseolus vulgaris* developed nodules and fixed nitrogen satisfactorily at surprisingly low pH levels provided manganese toxicity was not the limiting factor.

Excess Manganese

Low pH values may cause an increase in manganese concentration in the soil solution and subsequent toxic effects on legumes and depression of the rhizobia-host symbiosis (Holding and Lowe, 1971). Ssali (1981) compared five soils from Kenya in a pot experiment of which two had high levels of Mn. On liming the Kericho soil (Orthic Palehumult), and thus raising the pH from 4.2 to 5.7, he found that there was an increase in nodule weight of the bean plants in both the inoculated and non-inoculated plants. The increase in dry matter yield, on the other hand, was significant at a low lime rate of 2.2 tons/ha with an increase from 1.99 to 2.64 g/plant, but further pH adjustment did not significantly increase yields. The lack of additional response may have been due to the fixation of Mn and subsequent Mn inadequacy. Working with an Andosol in Kenya, Nuwamanya (1984) found exceptional results in that exchangeable Mn increased 10-fold with the first level of lime and then decreased with subsequent levels.

Excess Aluminium

Coleman and Thomas (1967) found exchangeable aluminium to be the dominant cation associated with acid soils. He proposed that exchangeable Al extracted by an unbuffered salt solution such as KCl, $CaCl_2$ and/or $BaCl_2$ should be used to determine levels of aluminium that are detrimental to plant growth and biological nitrogen fixation. An Al concentration in solution in excess of one ppm is detrimental to many bean varieties. Ruschel *et al.* (1968) observed that nutrient solutions at pH 3.6 containing more than 7 ppm Al caused a considerable increase of Al in the roots and aerial portion of *Phaseolus vulgaris*. Out of the 20 experiments conducted in Uganda, significant responses of beans to lime were on acid soils with pH values of less than 5.1, and at this pH, there was an appreciable amount of exchangeable Al (Foster, 1970).

Aluminium toxicity causes root damage followed by poor root growth. An extremely rapid uptake of the Al^{3+} ion saturates the intercellular space of the cortex and inhibits further root growth (Rorison, 1958). Consequently, plants become phosphorus-deficient since excess Al restricts the uptake of phosphorus. Calcium, magnesium, molybdenum and other nutrients may also be restricted.

Some work by Abruna *et al* (1975) in Puerto Rico on snap beans showed a great increase in bean yield due to liming. There was a highly significant correlation between bean yield and percent aluminium saturation. Liming to a pH of 5.5 satisfied the Ca requirements of the bean crop and corrected the Al and Mn toxicities.

Levels of exchangeable Al decreased with increasing levels of lime in two humic Nitosols and one humic Andosol (Nuwamanya,

1984) in Kenya. Exchangeable Al was reduced to virtually zero at pH 5.5. Results further showed that dry matter yield of beans and mean nodule dry weight increased significantly with increasing lime levels up to a pH of 6.0. If the lime rates increased pH beyond 6.0, the dry matter yield and nodule weight of beans decreased progressively. He came to the conclusion that a pH range of 5.5 to 6.0 was considered optimum.

Phosphorus

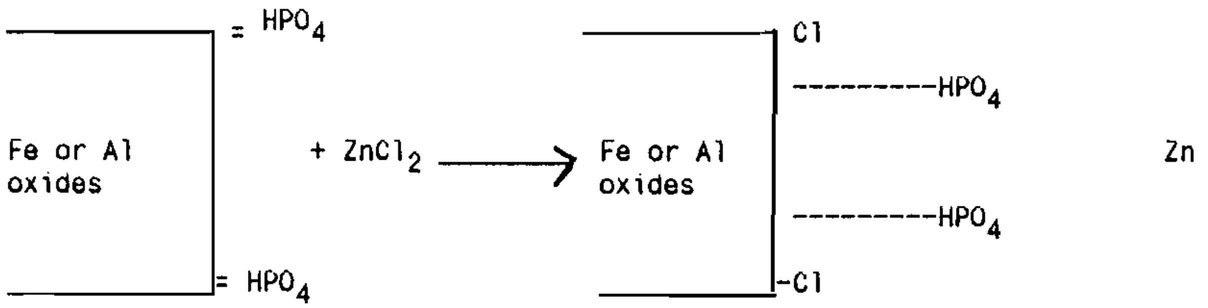
Phosphorus deficiency is common in most major bean growing regions of Africa. Many of these soils are capable of "fixing" large amounts of applied P into non-available forms. Normally, farmers in Africa do not apply fertilizer to beans. Many rely on the residual effects of fertilizer which were originally applied to another crop such as maize. Little residual phosphorus effect can be expected if the P fixation rates are high.

Grain legumes have been reported to be more responsive to P application than cereals (Drake and Stackel, 1955). Significant bean yield responses to the application of P have been reported for P rates ranging from as little as 20 kg P/ha (Uriyo *et al.*, 1980) to as high as 150 kg P/ha, reflecting the fact that different soils have different initial levels of P and also different capacities of fixing P (Mbugua, 1986). Mbugua (1986) found that phosphate fertilizer increased leaf area index (LAI) and plant growth rate when applied at 150 kg P/ha, although the application of only 50 kg P/ha appeared to be the best.

Moursi *et al.* (1974) found that P application in Egypt increased seed yield, pod yield and number of seeds/pod. They attributed these results to accelerated flowering, increased flowering capacity and increased percentage of fruit set. Similar results were obtained in Kenya in that application of phosphorus increased nodule mass, dry matter yield, nitrogen yield and biological nitrogen fixation at three growth stages, i.e., flowering, pod-filling and physiological maturity. The effects of P were most pronounced at flowering and pod-filling (Ssali and Keya, 1984). They concluded that P is an important factor in BNF. Mahatanya (1977) also found that plant height, LAI, pod number, pod weight and seed yield per plant increased with increasing levels of P. The effects of P were greater at higher plant densities.

Response of beans to P is dependent on environmental factors. Bonnetti *et al* (1984) showed that there was a greater positive response in plant weight when soil moisture tension was low. Soil applied P utilization was directly influenced by soil moisture content. In Kenya (Floor, 1984), when a season had low rainfall of poor distribution, the response of beans to fertilizer was low and uneconomical. On the other hand, if the rainfall was low and the distribution was good, beans responded to fertilizer. Anderson (1974) in Kilimanjaro Region of Tanzania, found that the mean seed yields ranged from 133 kg/ha on the poorest soil to 1120 kg/ha on the best soil, but that the yields were negatively correlated with annual rainfall and altitude. These unusual results are not unexpected in such a high altitude, high rainfall area.

Phosphorus has been reported to have an effect on molybdenum and zinc uptake. The effect of P on increased Mo uptake may be due to greater plant growth associated with P availability, but it appears that P directly affects Mo uptake (Hewitt, 1958). Phosphorus, on the other hand, decreases the concentration of Zn in the plant tissues. Singh *et al.* (1988) studied P-induced zinc deficiency on three Canadian soils with pH's ranging from 6.4 to 7.6. They concluded that stimulation of growth and subsequent dilution of tissue zinc concentration and restriction of the translocation of zinc from the roots to the plant tops accounted for the zinc deficiency. Also, suppression in growth of beans resulting from added P or "P toxicity" on low Zn soils may be due to P-induced Zn deficiency. In acid soils where Zn may be readily available, Zn can be complexed with high amounts of applied phosphorus. Zn adsorption occurs when P is added in the presence of hydrous Fe or Al oxides (Stanton and Burger, 1968). The mechanism is as follows:



In the absence of hydrous Fe or Al oxides, the addition of phosphate has little effect on Zn adsorption. An important criterion in estimating the amount of P and Zn required for a bean crop is determining the P/Zn ratio of both the soil and the plant.

The chief P deficiency symptoms are retarded rate of growth, dark- or bluish-green or purple colour and delayed maturity. Phosphorus application increases not only the weight of the plant and P concentration, but also improves the plants vigour resulting in more resistance to pathogen invasion (Sirry *et al.*, 1982).

Nitrogen

Legumes have been used in restoring soil nitrogen since the beginnings of agriculture (Bouldin *et al.*, 1979). Beans, an important source of dietary protein throughout east and southern

Africa, are not very effective, however, in the fixation of nitrogen and frequently respond well to nitrogen fertilizers.

Edje *et al.* (1975) obtained bean grain yields ranging from 2150 kg/ha at 0 kg N/ha to as high as 3779 kg/ha at 200 kg N/ha when the results were averaged for two years. Oelsligle *et al.* (1976) intercropped maize and beans and observed that not only did the total grain yield increase with increased nitrogen application, but also that nitrogen removed in the grain also increased (Table 1). The remarkable aspect of these data is the response of the beans in pure stand to fertilizer nitrogen. Apparently, the legume-*Rhizobium* nitrogen fixation system was not operating properly (Bouldin *et al.*, 1979).

Growth of beans and biological nitrogen fixation depends on such factors as time and rate of N application as well as light conditions, temperature and soil moisture. Growth habit of the host plant is also important. Amendment of the soils with low pH and low available P is often needed for good bean plant growth and N fixation.

Table 1. Nitrogen removal in the grain of sole-cropped and interplanted maize and beans at three levels of applied nitrogen.

Crop	Nitrogen in grain, Kg/ha		
	0 kg N/ha	100kg N/ha	300kg N/ha
Maize & bean	45	75	113
Beans	36	66	109
Maize	45	55	56

Source: Oelsligle *et al.*, 1976

Summary and Conclusion

The chemical and physical properties of the soils found in the bean growing regions in Africa differ as do the nutritional disorders associated with these soils. It appears, however, that most of the nutritional disorders are linked to low soil pH, including aluminium toxicity, manganese toxicity, low available phosphorus, phosphorus fixation, low CEC and low availability of basic nutrients. In most bean growing regions of Africa, the extent and severity of these problems have not yet been adequately determined to know if and what corrective measures should be taken. Much of the research has been of a short-term nature and done under controlled environmental conditions. A continuing investigation of these problems is needed involving both short- and long-term field research.

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Research Methods for the Diagnosis of Soil Fertility Problems

C.S. Wortmann, Teshome Regassa and S.K. Mughogho

C.I.A.T. Regional Programme on Beans in Eastern Africa, Inst. for Agric. Res., Nazret Research Center, Ethiopia, and Bunda College of Agriculture, University of Malawi, Malawi

Introduction

The diagnosis and correction of nutrient deficiencies and excesses is an essential part of crop management. The diagnostic procedure attempts to identify nutrient disorders that constrain plant growth. In most important agricultural areas, some diagnostic work has been done to identify nutrient disorders which limit crop production. In Africa, however, many questions remain about soil fertility problems which may be limiting crop production.

The diagnostic procedure may be of three stages. In the first stage, the land is classified according to soil fertility parameters so that results from research can be extrapolated to areas of similar soil-climate-crop conditions. The second stage identifies the nutrient disorders which are limiting to crop growth. In the third stage, we attempt to find the cause of disorders and to understand the mechanisms involved to know which corrective measures may be feasible.

Classification of Land into Soil Fertility Management Units

Grouping of agricultural land into land units according to soil fertility parameters allows for better identification of the target area to be investigated and for projection of results to other areas. Criteria used in grouping land for soil fertility management may include natural vegetation, common crops and management practices, topography, climate, geology and soil chemical and physical soil properties.

When available, soil survey results and maps may be useful in land classification. Direct interpretation for a specific use such as soil fertility management may be difficult, however, as criteria relevant to fertility management are confounded with other criteria, since soil classification systems normally incorporate many measurable soil characteristics. Subsurface soil properties are heavily relied on in soil classification because of their durable nature, whereas crop growth is largely a function of topsoil characteristics. Still, soil survey results contain information on the physical and chemical properties of soils which is useful in the grouping of soils into soil fertility management units.

The Fertility Capability Classification System (FCC) is a technical system of grouping soils according to the kinds of problems they present for the agronomic management of their chemical and physical properties (Buol and Couto, 1980 and Sanchez *et al.*, 1982). It emphasizes quantifiable topsoil properties as well as subsoil properties directly relevant to plant growth. The system consists of three categorical levels: type (topsoil texture), substrata type (subsoil texture), and 15 modifiers. Topsoil texture is classed as sandy (S), loamy (L), clayey (C) or organic (O). Subsoil texture is classed as sandy (S), loamy (L), clayey (C) or rock (R). The 15 modifiers are gley (g), dry (d), low CEC (e), Al-toxicity (a), acid (h), high P-fixation by iron (i), X-ray amorphous (x), vertisol (v), low K reserves (k), basic reaction (b), salinity (s), natric (n), cat clay (c), gravel ('), and slope (%). Sanchez *et al.* (1982) give an example of an Oxisol classified as a *C a e i k* (i.e., a clay soil with Al-toxicity, low CEC, high P-fixation by iron and low K-reserves). A young alluvial Entisol with no fertility limitations is simply classified as *L* (loamy soil). Further descriptions of the types, substrata types, and modifiers are given in Appendix A; Appendix B contains information about their limitations and management requirements. Sanchez *et al.* (1982) report that when soils were grouped by FCC-units and fertilizer rates determined from a generalized response curve for each unit, the average returns to fertilizers were 20% greater than when fertilizer recommendations were based on site-specific soil test results alone. Greatest returns were obtained by using FCC units and site-specific soil test results together.

Plant indicators are useful in the delimitation of problem soils and environments. Plant indicators are obvious landscape features that sometimes react dramatically to small changes in environmental conditions and they are the end product of their environment. If environmental conditions result in vegetation changes, then such environmental conditions are likely to affect agriculture and land use. Davidescu and Davidescu (1982) present a list of temperately-adapted plant species and discuss the soil fertility problems indicated by their presence.

Information of soils and of naturally occurring vegetation can be useful in classifying land for soil fertility management. Stocking and Abel (1981) utilized associations between soil types and plant species to classify land in Zimbabwe. Teitzel (1978) reports that soil parent material and natural vegetation were used in Australia to group range land into 48 soil vegetation units. These units were then used in the extrapolation of results of the soil fertility research programme. In this case, the groupings of more conventional systems of soil classification did not coincide well with the soil vegetation classification.

Diagnosis of Soil Fertility and Plant Nutrition Problems

Diagnosis of soil fertility and plant nutrition problems can be made by visual observations of symptoms expressed by plants, chemical tissue analysis, chemical soil analysis and nutritional screening experiments.

Diagnosis by External Plant Characteristics

Certain external symptoms expressed on plants may indicate an abnormal growth and development due to unsatisfactory plant nutrition. Although the changes that take place in plants due to nutrient deficiencies and excesses are not well understood and symptoms of nutrient disturbances differ with the species and even the variety, some of them are known and can serve in the identification of nutrition problems. The characteristic external symptoms of nutrient deficiencies have been described with photos by Davidescu and Davidescu (1982) and by Miller *et al.* (1986) for plants in general. Miller *et al* (1986) present a key for identifying nutrient deficiencies and toxicities on the basis of visual symptoms. Howeler (1980) provides photos and descriptions of symptoms caused by poor bean plant nutrition and this information is summarized in Table 1.

The vertical position of leaves on the plant showing symptoms is useful in the diagnosis of nutrient disorders. The lower, mature leaves are the first to express symptoms of nitrogen, potassium and magnesium deficiencies as these nutrients move easily in the plant to meet the needs of growing tissue. Similarly, symptoms of zinc and phosphorus deficiencies are first expressed on the older leaves. Deficiency symptoms of calcium, boron, manganese, copper, sulfur and iron are most expressed on younger parts of the plant.

With deficiencies of certain nutrients, there is a tendency of the leaf colour to change according to the intensity of the deficiency. Magnesium, nitrogen and sulfur deficiencies result in leaf colour changing from green to pale green to yellow. Phosphorous deficiency may result in colour changes from green to dark green to blue to red and the leaf may become necrotic. Greying leaves and necrosis of leaf tips and margins may indicate potassium and magnesium deficiency. When calcium is deficient, leaves may be dark green with only slight yellowing at the tips and margins. In boron deficient plants, leaves may become yellow with necrotic spots. Leaves of manganese or zinc deficient plants become yellow between the veins. Interactions of a deficient nutrient element with other deficient or excess nutrient elements, or with drought, insect damage or disease, can result in other secondary symptoms which complicate the interpretation.

Diagnosis by Chemical Tissue Analysis

Tissue analysis can be a useful tool for diagnosis of nutritional problems. Critical levels and sufficiency ranges of nutrients are used to gauge nutrient requirements. The chemical composition of foliage is, however, a result of plant age, plant part sampled and many other factors, environmental and nutritional, which affect plant growth. As critical values and sufficiency ranges rely solely on the ratios of nutrient to dry matter, the results can be misleading. An alternative way of interpreting

Table 1. Bean plant symptoms indicative of nutritional disorders

Nutrient disorder	Plant growth and development	Leaf colour	Position where first observed
Aluminium toxicity	Stunted growth and depressed yield; seedling death when severe	Uniformly yellow with necrotic margins	Lower leaves
Boron deficiency	Thick stems and leaves; leaves are crinkled and turned downward	Yellow leaves with necrotic spots	Upper leaves
Calcium deficiency	Small plants with reduced root growth; short internodes and rosette-type growth	Dark green with slight yellowing at margins and tips.	Upper leaves
Copper deficiency	Stunted plants with shortened internodes	Grey or blue-green	Upper leaves
Iron deficiency		Light yellow to white, with green veins, initially	Upper leaves
Magnesium deficiency		Interveinal chlorosis and necrosis	Older leaves
Manganese deficiency	Stunted plants	Golden yellow between small veins; mottled appearance	Younger leaves
Manganese toxicity	Small and crinkled leaves which curl in severe cases	Interveinal chlorosis	Young leaves
Nitrogen deficiency		Pale green to yellow	Lower leaves, progressing upward
Phosphorus deficiency	Stunted with few branches; reduced flowering.	Yellow and necrotic; upper leaves are dark green, but small	Lower leaves
Potassium deficiency		Yellowing and necrosis of leaf tips and margins	Lower leaves
Sulfur deficiency	Reduced top growth, but good root growth	Uniformly yellow upper leaves	Younger leaves
Zinc deficiency		Interveinal yellowing	Both upper and lower leaves

Source: Derived from Howeler, 1980.

plant analysis data is the Diagnosis and Recommendation Integrated System (DRIS). Work with this system has been recently reviewed by Walworth and Sumner (1987). It is apparently more accurate in gauging nutrient needs then the critical value or sufficiency range approaches for interpreting plant tissue analysis.

DRIS makes multiple two-way comparisons between the levels of various nutrient elements in the plant and also considers the ratios of elements to dry matter. DRIS norms for a species are estimated using the ratios obtained from many trials, both high- and low-yielding. It is generally less affected by time of sampling and by soil type than methods of interpretation which use critical values or sufficiency ranges. Walworth *et al.* (1986) compared the norms established for alfalfa on highly weathered Oxisols to those previously generated on midwestern soils of the United States which were much less weathered and had a high exchange capacity. They found the values for the two sets of norms to be similar. Amundson and Koehler (1987), however, found that locally calibrated norms for wheat were more accurate in diagnosing nutrient deficiencies than norms developed from plant materials gathered in other geographic regions.

Research results on bean plant tissue analysis were reviewed by Howeler in 1980. Bean leaf samples for tissue analysis are generally taken without petioles at the top of the plant from the uppermost mature leaves present at floral initiation. These are then dried, ground and analyzed. Comparison of the nutrient status of samples of adequately nourished plants to that of samples from areas suspected of having soil fertility problems is useful in identifying the deficient or excess nutrient. Nutrient level values for beans are summarized in Table 2.

Table 2. Critical, sufficiency and toxic levels of nutrients in the youngest fully expanded leaf in beans when sampled during early flowering

	Critical levels	Sufficiency levels	Toxic levels
Nitrogen (%)	<3.0	5.2	--
Phosphorus (%)	<0.25	0.40	--
Potassium (%)	<1.0	3.0	--
Calcium (%)	<1.25	1.60	--
Magnesium (%)	<0.30	0.85	--
Sulfur (%)	<0.14	0.25	--
Boron (ppm)	<15	25	>45
Manganese (ppm)	<20	140	>200
Iron (ppm)	<100	400	--
Copper (ppm)	<15	20	--
Zinc (ppm)	<15	45	--

Source: Derived from Howeler, 1983

Diagnosis by Soil Chemical Analysis

Soil testing has long been an important tool in the diagnosis and treatment of soil fertility problems. In their recent review of soil testing, Cope and Evans (1985) report that a recommendation for fertilizer use based on a soil test was made as early as 1894. The value of soil testing as a diagnostic tool continues to increase as laboratory procedures for different soil types become standardized and as soil fertility data bases become more assessable. Formerly, it was necessary to establish the adequacy levels of the various nutrients for each soil type for the soil testing procedure used. Now information gathered on similar soils in other parts of the world is successfully extrapolated to fertility problems of soils in areas not yet investigated. The use of computerized simulation models can now give a good indication of the problems to be expected and how these might be corrected (IBSNAT Progress Report, 1982-85).

Soil testing can be used to determine if the levels of a nutrient element in the soil are adequate and also to determine if there are any detrimental nutrient interactions. Soils with generally high, well-balanced fertility are likely to be deficient in a few nutrients only and can be amended by merely adding these nutrients. Soils with a low pH and low CEC, however, are likely to be deficient in several nutrients and when certain fertilizer materials are added to such soil, there may be nutrient imbalances resulting in detrimental interactions between the nutrients. On such soils, there may be a need to adjust the basic cation saturation ratios (McLean, 1977).

Nutritional Screening Experiments

Nutritional screening experiments to identify nutritional problems limiting plant growth may be conducted in field trials on sites representative of a particular land unit or in greenhouse pot trials using soil from 12 or more sites within the land unit.

The optimum nutrient source and application rates depend on the soil, climate and sensitivity of the crop to the nutrient. Common sources and rates for secondary and micro-nutrients required by plants are presented in Table 3 to act as a guide in conducting nutritional screening trials. This information should be used with caution, as on some soils the rates given may result in toxicity problems.

Nutritional screening field experiments can be conducted on station, but soils in farmers' fields are likely to be more representative of the land unit; the need to conduct them on many sites suggests that it would be better to conduct the trials on farmers' fields. Certain management practices should be researcher managed and standardized for a land unit. Plant density and planting pattern are likely to influence the responsiveness of a crop to immobile nutrients. The level of weed control is also important.

Table 3. Common sources and application rates of secondary and micro-nutrients required by plants

Nutrient	Source	Rate
Calcium	CaCO3 plus MgCO3	2-8T $CaCO_3$/ha
Magnesium	$MgSO_4$, $MgSO_4$ plus KSO_4	30-40kg Mg/ha/3-4 yrs
Boron	$Na_2B_4O_7$	0.25 to 3 kg B/ha
Copper	$CuSO_4$, CuO, $CuSO_4$ plus $Cu(OH)_2$, and Cu chelates.	3-6 kg Cu/ha is adequate for 3-4 yrs
Iron	Fe chelate or foliar application of 4% $FeSO_4$	30 kg chelate/ha or 150-250 l/ha
Manganese	$MnSO_4$	5-40 kg Mn/ha banded
Molybdenum	MoO_4 Moist seed application of Na_2MoO_4	18 to 36 g Mo/ha
Zinc	$ZnSO_4$ or ZnO ZnEDTA	3-4 kg Zn/ha 0.5-1Kg Zn/ha

Source: Derived from Mortvedt and Cunningham, 1971

An alternative approach to nutritional screening is to apply corrective treatments to fields which are obviously suffering with a nutritional disorder. This would involve the application of foliar treatments and observation of the crop's response to each treatment.

Several experimental designs may be considered in designing a nutritional screening experiment. If little interaction is expected between nutrients, but a large number of nutrients are under test, the so-called "plus one" and "minus one" designs may be useful. In the "plus one" design, treatments with a single nutrient added are compared to the treatment in which no nutrient is added. In the "minus one" trial, one treatment has all nutrients applied to a sufficient level, and other treatments have all but one nutrient applied to a sufficient level. Treatments for such experiments may be as follows.

"Plus one"	"Minus one"
1. No nutrients added	Complete package of nutrients
2. Phosphorus added	Complete package minus phosphorus
3. Potassium added	Complete package minus potassium
4. Magnesium added	Complete package minus magnesium
5. Calcium added	Complete package minus calcium

If there are interactions between added nutrients, both the "plus one" and "minus one" designs may be inadequate. The "minus one" design may not detect the need for an added nutrient if it has a negative interaction with another added nutrient. The "plus one" design may fail to detect a need for a nutrient, if the plants respond to that nutrient only when another is added, i.e. in the case of a positive interaction between two nutrients. Such interactions are more likely to occur in soils with low levels of nutrient elements than if native soil fertility is high.

An advantage of the "minus one" design over the "plus one" design is that data collected can be used to estimate values for growth function equations, such as the Mitscherlich-Bray Growth Function, to be used for determining optimal levels of fertilizer use based on soil tests results (Melsted and Peck, 1975). If calibration and interpretation studies of soil tests results are likely to be done following the diagnostic work, the "minus one" design may be preferable to the "plus one" design. A disadvantage of the "minus one" design is that one or more of the added nutrient elements in the full package may result in toxic levels in the soil.

When interactions between added nutrients are expected to cover the effects of one or more added nutrients, the "plus one" or the "minus one" designs can be modified or a factorial design can be used. The "plus one" design can be modified by adding an extra treatment in which the two nutrients that are likely to interact are applied together. Similarly, the "minus one" design can be modified by adding a treatment in which the two interacting nutrients are both withheld. A disadvantage of factorial designs is that if the nutrients likely to be limiting are more than 3 or 4, the trial size may be too large to be conducted in the fields of a small farmer. If field size is too small for the desired experiment, only one replication could be planted per farm and the trial conducted on a greater number of farms to obtain the desired precision. Other options can be used: designing two complete factorial trials with some overlap of factors; using a partial factorial arrangement; using confounding of incomplete block designs (Cochran and Cox, 1957).

Determination of the Causes and Mechanisms of Nutrient Disorders

This important part of diagnosis is only introduced in this paper. A particular nutritional disorder may be caused by one or more of several factors or by interactions between factors. Cation exchange capacity, for example, may be a function of organic matter, allophane, clay minerals, hydrous oxides of iron and aluminium, silt fraction and soil pH. Soil pH is influenced by these properties, as well as by the comparative amounts of particular bases present in the colloidal complex. Phosphorus availability varies with pH, clay content, type of clay, free sesquioxides and colloidal materials which may cause low recoveries of both native and applied phosphorous due to "fixation". Knowledge of the causes and mechanisms of nutritional disorders is useful in the development of effective management practices to deal with the problem.

Conclusion

The diagnosis of soil fertility and plant nutrition disorders constraining crop growth is an essential part of soil fertility research. Stages in the diagnostic process include the classification of land into soil fertility management units, the actual diagnosis of the constraints to crop growth and determining the causes and mechanisms involved in the soil fertility problem. Once the problems are well understood for a land unit, alternative interventions, including the use of artifical fertilizers or amendments, phosphate rock, green manure crops or agroforestry, can be efficiently investigated.

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APPENDIX A

Description of Type, Subtype and Modifier Classes

(after Buol and Couto, 1980)

Type

Texture of plow layer or surface 20 cm (8"), whichever is shallower.

S=sandy topsols: loamy sands and sands (by USDA definition).

L=loamy topsoils: <35% clay but not loamy sand or sand.

C=clayey topsoils: >35% clay.

O=organic soils: >30% O.M. to a depth of 50 cm (20") or more.

Substrata type (texture of subsoil)

Used only if there is a textural change from the surface or if a hard root restricting layer is encountered within 50 cm (20").

S=sandy subsoil: texture as in type.

L=loamy subsoil: texture as in type.

C=clayey subsoil: texture as in type.

R=rocky or other hard root restricting layer.

Condition modifiers:

Where more than one criterion is listed for each modifier, only one needs to be met to place the soil. The first criterion given is preferred, but additional criteria are selected to facilitate semiquantitative use in the absence of desired data.

g=gley:
Soil or mottles $\leq$chroma within 60 cm (24") of surface and below all A horizons, or
saturated with water for >60 days in most years.

d=dry:
Ustic or xeric environment (dry >90 cumulative days/year within 20-60 cm depth).

e=low CEC:
(applies only to plow layer or surface 20 cm, whichever is shallower).

<4 meq/100g soil by bases + KCl extractable Al, or
<7 meq/100g soil by cations at pH 7, or
<10 meq/100g soil by cations + Al + H at pH 8.2.

a=Al toxic:
>60% Al saturation of CEC by bases + KCl extractable Al within 50 cm (20"), or
>67% EA (exch. acidity) saturation of CEC by cations at pH 7 within 50.0 cm (20"), or
>86% EA saturation of CEC by cations at pH 8.2 within 50 cm (20"), or pH <5.0 in 1:1 H_2O except in organic soils.

h=acid:
10-60% Al saturation of CEC by bases + KCl extractable Al within 50 cm (20"), or
pH in 1:1 H_2O between 5.0 and 6.0.

i=FeP fixation: (used only in clay [C] types)
%Free Fe_2O_3 / %clay >0.15, or
hues of 7.5 YR or redder and granular structure.

x=X-ray amorphous: (applies only to plow layer or surface 20 cm [8"], whichever is shallower).
pH >10 in 1N NaF test, or
positive to field NaF tests, or
other indirect evidence of allophane dominance in clay fraction.

v=Vertisols:
Very sticky plastic clay: >35% clay and >50% of 2:1 expanding clays;
COLE >0.09. Severe topsoil shrinking and swelling.

k=K deficient:
<10% weatherable minerals in silt and sand fraction within 50 cm of soil surface, or
exchangeable K < 0.20 meq/100g, or
K < 2% of bases, if bases < 10meq/100g.

b=basic reaction:
Free $CaCO_3$ within 50 cm of soil surface (fizzing with HCl), or pH >7.3.

s=salinity:
>4 mmho/cm of saturated extract at $25^{\circ}C$ within 1 m depth.

n=natric:
>15% Na saturation of CEC within 50 cm.

c=cat clay:
pH in 1:1 H_2O is <3.5 after drying and jarosite mottles, with hues of 2.5 Y or yellower and chromas 6 or more are present within 60 cm.

APPENDIX B

Sample Management Interpretations of FCC Nomenclature

(after Buol and Couto, 1980)

Classes of FCC types and substrata types:

L : Good water-holding capacity, medium infiltation capacity.

S : High rate of infiltration, low water-holding capacity.

C : Low infiltration rates, potential high runoff if sloping, difficult to till except when *i* modifier is present.

O : Artificial drainage is needed and subsidence will take place. Possible micro-nutrient deficiency, high herbicide rates usually required.

Interpretation of FCC condition modifiers:

When only one condition modifier is included in the FCC class nomenclature, the following limitations or management requirements apply to the soil. Interpretations may be slightly modified when two or more modifiers are present simultaneously or when textural classes are different.

g Denitrification frequently occurs in anaerobic subsoil and tillage operations and certain crops may be adversely affected by excess rain unless drainage is improved by tiles or other drainage properities.

d Soil moisture is limited during the growing season unless irrigated. Planting date should take into account the flush of N at the onset of rain.

e Low ability to retain nutrients--mainly Ca, K, Mg--for plants. Heavy applications of these nutrients should be split. Potential danger of overliming.

a Plants sensitive to aluminum toxicity will be affected unless lime is deeply incorporated. Extraction of soil water below depth of lime incorporation will be restricted. Lime requirements are high unless an *e* modifier is also indicated.

h Strong to medium soil acidity. Requires liming for most crops.

i High P fixation capacity. Requires high levels of P fertilizer. Sources and method of P fertilizer application should be considered carefully.

x High P fixation capacity. Amount and most convenient source of P to be determined.

v Clayey textured topsoil. Tillage is difficult when too dry or too moist, but soils can be highly productive.

k Low ability to supply K. Availability of K should be monitered and K fertilizers may be required frequently for plants requiring high levels of K.

b Basic reaction. Rock phosphate and other non-water soluble phosphate should be avoided. Potential deficiency of certain micro-nutrients, principally iron and zinc.

s Presence of soluble salts. Requires special soil management practices for alkaline soils.

n High levels of sodium. Requires special soil management practices for alkaline soils.

c Potential acid sulfate soil. Drainage is not recommended without special practices. Should be managed with plants tolerant of flood and high level of water table.

Rapid Diagnostic Survey Techniques for Soils: A Systems Perspective

Teshome Regassa

Melkassa Research Centre, Nazreth, Ethiopia

Introduction

Performance of a given crop variety is governed by two features: genetic make-up and the environment in which the crop grows. These two factors contribute 25% and 75% respectively to the performance of the crop. The environmental components include the soil on which the crop grows and the kind of soil management the grower uses.

Soil is the warehouse from where plants are provided with essential plant nutrients and water. Failure of soil to provide the needed amount of nutrients and water (excess or limited amount) indicates the existence of a soil problem as far as crop production is concerned.

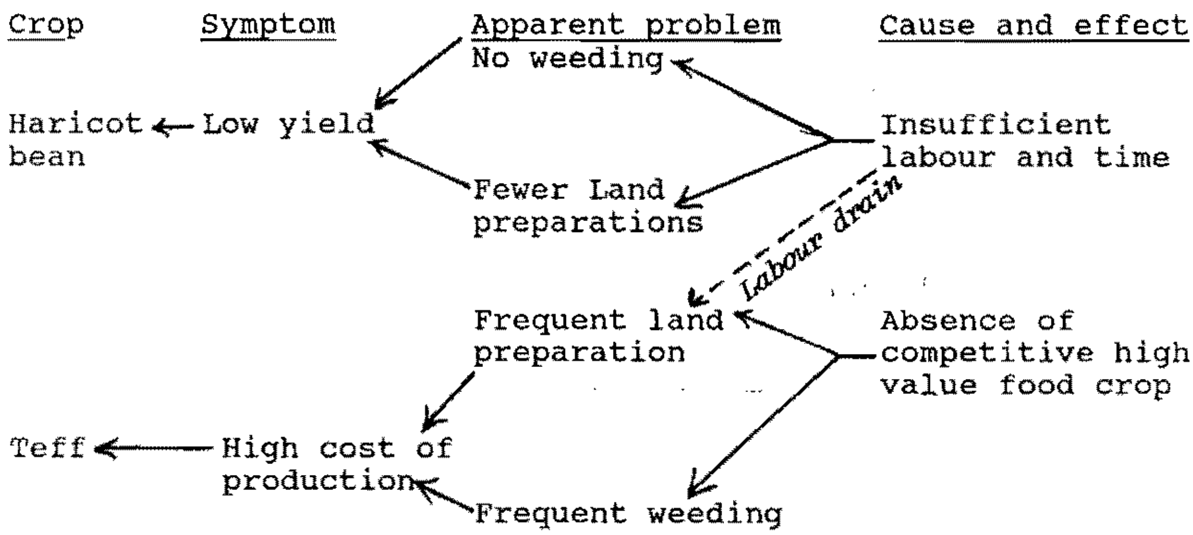
Unfavourable soil conditions cause different stresses on the crop based on the level of other essential climatic factors and management used. Soil-related stress on the crop also varies depending on the life cycle of the crop, the stage of growth at which the stress occurs and the level of other essential soil factors. A stress of one essential factor could make the crop more vulnerable to other factors that could have actually caused minor stresses provided the first factor was not limiting. Hence, in trying to diagnose the problem in a given soil or a plant problem in relation to soil, one needs to understand the complex interactions of all factors involved in the soil system as well as how the agrarian system operates globally and influences the soil system.

The most reliable tools for diagnosing soil problems are the various methods of soil tests and plant tissue analysis. These techniques give site-specific information. But due to limited resources, these tests are usually limited in coverage. Thus, for locations where such tests are not available, observations and systems analysis can be used as means of rapid soil diagnosis. This paper tries to suggest some ways of achieving such a goal.

Approach in Diagnosis

Soil, being part of a system, can be best understood through a systems approach. With a systems approach,the system is studied as an entity made up all its components and their inter-relationships, together with the reletionships between the system and its environment (Shaner *et al* ., 1982). Therefore, any attempt to diagnose soil problems should be holistic, taking consideration of the farming system (crop, livestock and consumption utilization aspects) and the environment (physical, biological and social) under which the soil exists at different levels of organization (global or region and the farm).

A holistic approach helps in determining the cause and effect relationship of a given soil problem. Determining this relationship is critical for identifying the actual problem rather than the symptom of the problem. It also enables a researcher to distinguish farmers' problems from their own solutions and management strategies. For example, lack of response to basal fertilizer application may be due to late weeding. By the time the weeds are removed, most of the fertilizer is removed with weeds in their biomass. Hence, in this case, the actual problem is not weed or fertilizer type but the labour shortage which hindered the farmer from timely weeding. An example from Nazret (Ethiopia) further illustrates this point:



Soil Diagnosis Factors

Climate

Climate is the dominant factor in soil formation, and rainfall is the most important of all. Climate influences soil formation in its association with geomorphology and other soil-forming factors. Acting on the parent rock, they shape the kind of soil developed. Based on the intensity of weathering, soils range from slightly weathered and young Entisols to the highly weathered Oxisols. Weathering of intermediate intensity usually results in Inseptisols, Alfisols, Ultisols and Vertisols. Intensity of weathering gives an idea about the availability of certain plant nutrients and their state in the soil system. Sahlemedhin and Ahemed (1983) reported an increase in phosphorus fixation as weathering intensity increases in some Ethiopian soils.

Topography

Topographic features of an area also affect the kind of soil developed and give an idea about the kind of soil association found. At the landscape level, several well-defined soil relationships are found in tropical areas. For example, Oxisols are associated with very old and stable land surface, while others such as Utisols and Inseptisols occupy the younger land surface. Also, a very common occurrence in the ustic (90 < dry cumulative days <180) tropics are the red andblack catenas. Red soils, mainly Alfisols, occupy the better drained sites, and dark cracking clays (Vertisols) the lower topographic position. In udic environments (< 90 cumulative dry days per year) Oxisol-Utisol-Inseptisol sequences are common in areas with very old parent materials. Hence, topography influences soil development, and sequences of soils can be predicted provided that other site specific characteristics are well understood. Figure 1 shows position of certain soil types in relation to the landscape.

Ecological Indicators

The plant community of an area is a product of the condition (environment) under which it grows. Soil is one of the most important factors that can influence or be influenced by the vegetation cover it supports.

Soil development as well as mode of soil nutrient utilization under different kinds of natural vegetation cover differs depending on the ecological time (age) of the vegetation (climax or succession) and degree of human interference. Vegetation cover plays a major role in soil and nutrient conservation, erosion control, recycling of nutrients from deeper horizons and leaching. For example, mature forests establish a near equilibrium state in which nutrients taken up in the forest vegetation are released for re-use after litter falls to the forest floor and decomposes. When man disturbs this cycle which nature uses for self-maintenance, some loss of nutrients from the system creates soil deficiencies as most of the nutrients are removed with the forest biomass.

Due to the interactions and interdependence existing between soil and vegetation cover, vegetation cover and plant associations can indicate general as well as specific soil properties. Plants naturally occur by segregating themselves to the best soil they can fit to. As a result, they indicateconditions and processes in the soil. For example, mesquite *(Prosopis)* is an indicator of a deep water table. In using ecological indicators, dominant species are the most important since they receive the full impact of the habitat, usually year after year. Stocking and Abel (1981) used associations between plant species and soil to classify land in Zimbabwe and urgued that trees and bush species were better indicators of soil characteristics than grasses.

In making soil diagnoses using ecological indicators as a tool, several considerations should be given due emphasis. Species with high fidelity (high degree of restriction to a specific situation) make much better indicators. Large species usually make better indicators than small species. This is because large species have a low turnover rate, indicating the long-term soil condition. Limits of tolerance or adaptation for a factor by a species should be known. More sensitive plant species make more suitable indicators. Plant populations or communities are often better than single species since the whole population reflects integration of conditions. However, there are certain cases when individual plants are good indicators. In most areas where the natural vegetation is destroyed, remnants of previous forest (referred to as *proy* variables) indicate past vegetation types, climate, and soil (e.g. *Olia african* in the highlands of Ethiopia).

Apart from natural vegetation cover, studying the morphology of cutivated crops can help in identifying certain soil problems. Crops grown in rich soils have roots that are shorter, more branched and more compact than those grown in similar but poor soils. Nicoa quoted in Sanchez (1976) reported a close correlation between yield (grain) and root density of the crop at the top 20-30 cm. Farmers in most parts of Ethiopia attribute the predominance of *Datura stramonium* and *Snowdenia polystacya* to "areda" soil (a highly manured soil) whereas another weed, *Eragrostis tenufolia* , indicates conditions of water-logging for a considerable time of the year, usually on vertisols, at valley bottoms and depressions associated with high rainfall.

The use of plants as ecological indicators in soil diagnosis is important but care must be taken against indiscriminate use and incipient conclusions. Careful study of factors that have direct influence on vegetation and experience in use of plant indicators are recommended.

Soil Biological Phenomenon

Soil is not a mass of inert inorganic material but the home of various living organisms. Occurences of soil macro-organisms such as earthworms, mites and springtails can give important indications in soil diagnosis. Earthworms are important in mixing the soil to maintain favourable consistency. They break down organic materials and plant litter into readily decomposable forms. Casts of earthworms are more numerous in soils with adequate levels of nitrate, exchangeable Ca, Mg, available P,K and CEC, when the soils are moist, with high organic matter and are well-aerated.

Biological nitrogen fixation is one of the most important phenomena to be considered in soil diagnosis, especially when beans (legumes) are part of the cropping system. Under normal conditions, beans are supposed to fix considerable amounts of atmospheric nitrogen in the soil system. Absence of fixation (nodulation), which can be observed in the field by uprooting beans and looking for effective nodules, is attributed to either of two factors: absence of the proper *Rhizobium* strain and ineffective or impotent *Rhizobium* due to a soil problem.

Absence of the proper strain of *Rhizobium* can be diagnosed by studying the history of the legume crop in the area. If the legume is a native, most likely the proper strain of *Rhizobium* can be found. In a study made in Ethiopia (Ohlander, 1980), soybean responded to inoculation while haricot bean did not due to the more recent introduction of soybean. The same author reported the need to inoculate haricot when introduced to a completely new area even if the crop was native to the country.

Apart from the existence of the proper rhizobial strain, soil conditions affect the legume symbiosis. The organic matter content of the soil affects the growth and survival of rhizobia. Tilak (1974) quoted by Dev and Tilak (1976) reasoned that organic matter improves the water-holding capacity and the surface area of soils which in turn improve the multiplication and survival of rhizobia in the rhizosphere. During a survey of haricot bean production methods carried out in one of the major production areas (Zeway) of Ethiopia, the author observed almost no nodulation on plots where plants experienced acute moisture stress and on plots of sandy soils. A remarkable increase in nitrogen fixation was observed by Dev and Tilak (1976) in soils amended with organic manure. Acid soils generally inhibit nitrogen fixation.

Socio-economic Circumstances

Socio-economic factors under which farmers operate can be grouped into two classes: internal factors, over which the farmer has same control, and external ones, which affect the farmer's managemnet decisions (e.g. land tenure system). Farmers will be in a crop sharing rental system farmers are reluctant to use inputs or intensive management. Tenure arrangements also govern long term investments in soil conservation and cropping systems such as agroforestry. In an insecure land tenure system, farmers do not bother with soil conservation. Under such conditions the tenant is interested in obtaining higher yield in a season rather than trying to sustain soil productivity.

Cropping System and Crop/Soil Management

Traditional cropping systems evolved from long-term trial-and error and are close to the best possible systems. As a result of long-term evolution of cropping systems based on the constraints faced by farmers, existing cropping systems and the crop/soil management are reliable factors to be considered and studied in rapid soil diagnosis.

Farmers allocation of crops to certain soils is not haphazard. At least two things are considered by the farmer: importance of the crop and the level of soil fertility. For example, farmers in Nazret area (Ethiopia) allocate the most fertile and manured soil for maize as it is the important staple food crop. The less fertile and coarse-textured light soils are mainly planted with haricot bean. Beans are not allocated to fertile soils for fear of lodging as farmers' experiences are that this crop does well in less fertile soils in comparison with other crops. In areas like Zeway (Ethiopia), farmers reduce the tillage practices for beans in order to restrict excessive vegetative growth in situations where the crop is planted on relatively fertile land.

Management pertinent to an area has an impact on soil-related problems. Sometimes to overcome certain types of problems, farmers use practices that can increase yield but which have deleterious effects on soil in the ong term. The best example of such managemnet is *guie* . *Guie* is a practice used in the central highlands of Ethiopia on Vertisols of poor internal drainage. Here the soil is built into a mound where it is burned by inserting dried manure; then the burned soil is spread on the field and ploughed to improve drainage. Effects of *guie* on the physical, mineralogical and biological properties of soil are described in Legesse (1968) and Mesfin (1980). Even if the practice increases yield for the first one or two years, it leads to loss of nutrients of up to 14 tons of carbon and one ton of N per hectare (Mesfin, 1980) as well as other changes in clay mineralogy which result in soil degradation. The example can show the importance of understanding cause and effect relations in identifying farmer's soil problems. In this case, *guie* is not the problem that leads to soil deterioration, but farmers use *guie* as a management strategy to overcome the drainage problem.

Cultivated crops vary in soil nutrient use as well as in their effects on physical and chemical soil properties. Composition of the cropping system and the way crops are associated in a single field also deserves consideration. Soil problems differ in a cereal-dominated cropping system from those where cereals and legumes occupy equal time on a field. Similarly, intercropping and multiple-cropping differ from sole-cropping. More nutrients are removed from the soil as the intensity of cropping increases. Crops also vary in the use of soil nutrients and the amount returned to the soil as crop residue provided the system allows replacement of crop residue. For example, potato and other horticultural crops return less biomass as compared to other field crops. Such conditions may necessitate amendment from some external source.

As far as small subsistence farmers are concerned, in which case use of energy subsidies is remote due to resource limitation, maximum effect in nutrient recycling constitutes the best option in soil nutrient conservation. Farmyard manure and crop residues can best serve this objective due to the considerable amount of essential plant nutrients and organic matter they contain. In places where manure is used for selling or as a source of fuel for the family, considerable stocks of plant nutrients are lost out of the system.

Another source of organic soil amendment is crop residue. Proper crop residue management controls erosion and improves physical soil properties. Residues contain many of the plant nutrients absorbed by the plant during its life cycle. Table 1 elaborates this point.

Table 1: Percent of N, P,K in crop residue compared with those in residue plus grain for nine crops

Crop	N	P	K
Barley	30	22	76
Corn (maize)	43	41	78
Sorghum	57	45	86
Wheat	29	15	70
Cotton	41	31	70
Soybean	38	36	48

Source : FAO, 1980

This shows the extent of loss of soil nutrients as crop residue is totally removed from a field. Table 2 concerns eastern Ethiopia where crop residues are removed from the farm for fuel, construction and animal feed.

Table 2: Amount of above-ground plant material removed and/or left on farm land in Alemaye Woreda, (eastern Ethiopia highlands)

Location	Crop	Above ground dry matter weight in Kg/ha	
		Removed	Left
Legambo	maize	7,600	0
Legambo	wheat	2,750	1,366
Batework	wheat	2,150	1,088
Finkile	wheat	3,600	1,759

Source : Tamire, 1982

The soil productivity in a given area is a function of the farming system and soil management. It is usually the result of various cause-and-effect relationships. In trying to diagnose a particular soil, one should consider all the factors responsible in shaping the identity of it. Figure 2 gives an idea how cause-and-effect relationships operate in a typical farming system.

Traditional Knowledge

Small farmers, being experimenters themselves, have accumulated a great deal of knowledge about their particular soils. This knowledge is the result of generations of trial and error. The importance of traditional knowledge and farmers' experience in diagnosing as well as searching for improvement has now been recognized by most agricultural researchers (Gilbert et al., 1980). Farmers' role in diagnosing a problem area is very important for local knowledge can be useful in understanding the root of a problem. As mentioned earlier, certain researcher-perceived problems may arise from farmers' strategy to overcome a problem. Incorporating farmers' knowledge helps in identifying trends of problem changes with time. It can also help to understand whether farmers' strategy to overcome a particular problem is leading to a better or worse, situation.

An average farmer in most parts of Ethiopia, for example, recognises more than four kinds of soil depending on the extent of soil heterogeneity found in a particular area. For each of the soils they identify, farmers can tell the characteristics, relative fertility, crops best grown and the kind of management needed. The only difference is that farmers describe soils using local terminology while researchers have a common terminology. Farmers can identify a given soil problem competently and can plan a strategy to overcome it . However, solutions may cause soil degradation in the long run (such as the practice of *guie*). On the other hand, farmers may have a solution whose efficiency is handicapped by resource limitations or inability of local crafts to provide the proper farm implement. For example, Debre Berhan farmers (North Shoa, Ethiopia), a long time ago used to drain Vertisols by constructing drainage ditches; these served the same purpose for seed beds as that of the broadbed-maker recently developed by ILCA. The difference is that the farmers' method requires high human labour input while ILCA's technology reduces the labour requirement substantially.

Farmers' traditional knowledge is a valuable resource and body of knowledge that must be used by researchers in problem identification as well as in planning improvement strategies. "Rural people's knowledge and modern scientific knowledge are complementary in their strength and weakness. Combined, the two may achieve what neither could do alone", (Chambers, quoted by Stroud, 1985).

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Discussant's Comments On Session Two

G.A.S Mitti

Msekera Research Station, Chipata, Zambia

Review of Zambian Findings

Beans, a long established and important source of protein for many people in Zambia, are grown widely in the central, northern and eastern regions. In the high rainfall areas of north and north- western Zambia, two crops per season are grown, the first as an intercrop with maize, the second as a role crop.

Intensive research on beans started only in 1982 with the establishment of the Grain Legume Research Team. Previously, some work had been done on pest resistance of bean materials. The new team initially concentrated on testing and selection of adaptable genotypes; breeding is only now starting. Little research has been done on fertility aspects.

The farming systems team in the Eastern Province of Zambia recently carried out two trials to address bean nutrient requirements. Results from three seasons of a legume/maize rotation experiment indicate that a crop of beans, soybean or groundnut provides benefit equivalent to approximately 30 kg N applied to a subsequent maize crop (Table 1). The contribution from beans was higher than expected. Inadequate laboratory facilities precluded soil tests.

Table 1. Residual effect of previous legume crop as measured by mean yields of unfertilized and topdressed maize on the station (kg/ha)

	Crop Preceding Maize (unfertilized or topdressed with 60 kg N/ha)							
Year	Maize		Groundnut		Soybean		Bean	
	-N	+N	-N	+N	-N	+N	-N	+N
I	1087	3613	2076	4458	2099	4800	3545	4820
II	2850	6140	5540	7660	4324	6980	5220	6950
Mean (2yrs)	1964	6877	3808	6059	3212	5890	4383	5920

Notes: 1. LSD (P=0.05) for main treatments = 1282 kg/ha
2. Main treatments (legume spp) CV = 25%
3. Subtreatments (maize fertilizer) CV= 16%

Source: Grain Legume Research Team Annual Reports

Also relevant here are the results from a bean exploratory trial (Table 2). The experiment was carried out across several farms and three seasons. The new variety, Carioca, improved bean yield by 60%.

Table 2. Bean yields from a three-year exploratory on-farm trial to evaluate the effects of variety, fertilization and seed dressing (kg/ha)

Treatment	1983/84	1984/85	1985/86	Mean
Local variety, farmer management	225	293	319	279
Carioca with farmer management	320	517	515	450
Carioca + fertilizer + seed dressing	691	740	915	781
LSD (P=0.05)	186	175	166	
CV (%)	38	36	26	

Notes: Fertilizer treatment = 100 kg/ha compound formula 20:10:10:5.
Seed dressing = endosulfan for beanfly

Source: Adaptive Research Planning Team Annual Reports

However, with fertilizer and insecticide for beanfly control, Carioca increased yield by 74%. This cost/benefit ration of 1:5.3, higher than for most crops including hybrid maize (1:5.1) grown in the same area, suggests a dramatic response to fertilization.

The two trials appear to give conflicting trends. In one case there were indications of residual N, in the other, beans needed additional N. This difference may be explained by fertility levels at trial sites. The residual N trial on station was located on land not cropped for 20 years, whereas the onfarm trials were superimposed on farmers' fields in an area dominated by sandy soils without fallow periods (farmers use better fields for maize, the staple crop). This emphasises the need for onfarm trials to assess technology under farmers' circumstances. Where farmers grow beans in marginal land, researchers should test potential technologies on such land. Although beans can fix N, this may not be possible under stress: nutrient deficiency may cause the crop to consume rather than to add N to the soil.

Research methods for soil fertility diagnosis

The commonest methods are soil testing and plant analysis. Facilities in Zambia are limited (until recently only one laboratory), and such analyses have generally been less important than nutrient deficiency symptoms as fertility indicators. Although it is difficult to be precise for certain crops, symptoms can be dramatic (e.g groundunt "pops" or empty shells can indicate soil acidity).

One may question the utility of present soil testing procedures for fertility assessment on small farms under conditions of limited laboratory capacity, as fields vary greatly with management. As a supplementary (rather than alternative) method, field studies should be done on farms. Depending on resources a fairly large number of farms, each with replications (2/3), should be considered. Cropping and management history, productivity, and nutrient responses should be compared to laboratory soil tests. An objective should be the development of recommendation ranges for common crop management styles of farmers. This approach to diagnosis may be more likely to realize the high returns that are possible from fertilizing beans on poor soils, to the eventual economic benefit of all crops in the system.

Summary of Discussion on Diagnosis of Fertility Constraints

Rapporteur: J. Kavuma

Suggestions made on field diagnosis included the following points:

- since farmers make decisions and allocate resources on their system rather than on the needs of individual crops, researchers need to do the same, and discussions in farmers' fields are an important part of this process;

- rotations should be documented, and the place of the bean crop within the rotation should be noted;

- farmers' fertilization practices should be noted carefully, as applications made to cereals may have residual effects upon other crops in the system;

- the purpose for which beans (or another crop) is being grown needs to be understood - soil fertility recommendations may be different for a cash crop than for a subsistence crop;

- crop residues may be recycled, e.g. through the livestock subsystem in much of Ethiopia;

- soil chemists, agronomists, economists and others often seem not to be working sufficiently closely together: e.g. care is needed in advocating crop residue management, since crop protectionists often discourage its use on grounds of pest carry-over;

Procedures for on-farm experimentation as a diagnostic tool can be controversial. It can be prohibitively expensive, although there are techniques that minimize the costs. Relatively simple trials carried out on many farms help to identify priorities for representative (rather than research station) situations, but may be less useful for identifying large numbers of factors. Few attempts have been made to correlate nutrient status with bean yields because of the belief that beans do not generally respond to fertilizers - this belief needs to be re-examined, particularly in view of reported (but poorly quantified) responses to nitrogen in Africa. A soil's capacity for fixing P may need to be determined.

If high levels of Al are detected in topsoil, subsoil concentration of exchangeable Al needs to be determined in order to diagnose possible restrictive effect on root growth. Where laboratory facilities for analyzing Al are poor, a potassium chloride extract should be prepared and Al determined by titration.

A review of micronutrient studies on beans in Africa would be useful. Plant tissue analysis also warrants further investigation as a diagnostic tool, while soil fertility classification in Africa is yet to be practical.

Adaptation of Beans to Infertile Soils

Jonathan Lynch and Melvyn Piha

Bean nutrition specialist, CIAT, Cali, Colombia and Dept. of Soil Sci. and Ag. Eng, University of Zimbabwe

Introduction

Soil infertility is an important constraint in many African bean production systems. *Phaseolus vulgaris* is considered to be less well adapted to adverse soil conditions than are other grain legumes such as cowpeas. As a consequence, a number of options should be considered. Significant inputs are required to improve soil fertility. Low yields must be anticipated. Alternative grain legumes with better inherent adaptation to infertile soils such as cowpeas, groundnuts, pigeonpeas, and lima beans should be grown in infertile soils. Bean genotypes with improved adaptation to infertile soils must be developed. This is the best long-term approach for improving bean production on marginal soils. In this paper we discuss some general considerations relative to the development of bean genotypes with improved adaptation to infertile soils.

Bean Nutrient Requirements

In addition to the standard nutrient requirements of higher plants, beans display the following particular characteristics:

1. N fixation, which entails reduced soil N requirements but may increase the requirement for P, Ca, Mo and Co, which are required in significant amounts for nodulation and fixation.

2. High Ca requirement, perhaps due to the cell wall composition of the bean plant.

3. Relatively low resistance to ion toxicity, including Na, Cl, Al and heavy metals. This may reflect inherent adaptation to alluvial soil habitats.

4. High soil P levels are required for maximum growth.

5. Rapid growth, necessitating rapid nutrient acquisition.

These factors do not favourably predispose the bean plant to cultivation in highly leached, acid soils common to many regions of the humid tropics. The poor inherent adaptation of beans to infertile soils represents both a challenge to breeding efforts and a potential for significant yield payoffs to genetic improvement.

Probable Nutrient Limitations to African Bean Production

At present, it is difficult to quantitatively evaluate the extent and significance of nutrient constraints to African bean production. We suggest that the first step in developing improved genotypes should be a diagnostic effort directed towards defining the soil constraints. This information can then be used to develop plant ideotypes with the appropriate suite of traits. A diagnostic effort might include the generation of an African bean production map that could be interfaced with soil data, edaphic characterization of benchmark sites, collation of existing data from national and international agencies and replicated field trials at diverse locations with a standard set of genotypes.

It is commonly assumed by many nonspecialists that soils are too variable and soil constraints too site-specific to be addressed in a centralized fashion. We suggest that this is a misconception based upon incomplete definition and characterization of soil constraints. A trait conferring resistance to high levels of soil Al should be advantageous in any soil having this problem. If a given soil has high Mn levels in addition to high levels of Al, then the Al resistance trait alone may not be sufficient to dramatically improve plant performance. However, we should certainly not abandon Al resistance traits simply because they do not also confer Mn resistance. Although any given site may have a distinct combination of soil stress factors, each of those factors in isolation may be ameliorated by physiological mechanisms effective in any soil environment. This is analogous with the biological stress of insect pests and diseases. Each bean field has a unique combination of potential and actual insect and disease problems because of the availability of inoculum, association with other crops, management factors etc. However, each unique complex of biological stresses can be broken down into component parts of specific insects and pathogens (even specific races of pathogens) that are more universally distributed and are vulnerable to more universal breeding solutions. There is no reason to believe soil stress factors are any different, with the possible exception that soil stress factors are often more difficult to identify than insect and disease organisms. Proper definition of soil constraints is therefore an essential step in developing bean genotypes adapted to infertile soils in Africa.

Despite the need for more precise definition of soil constraints, some generalizations are possible. In large parts of Africa, Oxisols (Ferralsols) and Ultisols (Acrisols, Dystric Nitosols) predominate. In general these soils are leached, acidic, have low nutrient contents and nutrient retention capacity and bear the risk of Al toxicity and P fixation. Some Andepts (Andosols) are also present; these also are prone to P fixation. Probable nutrient constraints in these soils are as follows:

1. Low availability of polyhydroxy anions, namely phosphate, surfate and molybdate. Molybdate is a micronutrient that can be economically supplied as a foliar or soil amendment. Sulfate could be a significant constraint in some soils but relatively little is known concerning its relation to bean production.

2. Low availability of Ca, especially in the subsoil. This is confounded by Al toxicity and low pH

3. Al toxicity.

4. Mn toxicity.

It is possible that nutrient constraints are less severe in other African bean production regions. Although N availability may be low in many soils, beans are capable of significant N fixation, and it is therefore unclear if N availability *per se* is a primary limitation at present levels of production.

Nitrogen Fixation Limitations of Bean

Assessment of Nitrogen Fixation Capacity

Nitrogen is the element most commonly limiting in crop production. Correction of nitrogen deficiency by addition of chemical fertilizers is usually the most expensive fertilizer input in annual cropping systems. Grain legumes are adapted to low fertilizer input systems because they obtain nitrogen via biological nitrogen fixation (BNF), thus avoiding high-cost nitrogen applications.

Beans have a reputation for poor nitrogen fixation. High-yield production systems usually apply nitrogen fertilizers to beans because the response makes this more profitable than relying on BNF. This is not the case with other grain legumes (e.g. cowpea, groundnuts, soybeans), which are most profitably produced via nitrogen fixation. For low-yield systems the poor fixation by beans may be masked by other limiting factors.

The reason for poor BNF by *P. vulgaris* must be understood if beans are to be promoted for low input systems. There are numerous ways of assessing BNF, but the method used will influence our assessment of nitrogen fixation capacity. Ultimately, a good nitrogen-fixer is a plant which can be produced more profitably via BNF than by using chemical nitrogen. All other methods for assessing nitrogen fixation have their place, but for grain legumes, comparison with nitrogen-fertilized controls is agronomically most meaningful.

The total quantity of nitrogen fixed by a grain legume is considered less useful as this will depend on the nitrogen status or the soil. Likewise, a short-season cultivar cannot fix as much nitrogen as a long-season cultivar because it is simply not capable of producing as much biomass. Methods such as acetylene reduction and ureide analysis can be useful but may not be agronomically meaningful.

Relative yield of BNF plants compared with optimally nitrogen-fertilized plants (RY) gives most information about the effect of stress on nitrogen fixation. Consider for example, the effect of low soil phosphorus on nitrogen fixation by beans. Total N fixed and acetylene reduction both indicate that BNF is reduced if soil phosphorus is limiting. On the basis of such a result, one may conclude that the cause of low productivity on P-deficient soils is some aspect of the bean *Rhizobium* symbiosis being sensitive to low P. One may recommend that addition of P fertilizer, or selection of low P tolerant strains would increase BNF, thus making it most profitable for the farmer to grow beans using BNF. If, however, yield or total N accumulation is compared with N-fertilized controls, a different interpretation emerges. For example, for a deficient soil, yield may be 500 kg/ha when dependant on BNF compared with 1000kg/ha when using nitrogen fertilizer. If phosphorus is sufficient, yields may be 1000 kg/ha when dependent on BNF compared with 2000 kg/ha when using nitrogen fertilizer.
Such data would suggest that it is the host plant which is sensitive to low P phosphorus and not the symbiosis. In such a case addition of P fertilizer has no effect on the relative performance on BNF plants versus chemically-fertilized plant. In such a case bean production might be more profitable if we applied fertilizer N, regardless of soil constraints.

Consider, on the other hand, the effect of high soil temperature on BNF by beans. A measure of the quantity of nitrogen fixed and acetylene reduction both suggest the symbiosis is adversely affected by high soil temperature. One may recommend lowering of soil temperature or selection of heat tolerant strains, as a means of making production via BNF more desirable. If relative yield or N-accumulation is compared with N-fertilized controls, this conclusion is supported. For example, a high temperature soil yield may be 500 kg/ha when dependent on BNF compared with 1000kg/ha when using nitrogen fertilizer. If soil temperature is lowered, yields via BNF may be increased to 750 kg/ha, whereas yields with N-fertilizer remain at 1000kg/ha. In this case, the effect of the adverse condition is on the symbiosis and not on the host plant. Particular attention must be paid to the rate of nitrogen fertilizer used. These rates must be high enough to supply the entire nitrogen requirement of the given legume (e.g. 150-300 kg/N/ha).

If a grain legume gives a poor relative yield when BNF is compared with N fertilizer application, this could be due to a number of reasons. There could be sensitivity of some aspect of the symbiosis to adverse soil conditions (e.g. low phosphorus, low calcium, aluminium toxicity, high soil temperature, etc) or to background nitrogen levels. There could be inefficient host-strain combination due to poor compatibility, or competition from native rhizobia. The host plant might have genetic inefficiency in its ability to meet its N needs via BNF. There might be inefficient conversion of photosynthetic energy into fixed nitrogen.

It is important to ascertain which of these reasons has the most influence on poor performance by beans. If relative yield of BNF beans is low due to symbiotic sensitivity to adverse soil conditions, then the problem can be cured by soil correction or selection of tolerant *Rhizobium* strains. If the reason is inefficient host-strain combinations, then selection for better strains is essential. If the problem is competition from native strains, then we need to select competitive-efficient strains and find ways to ensure that the introduced strain forms the nodules. If the problem lies with host-plant genetics, then the solution may be to select varieties which are better nitrogen fixers.

For *P. vulgaris* , all the above limiting factors have been suggested (Graham, 1981). Results have been difficult to interpret due to the lack of nitrogen-fertilized controls in many cases. In other cases, soil nitrogen levels may not have been limiting, leading to erroneous conclusions.

The performance of nitrogen-fixing beans was compared with N-fertilized beans, and with cowpea and soybeans under ideal conditions (i.e. no limiting nutrients, no toxicities, optimum root temperature, highly efficient host-strain combinations, no competition from less efficient strains etc., Piha and Munns, 1987 a, b). Relative nitrogen accumulation (BNF compared with N-fertilized) was consistently greater than 90% for numerous cowpea and soybean cultivars tested. For beans, relative N accumulation varied with the cultivar. Short-season cultivars, dependent on BNF, accumulated less N than that accumulated by N-fertilized controls. Some long-season cultivars were capable of relative N-accumulation similar to that of cowpeas and soybeans.

These results suggest that the poor BNF performance of short-season beans is due to host-plant genetics. The relative performance of BNF plants compared with N-fertilized plants remained constant and inferior to other species under low phosphorus and in the presence of strain competition. There is little evidence to suggest that the symbiosis is more sensitive to adverse soil chemistry factors or competition from native strains than is the soybean symbiosis. There is evidence to suggest that *P. vulgaris* is rather sensitive to acidity, salinity and low phosphorus. Such factors reduce the growth and photosynthetic capacity of the host plant thus reducing total N fixation. Because the host plant has to direct a constant percentage of its photosynthate for N-fixation, the relative performance of BNF plants compared with N-fertilized plants remains constant.

Selection for highly efficient, competitive strains able to tolerate adverse soil conditions will not result in short-season beans capable of meeting their N needs via BNF. Correction of adverse soil conditions should improve the actual yield of N-fixing beans but not relative to N-fertilized beans. Nitrogen fertilization of short-season beans is likely to be profitable due to inherently poor BNF by the cultivars.

In theory, the solution to improved BNF by short-season cultivars may be through genetic manipulation of the plant symbiont. What is it about these short-season cultivars that makes them genetically predisposed to poor N-fixation? Short-season cowpea cultivars are much more capable of meeting their nitrogen requirement via BNF than are beans. On the other hand, the N accumulation pattern of short-season cowpea is different to that of beans. Compared with cowpeas, nitrogen-fertilized beans accumulate a greater percentage of their total N requirement in the early part of the season. Early season N-fixation is particularly expensive, as relatively more photosynthate is needed for nodule development and because leaf N content is highest when plants are young. In theory, BNF plants are least likely to be able to satisfy their N needs during the early stages of growth. Because bean accumulates relatively more N at these stages it is predisposed to poor fixation.

Mid-season BNF by some short-season bean cultivars is adequate, and dry matter accumulation almost equals that of N-fertilized plants. This period of relatively good BNF does not last very long because flowering in beans is early. Once pods start filling there is competition for photosynthate between pods and nodules and so BNF is compromised. For cowpeas, flowering is later, and pod-filling is quicker, so that the period of successful, non-competive N-fixation is longer. In addition to the fact that the growth pattern is not conducive to optimum BNF, there is also evidence for inferior conversion of photosynthate into fixed nitrogen by beans.

All host-strain combinations of bean have been shown to evolve hydrogen from their nodules, whereas this is not usually the case for cowpea or soybean. Hydrogen evolution indicates that energy is being wasted by reducing H^+ to H_2 instead of using it to reduce N_2 to NH_3.

For late-maturing bean cultivars, once nodules have been established there is a longer period of vegetative growth conducive to BNF, before competition from pod filling sets in. These varieties have a higher source:sink ratio so carbon for N-fixation is less limiting. Such varieties can produce equally well whether using BNF or N-fertilizer and warrant careful consideration for low-input systems.

Application of Stress Concepts to Low P Resistance

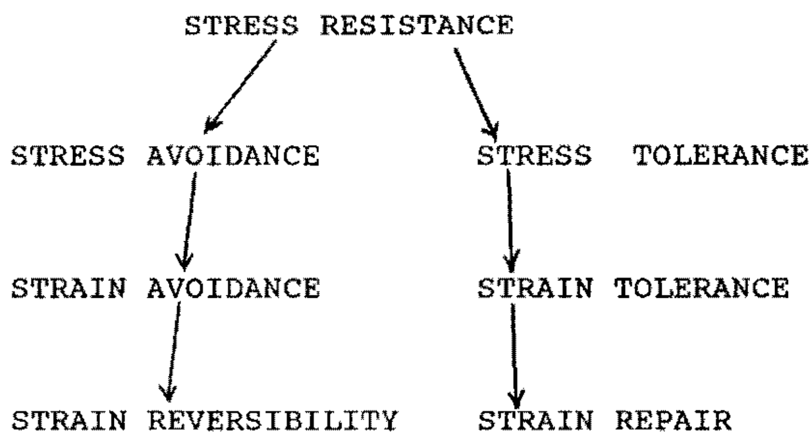
P stress is an illustrative example. In trying to develop genotypes adapted to low P availability we are concerned with stress physiology. Existing genotypes are stressed when confronted with low P availability; that is, they are prevented from achieving their yield potential. By analogy with physical definitions, Levitt (1980) has developed a conceptual model of stress physiology that may be useful in guiding thinking and research on this problem. Briefly, this model is as follows:

stress = external force acting on organism to deform it ("deformation" may include change in behavior).

strain = force present within an organism acting to deform it.

injury = deleterious deformation of organism.

Resistance to enviromental stress can be divided into avoidance and tolerance mechanisms, as follows:



It is evident from this model that a variety of different mechanisms may be advantageous under P stress, some of which may be redundant, complementary or antagonistic with each other.

Stress tolerance mechanisms are usually more interesting than stress avoidance mechanisms from the viewpoint of developing improved genotypes. Under the category of stress tolerance mechanisms, strain avoidance mechanisms would include traits permitting enhanced acquisition of soil P, thereby preventing the stress of low external P availability from generating the strain of reduced plant P status. Such mechanisms would include root transport properties (although see Barber, 1984), root growth and morphology, mycorrhizal symbiosis and rhizosphere modification through root exudates. Genotypic differences in P acquisition have been observed in beans (Salinas, 1978), are heritable (Lindgren *et al.*, 1977) and may be related to root growth (Fawole *et al.*, 1982a). In contrast to strain avoidance mechanisms, strain tolerance mechanisms would be important once plant P status had been reduced, and would be manifested as reduced internal P requirement. Such mechanisms might include reduced vacuolar P storage, efficient remobilization of P to key regions of the plant (e.g. from root to shoot, stem to leaf, older to younger tissue) and reduced metabolic requirement for P (an unlikely possibility). Genotypic differences in internal P requirement have been observed in bean (Whiteaker *et al.*, 1976), are heritable (Fawole, 1982b) and have been transferred from an exotic genotype to an adapted genotype using an inbred backcross method (Schettini *et al.*, 1987).

Future Prospects

The reported presence of diverse mechanisms of P efficiency in bean is promising and suggests that such traits could be combined to produce genotypes with significantly enhanced resistance to low-P soils. Additional traits that hold promise for investigation and possible breeding are the ability to form efficient mycorrhizal symbiosis, the ability to enhance soil P availability through rhizosphere modification and the ability to form root systems capable of acquiring P with reduced C cost (i.e. increased root efficiency).

It is important to note that simple selection criteria such as plant vigour at flowering or yield may be inadequate to discern useful nutritional traits. Parameters such as yield and vigour are influenced by many plant traits that may have little to do with resistance to the applied soil stress. This is especially problematic with a crop such as beans, with such diversity in phenology, habit, temperature/photoperiod adaptation, seed size, etc. The difficulty in achieving truly uniform stress treatments in field trials further obscures the relevance of apparent plant performance. We might also envision a situation in which a useful trait such as enhanced nutrient acquisition is masked by the presence of a maladaptive trait such as inefficient P utilization in the plant.

A trait that appears beneficial in the short term can be counterproductive in the long term, and vice versa. For example, Dr. Michael Thung (CIAT bean agronomist in Brazil) has noted that shoot vigour at flowering is inversely related to plant P efficiency in various bean genotypes (unpublished data). A dynamic computer simulation model (unpublished data) indicates that this may reflect suboptimal C partitioning between root and shoot in inefficient materials. Inefficient materials devote too much C to shoot growth. This results in vigorous shoots early in ontogeny but reduced growth later in ontogeny because of inadequate root development and consequent P deficiency. When more C is allocated to roots, shoot growth is initially slower but eventually greater due to a better balance between shoots as C sources/P sinks and roots as P sources/C sinks. The model validates Dr. Thungs observation that shoot vigour at flowering may be a poor criterion of plant performance under P stress, and suggests that selection on the basis of specific traits may be more fruitful. Another example of the utility of trait based selection is given by Schettini *et al.*, (1987), who selected a useful P trait in an otherwise maladapted material and successfully transferred it into an agronomically adapted material.

In order to use specific traits as selection criteria we must have an adequate understanding of the physiology of stress injury and stress resistance in bean. The stresses of Ca deficiency, Al toxicity and P deficiency are probably the most urgent areas for research relative to African soils.

Summary

Beans do not appear inherently suited to infertile soils.A diagnostic effort to define and evaluate soil constraints in African bean production is needed. We suggest bean BNF is host-plant limited, and that BNF in short-season bean is due to inadequate C and N dynamics in the bean plant. In infertile soils, improved host-plant resistance to edaphic stresses may improve BNF. Several studies indicate that heritable variation exists in bean with regard to resistance to low soil P. Additional promising avenues of research on resistance to low soil P include mycorrhizal symbiosis, rhizosphere modification and root morphology. For nutritional characteristics, specific physiological traits may be more fruitful selection criteria than plant vigour and yield. Mechanistic research on Ca deficiency, Al toxicity and P deficiency would be useful in defining traits to be used in breeding improved bean materials for infertile African soils.

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Summary of Discussion on Nutrient Requirements

Rapporteur: K. Haule

Micronutrient status of plants and soils are difficult to determine in the region due to poor analytical facilities. Consequently, critical levels in regions of Africa are not generally known. Bioassay in pot studies was suggested for identification of micronutrient deficiencies.

In practice, a starter dose of N is often essential to obtain good n-fixation, as the young bean plant is unable to obtain N from BNF. A typical starter dose would be 20 kg/ha N. As beans are quick maturing, split applications of fertilizer is not usually warranted, and effects of N applied at or after flowering have given inconsistent results in India and USA.

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Research Needs and Methods for the Use of Fertilizers and Soil Amendments in Bean-based Cropping Systems

S.K. Mughogho and C.S. Wortmann

Bunda College of Agriculture, University of Malawi, Malawi and C.I.A.T. Regional Programme on Beans in Eastern Africa

Introduction

The major soils in bean growing areas in Africa are low in pH and may have large quantities of exchangeable Al and/or Mn. Problems of nutrient deficiencies or toxic effects are often associated with these characteristics. In Africa, beans are grown primarily in association with other crops, including cereals, tuber crops and perennial tree crops. Furthermore, most beans are grown by resource poor farmers. In planning a research programme on fertilizer use, these points need to be considered.

Researchers working to improve intercropping systems must consider many more factors and interactions than when working with monoculture systems. The below-ground interactions between crops, such as those involving the use of water and soil nutrients, are probably more important than the above-ground interactions (Snaydon and Harris, 1979). The objectives of farmers further complicate the work. In some parts of Uganda, for example, when farmers grow maize and beans together they want to obtain full bean yield and some "bonus" yield of maize, whereas in other areas where maize is an important staple crop, the opposite is true.

Beans are grown primarily by resource-poor farmers. Therefore, it is necessary for research agronomists to improve the production systems using little additional purchased inputs. Indigenous materials suitable as soil amendments and fertilizers should be investigated. Nitrogen fixation needs to be stimulated. Opportunities may exist to manage existing or added soil nutrients to reduce losses. Low input systems of soil fertility management need more attention.

This paper briefly discusses relevant areas of research, suggests research requirements and methods and discusses relevant considerations. The main research areas considered are:

1. The adjustment of low soil pH to reduce exchangeable Al, to reduce phosphorus fixation, to increase cation availability and to obtain sufficiency levels of Mn,
2. Phosphate rock use,
3. Nitrogen fertilization, and
4. Phosphorus fertilizer application.

Amendment of Low pH Soils

High hydrogen ion concentration is probably less detrimental to plant growth and biological nitrogen fixation than other indirect effects of low pH. Aluminium and manganese toxicity problems often occur. Phosphorus availability is low and basic plant nutrients are displaced by Al and Mn and often are inadequate in low pH soils. Soil amendment with lime often can alleviate these disorders, but efficiency of lime use is important to improve its appropriateness for resource-poor farmers. Further research is needed on alleviation of Al toxicity effects and P fixation by liming; effects of liming on Mn, B and Zn; use of alternative Ca sources to neutralize Al, including lime, gypsum and ash;

Liming Effects on Aluminium and Phosphorus

Increasing soil pH by liming is expected to reduce Al toxicity and increase the availability of P. The amount of lime required to neutralize the toxic effects of Al is dependent on the level of exchangeable Al in the soil and the soil's buffering capacity. Highly buffered acid soils, for example, will require more lime than those that are less buffered at the same level of acidity (Singh and Uriyo, 1978). The use of exchangeable aluminium as the criterion on which to base lime rates has been proposed for soils with a low permanent charge and a relatively high pH-dependent charge (Kamprath, 1970). The level of exchangeable Al for a particular soil should be determined using an unbuffered salt such as 1N KCl. Kamprath (1970) suggests that the following formula can be used to estimate lime requirements, but that the milliequivalents of $CaCO_3$ required to neutralize the Al range from 1.5 to 3 for each milliequivalent of exchangeable aluminium.

$$\text{meq } CaCo_3/100g = (\text{meq exchangeable Al}/100) \times 2$$

Precipitation of Al results in increased phosphorus availability. The hydroxyl groups will react with $Al(OH)_2^+$ and precipitate it to $Al(HO)_3$, thus rendering the $H_2PO_4^-$ available for plant use.

$$Al(OH)_2H_2PO_4 + OH^- \longrightarrow Al(OH)_3 + H_2PO_4^-$$

Liming Effects on Mn,B,and Zn

The effects of Mn on plant growth varies from deficiency to toxicity, depending on several soil factors as well as genetic factors of the plant. Assessment of the Mn status of plants related to growth needs can be done by plant tissue analysis and interpretation according to toxicity and deficiency ranges. Increasing soil pH should alleviate toxic effects of Mn but may result in Mn deficiency as well as lime-induced deficiencies of other elements such as boron and zinc.

Boron and zinc are less available at high pH levels and may become deficient with liming resulting in lack of bean yield responses. Zake (unpubl.) failed to get a response to lime application, possibly because of lime-induced micronutrient deficiencies. This problem is accentuated on poorly buffered soils. B and Zn deficiencies can be alleviated by applying these micronutrients to a soil that has been limed.

Liming Materials

Liming materials commonly used are $CaCO_3$ and $Ca(OH)_2$. When magnesium is limiting, it may be preferable to use dolomitic limestone which supplies both Ca and Mg. When available, ashes can be used. Zake (unpubl.) obtained greater response in bean yield from ash incorporation than when the soil was amended with $CaCO_3$ or with $CaCO_3$ + K. In fact the latter amendments resulted in lower yields than the control. He attributed the beneficial effect of ashes to their K content. Results in Table 1 indicate that nutrients other than K and Ca were released (Benites and Valverde, 1980). Greenhouse trials by Whiteway and Nduku (1967)

Table 1. Nutrient contribution of ash and partially burned material to an Ultisol of Yurimaguas, Peru after burning a 17 year-old forest

Element	Concentration	Total Additions, kg/ha
N	1.72%	67
P	0.14%	6
K	0.97%	38
Ca	1.92%	75
Mg	0.14%	6
Fe	0.19%	7.6
Mn	0.19%	7.5
Zn	132 ppm	0.5
Cu	79 ppm	0.3

Source: Benites and Valuerde, 1980

in Zimbambwe obtained no yield response to S and Mo unless used together with $CaCO_3$, and then there was also a positive interaction between S and Mo. Liming effects on the availability of other elements must be considered when conducting liming research.

In soils that do not have an appreciable amount of exchangeable Al and/or Mn, only small amounts of lime may be needed to supply Ca to the plant and the *Rhizobium* species. Such small amounts of lime can be applied as lime pellets or in a basal application and allowed to equilibrate with the soil for some time before a crop is planted. Pelleted lime dissolves slowly, reducing chances of lime-induced nutrient deficiencies.

Phosphate Rock Use

Phosphorus deficiencies on acid soils can often be alleviated with applications of phosphate rock (PR). Indigenous PR deposits may offer a relatively inexpensive means of supplying phosphorus to crops. The agronomic effectiveness of PR under field conditions is variable but PR has been most effective when soils are acid and extremely deficient in P (Khasaweh and Doll, 1978). An additional advantage of using PR is its effect as a liming material. There is usually an increase in pH when PR is applied to an acid soil and a corresponding decrease in the exchangeable aluminium. Excellent reviews of PR research have been written recently by Hammond *et al.* (1986) and Le Mare (1987).

Characterization of Phosphate Rock

The first thing to be done is to characterize the phosphate rock. The rock materials occur in three main groups, namely the iron and aluminium phosphates, the calcium-iron-aluminium phosphates and the apatite minerals. Laboratory analysis can be done to determine the composition of the PR material, its reactivity and its P_2O_5 content. Reactivity varies widely with the PR composition.

Determination of Processing Requirements

The effectiveness of PR and its processing requirements are dependent on its P_2O_5 content and its reactivity. Minimizing the amount of processing may result in a less expensive product. On low pH soils, with low levels of P, some PR materials may only require fine grinding to be agronomically effective. In some PR materials, silica and carbonate contents are high. With heavy-media separation, using a magnetite suspension, a rock which contains only 18% P_2O_5 can be beneficiated to contain 27%. P recovery can be as high as 75% (Lombe, 1987). Partial acidulation (PA) can improve the solubility of the ore-using acids such as nitric, phosphoric and sulphuric acids. Since sulphur is deficient in many acid soils in Africa, it may be advisable to partially acidulate with sulphuric acid to produce sulfuric acid based-partially acidulated phosphate rock (SAB-PAPR). SAB-PAPR can then be a source of both the P and S for plant use. The silica and calcium in it will react to neutralize exchangeable Al ions.

Determination of Rates and Timing of PR Application

The agronomic effectiveness of the PR product is affected by soil characteristics, the reactivity of the product and its P concentration. The use of PR products needs to be studied to determine when and in what quantities the product should be applied. Highly reactive phosphate rock can be applied directly to the soil at planting time. If reactivity is low, however, it may be advisable to apply some time before planting to allow the PR more time to react with the soil solution, and it may be necessary to apply larger quantities so that P is released gradually over several seasons. It may be necessary to apply a small dose of single superphosphate to supply the immediate needs of the crop. Early application of PR may improve the effectiveness of the soluble P fertilizer as the silicate and carbonate contained in the ore will react with exchangeable Al such that there will be less fixation of the soluble P applied subsequently (Smyth and Sanchez, 1982). The rates of either PR or super phosphate to be applied will depend on the fixation capacity of the soil and also the crop's requirements.

A measure of the effectiveness of PR is its Relative Agronomic Equivalence (RAE), or simply the superphosphate equivalent (SPE). This is determined using a complete yield response curve for superphosphate. One can then estimate the superphosphate equivalent of the PR source.

Effects of Soil Factors on Phosphate Rock

The agronomic effectiveness of PR increases with decreasing pH until a point where fixation of P exceeds dissolution of PR. The solubility of PR increases as pH decreases, though the agronomic effectiveness of the PR may decline at lower pH as more of the released phosphate will be fixed. Francolite-like apatites, for example, are very unstable at low pH levels and they release the P to react with Al and Fe in the soil matrix and form more stable Al and Fe compounds (Smyth and Sanchez, 1982).

Solubility of PR is affected by the availability of P and Ca in the soil. These are products of PR dissolution. A soil's affinity for P and Ca promotes the dissolution of PR because it provides a sink for $P_2O_4^-$ and Ca^+ that are released by the congruous dissolution of appetite. To determine PR solubility, one can measure the changes of the soil P fractions, namely the Ca-P and Al-P which form shortly after PR has been applied to an acid soil.

Use of Other Materials with PR

The addition of other materials with PR may hasten its dissolution in the soil. Acid-forming nitrogenous fertilizers such as ammonium sulphate may enhance dissolution of PR. When the ammonium is oxidized, two moles of hydrogen ions are released for each mole of NH_4^+ and become available for the dissolution of the PR.

$$(NH_4)_2SO_4 \longrightarrow 2NO_3^- + SO_4^= + 2H_2O + 4H^+$$

This reaction will also supply sulfur to the crop. Applying elemental sulphur with PR may improve the availability of phosphorus because the sulfur will be oxidized by *Thiobacillus* bacteria to produce sulphate ($SO_4^{=}$) which will react with water to form sulfuric acid. The sulphuric acid will further acidulate the PR in the soil and both sulphur and phosphorus will be supplied. Composting PR with organic materials or applying PR with farmyard manure may increase the availability of P as the organic acids produced will act to acidulate the PR.

Bean Plant Factors Affecting PR Effectiveness

Differences among plant species or varieties in their ability to utilize phosphorous from PR depends upon their requirements for both phosphorus and calcium, and how they affect the soil solution in the rhizosphere (Le Mare, 1987). The effects of root exudates on the pH of the rhizosphere, extensiveness of the root system and the effectiveness of the plants' relationship to mychorrizae are likely to be important. Genetic variation probably exists among bean cultivars for these characteristics.

Nitrogen Application in Bean-based Cropping Systems

The nitrogen economies of the cereal/legume system, the tuber crop system, and the tree/legume system are complex. Nitrogen is very liable to competition between intercrops because of its mobility. Further, legumes may either improve the soil N status through N fixation and excretion, or in the absence of fixation, compete for N. A monoculture experiment conducted by Edje *et al.* (1975) indicated that nitrogen fixation in dry beans is inadequate as they responded to fertilizer nitrogen up to 200 kg N/ha. The yield was 2150 kg/ha at 0 kg N/ha to 3779 kg/ha at 200 kg N/ha. The quantity of N_2 fixed by the legume in a intercropping system will depend on the species, plant growth habit, density of the legume in the mixture and the management of the system (Ofori and Stern, 1987). Further research is needed on bean plant physiological characters affecting genotype by cropping system interactions for biological nitrogen fixation and on the effects of management practices on nitrogen fixation and efficient use of soil nitrogen.

Bean Plant Factors Affecting the Nitrogen Economy

Indeterminate varieties generally will fix more nitrogen than determinate varieties due to the greater "sink" in the indeterminate variety. Table 2 demonstrates this point clearly whereby a indeterminate cowpea variety fixed more N than the determinate cultivar. The importance of growth habit and time to maturity in beans on the nitrogen accretion in the polycrop system should be further investigated.

Table 2. Nitrogen balance in determinate and indeterminate cowpea cultivars

Cowpea Cultivar	N Uptake (kg/ha)	N Fixed (kg/ha)	Seed N (kg/ha)	Residue N (kg/ha)	N Balance (kg/ha)
ER-1 (Det.)	32	50	48	34	+2
TVu-1190 (Indet.)	33	101	49	85	+52

Source: Ofori and Stern, 1987

Nitrogen Management

The legume plant in the intercropping system must be adequately nourished for the legume crop to grow well and to create a substantial "sink" to stimulate fixation of N_2. Legumes generally conserve what soil nitrogen is available and add to it in direct proportion to the size of the "sink" created by the yield potential of the crop (Bouldin *et al.*, 1979). When soil N is not readily available to it, a grain legume is likely to more actively fix nitrogen if other edaphic factors are favourable (Burton *et al.*, 1961). There is a need to study how N can be applied to non-legume species without inhibiting the fixation of nitrogen, possibly using applications of low N amounts at planting time or using slow-release N fertilizers. Ofori and Stern (1987) give a number of suggestions for future research on nitrogen in cereal-legume intercropping systems including:

1. Investigation of pathways of N losses to reduce losses and improve N use efficiency;
2. Research on the effects of early applications of low doses of N on nitrogen fixation;
3. Research on the effectiveness of slow-release fertilizers on the nourishment of the cereal component and on nitrogen fixation;
4. Determination of the amounts of fixed N in below-ground parts of component crops to be able to accurately estimate N balances.

Phosphorus Application in Bean-based Cropping Systems

Phosphorus is one of the major nutrients that determine the productive potential of most polycrop systems. Normally legumes are poorer competitors for P when intercropped with nonlegumes, because of their less extensive root system (Ofori and Stern, 1987). Ofori and Stern (1987) reported on work by Lai and Lawson (1962) who evaluated root competition for P between maize and intercropped bean using ^{32}P-labeled fertilizer placed at different depths. They found that maize was more vigorous in taking up P than beans, apparently because the maize had a more extensive root system. Research on fertilizer P rates and placement is needed to determine how it can adequately nourish the component crops in such a way as to meet the farmers' objectives.

Examples of fertility responses equations for multiple cropping situations are scarce. Waghmare and Singh (1984) used multiple regression equations for predicting responses to applied fertilizers. Wahua (1983) proposed the use of a nutrient supplementation index (NSI) for the estimation of fertilizer requirements for multiple cropping systems based on the relative nutrient uptake of the system compared to the sole crop system and basing fertilizer requirements on sole crop recommendations. Barker and Francis (1986) suggest that computer simulation models may play an important role in the future in screening through many combinations of management practices, including fertilizer practices, to identify the most promising combinations which could then be field tested. In soils with high P fixation rates, point or band placement of P is likely to improve the efficiency of P use. The placement of P fertilizers relative to the bean plants and other crops in the system is likely to affect the relative competitiveness of the component crops.

Economic Analysis of Fertilizer Experiments

Research on fertilizer use is usually conducted with the goal of making recommendations to farmers. While statistical analysis is useful in determining what is happening biologically in a system, economic analysis is needed to determine if a practice is more profitable and less risky than the farmers' practice. The manual by Perrin *et al.* (1979) is well written for agronomists wishing to conduct economic analysis. They discuss various procedures for identifying and evaluating alternative management practices in consideration of farmers goals, including the estimation of net benefits of technologies, the costs and returns to investment capital of technologies and the stability of technologies.

Partial budget analysis is useful in the estimation of net benefits for the various technologies. Basically, this is done by estimating the difference for each technology between gross field benefits (total of net yield times field price for all products of the crop) and total variable costs. This analysis is usually done on the average yields for each treatment when the experiment is conducted in a number of environments.

Marginal analysis is conducted to reveal how the net benefits from an investment change if the amount invested increases. Marginal net benefit is the increase in net benefit obtained from a gross increment of investment. Estimation of marginal net benefit is important because most farmers, both large and small, face capital scarcity. A farmer generally considers several alternatives when deciding where to invest capital, and will probably try to invest where high, but reliable, returns are expected. Further, many farmers need to borrow money and as the cost of their capital increases, often the marginal net benefits of other investment alternative that the farmer has are unknown to the researcher if these are outside the range of the experiments. Therefore, Perrin *et al.* (1979) suggest that an investment should give returns of 40% per production cycle if it is to be viable.

Farmers try to avoid possibilities of occasional high losses while seeking higher profits. Therefore, an analysis of the variability in net benefits (risk-analysis or benefit stability analysis) should be done before making a recommendation. Variability of net benefits of a treatment is a function of yield variability and price variability. Perrin *et al.* (1979) suggest that one procedure for incorporating risk aversion into the process of deriving recommendations is to add a 20% "risk permission" into the direct cost of capital. Relative risk of "disaster" among alternatives can be determined using the mean of minimum returns analysis in which the 25% or so worst outcomes of each treatment are compared to those of other treatments. Because prices and costs are expected to change from year to year and farmer to farmer, a technique called *sensitivity analysis* should be used. In this procedure, the costs and prices are changed within reasonable bounds of the original estimate to determine if the ranking of alternative treatments is affected.

Summary and Conclusion

Bean yields are expected to increase due to improved varieties and better cultural and harvesting practices. Higher yields increase the nutrient requirements of the bean crops and the complexity of management. Better low input management practices will be needed for beans grown in pure stand and in multiple cropping systems.

Research in bean growing countries of Africa should not only concentrate on the use of soluble fertilizers to solve nutrient deficiency problems, but also investigate ways of improving the availability of native and applied soil nutrients. Phosphorus deficiency problems should be studied together with those of aluminium toxicity. Efforts should continue to improve the efficiency of use of P fertilizers and phosphate rock. When P is being applied to soils at high rates, the relationship of P to other soil nutrients, especially zinc, becomes more important. Nitrogen needs to better managed to meet the needs of the component crop without inhibiting N fixation by the bean crop. The management of applied nitrogen, phosphorus and other nutrients needs further research for beans grown in association with other crops to increase the yield of all component crops and to provide an adequate "sink" to stimulate nitrogen fixation.

The ultimate goal of fertilizer research is to develop superior soil fertility management practices. The viability of the alternatives is dependent on how they affect the productivity of the system, but also on how they affect the stability and profitability of the system. Economic analysis of the profitability and stability of alternative practices should be a part of the research process.

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Review of Bean Responses to Applied Fertilizers in Africa

C. S. Wortmann and J.Y.K. Zake

CIAT Regional Programme on Beans in Eastern Africa and Faculty of Agriculture, Makerere University, Uganda

Introduction

Bean yields in Africa are generally low, though high yields on small plots are frequently obtained. Yield is often constrained by inadequate plant nutrition. To improve plant nutrition, two strategies among others can be followed, either improving the adaptation of the crop or by adjusting the soil properties to better meet the needs of the crop. With the first approach, varieties are sought which are tolerant of the prevailing stresses. With the second approach, soils are amended by applying fertilizers, adjusting soil pH, adding organic matter, etc..

Beans fix atmospheric nitrogen, but generally the amount fixed is insufficient for a crop to meet its full yield potential. Beans are frequently grown on soils with high phosphorus fixation rates and low phosphorus availability which often limit bean yield. Yield responses to applied nitrogen and phosphorus are frequently observed. Potassium deficiency is less commonly observed than deficiencies of nitrogen and phosphorus, but can be expected on many soils if they are continuously cropped. On low pH soils, yield responses to lime are common. Responses to secondary and micro-nutrients have been studied, although not widely, and occasional responses have been documented. Beans are frequently grown in association with other crops and their relative importance varies considerably across recommendation domains. This makes it more difficult to determine how best to manage soil fertility to best meet the farmers' objectives. This paper reviews work which has been accomplished on responses of beans to fertilizers and amendments.

Nitrogen, Phosphorus and Potassium

Edje *et al.* (1975) applied six levels of nitrogen to irrigated crops of beans for two years in Malawi and obtained a linear increase in yields ranging from 2150 to 3779 kg/ha. Increased pods per plant contributed to the increased yield, but the response to increasing levels of nitrogen was quadratic and pods per plant were most numerous at intermediate nitrogen levels. Seed size increased linearly with increasing levels of nitrogen to 26.6 % more than the size for the no nitrogen treatment, and accounted for much of the increase in yield. A quadratic response to nitrogen was observed under non-irrigated conditions where grain yield increased by 60% with 40 kg/ha N, but little additional response was gained when 80 kg/ha were applied (Edje, et al., 1976). Results from other NPK factorials in Malawi have shown highly significant responses to N and P, but negative responses to K, even at 5 kg/ha (Edje et al., 1980). The compound fertilizer 20-8.7-0 (N-P-K) at the rate of 200 kg/ha, depending on soil test results, was the 1980 recommendation for bean production in Malawi.

Responses to nitrogen in the southern highlands of Tanzania have been inconsistent, though generally positive in recent years (Mayona and Kamasho, 1988). Beans have consistently responded to phosphate application with increased yield. No response to potassium was found. Based on village level trials, recommendations have been formulated to apply 60 kg of both nitrogen and phosphate to beans in Iringa region and 30 - 40 kg of both nitrogen and phosphate in Mbeya region.

Anderson (1974) reported on 91 bean trials on Mt. Kilimanjaro in Tanzania. He noted that the mean yields ranged from 133 kg/ha on one poor soil to 1115 kg/ha. The PK treatment gave the highest mean yield, 763 kg/ha, and the PK plus lime treatment was a close second with 735 kg/ha. Soil associations with the widest Mg/K and Ca/K and low percentage exchangeable potassium had significant responses to potassium and some yield depression with lime application. In the Marang'a-Lombeta soil association, part of the response to K was attributed to leaching of K from the bean leaves by heavy rain. Responses to P occurred only at the middle and high altitude zones, i.e. above 1160 masl. P response was negatively correlated with soil pH and base saturation, probably because of reduced P availability in the more acid soils, but also due to reduced fixation of nitrogen. Bean leaf nitrogen was increased by P application suggesting that reduced nodulation in the low pH soils was limiting yield. Overall, the response to P was highly significant ($P = 0.001$) and to K and lime significant ($P = 0.05$). There were slight yield depressions with K and lime application on some soil associations, whereas no negative effects of P application were noted.

Mongi (1972) reported good yield response when N, P and lime were applied together in Morogoro, Tanzania. They suggest that on these Oxisols, which had less than 0.2 me/100g of exchangeable Al in the absence of lime and nitrogen, the amount of exchangeable Al was not a suitable criterion for liming. Rather, liming to correct soil pH was more satisfactory. Rweyemau and Ndunguru (1984) studied the effects of organic manure and fertilizers on bean yield in Morogoro. Manure was applied at rates of 7.5, 15.0 and 30.0 t/ha. Other treatments included 7.5 t/ha manure, plus 10 kg P and 25 kg N, and 20 kg P plus 50 kg N. Highest yields were obtained with 7.5 t/ha of manure, plus 10 kg P and 25 kg N. All treatments were superior to the control.

In western Kenya, on-station trials have shown little or no response to applied nitrogen or phosphorus (GLP Reports, 1980-1982). These findings are partly supported by results of on-farm trials. In Kakamega district, the response to fertilization were not economic, but in Kisii district, there was an economic response to applied phosphorus, but not to nitrogen (Floor, 1984).

Yield responses to fertilizer in central and eastern Kenya have been varied. There was no response to fertilization in on-station trials in Marang'a and Machakos districts (GLP Report, 1980-82), though in earlier work on ferrasols in Thika, beans responded to N in the presence of P (Floor, 1978). Yield increases were obtained at Kabete with phosphorus application (Ssali *et al.*, 1981, Ssali and Keya, 1980, and Mbugua, 1986). but responses to nitrogen have been inconsistent (Ssali *et al.*, 1981, Ssali and Keya, 1980, Chui, 1988). Greater responses to fertilization were observed in on-farm trials (Floor, 1984). In Machakos, 77 trials were conducted and benefit/costs ratios exceeded two for 58, 24, and 33% of the trials, respectively for 138 kg CAN, 200 kg TSP and 200 kg DAP / ha. The response to nitrogen fertilizer was considered to be economical when soil N was less than 0.10%, but the response to phosphorus was not economical in Machakos district. In Embu district, bean yields were increased by DAP, but the response to either nitrogen or phosphorus applied alone were not economical.

Ohlander (1980) reviewed results of fertilizer research between 1972-76 on beans in Ethiopia. In trials conducted at Koka, Nazret and Melkassa, yield responses to 30-50 kg/ha P were frequently significant, especially if the soil was low in available P, but there was no response to P at Melkassa in later work (Desta, 1986). Response to nitrogen was generally not significant, unless applied with P. There was no response to potassium, sulfur, nor to residue P following sorghum or maize in this province. In Bako, responses to P were significant in 4 consecutive years, but significant responses to N were observed in two of these years only. In the Awassa area, significant responses to DAP and TSP were obtained at 4 of 5 locations. The response of beans to 46 kg/ha P was significant in Chilalo, and there was a response to 20 kg N in Adu. No responses were obtained in Wollano, Debre Zeit or Jimma. In more recent work at Melkassa, beans responded to both N and P one year but did not respond to either nutrient in the second year (Amare, 1987).

Stephens (1969) reported on responses to fertilization of six crops, including beans and groundnuts, in 8 locations in southern and western Uganda over 12 seasons. Beans responded to 104 kg/ha N at all locations with the exceptions of Kachwekano and Namulonge. Yield response of beans to 50 kg/ha TSP was significant at Kawanda only, but the responses to 50 kg/ha of muriate of potash were significant at three locations, including Rubale, Kawanda and Kakumiro.

Fertilization of groundnuts has been more studied in Uganda than that of beans. Foster (1980) analyzed the results of 1300 groundnut fertilizer trials testing the application of 0, 120 and 240 kg/ha of single super phosphate. He tentatively concluded that groundnut performance on ferallitic soils in Uganda is largely dependent on the influence of soil organic matter mineralization on the availability of soil phosphate. Groundnut responses to phosphate were related to mean organic matter levels and to factors which affect mineralization, including intensity of previous cultivation, hours of sunlight and mean rainfall. Groundnut response to P was not related to soil properties, but as response was related to factors which affect rate of mineralization, possibly the unpredictable effects of weather on mineralization during the season overrode the effects of soil properties.

Foster (1972) reported responses to potassium with several crops on a few low pH soils in Uganda, but only after 10 seasons of continuous cropping. The average increase in bean yield over all sites was 12% during the phase of 10 to 16 seasons of continuous cropping when 260 kg of muriate of potash per hectare was applied in alternate seasons. Little response to K occurred, however, unless soil pH was 5.2 or less. Greater response to potassium was observed in later and better managed trials conducted on Ugandan ferrallitic soils (Foster, 1979). Trials were conducted at five sites for six seasons. In contrast to earlier results, in which responses to K occurred only after four years of cropping, in these later trials, responses to K occurred in the first few years of cropping.

In Mauritius, (Mauritius, Ministry of Agriculture, Natural Resources and the Environment, 1968) two levels of NPK and manure were tested. The rates tested were 44.8 kg N, 89.6 kg each of P and K, and 37.5 t/ha of manure. All treatments yielded more beans than the control (3575 kg/ha) except the K and K + manure treatments. The mean yield for NP plus manure was 6500 kg/ha.

Salih and Salih (1980) reported on bean responses to N application over three years in Sudan with mean yields of 1286, 1613, and 1690 kg/ha at 0, 43, and 86 kg N/ha, respectively.

Liming

Beans are frequently grown on soils with pH's of less than 5.5. In Uganda, Mukassa-Kiggundu (1975) reported findings which indicate that soil acidity was the main factor responsible for the poor performance of beans in several areas of Uganda. On the other hand, Leakey (1970) regularly obtained 25-50% bean yield increases by applying a mixture of calcium ammonium nitrate, muriate of potash and SSP, but yield declined when lime was applied alone. Foster (1970) concluded that beans are likely to respond to liming of continuously cultivated Uganda soils only when the exchangeable calcium level is below 6 m.e./100g and also the soil pH is below 5.25. The beneficial effect of lime on beans was due to the removal of toxic aluminium. No consistent interactions of lime with other nutrients nor harmful effects of lime on Uganda soils were found. In later work on ferrallitic soils in Uganda, however, in which the yields were higher, bean yield increases regularly occurred with the application of 2.5 t/ha of lime on soils with pH's less than 6.0 (Foster, 1979).

These yield increases were accounted for by increased availability of phosphorus. Liming did result in higher P concentrations in the leaves. Foster (1976) reported significant and positive correlations between soil pH and available P for many Uganda soils, where on average, an increase in soil pH of 0.15 corresponded to an increase of 1 ppm in extractible P.

Anderson (1974) observed responses to lime in on-farm trials in Kilimanjaro district in Tanzania in 2 of 9 soil associations. These had pH's ranging from 4.9 to 5.9, with a mean of 5.4. In one high altitude association, response to lime was associated with low base saturation. Responses to lime elsewhere were found to be associated with low Mg/K and Ca/K ratios more than low base saturation. Depressions in yield occurred when Ca/K ratios were high. The percentage response to lime was negatively correlated with percentage base saturation, total base content, percent calcium saturation and pH. Regarding exchangeable calcium levels, all soils studied by Anderson had levels of exchangeable calcium in excess of 6 m.e./100g. In a pot experiment with five Kenya soils, Ssali (1981) obtained a yield response by adjusting pH from 4.2 to 5.7, but further increase of soil pH did not result in increased yields. Nuwamanya reported increasing yields with increasing levels of lime until soil pH reached 6.0, after which yields declined. Exchangeable Al was negligible at 5.5.

Sulfur

Apparently little field experimentation with sulphur fertilizer has been done in Africa on beans, and it is likely that other nutrients, such as nitrogen and phosphorus are generally more limiting. Also, sulfur was usually supplied in the inorganic fertilizers. Now, many fertilizers that supply the major nutrients contain little or no sulfur. On eroded soils, little sulfur is supplied through mineralization of soil organic matter, and sulfur deficiencies are likely to become more common. Some results are available from Kenya and Uganda. Bromfield et al.. (1980) observed inconsistent responses to applied elemental sulfur and gypsum in western Kenya. Bean crops which followed plough down of natural vegetation or pastures frequently gave a response to sulfur fertilizer. Esilaba and Ssali (1987) analyzed agricultural soils from around Kenya and concluded that most have low sulfur reserves and crops would probably respond to sulfur fertilization with continuous cropping. Foster (1972) used groundnuts as a indicator crop and found possible response to sulfur in only two of 457 on-farm trials conducted in Uganda, concluding that other crops which use less sulfur than groundnuts could not be expected to respond to sulfur fertilizer. Jones (1975) agrees with this conclusion but says that pot tests indicate that response to sulfur is possible on old arable soils if adequate nitrogen is present.

Other secondary and micro-nutrients

Little information is available on bean yield responses to secondary and micro-nutrients. Mayona and Kamasho (1988) reported an increase in yield from 1580 to 1828 kg/ha when copper was applied to soils at Uyole in the southern highlands of Tanzania. They also reported that a 10% increase in yield occurred due to foliar application of a cocktail of micro-nutrients. Zake and Nkwiine (1981) compared applied ash to lime and potassium, applied separately and together on an Oxisol at Kabanyolo in Uganda. Magnesium and phosphate were applied to the whole trial site. Best mean yields were obtained from the ash treatment, suggesting that either nutrient balances are important or that the ash supplied or improved the availability of some secondary or micro-nutrients which were limiting yield. In other field experimentation in Uganda, beans did not respond to 52 kg/ha magnesium oxide, nor to soil application of a cocktail of micro-nutrients, including zinc, iron, copper, boron and molybdenum (Stephens, 1969).

Organic manures

At Uyole, in the southern highlands of Tanzania, beans responded with increased yield to organic manure in two years of experimentation, though the response was statistically significant in one year only. The response was more pronounced at another location called Mbimba. Still, the yield was less with the organic manure than with 30 kg/ha of both N and P. No difference was detected between farmyard manure (FYM) and composted manure (Mayona and Kamasho, 1988). Also in Tanzania, Rweyemau and Ndunguru (1984) obtained the highest mean yield with a moderate rate of organic manure application (7.5 t/ha), together with an intermediate rate of nitrogen and phosphate fertilizers (10 kg P and 25 kg N).

Responses of beans to FYM in Kenya were generally positive, but often not significant. The greatest effects were observed in the relatively dry Machakos area. The lack of consistency in response to the manure suggests that farmers are not likely to apply it to beans, especially if other crops are more responsive. Furrow application of FYM was compared to broadcast application, and when results were significant, broadcast application was superior (GLP Reports, 1980-1982).

FYM was more successful than any combination of inorganic fertilizers in increasing bean yields on Uganda soils (Stephens, 1969). In these trials, however, negative interactions occurred between FYM and P, as well as FYM and K. Stephens (1969) concludes that the main benefit of FYM is the ample supply of K and a lessor benefit is the supply of P. The ability of manure to render available small amounts of a range of nutrients may collectively add up to an appreciable effect.

Phosphorus placement

Band or spot placement of phosphate fertilizer is expected to give more efficient phosphate utilization than broadcasting, especially on soils with high P fixation. Few research results are available for beans in Africa. Ssali *et al.* (1981) observed no significant difference between banding and broadcasting phosphate fertilizer on a Nitosol in Central Province of Kenya. In the southern highlands of Tanzania, however, Mayona and Kamasho (1988) obtained improved yields with banding, but an unexpected greater response to banding at higher phosphorus rates. Phosphorus fixation did not appear to be a serious problem in Uganda soils (Foster, 1980). He found the mean responses of groundnuts to phosphate application to be closely related to mean leaf P levels, indicating that absence of a response was due to an adequate soil phosphate supply and not to fixation of the applied fertilizer. Working with maize in Uganda, Mukassa-Kiggundu (1986) did not find any advantage to band placement of single super phosphate when compared to broadcast application, even after four seasons of continuous cropping.

Fertilizer management in multiple crop systems

Beans are most frequently grown in rotation with other crops or intercropped. Farmers often fertilize grain crops which precede beans in the rotation. Also, organic or inorganic fertilizers are often applied to benefit bananas or maize when they are intercropped with beans. Beans may benefit from such fertilization. In cases where the farmers value the associated crop more than the bean crop, enhanced bean competitiveness due to the fertilizer may be undesirable as the yield of the associated crop may be reduced.

Chui (1988) studied responses to intercropped maize and bean responses to N application in central Kenya and reported 14% and 5% increases in bean yield when grown in pure stand and when intercropped with maize, respectively. However, soil nitrogen levels were high at the start of the experiment and even the maize did not respond to the nitrogen fertilizer. Hinga, (1979) observed increased, decreased and no bean yield effects due to residual effects of phosphorus applied to the previous crop of maize. At Koka and Melkassa in Ethiopia, no residual effects of phosphate applied to both maize and sorghum were detected on the following crop of beans, though up to 115 kg P_2O_5/ha were applied (Ohlander, 1980).

Correlations between soil data, yields and responses

Anderson (1974) found pH and percent base saturation to be significantly correlated with percentage response of beans to P, K and lime. In this study, responses to lime occurred where the pH was below 5.5 and the base saturation below about 75%. Potassium responses occurred when the pH was below 5.6, the base saturation below 75% and the exchangeable K less than 0.72 m.e./100g. Responses to P occurred when the pH was less than about 5.7, the base saturation less than 78% and the HCl soluble P less than 36 ppm. Thus, Anderson concluded that bean yield responses to lime, phosphorus and potassium are likely to begin with soil pH of less than 5.6 and a base saturation of less than 75 percent.

Floor (1984) studied the relationships of bean response to fertilizer and soil parameters in Kenya. In Machakos district, he concluded that an economic response to 138 kg CAN /ha could be expected when percent soil nitrogen is less than 0.10% and there is good soil moisture. In the coffee zone of Embu district, response to 200 kg DAP /ha could be expected when percent soil N is less than 0.32%, when potassium is above than 0.30 me/100g and Al toxicity does not occur. For the cotton zone of Embu district, he recommended 200 kg TSP or 180 kg 20:20:0 /ha when %N is above 0.12% and potassium is adequate. In Kisii district, bean yield was found to be a function of soil pH, and P fertilization was recommended when soil P level was less than 25 ppm and pH over 5.9. CAN application was recommended for Kakamega district when soil pH is less than 5.8, K is adequate, and %N is less than 0.25%.

Stephens (1969) presented the results of nearly 100 fertilizer experiments conducted at more than 30 sites in Uganda. He found a significant relationship between yield response to applied N and soil carbon and nitrogen. For bean responses, he estimated the relation to be: $y = 50.59\ x - 61.01$, where $x = (\log C - 3/2 \log N)$. The mean response of a number of crops to applied P was estimated to be: $y = -6.92\ x + 45.9$, where x = soil pH. The mean response to applied potash was also correlated with soil pH, $y = -9.73\ x + 60.3$, where x = soil pH. The regression equation between soil pH (x) and response to FYM (y) was: $y = -23.86\ x + 149.3$. In other trials, the rate of mineralization of organic matter affected crop responses to fertilizers, and factors affecting rate of mineralization, including temperature and rainfall, were correlated to yield response (Foster, 1980). In another set of trials, little response to K occurred unless soil pH was less than 5.2 (Foster, 1972), but in later work, responses were observed at all sites when soil extractible K was less than 10 mg/100g and no significant response occurred when there was more than 18 mg/100g extractible K (Foster, 1979). On continuously cultivated soils, Foster (1970) concluded that beans are likely to respond to liming when exchangeable calcium is less than 6 me/100g and soil pH is less than 5.2. In later work, in which yields were higher, significant increases in yield were obtained with liming up to pH 6.0.

Conclusion

Responses of beans to fertilizers and soil amendments have frequently been observed. The responses, however, are probably less than observed for some other crops and less consistent.

Apparently, farmers have observed this also and are more likely to fertilize maize and other crops rather than beans. Economic responses to fertilization of beans have been observed, however, responses have occurred when maize failed to respond.

Frequent responses to the residue effect of manure suggest that the benefits may be largely due to the supplying of small amounts of many nutrients. Other evidence suggests that nutrients other than N, P & K are important. Zake and Nkwiine (1981) observed response to ash, but little to lime and K. In the Southern Highlands of Tanzania, best yields were obtained with a combination of FYM, plus N and P.

More response to fertilizers can be expected when management levels are high. Edje et al. (1975) observed dramatic responses to nitrogen under high management conditions. Foster (1979) did not observe much response to K and lime when pH was above 5.2 until overall management of the crop was improved.

Beans are frequently grown in association with other crops and this complicates the determination of optimal soil fertility management practices. Farmers' perception of the relative importance of the associated crops differ and further complicate the determination of how soil fertility should best be managed. Little information is available from work in Africa on the fertilization of this association. Guidelines are needed, possibly based on the needs of the component crops, to approximate the optimal fertilization practice given the farmer's objectives.

Information on the feasibility of extrapolating results from one zone to another are sketchy. Studies which related yield response to soil parameters give clues. Soil pH has been found to be an important determinate of response to nutrient applications in Uganda, Kenya and Tanzania (Stephens, 1969; Foster, 1979; Floor, 1984; Anderson, 1974). The Fertility Capability Classification (FCC) system of land classification relies heavily on soil texture and parameters which are associated with soil pH. It contains modifers for low CEC and low exchangeable K as well which Anderson (1974) found to be important in determining responses to some fertilizers. The importance of these soil parameters to the responsiveness of beans to fertilizers suggests that FCC may be useful in the extrapolation of research results on soil fertility management.

Questions concerning the use of fertilizers and system sustainability have not been well addressed by researchers in Africa. Stocking (1988) warns against seeing nutrients applied 'out of the bag' as the panacea for nutrient losses. Fertilization of inherently infertile soils may led to problems of acidification, nutrient imbalance and trace element deficiency. Fertilizer use needs to be studied as a means of increasing the duration of productivity of a soil before it needs to be fallowed, keeping in mind that its use on some soils increases the changes of causing irreparable damage.

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Agroforestry Research in Bean-based Cropping Systems of Subsahalien Africa: A Review of Research Methodologies and Results

Willi Graf and Dr. Valence Ndorehayo

CIAT Great Lakes Bean Program, Rwanda and Institute des Sciences Agronomiques du Rwanda

Introduction

The objective of this paper is to review the research done in the field of agroforestry in bean-based cropping systems. Since the definition of the topic narrows the number of relevant research experiences, some interesting results from other regions are considered also. In turn, there may be a bias in the selected literature towards research done in Rwanda which is a country with particular interest in agroforestry.

Agroforestry is a cropping system where perennial trees are interacting with annual crops or with livestock (Combe, 1979). The result of intercropping trees and crops is a higher return on land (Muyarugerero, 1985) which is the primary reason why traditional agroforestry systems are being observed in areas where high productivity of land is the main agronomic goal of farmers. This is usually the case in the fertile parts of African highlands which are densely populated. Agroforestry techniques are considered especially valuable and have become a major objective of the research centres attached to the Consultative Group for Agricultural Research (CGIAR, 1988).

The agro-ecological features of the regions with highly intensified agricultural production using traditional agroforestry techniques fit perfectly with the requirements of the bean crop which plays a major role in the diet of the rural population in these areas. As an example, beans provide over 50% of the protein in the average diet in Burundi (ISABU, 1987). In Rwanda, where beans are equally important as in Burundi, up to 60% of the total bean production is produced in association with bananas which is considered here as an agroforestry system. Much of the remaining bean crops interact in some way with perennials.

On top of the agro-ecological and agro-economic coincidence of requirements for the development of agroforestry and bean-based systems, beans is a crop which is physiologically well adapted to the type of competition which occurs in association with trees. Eriksen (1984) found that compared with soybeans *(Glycine maximum)* and cowpea *(Vigna ungiculata*) beans yielded better under shade, and its nitrogen-fixation was not as dramatically reduced as that of the other legumes. The findings of Edje (1983a) and of Redhead *et al.*(1983) are similar but there the comparison was with maize which is, as a cereal, more susceptible to light competition than legumes.

In general, beans have their roots in the first 30 cm of the soil which makes them compatible with taprooted trees. Therefore the main type of competition is light competition except for the *taungya* systems where trees are intercropped in the establishment phase.

Table 1: Classification of Agroforestry Research Activities

Type of Activity	Definition
Tree-focussed	- Evaluation of different tree species/cultivars in association with crops - Evaluation of different management practices for trees grown in association
Crop focussed	- Evaluation of variety/system interractions - Evaluation of crop production/tree management interactions - Introduction of trees for immediate crop benefit
Soil and fertilizer focussed	- Monitoring of soil parameters under agroforestry conditions - Evaluation of soil parameter/crop or/and tree management practices interactions
Farmer-focussed/ Economic analysis	- Research including systematic evaluation of proposed technologies by farmers - Active participation of farmers in trial design - Cost/benefit analysis on farm level for new agroforestry systems

Classification of Research Activities

Agroforestry research is conducted by researchers with very different backgrounds, and according to the backgrounds, their objectives and methodologies may vary considerably. We would like to suggest the following classification scheme which may cover most of the actual activities.

Tree-focussed Activities

The consultative meeting on "Plant Research and Agroforestry", held under the auspices of the International Council for Agroforestry Research (ICRAF) in Nairobi in 1981, which brought together crop scientists, foresters and ecologists, made extensive recommendations on how to select and manage trees. Working groups on plant management and plant types useful in agroforestry emphasised the importance of considering the multiple goals of farmers when designing agroforestry systems. The group working on selection criteria for trees was concerned with benefits expected from the tree environmental resources, time available to achieve first positive results (e.g. end of erosion), preferences for local species and maintaining genetic variability.

The group studying plant management aspects concluded that plant management practices should not compete with other land-use practices and should be socially acceptable to farmers. Labour requirements should be measured regularly.

Tree-focussed agroforestry research in bean-based cropping systems means doing crop evaluations also. Edje (1983) tested *Gmelina arborea, Leucaena leucocephala, Acacia Albida and Eucalyptus camaldulensis* in 3x3 m spacing in association with beans and maize. He found that beans did not reduce growth of any of the tested tree species, where as maize hampered develepment of the relatively slow-growing *Acacia albida* (Table 2). On the other hand, Eucalyptus reduced yields of beans by 8%, Gmelina by 16.3% and Leucaena by 18%, as Acacia caused yield losses of only 5.3% in the first two years after tree establishment. The authors of this paper observed negative effects of beans on *Leucaena leucocephala, Calliandra calothyrsus* and *Sesbania sesban* during the establishment phase of the trees compared to plots with sweet potato or maize as association partners. No yield losses of crops were noted in the same period of time through the presence of trees.

Table 2: Plant height (cm) of trees in monoculture or in association with crops at 18 months

Crop	Mono-culture	In association with: Beans	G/nut	Maize	Mean	S.]
Acacia	144.3	130.1	127.9	89.5*	123.0	10.
Eucalyptus	254.6	242.3	257.7	240.2	248.6	20.
Gmelina	238.7	262.3	245.9	251.2	249.5	9
Leucaena	289.8	211.9	324.6	311.6	284.5	16.

* height significantly reduced at (p = 0.05)
Edje, 1983

Redhead (1983) provided another interesting example of a *tungya* system approach. *Eucalyptus camaldulensis* was intercropped with maize and beans in the first 12 months. A clean weeding treatment and spot weeding treatment completed the trial. Differences of tree stem diameter between treatments were significant with bean intercrop and clean weeding being the best treatments (Table 3).

Table 3: Height and trunk diameter of 12-month-old *Eucalyptus camaldulensis* intercropped with beans and with maize, compared with trees clean-weeded and spot-weeded

Treatment	Height m	Diameter mm
Intercropped maize	238	1141
Intercropped beans	247	1560
Clean-weeded	254	1777
Spot-weeded	191	668
LSD p = 0.05	NS	640
LSD p = 0.01	NS	919

NOTE: Spot weeding involves clearing a circle of one metre diameter (measured at the root collar).

Source : Redhead *et al.*, 1981

Crop-focussed Activities

Similar to the orientation for tree selection and evaluation, the ICRAF workshop in 1981 defined some guidelines for crop research in agroforestry. The respective working group stated:

> For this (selection of understorey crop) it is necessary to undertake the following:
>
> - first to study the socio-economic context
>
> - then, to promote dissemination of genetically diverse herbaceous crops (not just sole-crop cultivars) for farmers themselves to integrate into complex site-specific agroforestry systems (Huxley, 1981, p. 580).

Agronomists especially have been comparing the adaptation of different crops to agroforesty conditions. It is not only that the best crop should be grown; other goals are constant food supply, self-sufficiency in agriculture and the need to rotate crops. Edje (1981) found that beans are better adapted to agroforestry systems than groundnuts and those again better than maize. Beans yields, increased whereas groundnuts stayed stable and maize yield declines. His results were not confirmed from Nyabisindu data over 5 cropping seasons (Table 4). There maize took (next to sweet potatoes) benefited more from the presence of . These data are somewhat surprising and were not confirmed in ISAR trials (Egli, pers. comm.)

Table 4: Influence of tree presence on yields of understorey crops (means over 5 cropping seasons in (kg/ha)

Crop	Yield		Yield	LSD	
	without trees	with trees	differences %	5%	1%
Maize	1204	1476	23	169	225
Beans	798	885	11	68	94
Soybeans	312	244	22	55	74
Sweet-potatoes	2439	3375	38	814	1102

Source : Neumann and Pietrowicz, 1986

Completely different are the trails where the tree component is entirely designated to serve the crop. Rachie (1981) described an experiment in Colombia at CIAT where high densities of *Leucaena leucocephala* were planted and killed with herbicide when they reached the stage where they could serve as stakes for climbing beans.

Similarly, the authors of this paper are trying to link the integration of leguminous, fast-growing trees in Rwandan farming systems with the promotion of climbing beans in bush bean-growing areas. Climbing beans have a higher yield potential than bush beans but require more input in the form of labour for staking, harvesting and fertilization. In on-station experiments in two agro-ecological zones *Sesbania sesban*, *Leucaena leucocenphala* and *Calliandra Calotyrus* were planted in a systematic design (1852 to 6667 trees/ha) and intercropped with a traditional rotation of beans maize/sorghum and sweet potatoes. Tree-to-tree variation and nonhomogeneity of fields accentuated problems inherent to systematic designs, but the results show that Calliandra is much superior in stake quality and biomass production to Leucaena (Table 5).

Sesbania was ruled out for its bad coppicing rate. Tree density influences crop yields even when the trees are regularly cut at 1.5 m height in order to produce stakes; this does not hinder the development of the understorely crop. Such is shown in the same trial series by the example of sweet potato which fails to yield at tree densities of approximately 5400 trees/ha (ISAR, 1988).

Table 5: Stake and organic matter production of selected agroforestry species grown in association with climbing beans in Nyamishaba, Rwanda

Species		Stakes/ha	Fresh matter t/ha
Leucaena leucocephala	*	5566	10.0
Calliandra calotyrus	**	7400	14.4
Sesbania sesban		1160	2.0

* 18 months after planting
** 18 months after cutting at soil level
Source : ISAR, 1988

In another experiment by the authors, *Sesbania magrantha* is simultaneously grown with sorghum in season B (March to July) in a random association at densities of 50,000 Sesbania and 100,000 plants of sorghum approximately. After the sorghum is harvested, the Sesbania are left on the field in order to serve as stakes for climbing beans in season A (September to January). The data obtained so far indicate that the presence of *Sesbania magrantha* in the first season does not reduce yields of the associated crops. However, *Sesbania mangrantha* caused 65% yield loss of climbing beans because of water competition during the germination of beans (ISAR, 1988).

Preliminary results were obtained from trials on bean genotype/system interactions. Of special relevance is the banana/bean association which accounts for maybe 50% of bean production in the Great Lakes Region of Africa and is important in other areas too. Semi-climbing beans seemed to be better adapted than bush or climbing beans (ISAR, 1988). Similar experiments under different densities of *Grevillea robusta* do not, however, confirm these findings, but the unexplained variation in trials was far too high to permit persistent conclusions. In the Grevillea/bean trials, serious water competition effects at early flowering were observed with 7 year old Grevellea. Equally, an experiment on a 15m wide north/south terrace bordered by 12-year-old Grevillea revealed clear competitive effects of the trees at the interfaces (first 5 m from tree lines) compared to the central zone but no interaction between growth habits and zone of cultivation of beans (ISAR, 1988).

Soil and fertilizer focussed activities

One of the primary concerns of agroforesters is the effect of agroforestry systems on soil conservation as one of the major controllable factors which influence the sustainability of agricultural production system. The argument of soil improvement has often been used to justify the promotion of agroforestry (Pathak, 1982), but in practice it may be difficult to measure the impact of agroforestry on soil parameters.

In Nyabisindu, the earlier cited researchers compared an agroforestry system composed of *Grevillea robusta* (6 years old at beginning) and maize and beans as understorey food crops and a control without trees. Soil parameters were virtually the same, although the variation within one cropping season was somewhat smaller in the agroforestry plot. The parameters evaluated were: pH, total nitrogen (Kjeldahl), C/N ratio, calcium and magnesium. In this experiment, there was no response of crops to fertilizer though leaf drop was observed.

Other researchers however found different results. Schnurr (1984) reported remarkable increases for total nitrogen, potassium and organic matter as well as higher phosphorus contents in maize plants when intercropped with a mixed *Grevillea robusta, Erythrinia abyssinica* and *Albizzia shimperiana* population. Sanchez (date unknown) presented an exemplary experiment studying the effect of *Gliricidia sepium* as an intercrop on a maize/bean relay cropping system in Costa Rica. The complicated trial included superimposed treatments with nitrogen fertilizer and herbicide applications for weed control. The multilocational trial was conducted over four bean and three maize cycles. The leaves of Gliricidia were used as mulch at the rate of 1.5 kg/sq.m. The results suggest that the mulching treatment without herbicide or additional fertilizer is equal or better than the high input treatment with fertilizer, nitrogen and mulch. But at the same time yields of the input control were not always inferior to mulching or other input treatments. The authors acknowledged that the number of *Gliricidium sepium* planted (6667 plants/ha) would not be sufficient to provide 1.5 kg of mulch per/sq m and that Gliricidia was a modest supplier of phosphorus.

Edje (1983) reported that beans responded to 15 tons of Leucaena with higher yield than to 250 kg/ha of a compound fertilizer (20-8.7-0). He, however, noted that P-levels in Leucaena leaves were much lower than reported by other researchers (0.09%) compared to up to 0.4%). He estimated that 0.25 ha planted with Leucaena could provide as much nutrients as 150 kg calcium ammonium nitrate. Edje's findings are supported by later results obtained with fertilization of other crops as well as beans (Hussein, 1988; Ghagas, 1981). Leucaena prunings appear to be an excellent source of nutrients compared to other leguminious trees (Table 6).

Table 6: Effect of leguminous tree leaves on dry weight (g/pot) and nutrient (N,P,K,Ca, and Mg) uptake (g/pot) by sorghum.

	Dry weight	N uptake	P uptake	K uptake	Ca uptake	Mg uptake
Control	71.42 d	0.45 h	0.027 c	1.09 e	0.096 h	0.193 e
Urea	116.12 ab	1.43 b	0.019 b	2.82 b	0.306 b	0.613 ab
Bauhinia purpurea	104.50 bc	1.23 d	0.086 c	2.37 c	0.238 e	0.500 c
Cassia fistula	92.92 c	1.05 e	0.074 c	1.90 d	0.225f	0.370 d
Prosopis juliflora	104.00 bc	1.09 e	0.082 c	2.23 cd	0.225	0.460 cd
Albizia procera	87.45 c	0.90 f	0.064 c	1.79 d	0.179 g	0.380 d
Dalbergia sissoo	92.35 c	0.68 g	0.065 c	1.92 d	0.218 f	0.380 d
Pongamia pinnata	95.95 c	1.06 e	0.072 c	2.00 b	0.238 e	0.420 d
Sesbania sesban	108.55 b	1.31 c	0.112 b	2.51 c	0.277 c	0.570 b
Leucaena leucocephala	122.35 a	1.56 a	0.127 a	3.11 a	0.362 a	0.670 a

Source: Hussein, 1988

Several working groups of the above cited ICRAF meeting in Nairobi in 1983 stressed the need to properly describe and analyse existing agroforestry systems. The recommendation to allow farmers the choice of plant selection within a wide range of herbaceous crops made available to them sounds almost revoulutionary to agronomists' ears. This level of farmer involvement in the design of interventions in cropping systems is rather unusual. On the other hand the statement may be considered as a sign of resignation in face of the complexity of the evolving systems. Agroforestry researchers have as their primary goal the development of a system beneficial to farmers. However, we only want to consider research as farmer-focussed, when farmers are actively involved in the research process.

Economic Analysis

The agroforestry project in Nyabisindu based its economic analysis almost entirely on returns and did not integrate important costs such as labour in overall analysis. Also, it only considered the complete system, excluding the establishment phase (Neumann, 1986). Table 7 gives an idea of the calculations made in Nyabisindu where beans are one of the principal annual crops.

The same observation is true for economic calculations carried out by ISAR for a *Morus alba*/bean trial with *Morus* laid out in a systematic design (ISAR, 1987).

Table 7: Influence of tree presence on monetary return of two crop associations (FRW/ha) (1 US$ = 80 FRW)

Crop combination	Value of trees excluded		Value of trees included		LSD
	absolute (Frw)	relative %	absolute (Frw)	relative %	5% (Frw)
Maize Beans (short rainy season)	41994	100%	52415	125%	6757
Maize/soybeans/ sweet potatoes (long season	60459	100%	70130	116%	n.s.

Source : Neumann, and Pietrowicz 1986

Farmer Participation

ICRAF, in its methodological guidelines, gives highest importance to the description of existing systems (diagnosis and design), but field cases in which farmers were actively involved in the design of agroforestry systems are rather rare. This is true for bean-based systems as well as others. Some of the work done with active participation of farmers may, however, not be available in research documentation because they are sometimes confounded with extension.

The authors of this paper see aspects of their own work in agroforestry linked with climbing bean promotion as possible examples. The study in question was carried out in collaboration with the German Project in Nyabisindu and local authorities involving various researchers of different disciplines.

Seed of climbing beans was distributed to over 100 farmers in southern Rwanda (Plateau Central/Dorsal Granitique) with recommendations on how to grow climbing beans since most farmers grew only bush beans. After one season farmers acknowledged the higher yield potential of climbing beans as compared to bush beans but complained about the problem of finding enough stakes (Ukiliho and Graf, 1987) (Table 8).

Table 8: Importance of staking as factor limiting climbing bean production as seen by farmers (% of the farmers interviewed)

Very important	82
Moderately important	15
Little important	3
No. of farmers	81

Source : Ukiliho and Graf, 1987

The idea of using agroforestry techniques for stake production has long been considered by researchers in Rwanda (Egli, pers. comm.). The link with climbing bean extension in areas where they are not currently grown may drastically change the cost/benefit structure during the establishment phase of the whole system and therefore its acceptability to farmers. Tree seedlings of *Leucaena leucoephala*, *Sesbania sesban* and *Calliandra calothyrsus* were given to a small number (5) of farmers among the 100 collaborators in the climbing bean study. All of these farmers expressed interest in growing more climbing beans but were concerned about the availability of stakes. The trees were established on edges as the most obvious way to integrate trees in the Rwandan farming system where anti-erosion lines have become a standard due to government interventions and various extension activities.

Farmers are regularly visited, and the management of the trees as well as their various products (forage, stakes, green manure, fuelwood) are discussed.

The reactions of farmers to the new trees varies considerably depending on farmer circumstances. It appears that richer farmers are less interested in both trees and climbing beans. If interested in the trees, they rather see forage as a primary benefit. Smaller farmers have more interest in the system as a whole and are more motivated to start experimenting with management techniques such as different prunings, propagation and different uses. This difference may be due to the fact that richer farmers have more land and evaluate a system for return on labour rather than on land.

Group meetings of farmers were held to introduce the idea of planting trees to produce stakes, but a second phase of tree distribution has yet to be initiated. The potential success of the proposed system will be evaluated by the number of farmers adopting the system and the extent of this adoption. At the same time, complementary studies on the benefits of agroforestry on soil conservation and fertilizer application on associated crops are carried out on-station. Other options for stake production like the *Sesbania magrantha* /sorghum experiment described earlier are tested on-station and discussed with potential climbing bean farmers brought to the station. The way *Sesbania magrantha* will be tested with farmers will depend on their comments on the tree and possible integration in the system. At the same time a third option is tested in on-farm-experiments; this is a relay system with maize and climbing beans.

Summary

Results in the have been literature reviewed. It is striking that more publications are available for the first three types of research than on farmer-focussed work, although the review may be incomplete.

The results show (with some exceptions) that beans are a particularily well adapted crop to agroforestry systems and that they are able to take advantange of tree products. Stakes for climbing beans and nutrients recycled through the use of leaves as green manure are the most evident benefits. Beans appear to be tolerant to shade but suffer especially from water competition at germination and early flowering. Thus they tolerate high densities of trees when there is either sufficient water available or when only minimal root competition for water occurs. Water competition may be minimised through adequate management of trees or through species selection for compatible, natural rooting patterns.

Because green manures provided by tree leaves tend to be low in phosphorus, this ought to be studied; in many areas where beans are grown, phosphorus-deficiency occurs due to soil acidity. Additional sources of phosphorus or techniques to increase soil pH may be needed to assure high bean production in agroforestry sytems.

Although not widely accepted as a research topic, system x genotype interaction studies should be initiated, especially for the widely distributed systems like the banana bean association. It is also known that different tree species react differently to the presence of beans during tree establishment. It is not clear how these initial effects affect the cost/benefit analysis of the whole system seen over a longer period of time, but it affects this ratio for the first phase of tree establishment and therefore the acceptability of the system. Data on adoption of systems proposed through research are rare or not yet available. The same is true for detailed economic analysis and models.

Methodologies

The results available for agroforestry systems in relation to beans is considerable. Many useful conclusions can be drawn from them to guide the promotion of agroforestry, especially in small-holdings. However, it is necessary to review the types of trials and studies in order to see how appropriate, relevant and acceptable they are to farmers.

The tree-focussed activities mostly use an approach where a few tree species are compared in a system with one bean variety as an understorey crop. The question we would like to ask for these trials is whether it should be the objective to select one species of trees for the final system. A mixture of species would make more sense. In the example of producing stakes of climbing beans, *Calliandra colothyrus*, *Leucaena leucoceohala* and *Sesbania sesban* were tested simultanously but not mixed. Of the three species, only one (Sesbania) was rejected; the other two are being investigated with the clear intention of integrating both into the final system. It is also clear that many other species such as *Cassia spectabilis* could go into the system without extensive prior testing. It might have been better to test a mixed tree population or work with just one species as an example. This would have added possibilities of more relevant factors such as management of trees or different varieties of crops. The same is true for the comparison of different crops as long as it is not in a *taungya* system.

On the other hand, the authors do know of one case where large numbers of trees are screened under constant presence of crops. It would be an obvious and easy thing to integrate tested trees into agroforestry systems.

The preliminary studies on system x genotype interactions revealed quite a number of methodological problems which need solutions before large numbers of genotypes can be evaluated. One is the heterogeneity of experimental plots induced not only through soil heterogeneity but also, and important, through tree-to-tree differences in growth pattern, leaf fall and other factors. It may also be difficult to keep soil preparation equal over a large field with trees planted on it.

Systematic designs have been used by a number of researchers. These make it possible to evaluate a wide range of tree densities on little space. However, it is probable that optimal densities from the farmer's point of view would vary according to his production goals and that farmers would find it easy to adjust densities by cutting or planting trees. For this reason it might in general be more appropriate to test different densities of trees in randomized block design. Problems with heterogeneity would be less severe and again it would be easier to superimpose other factors.

From the papers reviewed it seems to be a major problem for researchers to decide on what parameters to measure. Nobody wants to tie up all his resources with just one experiment which would be easy if all relevant observations in an agroforestry system would be carried out using standard methodologies. Obviously the objective of the trial should help answer this question. For a genotype x system experiment it would be necessary to understand the mechanisms causing interactions but less important to do extensive soil analysis or to evaluate tree production parameters.

Disappointing is the fact that only relatively little work is done which can claim to integrate farmers adequately in the research process. Looking at the work relevant for bean production, it appears that agroforestry research is going a similar neo-technocratic way as did intercropping research (Graf, 1987). This is in spite of the emphasis ICRAF has given in its set of methodologies to farmer involvement. Researchers generally are ready to go into extensive diagnosis of existing systems, but when it comes to designing new systems or to incorporate new components into a system, farmers are put aside. Some researchers even try to justify the transfer of entire systems from one area to another through wired theories about the inability of farmers to respond to the constantly changing environment. This is especially dangerous when we consider how rare serious economic evaluations of agroforestry systems are. The cost/benefit ratio from implementation to final stage of the system needs further attention and might explain many problems with extension of agroforestry systems, especially when soil improvements are the primary objectives.

The fact that high returns on land are an important characteristic of traditional agroforestry systems should guide the promotion of new systems. Also, in traditional systems, species with a high value primary product like fruits or first class construction wood are particularily frequent (Hummel, 1985).

Tree introduction along with climbing bean promotion could be an example of how to better distribute benefits over time. The possibility of growing more climbing beans would be the main benefit in the first phase of the establishment of the system. Later, farmers would profit from other advantages such as firewood, forage/green manure production and soil improvement. This sequence does not mean that all potential benefits must be outlined to farmers at the beginning of experimentation.

As methodological tools to achieve increased farmer involvement, on-farm-trials and group evaluations of on-station-experiments need to be used much more. Economic models could help to further the adoption of a proposed system in concert with systematic evaluation and fine tuning by farmers, assisted by researchers.

The authors disagree with the recommendation of the ICRAF working group which was to just let farmers choose from a wide range of crop species. In this field there is potential to do a lot of interesting research using participatory methods. Farmers' opinions should be taken as much or more into account as are other factors. The methodology used to find these opinions should be recognized as an essential research tool for agroforesters.

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Discussant's Comments On Session Five

Enos Shumba

Department of Research and Specialist Services, Harare, Zimbabwe

The extensive review, of research results on Agroforestry (AF) tends to suggest that AF has yet to be proven as a technically sound land use system. I am therefore not surprised by the poor farmer participation which you raised as an issue. My conclusion is based on the fact that most of the results do not verify the stated objectives of AF, namely: a) the provision of higher returns to land and b) the maintenance of system sustainability. I will briefly critique the ways in which these objectives were evaluated:

a. Higher returns to land as measured by the yield and economic return from an AF system.

   (i) For trees, plant height and diameter were used to compare the superiority of different AF systems (Tables 2 and 4). Unless these parameters are strongly correlated with yield (biomass), this analysis is misleading.

   (ii) For field crops, the yield benefit from the different AF systems is inconsistent.

   (iii) With respect to economic returns, the 20% improvement (Table 12) is misleading because it excludes costs of establishing the trees and the long term benefits from the practice.

b. System sustainability as measured by improved soil fertility and soil conservation.

   (i) Improvement in soil fertility:

   - Changes/improvements in soil parameters as measured in different AF systems have been inconsistent.

   - The effects of mulches on crop performance in an AF system have not always been superior to the no-mulch system. Furthermore, it is questionable whether such systems will provide sufficient herbage for mulching.

   - The result that 250kg/ha of a compound fertilizer gives a similar yield as 15T/ha of Leucaena leaves (Edje) does not prove much because the economic values of the two nutrient sources were not worked out.

   (ii) Better soil conservation. No results were presented on this aspect.

This critique shows that although AF is a conceptually sound practice, the results reviewed do not portray it as a technically superior practice in the short and long term. I therefore suggest that the discussion groups should consider the following issues as they relate to AF:

a. Short versus long term benefits: To get the farmer interested in AF it might be worthwhile to identify and emphasize the short term benefits based on the farmer's needs, e.g. the use of trees in an AF system as stakes for beans (Graf).

b. Comparing the benefit from the use of tree herbage when used as fodder for livestock and as a mulch: using the herbage as fodder could also improve the quality of manure.

c. The need for: (i) systematic long term studies to quantify the benefits of AF under controlled conditions on the research station,and (ii) the streamlining of AF evaluation criteria.

d. Methodological issues raised in the paper included:

   (i) Testing a mixture of tree species in an AF system. This would complicate the evaluation of the system given the already existing tree x tree variation within species.

   (ii) Going for simpler designs in agroforestry. Given that AF is still in its early stages of development (based on the reviewed data), systematic designs have a place especially in on-station trials.

I further propose that subgroup discussions focus on other cropping systems that can improve soil fertility:

a. Crop rotations: Given that beans give a lower response to N and P compared to cereals and some legume crops and that its response to N and P depends on the initial soil nutrient status, planting beans after a well fertilized cereal crop could have some merit. However, as the rotation system eventually implemented by the farmer is influenced by other non-technical factors such as crop prices, family objectives should not be overlooked in research design.

b. Intercropping: Although absolute yields from the individual crops are sacrificed, returns to land are maximised and the combined fertilizer input is reduced. Issues to be addressed in this cropping system include:

   i) the choice of bean cultivar should take into account the fact that climbing, late maturing cultivars fix more nitrogen than bush types;

   ii) the effect of the intercrop on soil fertility in the subsequent season.

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Soil Organic Matter: Review of Research Results

Kidane Georges and Roger Kirkby

Institute for Agricultural Research, Nazreth, Ethiopia and CIAT Regional Programme on Beans in Eastern Africa

The Role of Soil Organic Matter

Traditional forms of soil fertility maintenance, described by Edje, Semoka and Haule in this volume, often depend upon conservation and use of organic matter from crop residues, tree leaf fall, and so on. The earliest known reference to green manuring is for China prior to 1134 B.C., and lupins were used by the ancient Greeks. Research in Africa since the 1960s has concentrated upon inorganic fertilizers, and recent literature on organic matter is scarce despite the low rates of inorganic fertilizer use in Africa.

Soil organic matter (OM) comprises humic material (mostly negatively charged colloids, bound to clay) and plant debris in various stages of decomposition.

Soil OM is important in determining soil physical structure, chemical properties, water relationships and biological activities. In addition, OM lying on or close to the soil surface confers particular properties that can affect the fertility and productivity of the soil mass.

Soil physical properties

Porosity and infiltration rates for water are increased by OM. Infiltration rates exceeded 12.5 cm per hour in mulch experiments at Samaru, northern Nigeria (Lawes, 1962). Runoff from soil liable to encrustation (capping) by raindrop impact is reduced by surface OM, and close linkage has been noted between increased infiltration and erosion control on fine sandy soils in East Africa (Russell, 1973).

Similarly, drainage of clay soils is improved by raising OM content. Water-holding capacity is enhanced, although availability of water is increased only in sandy soils, due to the tight binding of water to OM, especially in peat soils. Evaporation losses are reduced by surface OM.

Aeration is improved by greater porosity associated with soil aggregation. Physical tilth is improved by soil particle aggregation, with the result that timing of cultivations is rather less dependent upon ideal weather and soil moisture conditions, and farmers' tillage bottlenecks may be relieved by end-of-season or early-season ploughing.

Maximum soil temperatures are lowered, particularly by surface OM, giving improved germination, seedling establishment and biological nitrogen fixation (BNF) in lowland tropical situations - whether this is important for beans (e.g. in Somalia or Mauritius) is not known.

Chemical properties

Cation exchange coefficients (CEC) are higher in soils with more humified OM, and the negatively charged organic colloids generally have a higher CEC than the clay portion of the soil. Nevertheless, the clay component can be dominant in determining overall CEC of some soils having a high OM content (Murphy, 1963).

Buffering capacity is provided by the colloidal properties of humus and clay, and is highest in fine textured and organic soils. This prevents damage to crops as acid and base composition of a soil changes during the season.

Chelation of metallic ions by humic colloids can make micronutrients more available, provided that they are not too strongly bound or fixed.

OM is an important source of plant nutrients, particularly nitrogen: one-third to one-half of cereal crop N is left in residues at harvest, and P, K, Ca and Mg are also commonly available. Nutrients are released by mineralization at the start of the rains. Nitrogen cycling in agricultural ecosystems was recently reviewed by Wilson (1988).

Biological effects

Organic matter enhances the level of microbial activity within the soil. Provided other factors (such as moisture) are not limiting, rates of microbial decomposition of plant residues and mineralization of nutrients increase with OM content. The resultant increase in soil aggregation leads to general improvement in soil structure.

Crop root penetration is facilitated by high OM content and low bulk density of soil. Greater rooting depth increases the available volume of soil water; greater root development, both superficially and deep in the profile, increases the uptake of P.

Interactions of Management Practices with Soil OM

Implications of seasonal effects on decomposition

Under steady environmental conditions, net mineral-ization of soil N is at a low level. OM decomposition rates are at least doubled by each 10^{o} C rise in temperature (in USA soils), and are promoted by a soil moisture regime between wilting point and field capacity. (Soil micro- and macro-organisms and OM composition are the other factors controlling residue and OM decomposition).

Interruption of soil biological activity, most commonly by dry conditions, is usually followed by stimulation of mineralization of N in easily decomposable humus. This leads to the nitrogen flush at the start of the rains, first demonstrated under field conditions in Kenya by Birch (1960a) and now sometimes referred to as the "Birch effect". Its widespread occurrence in different soils and climates of East Africa was confirmed by Semb and Robinson (1969). Soil nitrogen levels remain low during periods of regular rainfall, due to plant uptake and to lower rates of mineralization and nitrification. Net mineralization resumes as the rains end and nitrification continues as long as soil is moist.

The initial flush of N is highly leachable. Taking advantage of showers before the main rains to plant early, or practising dry planting ahead of the expected start of the rainy season, enables a quickly growing crop to benefit from this flush. As the amount of N mineralized in this flush is greater the longer the dry season (Birch, 1960b), early crop establishment may be particularly beneficial in semi-arid monomodal rainfall areas such as the Ethiopian Rift Valley and Southern Africa bean production areas.

Bare fallow, and soil having an exposed surface during the dry season (due to crop removal or heavy grazing), also tend to have high levels of nitrate-N at the top of the profile due to more humus decomposition. At Kawanda, Uganda levels of 100 ppm in the top 15 cm of fallow soil were recorded by Griffith (1951) and of 200 ppm in the top 5 cm by Mills (1953).

Crops that are traditionally planted late in the rainy season, such as cotton, sunflower, sesamum and chickpea in Eastern and Southern Africa, develop on residual soil moisture and cause more rapid drying of the soil profile. Following crops might be expected to benefit from a larger flush of N, although this aspect of annual crop rotation does not appear to have received research attention.

Nutrient cycling in cereal-legume systems

Cereals usually benefit slightly or not at all from nitrogen fixed in the root nodules of intercropped legumes. Rather, the benefit usually accrues to the subsequent cereal crop. In eastern Kenya beans contributed 44 to 80 kg N/ha in a bean-maize rotation, the higher increment being recorded in a wetter season (Nadar and Faught, 1984). Soil OM plays an important intermediate role in this transfer. Kang's (1987) review of N cycling in these systems indicates that much less attention has been paid by researchers to the efficiency of the transfer process than has been paid to increasing the N supply through BNF.

Minimising losses of OM and nutrients

Soil erosion causes a disproportionate removal of the OM portion; hence all practices that minimise erosion contribute to the maintenance of OM and of soil properties conferred by it. Bean crop management trials at Nazreth, Ethiopia showed that the innovation of ridge planting was more effective than traditional broadcast planting on the flat in controlling erosion, provided that heavy rain did not fall before ridges had stabilized. However, in a year when heavy rain fell only 13 days after ridging, the traditional local bean practice was much better (and as good as natural grass cover) in preventing runoff and conserving soil and OM (Table 1; Abiyo, 1987). In the Nazreth area farmers' practice of not weeding beans has some mitigating effect in further reducing erosion early in the season.

Table 1. Mean soil moisture, organic carbon, bulk density and infiltration rates for bean planting methods at Nazreth, Ethiopia. 1981-82.

Treatment	Soil moisture (%)	Organic carbon (%)	Bulk density (g/cc)	Infiltration rate (mm/h)
Beans on ridges	11.81	0.47	1.24	248
Broadcast beans	12.18	0.87	1.35	260
Bare fallow	9.92	0.76	1.32	224
Natural grass cover	12.34	0.86	1.29	196

Source : Abiyo (1987)

Leaching of nitrate in high rainfall areas can be reduced by early planting, by cereal-legume intercropping and by relay cropping practices that involve a longer period of rapid crop uptake and dense root development. Cereals and legumes are complementary in mixed cropping patterns; under sole crops in Senegal, nitrate leaching was found to be higher under groundnuts than under millet (Gigou *et al*, 1985).

Minimum tillage techniques are used traditionally to permit early planting in some areas of Eastern and Southern Africa (Kirkby, 1989). These techniques include pre-digging of planting holes. However, constraints of labour availability and the weakening of draft animals by dry season feed shortage severely limit many small farmers' ability to plant early (Collinson, 1984).

Even in higher rainfall areas, alternating wet-dry conditions can occur on steep hillslopes and lead to a series of small N-flushes. Only with careful management can N be conserved for crop production. In one such situation in eastern Zaire, farmers cut and lightly incorporate early weed growth before planting beans. During later weeding of the bean crop, "good" weeds (recognised as those which are easy to remove and which decompose rapidly) are selectively applied as green manure around coffee and banana plants at a time when soil nitrogen levels have decreased (Fairhead, 1987).

Lynch (pers. comm.) has suggested that incorporation of crop residues having a high C:N ratio (e.g. stalks not consumed by livestock) at the end of the season might be an effective trap for the N flush. This effect could strengthen current research in Southern Africa on end-of-season ploughing to permit earlier planting (Collinson, 1984).

Lowering soil temperature, by crop cover or mulching, reduces OM decomposition rates but may not be an important factor in highland bean production areas.

Source of OM

Plant root residues are more effective than tops in promoting the beneficial properties of humus. This difference is due to the more intimate contact between soil and decomposing roots; the gums produced are stabilized by protection from further microbial action, whereas aggregates formed from top residues are promoted by fungal mycelia which later break down together with the aggregate. Grass roots, being fine, can be suitable for short-term planted fallows to restore OM, although they do not act as a mineral pump to the same extent as a deep-rooted tree and do not have the N-fixing ability of legume fallows.

Top residues of different species vary in their effectiveness in cycling nutrients and maintaining humus content. High quality, rapidly decomposable residues are those which have high N and P content, high concentrations of readily metabolized sugars, low lignin content and absence of allelopathic compounds (Swift, 1988). These aspects are important in selecting green manure crops. The C:N ratio of residues can be useful in predicting the rate of decomposition, and low-N cereal residues may not contribute to an expected seasonal nitrogen flush. Parr and Parendick (1978) caution against relying upon the C:N ratio as this "says nothing about the availability of the C or N to microorganisms".

In a stable, natural system, different sources of OM contribute to soil fractions. These fractions decompose at different rates, tending to lead to a more constant availability and cycling of nutrients (Swift, 1988). This effect is distinct from another feature of the use of deep-rooted trees and shrubs in improved fallow and agroforestry systems, which is to pump nutrients, especially basic cations, from below crop rooting depth (Greenland, 1975).

Application of large amounts of organic residues can have long-lasting effects upon OM accumulation in soils at high altitude, as reported from Madagascar (Gigou *et al*, 1985). In most studies, however, OM levels have not been affected in the long term by application of OM, although microbial activity may be enhanced with long-lasting effects.

Management of crop residues

Between one-third and one-half of cereal grain crop N remains in crop residues at harvest. Other nutrients, particularly P, K, Ca and Mg, can also be recycled through management of crop residues in various ways:

- by burning: virtually all N is lost, as well as the potential anti-erosion and soil-conditioning properties; this practice commonly persists because little labour is required.
- by use as mulch: additional benefits of OM for soil surface properties have been mentioned above; no-till seeding through the mulch, and control of perennial weeds, can present problems.
- by incorporation of stover: short term storage of OM increases as the residues decompose but, in general, cultivation leads to a rapid decline in OM. In temperate agriculture, conventionally tilled fields have a similar average OM content to no-till but effects are not concentrated near the soil surface (Elliot & Papendick, 1986). Incorporation is labour-intensive but is used in some traditional systems such as the Sukuma split-ridge system and the matengo pit cultivation system of Tanzania.
- conversion by livestock: where livestock are closely integrated with crop production (e.g. much of Ethiopia, Zimbabwe), alternative uses for crop residues are difficult to consider; however, kraal manure is often very poor in quality by the time it is applied to crops. Alley-cropping research by ILCA and others may lead to more efficient cycling of nutrients between the crop and livestock components, with benefits for both.
- by composting: blending with complementary materials can promote microbial activity and conserve nutrients, but is labour intensive. Composting is discussed below.

Green Manuring

Effects on organic matter and nutrients

The most widely reported reasons for using green manures have been OM maintenance and as a nitrogen fertilizer; the latter was probably its original use (Joffe, 1955). Other inorganic plant nutrients, including P, K and Ca, can be returned to the soil as insoluble organic materials by incorporation of green manures.

Evidence on the value of producing green manuring crops for maintaining or increasing soil OM is conflicting. The incorporation of plant material with a high C:N ratio, which decomposes slowly, has been effective in improving OM content in some cases (Leukan et al, 1962). Differing results are likely to be due to other factors that influence soil microbial and faunal populations (MacRae and Mehuys, 1985). The higher rates of mineralization in the tropics make OM maintenance by direct application of OM even more difficult and, at best, repeated heavy applications are required (Kalande, 1968). Overall the literature suggests that green manuring has been much more effective as a source of N than of OM (Russell, 1973).

Effects on soil physical properties

The effect of green manuring on soil aggregate stability varies with soil texture and with the kind of green manure used; effects are of short duration unless frequent additions are made. Silty loam soils appear to be more responsive in this respect than clayey and sandy soils, and alfalfa is a particularly good source (Chester et al, 1957). An improvement in aggregate stability improves infiltration of water (Joffe, 1955). A more important effect of green manuring can be upon water retention capacity, particularly in sandy soils.

The addition of organic materials to a soil zone can be expected to decrease its bulk density because of the lower density of the added material, but field results are not consistent (Benvit et al, 1962; Mortensen and Young, 1960).

Effects on crop performance

Experiments in Malawi indicated that incorporation of *Leucaena* prunings increased bean yields; yield was increased further to 1706 kg/ha, 86% over the control, by also applying 250 kg/ha of a NPK fertilizer (Edge, 1983). The effect of the combined application may have been due to improvement of soil physical properties. Preliminary results from similar work in Kenya indicated better bean growth following green manuring with *Leucaena*, *Cassia* and *Terminalia*, although yield was not increased significantly (Sang et al, 1985). In south-west Ethiopia (where maize/bean intercropping is common), maize yields were substantially increased when planted after ploughing in *Dolichos lablab*.

Sources of green manure

Early experimentation in the tropics focused upon herbaceous legumes as green manure crops, in attempts to improve on traditional sources such as weeds and grain crop residues. Even where beneficial effects for succeeding crops were noted, there was little acceptance of the technique: land shortages in bean-growing areas deter producers from dedicating resources to an indirectly profitable crop, particularly in the case of small farmers in semi-arid areas where cropping periods are reduced.

The use of shrubs that retain foliage in the dry season may offer more potential, and recent research on alley cropping attempts to develop an acceptable system for simultaneous production of green manure and a productive crop. Additional benefits of intercropping with deep-rooted shrubs are nutrient pumping from subsoil, shading that reduces temperature and rates of OM decomposition and surface evaporation. Present work in this field includes alley cropping of beans with *Sesbania* and *Cajanus* spp in the Rift Valley of Ethiopia.

Mulching

Application of a layer of mulch to the soil surface alters microclimates in the vicinity of the soil/air interface. Beneficial effects on soil fertility have been found in many tropical ecological environments, but the nature of this utility varies greatly with soil type and with prevailing environmental limitations to crop growth.

Benefits

Generally the most important effects of mulching in semi-arid areas are upon soil moisture levels. Rainfall infiltration is enhanced by preventing breakdown of aggregates and surface crusting, and through favouring earthworm and termite activity. Evapotranspiration losses are reduced by restricting the growth of weeds, and evaporation from the soil surface is lowered by cooler temperatures and protection from wind. As decomposing mulch contributes to soil OM, improvements are also made to structure, moisture retention and retention period (Mane and Shingle, 1982).

Results from many African countries confirm the reduction in erosion by mulching (Hudson, 1971). However, the quantity of mulch must be sufficient (Lal, 1979), but minimum amounts generally have not been determined for most situations of soil, slope, rainfall and crop.

The OM added to the soil by the decomposition of vegetable mulch helps to improve structure and adds nutrients. On some acid soils organic mulches enabled plants to utilize a greater proportion of applied phosphate fertilizer by promoting root development near the surface, by decreasing P fixation, and increasing the downward mobility of P.

Effects on nitrate levels are varied. Levels of nitrate in surface layers were reduced in an acid soil in Uganda; this may have been due to the wet-dry cycle being diminished, to an increase in leaching, or to less upward movement of nitrate during surface evaporation (Griffith, 1951).

There can be other, more specific, benefits from mulching. The banana/bean association of Kagera, Tanzania constitutes a minimum tillage system maintained by banana leaf mulch. Suppression of weed growth is probably an important benefit. Beans are planted by chopping holes through the mulch, and overall labour requirements are low.

Interactions with pests and diseases are highly specific. Mulching of beans is recommended in Central America as a component in the management of web blight *Rhizoctonia microsclerotia*, which is soil borne and spread by rain splash. Termite damage to maize was reduced substantially in Nigeria (Lal, 1979), but termites are also responsible for the too rapid decomposition of termite-susceptible mulch materials.

Sources of material and feasibility

Mulching is a traditional feature of some systems (Stigter, 1984). The commonest mulches are made from organic materials, including cut grass, cut or fallen leaves, straw or processed residues (e.g. coffee hulls) and weeds. Well managed bananas are self-mulching with relatively little labour input. Beans intercropped in a slower growing cereal may confer some characteristics of a living mulch, but attempts to develop specialized living mulches (e.g. *Desmodium* spp) do not appear promising for adoption by small farmers.

Much research has tended to concentrate on the technical effects of mulching using materials transported from outside the field, without concern for socioeconomic feasibility. For this reason very little non-traditional mulching has been adopted in Africa except where this has been enforced, as in coffee production in some countries.

An inorganic mulch can be made from plastic or other wastes near towns. In the Canary Isles the value of volcanic ash for crop production in a hot, arid climate has been documented (Caldas, 1986). While there are plans to experiment with rock mulching in Ethiopia, this practice appears more suitable for robust and high value crops such as citrus.

Availability and cost are the principal limitations to mulching, which appears to need 5-10 t/ha of organic matter. Small farmers with mixed farming systems tend to value crop residues for dry season fodder, and labour requirements for cutting and transporting material are often unacceptably high. The greatest promise now lies in agroforestry systems in which suitable trees or shrubs are lopped *in situ* for mulching the associated crops. Possible competing uses for the woody material still need to be taken into account.

Composts

Composting is a biological process whereby a mixed microbial population converts heterogeneous organic matter into a stable, humus-like product useful as a soil conditioner and fertilizer.

Biological aspects have been summarised by Borowski and Liebhardt (1983). The origin of the practice seems to have been the need for an easily handled fertilizer in situations where animal manure was not readily available.

Benefits

Animal manure allowed to rot in the open loses at least 50% of N by leaching and to the atmosphere as ammonia. Labour constraints usually prevent incorporation of fresh manure into soil, a practice which can greatly reduce these losses, although "folding" a portable animal enclosure across a field shortly before ploughing is a traditional low-labour technique used in the western highlands of Ethiopia.

Adding to the manure readily decomposable but low-N wastes, such as crop residues, in a moist aerated stack conserves N and utilizes more of the residues. Some organic soil, partially decomposed manure or previously composted material is usually layered into the stack as a source of microorganisms. Incorporation of the finished compost provides a relatively stable source of OM, where much of the material is already decomposed; incorporation is easier than with fresh residues.

There have been very few reports of field trials with composts in Africa. In the Ivory Coast compost incorporated in a low-N soil at the rate of 10 t/ha produced an immediate yield response from maize; on fertile (N-rich) soil a considerable yield improvement also occurred, but only after a 4-year lag period. This delayed effect is likely to be linked with the long-term improvement seen in microorganism activity in organically-farmed soils in the USA, where this occurs despite the lack of effect of organic versus inorganic manuring upon total soil OM levels.

Occurrence in Africa

A traditional but crude form of composting consists of allowing manure, bedding and fodder remains to accumulate in the semi-permanent enclosures of zero-grazed livestock, as in high-density areas of northern Tanzania (Kasembe *et al*, 1983). In Africa's most densely populated area in northern Rwanda, household refuse is routinely composted in stacks or pits. Very large amounts of compost (e.g. 1200 t) were made on large coffee farms in Kenya before the advent of inorganic fertilizers (Wolryche-Whitmore, 1938). Approximately 10,000 t of compost were made in 1950 in the Murang'a area of Kenya by small farmers, schools and at local markets (Rimington, 1951).

Research results from Africa

There was considerable applied experimentation, informal and formal, with composting methods and materials in East and Southern Africa between 1925 and 1945. Advances were reported in a series of articles in the *East African Agricultural Journal*.

One line of investigation focused on the compostability and performance of waste products from coffee dehulling, cotton ginning, sisal extraction, local markets, etc. Although no overall assessment is provided in the literature, clearly large amounts of compost were produced in large "factories" and some was sold regularly to small farmers. Locally available materials for on-farm composting were sometimes too low in N; for example, the weedy grass *Imperata cylindrica* in Serere, Uganda produced a very poor compost with little humus formation (Stephens, 1937). Production of Napier grass specifically for composting could be economic on commercial farms but was not always considered to be so on small-scale farms (Stephens, 1937). Nowadays it is accepted that legumes need to be included in compost to provide N where manure is not available (Ngeze *et al*, 1983). A survey by FAO in 1979 which elicited responses from 57 countries suggested that few were able to provide information on amounts and kinds of organic wastes and residues that might have potential for increasing compost or mulch production.

A related line of research was on composting techniques. Various modifications were developed on the Indore technique from India (Beckley, 1937), particularly in order to simplify the process and to reduce or eliminate the need for carrying water. Either rain was allowed to wet the substrate before composting, or it was composted fresh before wilting (Tofte, 1937). Addition of roughly mashed leaves of the introduced spineless variety of *Opuntia* cactus was also said to be promising, due to its 80% water content.

Requirements for labour were reduced further by composting in an above-ground stack rather than in a pit (Rimington, 1951) and by the introduction of ox carts for hauling the finished product. This objective may be incompatible where pits are needed to conserve moisture.

Most authors at this time agreed on the need for 3-4 turnings of the heap during a composting period of three months. Total labour requirements were found to be 10 mandays and 3.5 oxdays per tonne.

More recently, the topic has been the subject of research by IRAT scientists in West Africa (Gigou *et al*, 1985). They found that the normal, aerobic methods with millet straw and manure involved a 25-50% loss in N during the initial two months, but that N-fixing microorganisms subsequently returned the N content to around its initial level. A longer composting period of 6 months (more if unchopped straw is used) is therefore necessary.

These authors also reported work in Senegal on anaerobic composting where methane (biogas) production was needed. The cereal straw component appeared little modified during this composting, and although laboratory tests showed the expected immobilization of N by the large amounts of straw, this was not a problem in field trials.

Some recent work, notably in Canada (Mathur et al, 1987) and now proposed in Burundi (Niyondezo, 1987), has examined composting as a technique for rendering rock phosphates into a more utilizable form. Peat has proven an effective acidulating agent for co-composting, but may not be necessary: decomposing OM from manure in normal composting can apparently achieve similar results. Current world literature and practices on co-composting of a nightsoil or sewage sludge with organic domestic solid wastes was recently reviewed by Obeng and Wright (1988). Health aspects and uses are also discussed.

Research Gaps in Africa

As Swift (1988) has commented, agriculturalists rarely study soil biological processes, due to the success (at least under resource-rich circumstances) of high input farming reliant upon fertilizers, pesticides and tractors rather than upon soil processes. Agricultural research in Africa, and more particularly that concerned with small farmers' productivity, has received most attention after the advent of the high-input era. A search of 50 years of the *East Africa Agriculture and Forestry Journal* revealed many papers on composting techniques prior to 1951, and none subsequently. Concern with the processes of accumulation and decomposition of soil OM was also concentrated in the first half of this period. We have a much better knowledge of the fate of N fertilizers, and incidentally on quantification of BNF, than we have of N losses to the atmosphere.

Within Africa, we have a better understanding of soil processes and their improvement in humid lowlands, on account of the research programmes of IITA and others in West Africa, than we have for bean growing areas.

Some suggestions for the future, with particular reference to bean production, include:

1. Nitrogen and phosphorus cycling studies in a few key cropping systems of Eastern and Southern Africa, concentrating particularly upon determining the nature and extent of losses. Potential innovations, e.g. in residue management and introduction of agroforestry, should be identified and evaluated so as to limit these losses in sustainable crop-soil systems for specific environments. These studies should form part of integrated research programmes to improve cereal-legume and banana-bean systems. Microbiological aspects should be included.

2. Farmer verification trials on management techniques for kraal/boma manure, to reduce nutrient losses and to determine the acceptability of labour requirements.

3. Survey densely populated, land-scarce areas for local sources of OM potentially for mulching and composting, and identify complementary materials for co-composting. Economic feasibility

should be determined before proceeding to evaluate local performance.

4. Develop an ability to predict, for given sets of materials and local conditions, how long surface-applied mulches will last. Conduct on-farm research on mulching effects and acceptability in situations where diagnostic studies suggest promise for the technique.

5. Evaluate agroforestry species and systems for mulching in different agroecological conditions.

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Role of Soil Organic Matter and Use of Green Manure Mulching Methods for Organic Manure Research

G.B. Singh

International Council for Research on Agro-forestry, Nairobi Kenya

Introduction

Soil organic matter has, since the dawn of history, been the key to soil fertility and productivity. In the earlier years, as nomadic populations moved about in search of places where they could settle down and till the soil, they selected the soils that were most productive, and this meant the highest in organic matter, even though they may not have recognised this fact. They knew almost nothing about soil organic matter, or how it functioned, but they reaped the benefits of it. In recent years, scientists have determined with considerable exactitude the reasons for the benefits commonly realised from soil organic matter (Allison, 1973).

Role of Soil Organic Matter

Organic matter plays major roles in the chemical, microbiological and physical aspects of soil fertility. Some of these effects are so hidden and intangible as to be almost ignored and greatly under-evaluated. The role of soil organic matter as a source of nutrients, primarily nitrogen, is the one phase of the subject that has been most emphasized, but it is only one of the important factors. The dynamic nature of soil organic matter is of far greater importance than knowledge of the exact nature of the organic constituents in humus. The transformations involved in the decomposition of plant and animal residues are brought about almost entirely by biological agencies, primarily micro-organisms and to a lesser extent soil fauna. In fact, humus itself is a colloidal amorphous material containing many living and dead bacteria. Micro-organisms and their products play important roles in soils, including their genesis, tilth, nutrient release and retention, erosion control and productivity.

Organic Matter in Major Soils of the Tropics

It is commonly believed that soils of the tropics have lower organic matter contents than soils of the temperate region (Mc Neil, 1964; Gouru, 1966; Bartholomew, 1973; Bohn, 1976). The red colour of many soils in the tropics, high temperatures and high rainfall are among the reasons cited in support of this generalisation. However, a detailed study carried out by Sanchez *et al.*, (1982) did not indicate any significant differences in percent carbon and C/N ratios between soils from tropical and temperate regions at any depth intervals (Table 1). Tropical soils with udic soil moisture regimes had significantly higher carbon and nitrogen reserves than ustic tropical soils at all depth intervals. Soils under tropical forest vegetation had significantly higher carbon and nitrogen contents and signigicantly lower C/N ratios at all depths than soils under tropical savanna vegetation. This study suggests that the organic matter status of tropical soils classified as Oxisols, Ultisols, Alfisols and Mollisols compare quite favourably with the main temperate region soils classified as Mollisols, Ultisols and Alfisols.

Table 1: Organic matter contents in soils from the tropics versus soils from the temperate regions

Perameter	Depth (cm)	Tropical soils (n=61)	Temperate soils (n=45)	Significance	CV% Tropics	CV% Temperate
% C	0–15	1.68	1.64	NS	53	64
	0–50	1.10	1.03	NS	57	69
	0–100	0.69	0.62	NS	59	75
% N	0–15	0.153	0.123	*	62	57
	0–50	0.109	0.090	NS	57	57
	0–100	0.078	0.060	**	57	52
C/N RATIO	0–15	13.7	13.6	NS	79	35
	0–50	11.3	11.3	NS	46	32
	0–100	9.6	10.0	NS	46	35

Source: Sanchez *et el.*,1982

Decline in Organic Matter Content of Tropical Soils

The organic matter content of cultivated soils in tropics declines more rapidily than that of soils in temperate regions; consequently, cultivated soils in the tropics generally show lower levels of organic matter (Bates, 1960; Greenland and Kowal, 1960; Jenny and Raychandhry, 1960; Klinge, 1962; Bourliere and Hadley, 1970; Bartholomew, 1972; Davidson, 1975; Volkoff, 1977; Gaikwad and Goel 1977; Kadeba, 1978, Aina, 1979; Smith, 1979). Several factors are responsible for the rapid decomposition and decline in organic matter content. Some important ones are deforestation and shifting cultivation, high temperature and decomposition rate, and soil erosion. Rapid decline in soil organic matter content and mean annual temperature (Jenny and Raychandhry, 1960). According to Vant Hoff's temperature rule, the rate of decomposition increases by two to three times with every $10^{o}c$ increase in mean annual temperature. High climatic erosivity, low concentration of organic matter and clay contents in the surface horizon and undulating terrain render large areas of humid, sub-humid and tropical Africa extremely vulnerable to erosion by water. Water erosion results in a preferential removal of the fine soil fraction comprised of the clay and soil organic matter content. Consequently, Lal (1980) reported a linear decline in soil organic matter content with accumulative soil erosion.

Management of Soil Organic Matter

In a given ecology, the upper limit of soil organic matter content is defined by the soil, vegetation and prevalent climate. Despite the differences due to natural factors, cultivation lowers the organic matter content to a new level of equilibrium, depending on soil and crop management practices that govern the addition and losses of this finite but vital resource. Crop rotation affects the humus content of the soil through effects on the amount of crop residue, root to shoot ratio, canopy over and protection against erosion. Crops that produce large quantities of residue with high C/N ratios favour higher organic matter content than those that produce less residue with low C/N ratio. Organic matter content is generally higher under fallow than in croplands. Many studies in the humid and sub-humid regions of West Africa have indicated that annual increase in humus during the natural fallowing phase depends on the annual amounts contributed by decaying litter and root residue minus the losses incurred through mineralisation and leaching (Nye, 1959). Planted fallows are sometimes more efficient than natural regrowth in improving soil physical properties, fertility and organic matter contents. The rate of build up in soil organic matter content depends on the amount of biomass production and fallow management. The practice of incorporating green plant materials into the soil has been extensively used, presumably for improving the soil. The positive effects of green manure in restoration of soil organic matter and crop yield in tropical regions have been reported by many researchers, including Foster (1953) in Hawaii; Singh (1963, 1965), Rai (1966), Primavesi (1968) Darra *et al.*(1968), Kute and Mann (1969), Somani and Saxena (1976) in India and Martin (1963) and Taha *et al.* (1968) in Africa. The conclusions of these and perhaps of other studies are best summarised by Singh (1963) who reported that after removal of above-ground parts of *Crotolaria juncea* grown as a green manure crop, it still increased the yield of subsequent sugarcane crops. Green manure had little or no residual effect on the organic C in the soil. Singh (1965) also mentioned that in the context of today's agriculture we cannot afford the practice of green manuring, but we can certainly grow one fodder or grain legume in a multiple-cropping sequence.

The use of compost and farmyard manure has long been recognized in the maintenance of organic matter status and in amelioration of soil physical properties. However, any substantial increase in soil organic matter content of the soil would require a rather sizeable amount and continuous application of farmyard manure over a long period. These conclusions were supported by many researches in India (Kanwar and Prihar, 1962; Singh, 1964; Das *et al*., 1966; Sandhu and Bhumbla, 1967; Sharma, 1969; Mishra *et al*, 1974; Basu, 1977; Poonia and Pal, 1979; Singh *et al*., 1980). Regular and substantial additions of crop residue, left on the surface rather than incorporated into the soil, have proven to be beneficial practices for a wide range of soils and agro-ecological environments. The main benefits include better soil and water conservation, improved soil moisture and temperature regimes in the root zone, favourable biological activity (particularly earthworm activity), addition of plant nutrients and build up of soil organic matter reserves (Lal and Kang, 1982). Tillage systems and methods of seedbed preparation have a significant effect on soil organic matter content. In general, frequently ploughed soils have lower organic matter content in the surface horizon compared to less frequently ploughed or unploughed soils. Burning, widely practiced as a method of land-clearing in traditional systems in the tropics, affects ground cover, soil temperature and moisture regimes which may influence the decomposition rate and losses due to soil erosion.

Organic Matter Research

Most of the research in the past has been on the nutritional aspects of organic matter. Time, rate and method of application of farmyard manure, green manure, oil cakes, bonemeals and crop residues have been investigated in a number of situations the world over. With the advent of chemical fertilizers, the interest in organic sources declined and a number of compound and complex fertilizers found large acceptability as a source of replenishment of the plant nutrients in the cropped areas. However, chemical fertilizers are no longer as readily and economically available as they were a couple of decades ago. Thus the potential of traditional organic fertilisers needs to be better exploited. In this connection, the usefulness of compost, farmyard manure, crop residue mulch, planted fallow and agroforestry cannot be overemphasized. Even if the nutrient requirements are met, soil physical properties can become limiting factors for crop production. Improvements in soil physical properties can be partially achieved by maintaining organic matter content of soil at high levels. Intensive investigation is still needed on the effect on soil erodibility; the influence of rapidly decomposable organic matter on soil physical properties, nutrient availability and uptake and crop growth; and the effect on soil organic matter burning.

Research Methods

Research on soil organic matter and use of green manure and mulching can be classified based on its functions. These are supply of plant nutrients, improvement in the physical properties of the soil and soil conservation roles. Although it is difficult to prescribe a rigid method for assessing the roles of organic manures, it is possible to mention some of the prevalent research approaches through which such assessments are being made in the fields.

Supplies of Plant Nutrients

Application of different organic manures-farmyard manure, green manure, crop residues and tree loppings-have been experimented with primarily for their capacity to supply nitrogen to the field crops. Some of the questions addressed to such experiments were of the following nature:

1. What is the best time of application (relative to crop sowing and stage of crop growth)?

2. How much is to be applied to meet total or partial nitrogen requirements?

3. What is the best method of application (incorporation or mulching)?

4. What should be the frequency of application for long and short-term gains (particularly for available nitrogen and organic carbon)?

To answer some of the questions, time and method of application vary and the best levels are identified by comparing crop response. Crop response obtained due to application of different quantities of organic resources in varying frequencies, with and without different levels of nitrogenous fertilizers is compared with crop response obtained from the different levels of nitrogenous fertilizers alone. For assessing long-term effects of the application of organic sources on the soil, annual change in chemical and physical properties of the soil is a good indication.

Improvement in the Physical Properties of the Soil

Change in the following soil parameters due to applicaton of organic sources of manure is indicative of the improvement in soil physical properties:

soil aggregates, bulk density, inflitration rate and porosity.

Soil Conservation Role

For assessing the effectiveness of the application of organic sources in reducing the soil and water loss it is necessary to trap the runoff water and estimate the silt yields.

In addition to the common issues relating to organic manure research, some of the following issues may also be of considerable importance in specific situations.

1. The relative benefits of *in situ* decomposition and application of decomposed material from outside.
2. Ways to cope with the temporary immobilisation of available nutrients due to large application of crop residues with high C/N ratio.
3. The most appropriate site for the production of organic manure--in the crop field or elsewhere.
4. Role of cultivated leguminous crops providing organic resudues-potential of beans.

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The Use of Green Manures and Mulching in Rwanda

Andre Sebahutu

Insititut des Sciences Agronomiques du Rwanda

Introduction

Agricultural problems in Rwanda to which solutions must be found through research are numerous and long-standing. Rwanda is a small, extremely over-populated country, and almost all arable land is already under cultivation. Existing farmland is becoming increasingly infertile.

The only option for survival is to increase production per unit area. One important approach being followed to achieve this objective is to improve and conserve soils by utilizing all available sources of fertilizers including animal manure, compost, crop residues, green manures, mulch, mineral fertilizers and so on. Soil OM content in Rwanda is generally low and farmers endeavour to maintain it by applying manure and compost, particularly to staple crops including beans. However, only 6% of farmers have sufficient manure or compost to apply 20 t/ha to an average farm of 0.9 ha; 45% of farmers can fertilize only one-quarter of their land. Fallowing is fast disappearing: a typical farm keeps only 0.23 ha under vegetation cover for more than two years, and 0.11 ha in true fallow for less than two years.

Green Manuring

The following legumes are generally utilized as green manures in Rwanda: *Mucuna utilis*, *Desmodium uncinatum*, vetch (*Vicia sativa*) and lupins (*L. albus*, *L. luteus*, *L. angustifolius*). Non-legumes are rarely utilized except in high altitude regions where some projects use rye or buckwheat.

Soil fertility may be improved by intensive short-term fallow using only plants with deep root systems or plants with free nitrogen fixing ability.

After the green manure is worked into the soil and converted into minerals the fixed nitrogen, in the form of organic compounds, is transformed into a mineral which is utilized by subsequent crops. Green manures from legumes with a well developed root system and deep-rooting potential also extract nutrients from lower soil layers, and absorb phosphorus and other nutrients from insoluble compounds.

Crop yields have been increased by 10% to 20% by these techniques in Rwanda, and it has been noted that effectiveness and duration tends to increase with the amount applied.

While the theoretical advantages of green manuring are well known and are described elsewhere in this volume, the practice is mostly employed in Rwanda by development projects and a few large commercial farms having paid labour or tractors for ploughing. Elsewhere, shortage of land precludes this form of green manuring, and other constraints include the dry season prior to ploughing in August and the very short turnaround time between the two annual rainy seasons that occur in the highlands.

Current research in Rwanda is therefore examining agroforestry as a method for replacing, at least partially, short season green manure crops with deep-rooted trees and shrubs. Care is needed in species selection for agroforestry, so as to minimize both the proportion of nutrients remaining in woody material and the competition of the woody species with staple crops. Rwanda is working principally with deep-rooted legumes having high nitrogen fixing capacity, large leaf fall or those tolerant to regular pruning. Species include *Grevillea* sp, *Leucaena leucocephala*, *Cajanus cajan*, *Cassia spectabilis*, *Markhamia lutea* and *Calliandra calothyrsus*. Current recommendations are to use 50% as fodder and to work in the rest as green manure. These species also have the advantage over short term fallow crops of being more drought tolerant.

Mulching

The practice of applying mulch to food crops in Rwanda is extremely limited due to the removal (and often the sale) of crop residues for mulching coffee in particular. Bananas are sometimes mulched and the use of other crop residues as fuel ensures that none are available for application to beans. The removal of bean and other crop residues depletes soil fertility in fields that produce annual food crops, and concentrates it on the official cash crop.

Some research has been conducted on mulching, and it is felt that the practice should be given serious consideration in Rwandan agriculture. Applications of phosphate fertilizer have increased yields significantly only when used in combination with mulch, perhaps because superficial root development was stimulated by mulching and this increased the plants' capacity to absorb phosphate.

Summary of Discussion on Organic Matter

Rapporteur: Tenaw Workayehu

Sources of OM that are currently under investigation in research stations and in on-farm trials in Burundi include coffee hulls and pulp, and brewers waste. Trials are also in progress there to improve techniques for composting, including the treatment of the low-grade Ratongo-Bandaga deposits of rock phosphate (5% P_2O_5).

The potential of a Crotalaria spp as a green manure crop is being investigated in Kahama district of Tanzania by the District Agricultural Development Office. Farmers are slowly adopting it as a planted fallow crop. Relay cropping of Crotalaria with maize is being investigated, and though there were some problems in seeding establishment during the 1987-88 season, preliminary results indicate that Crotalaria benefits the current crop of maize. The Crotalaria roots were well nodulated and considerable biomass was being produced, indicating that the Crotalaria should make a substantial contribution to crops of future seasons.

Relay cropping of *Crotalaria ochleanca* into maize is also being tested in Tanzanian fields. Seed is broadcast during the first weeding of the maize crop, and Crotalaria grows faster after harvest of the maize. Crotalaria stems and leaves are cut and left on the surface to decompose slowly. No data on effects on the subsequent crop are available yet.

Research Experiences with Inorganic and Organic Fertilizers In the Southern Highlands of Tanzania

C.M. Mayona and J. Kamasho

Uyole Agricultural Centre Mbeya, Tanzania

Introduction

Common beans *(Phaseolus vulgaris L.)* are the most important grain legume crop grown in the Southern Highlands (Rukwa, Mbeya, Iringa and Ruvuma Regions) of Tanzania, particularly in areas between 1000 and 2000 m.a.s.l. (Map 1; Table 1). Beans grown in this part of the country which covers more than a quarter of Tanzania) are mainly for grain (as a source of protein) as well as for their leaves (as vegetable), and are usually used in homesteads or sold in local markets.

Beans in the Southern Highlands are usually planted twice a year, from September to December and February to April. Early planted beans are mostly intercropped and are of inferior quality due to disease infestations. The later beans, on the other hand, are sole cropped and generally sucumb to insect pests and moisture stress.

The average yield of beans is often low (300-500 kg/ha). However, the yield potential as obtained in research stations is normally well over 2 tons per ha. The low bean yields are attributed, among other factors, to low available soil nitrogen and phosphorus (Jakobsen, 1980; see also Table 2). Research from other parts of East Africa also indicates that low available nitrogen and phosphorus often limit bean yields, and responses to these elements have been reported (Edje *et al.*, 1971; Qureshi, 1979; Hasselbach, 1980; Floor and Okongo, 1982; Magehema and Ndunguru, 1984). The situation is made more complicated because Southern Highlands farmers use little or no fertilizers in bean production because of high cost and the little knowledge about use.

In order to raise bean yields in the Southern Highlands a number of experiments employing inorganic and organic fertilizers have been conducted since 1974. In these experiments treatments of different rates of inorganic fertilizers and manures and their combinations were tested and compared. Some of the results are reported below.

Research on Inorganic Fertilizers

Because N and P are among the most limiting nutrients in bean production in the Southern Highlands a number of experiments were inititated by the Bean Improvement Programme at Uyole to study their effects on growth and yield of beans. This work started in the mid-1970s. The need for trace elements in beans was also evaluated.

Map 1: Southern Highlands of Tanzania and Uyole Agricultural Centre Research Substations

Table 1: Uyole Agricultural Centre Research Substations

Substation	Altitude (m)	Rainfall (mm)
Nkundi	1750	700
Mbimba	1525	1370
Uyole (HQs)	1850	900
Mitalula	1052	2300
Ismani	1350	560
Igeri	2288	1360
Ndengo	1450	1200
Suluti	860	1260

Table 2: Soil analysis data from selected villages in Mbeya Region (1987/88)

		Test Results*							
District	Villages	pH		%	ppm	me/100g soil			
		H_2O	KCl	OC	P	K	Mg	Na	Ca
Ileje	Izuba	5.75	4.30	0.99	35.96	1.02	2.20	0.13	3.97
	Mbebe	5.75	4.68	0.89	4.82	1.02	2.91	0.19	1.50
Mbeya	Santilya	6.10	4.98	2.09	4.82	2.35	3.70	0.30	6.52
	Matanji	6.10	5.00	2.49	4.82	1.74	1.85	0.09	6.52
	Uyole P/S*	6.30	5.05	2.89	20.65	3.56	1.32	0.58	10.03
Mbozi	Isandula	5.85	4.50	1.49	7.02	1.38	2.11	0.10	3.25
	Isangu	5.65	4.60	2.49	4.82	1.74	1.85	0.09	6.52
	Iwindi P/S**	7.0	5.35	1.39	7.02	3.68	1.32	0.31	7.48

Source : FAO Fertilizer Programme, Mbeya

* Methods: P = Bray I; K and Na = Ammonium acetate extract; Mg and Ca = EDTA (titration)

** P/S means primary school

In 1974/75 experiments to investigate the effect of nitrogen, rate and method of phosphorus application and the need for copper and other trace elements in beans were conducted at Uyole, Nkundi and Ismani. The data generally gave insignificant response to application of nitrogen. In some cases, nitrogen reduced bean yield and number of nodules (Anon, 1974/75). In the drier areas of Iringa region however, data suggest that nitrogen could be important in attaining maximum bean yields (Table 3). Observed yield reduction for N in Kabanyolo might be accidental because previous experience has shown that the cultivar responds well to N application. Strong negative effects on bean yield and nodulation were also reported in Kenya, particularly when N was applied alone; in Sudan, El-Hilo (1978) and Abdel-Gaber (1979) reported increased bean yields with the addition of N either alone or with complete fertilizer. Edje *et al*. (1971, 1973 and 1976) in Malawi also reported that beans need to be fertilized with nitrogen in order to realize high yields.

Results from Uyole revealed a marked response to P application (Table 4). Yield, stand count and number of nodules always increased with increasing rate of phosphorus application (Tables 4 and 6). The response of beans to P also varied according to the variety used. For example, in an experiment conducted at Uyole in 1974/75, it was observed that Canadian Wonder, Sostex, Kabanima and Diacol Nima responded markedly well to P application. However, a local cultivar, Masusu, appeared to be better adapted to the low soil P at Uyole. A marked response to phosphorus levels was also observed at Nkundi, in Rukwa Region (Table 5).

When banding method of P application was compared with broadcasting it was found that the former method was more effective in improving yield of beans. Higher bean yields in the band-applied P appeared to be associated with better survival of plants (Table 6), thus stressing the need of applying less P when the fertilizer is applied in a band close to the seed. However, Ssali *et al*. (1981), working in Kenya, obtained nonsignificant differences between the two methods of P application, contrary to what was obtained at Uyole.

Nitrogen and phosphorus interaction studies were conducted during the 1974/75, 1977/78 and 1981-83 seasons. For example, an experiment carried out at Ismani in 1974/75 revealed that there was a marked nitrogen and phosphorus (as 100 kg ha^{-1} of Triple super phosphate and 100kg ha^{-1} of sulphate of ammonia) interaction, suggesting that the two nutrients might be important for maximum bean yields, depending on the variety (Table 3). Canadian Wonder responded extremely well to N and P compared to the other four varieties of beans used.

Again, in a network of village trials carried out in 1977/78 in Iringa (4 villages), Ruvuma (1 village), Rukwa (1 village) and Mbeya (4 villages) regions significant N and P interaction was obtained in most sites. In Iringa, for instance, a 250% yield increase was obtained with the application of 60 kg of N and P ha-1, compared with N alone or unfertilized control. Economically, 60 kg of both N and P appeared attractive but still recommendable. In Mbeya, on the other hand, the best treatment was 30-40 kg of both N and P kg ha-1. No response to K was obtained at any of the locations (Mayona, 1978; Karel *et al*., 1980).

Another experiment to study the effects of three levels of nitrogen (0, 50 and 100 kg ha-1) and five of phosphorus (0,50,100, 150 and 200 kg ha-1) and their interactions on yield of two bean cultivars (Kabanima and T3) was conducted at Mbimba (Mbozi) and Uyole (Mbeya) during the 1981/82 and 1982/83 seasons. The 1981/82 results which have previously been reported (Mayona, 1982) revealed that combined N and P fertilizers produced the highest responses in bean seed yield compared with N or P alone at Mbimba and Uyole. Single

Table 3: Effect of fertilizers on yield per plant (g) in 4 bean varieties at Ismani (Iringa Region) 1974/75

Variety	kg of fertilizer ha^{-1}			
	0	100 TSP	100 TSP 100 SA	Mean
Canadian Wonder	4.0	5.6	8.6	6.1
Kabanyole 129	1.7	5.0	2.3	3.0
Masusu	2.9	4.2	6.3	4.5
Mkonge	3.5	5.2	6.7	5.1
Mean	3.0	5.0	6.0	4.7

Table 4: Effect of phosphorus fertilizer on yield of 6 bean varieties at Uyole, 1974/75

Variety	Yield, kg/ha^{-1}	
	Without P	With P
Canadian Wonder	1650	2140
Mexican 142	1340	1660
Sostex	1270	2150
Kabanima	1420	2370
Diacol Nima	1130	2030
Masusu	2040	2380
Mean	1470	2120

Table 5: Effect of phosphorus rate on bean yield at Nkundi (Rukwa Region), 1974/75

kg ha^{-1} of P	Yield, kg ha^{-1}
0	360
10	580
20	660
40	880
Mean	620

Cultivar used: Local mixture of beans

Table 6: Effect of rate and method of P application on bean yield, final plant density and number of effective nodules per plant, UAC 1974/75

$Kg\ ha^{-1}$ of	Yield, $kg\ ha^{-1}$			Plant density, plants m^{-2}			No. of effective nodules		
	BC	BA	Mean	BC	BA	Mean	BC	BA	Mean
0	443a	443c	443	16.2abc	16.2abc	16.2	45	45	45
10	424a	500c	462	13.8-	15.9abc	14.9	53	97	75
20	477a	492c	485	14.9bc	16.1abc	15.5	63	101	82
40	442a	777ab	610	14.2c	16.9ab	15.6	81	99	90
80	519a	813a	666	16.1abc	18.3a	17.2	90	138	115
Mean	466	646		14.8	16.8		72	109	
CV, %	30			10			30		

Figures followed by the same letter are not significantly different at P=5%
BC = Broadcasting; BA = Banding

*Calculated as single factor experiment
Variety used: Canadian Wonder (bush type)
Planting data: 10/12/74

Table 7: Effect of nitrogen and phosphorus on the yield of beans at Mbimba, 1982/83

	Nitrogen rate, kg ha^{-1}			
Variety	0	50	100	Mean
Kabanima	824	984	1246	1018 NS
T3	879	1094	1328	1100 NS
Mean	852	1039	1287*	

*Significant at 5% level
NS - not significant at 5% level

	Phosphorus rate, kg ha^{-1}					
Nitrogen rates kg ha^{-1}	0	50	100	150	200	Mean
0	447	960	1061	845	948	852
50	978	1328	996	952	942	1039
100	1144	1433	1361	1309	1191	1280*
Mean	856	1240*	1139	1035	1027	
LSD, 0.05	294kg ha^{-1}					
CV, %	19					

* Significant at 5% level

nutrient responses were also obtained at both sites, especially N and P at Mbimba and N alone at Uyole. Similar responses were also obtained in 1982/83 except for the unsignificant N effect alone, and N and P interaction at UAC and P effects at both sites (Tables 7 and 8). Kananima was found to be more responsive to N and P than T3, except at Mbimba in 1982/83 (Table 7).

The need for copper and other trace elements (combined with N and P) was also evaluated at Uyole in 1974/75 in two sets of field experiments. The first experiment used Blitox (50% copper oxychloride) as a source of copper, while the second utilized Wuxal as a trace element source (e.g. Fe, Mn, B, Zn, etc). Apart from a significant positive effect on grain yield and nodulation due to N and P, Cu fertilizer also had a positive effect on yield and nodule count, particularly when applied with 40 kg of P ha-1 (Table 9).

Table 8: Effect of nitrogen and phosphorus on the yield of two bean varieties at UAC, 1982/83

Variety	Nitrogen rate, kg ha^{-1} 0	50	100	Mean
Kabanima	2096	2136	2352	2136*
T3	1734	1771	1897	1001
Mean	1915	1954	2125	

Variety	Phosphorus rate, kg ha^{-1} 0	50	100	150	200	Mean
Kabanima	2020	2192	2249	2326	2185	2136
T3	1865	1815	1831	1767	1725	1801
Mean	1943	2004	2041	2047	1956	
LSD, 0.05	242					
CV, %	8					

* Significant at 5% level
Also: Main effects: Variety and nitrogen = Sign (P = 0.05)
Phosphorus = nonsign. (P = 0.05)
Interaction: Nitrogen x phosphorus = nonsign. (P = 0.05)

Table 9: Effect of N, P and Cu on bean yield, seed weight per plant and nodulation at UAC, 1975

Treatment (kg ha^{-1})	Yield (kg ha^{-1})	Seed wt. per plant (g)	Nodules per plant
No fertilizer	1360cd	7.5c	8c
10P	1225d	7.3c	48cd
20P	1500c	8.3bc	62bcd
40P	1580bc	9.0bc	123a
80P	1568bc	8.5bc	83abc
20P + 20N	1373cd	8.6bc	40de
40P + 20N	1775ab	10.1ab	44de
40P + 0.5Cu	1828a	11.5a	93ab
40P + 1.5Cu	1778ab	9.9ab	88ab
Mean	1554	9.0	66.6
CV, %	9	12	36

Figures followed by the same letter are not significantly different.

Variety: Diacol Nima; Planting date: 17/4/75

Table 10: Effect of wuxal* on grain yield and yield per plant of 6 l cultivars, Uyole

Variety	Yield, kg ha $^{-1}$			Yield per plant (g)	
	-Wuxal	+ Wuxal	Mean	-Wuxal	+ Wuxal
Kabanyolo	1873a	1336b	1604	13.9	10.5
C. Wonder	738cd	812cd	775	6.2	7.6
Long Tom	480d	808cd	644	4.2	6.8
Saxa	618cd	631d	624	4.6	5.2
Triomphe de Fucy	441d	740cd	590	3.9	5.6
Diacol Nima	776cd	1024bc	900	5.5	7.4
Mean	821	892		6.4	7.2
CV, % Wuxal	8				
Variety	30				

Figures followed by the same letter are not significantly different at P = 5%.

Planting date: 3/11/74

* Wuxal contains N, P, K, Fe, Mn, B, Zn, Ni, Co, Mo, Na, chelates, horumies and vitamins.

One spraying with 0.6 Blitox one month after sowing was enough to give the observed effect. Data also revealed a more or less direct relationship between yield and seed weight per plant suggesting that where the seed weight per plant was high, there was also a corres- ponding yield increase. Nielsson (1973/74) and Jakobsen (1980) reported low Cu content in most soils of the Southern Highlands and cautioned on the possible need of using Cu fertilizers to improve the yield potential of crops. A balanced foliar spray of trace elements (Wuxal) resulted in a significant positive effect on the mean yield of all bean cultivars tested, except Kabanyolo which responded negatively (Table 10). Nodulation was not affected (Anon, (1974/75).

Research on Organic Manures

From 1983 experiments on organic manures and fertilizers were initiated at Uyole. These experiments were later extended to Mbimba in 1986/87, with the following objectives:

- To study the effect of farmyard and compost manure on soil properties and bean yield.

. Possibility of substituting mineral fertilizers or half the rate by adding farmyard or compost manure.

The effect of organic manure and mineral fertilizers on bean yield for the past four seasons at Uyole and one season at Mbimba are presented in Table 11a and b. It is evident from the data that application of manure increased bean yields when compared with zero treatments. But the combination of organic manures and inorganic fertilizers appeared to have given the highest yields in the subsequent seasons at Uyole, suggesting that the two materials complement each other. The mineral fertilizers might have corrected nutrient imbalances nutrients inherent in manures, particularly P, whereas manures might have supplied other nutrients bordering on deficiency (Kasembe *et al* ., 1983). Moreover, soil analysis data (Table 12) reveal that N is also inadequate in most soils of the Southern Highlands. Responses to organic manure application on beans have also been reported at the Sokoine University of Agriculture (SUA),in Morogoro, Tanzania (Rweyemamu and Ndunguru, 1984). Similar responses have been reported on groundnuts (Le Mare 1953; Scaife, 1971) and pigeon peas (Evans and Mitchell, 1962).

Effects of different rates of manures can be depicted from Table 13. In three out of four seasons, 10 tons ha^{-1} of both farmyard and compost manure plus half of recommended rate of nitrogen and phosphorus gave highest yield of beans at Uyole compared to other treatments, suggesting that the combination of the two gives an optimum yield advantage. In the 1986/87 season, however, this treatment appeared a bit inferior probably due to depletion of nutrients from the soil by the beans. At Mbimba, on the other hand, 5 tons ha^{-1} of both farmyard and compost manure plus half NP rate were found to be superior to the other treatments. Rweyemanu and Ndunguru (1984) also recorded highest yields of beans when they used a combination of organic manure (7 tons ha^{-1}) and inorganic fertilizers (10P and 20N kg ha $^{-1}$) compared to either of them. The recommended rate of chemical fertilizers (30N and 30P kg ha $^{-1}$) gave much higher bean yields than the control, thus stressing the need to use fertilizers in order to raise bean yields. Le Mare (1953) reporting on studies of farmyard manure and artificial fertilizers made in the old groundnut scheme areas of Kongwa, Nachingwea and Urambo obtained a significant response of groundnuts from farmyard manure, particularly about 25 tons ha $^{-1}$. In some of these studies the response from artificial fertilizers was higher than or equal to farmyard manure, in the year of application. However, Peat (1953) reported at Ukiriguru that the residual effects of farmyard manure were felt up to eight years later in some cases.

Soil analysis carried out at the beginning of the trial and at harvesting time in each season (Table 12) showed that soil organic carbon, total N and extractable P were low at

Table 11a. Effect of organic manure on yield of beans (kg/ha) at UAC (Mbeya district) and Mbimba (Mbozi district), 1983-1987

	UAC					Mbimba
Treatment	1983/84	1984/85	1985/86	1986/87	Mean	1986/87
Control	1210	884	900	1088	1021	786
Organic manure*	1369	1401	2050	1350	1543	1214
Recommended NP**	1542	1630	2200	1548	1730	1421
Org. man + NP	1405	2029	2700	1555	1922	1567
Mean	1382	1486	1963	1385		1333
LSD, 0.05	NS	650	908	NS		?
CV, %	12	12	19	18		26

* Organic manure comprised of 5.10 t ha $^{-1}$ of FY and compost manure.

** N = 30kg ha $^{-1}$, P = 30 kg ha $^{-1}$

Table 11b: Organic manure nutrient composition

Year	Manure	Org. C (%)	P (%)	N (%)
1985	FYM	28	0.23	0.58
	OM	35	0.65	0.42
1986	FYM	30	0.42	0.46
	CM	38	0.56	0.32

FYM - Farmyard manure

CM - Compost manure

the start of the experiment. These tended to increase slightly with the addition of manure and with the advancement of the experimental period. Soil pH more or less remained constant across all manure treatments. However, there was a slight increase in pH with time. The small pH change could be attributed to the good buffering effect of the decomposition products from the manure.

These results show that the use of manures on beans can increase yields and sustain the fertility and productivity of the soil. They also show that supplementing manures with inorganic fertilizers can increase yields even further.

Table 12: Trend of soil (0-20cm) chemical compositon at UAC, 1983-1987

	Control	5t FYM	10t FYM	5t CM	10t CM
1983/84					
pH (H_2O)	6.2	6.1	5.9	6.0	5.7
Org. C (%)	2.1	2.9	3.2	2.7	3.2
Total N(%)	0.10	0.16	0.16	0.17	0.18
Ext. P (ppm)	5.3	5.9	5.9	6.0	6.0
1984/85					
pH (H_2O)	6.7	6.8	6.7	6.7	6.8
Org. C (%)	1.2	1.7	1.7	1.4	1.7
Total N(%)	0.18	0.19	0.19	0.17	0.18
Ext. P (ppm)	6.0	7.0	7.0	7.0	7.0
1985/86					
pH (H_2O)	6.7	6.8	6.7	6.7	6.8
Org. C(%)	1.2	1.7	1.7	1.4	1.7
Total N(%)	0.18	0.19	0.19	0.17	0.18
Ext. P (ppm)	6.0	7.0	7.0	7.0	7.0
1986/87					
pH (H_2O)	6.7	6.8	6.7	6.7	6.8
Org. C (%)	1.0	1.5	1.3	1.4	1.3
Total N(%)	0.15	0.16	0.15	0.15	0.12
Ext. P (ppm)	5.0	6.0	7.0	6.5	6.0

Before start of experiment

pH	Org. C	Total N	Ext. P (ppm)
6.4	2.1	0.13	5.9

Table 13: Effect of rate of farmyard and compost manure on yield (kg/ha) of beans at UAC amd Mbimba, 1983-1987

	UAC				Mbimba
Treatment	1983/84	1984/85	1985/86	1986/87	1986/87
Control	1210	884	900	1088	786
5t FYM ha $^{-1}$	1284	981	1500	1401	1265
10t FYM ha $^{-1}$	1454	1722	2100	1331	1180
5t cm ha $^{-1}$	1260	1300	2000	1285	1133
10t cm ha $^{-1}$	1477	1600	2600	1382	
Recommended NP*	1542	1630	2200	1548	1421
5t FYM + NP	1371	1849	2300	1590	1668
10t FYM + NP	1384	2176	2900	1519	1326
5t cm + NP	1384	1961	2900	1608	1760
10t cm + NP	1482	2130	?	1502	1515
Mean	1382	1486	1963	1385	1333
LSD, 0.05	NS	650	908	NS	?
CV, %	12	12	19	18	26

*N = 30 kg ha $^{-1}$ P = 30 kg ha $^{-1}$

Summary

It is evident from the foregoing discussion that P had a significant positive effect on bean growth and yield. Nodulation and grain yield of beans in particular increased with increasing P to about 40 kg ha $^{-1}$. Banding as a method of P application was superior to broadcasting. On the other hand, N alone had a negative effect on bean nodulation and yield in most sites except at Ismani where N markedly increased yield. But N had a significant positive effect on nodulation and yield when it was combined with P. At Uyole there was also a response to Cu and a balanced foliar spray of trace elements without influencing nodulation significantly. Addition of Cu to 40 kg P ha $^{-1}$, for instance, gave highest yield of beans.

As regards to organic fertilizer, data revealed that a combination of farmyard and compost manure plus half the rate of inorganic (NP), fertilizers were superior in giving highest bean yields compared to the other treatments. The application of these organic fertilizers also improved the nutrient status of the soil.

Future research on soil fertility at UAC will involve studies on effect of *Rhizobium* strains on bean growth in order to minimize the use of expensive nitrogen fertilizers; indentification of suitable cultivars in the available germplasm which are efficient in utilizing low soil P and giving high yield increases per unit P added to the soil; tillage as a soil conservation and fertility improvement measure; rotation and intercropping; and use of organic manures.

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Nature and Importance of Soil-Related Constraints to Bean production in Kenya

P.T. Kamoni

National Agriculture Laboratories, Kenya Soil Survey

Introduction

Dry beans are a long-standing staple for many Kenyans. They form a cheap source of protein, rich in the essential amino acid lysine, found in less quantities in maize and other grains. Research on dry beans in Kenya is mainly carried out by the Grain Legume Project (GLP), based at the National Horticultural Research Station, Thika.

The major bean producing areas in Kenya are Trans-Nsonia, Uasin Gishu, Kakamega, Bungoma, Kirinyaga, Nyeri, Muranga, Kiambu, Meru, Embu, Katumani, etc. The major soils found in these areas are: Nitosols, Acrisols, Ferralsols, Luvisols, Cambisols, Andosols, Phaeozems, Planosols and Vertisols.

Since its inception in 1971 the Kenya Soil Survey has accumulated a lot of chemical and physical data on these soils. A general summary of these soils based on some of the Kenya Soil Survey Publications is given below. The references consulted cover a great percentage of the country where the above soil types are found and hence give a good approximation of the chemical and physical properties of these soils. The analytical methods used are: Texture - hydrometer method, CEC-ammonium acetate extration adjusted to pH 7; %C - Walkley and Black method; pH-H_2O - measured in a 1:2.5 soil water suspension; available nutrients - Mehlich method (HCl/H_2 SO4 extraction).

Nitosols

Nitsols are well drained, very deep to extremely deep friable clay soils. They show evidence of clay movement and have conspicuous faces especially in the lower part of the B-horizon. They have high porosity and high aggregate stability throughout the profile.

Summary of physical and chemical properties

Colour:	reddish colours, mainly dark reddish-brown, red, dark red, yellowish-red,reddish-brown, dusky red and dark yellowish-brown
Texture:	mainly clay
Structure:	subangular and angular blocky
Drainage:	well drained
CECpH 7.0:	5.9-25.7 (CEC in me/100g soil)
%C:	0.23-3.5
Base saturation:	14-100%
pH-H_2O:	4.5-7.0

Fertility aspects (Ca, Mg, K and Mn in me/100g soil, P in ppm)

Ca:	0.4-24
Mg:	1.1-6.0
K:	0.17-2.5
P:	3-110
Mn:	0.68-1.86
%N:	0.1-0.3

Most Nitosols are sufficiently supplied with most plant nutrients but may be deficient in phosphorus.

Acrisols

Acrisols are mainly well drained, moderately deep to deep, strongly weathered, friable to firm soils. The topsoil is relatively low in organic matter and/or is acid. Like the Nitosols they show clay illuviation. The base saturation is less than 50% (by NH_4OAC) in at least some part of the subsoil within 125 cm of the surface. They have a good structure stability. Some Acrisols contain large amounts of indurated plinthite.

Summary of physical and chemical properties

Colour:	as for Nitosols
Texture:	sandy clay loam, sandy clay and clay
Structure:	subangular blocky and angular blocky
Drainage:	well drained
CECpH 7.0:	2.7-21.3
%C:	0.03-4
Base saturation:	18-84%
pH-H_2O:	4.1-7.2

Fertility aspects

Ca	0.2-7.7
Mg:	0.5-2.6
K:	0.14-4 but mostly below 1 me/100g soil
P:	2-78 but mostly below 10ppm
Mn:	0.12-1.9
%N:	0.05-02.1

Acrisols are deficient in both nitrogen and phosphorus.

Ferralsols

Ferralsols are strongly weathered and highly leached mineral soils with indistinct soil horizon differentiation. They are very friable, highly porous and permeable. Ferralsols have excellent water holding capacity.

Summary of physical and chemical properties

Colour:	mainly dark reddish-brown, dark red, yellowish-red, reddish-brown, dusky red, red, dark red, strong brown and very dark greyish-brown
Texture:	sandy loam, sandy clay loam and clay
Structure:	massive to subangular blocky
CECph 7.0:	1.5-15.4 but mainly below 10
%C:	0.15-3.5 but mainly below 2%
Base saturation:	1-99%
pH-H_2O:	4.6-6.1

Fertility aspects

Ca:	0.2-10.4
Mg:	0.1-4.0
K:	0.1-0.9
P:	4-29 but mainly below 10 ppm
Mn:	0.24-1.1
%N:	0.01-0.18

Ferralsols are highly deficient in both nitrogen and phosphorus.

Luvisols

Luvisols have similar morphological characteristics to the Acrisols. They are separated on the basis of the base saturation of the lower part of the B-horizon. Luvisols have a base saturation of 50% or more while Acrisols have a base saturation of less than 50%. Luvisols are moderately to strongly weathered soils. They have a tendency to form a strong sealing on the surface which renders them susceptible to water erosion (due to strong surface run-off).

Summary of physical and chemical properties

Colour:	dark reddish-brown, dark red, yellowish-red, dark yellowish-brown, dark brown, very dark brown, very dark greyish-brown
Texture:	mainly sandy clay loam, sandy clay and clay
Structure:	subangular blocky and angular blocky
Drainage:	well drained
CEEpH 7.0:	8.8-100+
%C:	0.4-1.3
Base saturation:	46-100$^+$%
pH-H_2O:	5.3-8.8

Fertility aspects

Ca:	0.8-30
Mg:	0.6-10
K:	0.2-2.2
P:	2-174
%N:	0.07-0.15

Most Kenyan Luvisols are deficient in nitrogen but have enough of the other plant nutrients.

Cambisols

Cambisols are young soils that are little weathered. They have a cambic B-horizon that has significant amounts of weatherable minerals. The texture of these soils is variable but usually finer than sandy loam.

Summary of physical and chemical properties

Colour:	various colours, dark reddish-brown, dark red, red, yellowish-red, dark yellowish-brown, dark brown, strong brown, very dark brown, very dark greyish-brown, olive and black
Texture:	sandy loam, sandy clay, sandy clay loam, clay loam and clay
Structure:	angular blocky, subangular blocky and prismatic
Drainage	well drained to imperfectly drained
CECpH 7.0:	5.2-49
%C:	0.11-5.9
Base saturation:	8-100+
pH-H_2O	4.3-9.6

Fertility aspects

Ca:	0.2-20
Mg:	0.3-6.0
K:	0.14-3.7
P:	4-250
Mn:	0.22-1.4
%N:	0.08-0.47

Most of Kenyan cambisols are deficient in N. About 50% of the cambisol profiles perused had high to extremely high values of P while the rest were deficient in P. Generally cambisols have relatively high natural fertility.

Andosols

Andosols are soils having a mollic or an umbric A-horizon possibly overing a cambic B-horizon. They have bulk density (at 1/3-bar water rentation) of the fine earth fraction of the soil of less than $0.85 g/cm^3$ and an exchange complex dominated by amorphous material. They contain 60% or more vitric volcanic ash, cinders, other vitric pyroclastic material in the silt, sand and gravel fractions.

Summary of physical and chemical properties

Colour:	dark colours: dark brown, dark reddish-brown, dark grey, black, dark yellowish-brown, very dark grey, very dark greyish-brown
Texture:	sandy loam, sandy clay loam, loam, sandy clay, clay loam and clay
Structure:	crumb, subangular blocky and prismatic
Drainage:	well drained to somewhat excessively drained
CECpH 7.0:	5.6-40
%C:	0.18-4.96
Base saturation:	$37.5-100^{+}$%
$pH-H_2O$:	4.9-9.2

Fertility aspects

Ca:	4.4-31
Mg:	2.1-6.9
K:	0.82-2.7
P:	13-102
Mn:	0.1-1.35
%N:	0.07-0.6

Andosols are deficient in either nitrogen, phosphorus or both. Erosion may be a serious problem, since the soils consist of rather loose materials and often occur on steep slopes of volcanic areas.

Phaeozems

Phaeozems are soils which are characterised by a dark-coloured topsoil that has a high organic matter content (mollic A-horizon); they are well developed and non-acid. They are generally formed in areas with non-flushing moisture regime so that leaching is restricted.

Summary of physical and chemical properties

Colour:	dark reddish-brown, dark greyish-brown, dark grey, dark brown, olive, very dark grey, very dark greyish-brown, red, reddish-brown, and black
Texture:	sandy clay loam, sandy clay, clay loam and clay
Structure:	Subangular blocky, angular blocky and prismatic
Drainage:	moderately well drained to somewhat excessively drained
CECpH 7.0:	8.8-63
%C:	0.15-2.9
Base saturation:	$14\text{-}100^{+}$%
$pH\text{-}H_2O$:	4.8-8.1

Fertility aspects

Ca:	2-13.2
Mg:	1.0-8.8
K:	0.1-2.0
P:	4-266
Mn:	0.3-1.68
%N:	0.1-0.25

Most Kenyan phaeozems are deficient in both P and N but have high levels of Ca, Mg, K and Mn. Narok phaeozems however have very high levels of P (24-266 ppm).

Planosols

These are imperfectly to poorly drained soils with a pronounced and abrupt transition between a relatively light textured and permeable topsoil, part of which is whitish and a heavy textured and slowly permeable, compact and hard subsoil (B-horizon) within 125 cm of the surface. They are often waterlogged and have very slow verticial and horizontal drainage.

Summary of physical and chemical properties

Colour:	grey, dark grey, greyish-brown, very dark greyish-brown, very dark grey, very dark brown, yellowish-brown and brown
Texture:	clay and sandy clay loam
Structure:	subangular blocky, angular blocky, prismatic and in a few cases porous massive
Drainage:	imperfectly drained to poorly drained
CECpH 7.0	1.7-53
%C:	0.1-3.2
Base saturation:	15-100%
$pH\text{-}H_2O$:	4.6-8.2

Fertility aspects

Ca:	0.4-2.5
Mg:	0.6-2.2
K:	0.1-0.2
P:	4-12
Mn:	0.1-0.48
%N:	0.03-0.29

Most of the Kenyan Planosols are deficient in phosphorus and calcium. A big percentage (up to 50%) are deficient in nitrogen. Another problem in these soils is their poor drainage. Beans cannot be grown unless the drainage is improved.

Vertisols

These soils are populary known as black cotton soils. They expand and contract appreciably with changes in moisture content and do not have distinct horizonation. The clays are dominated by montmorillonite which accounts for the great plasticity and stickiness of the soils when wet and the pronounced hardness when dry.

Summary of physical and chemical properties

Colour:	dark reddish-brown, brown, dark brown, light grey, dark grey, very dark grey, very dark greyish-brown, dark yellowish-brown and black
Texture:	mainly clay
Structure:	angular blocky and prismatic
Drainage:	moderately well drained to very poorly drained
CECpH 7.0:	4-65 but mostly above 25
%C:	0:24-2.94
Base saturation:	73-100+
pH-H_2O:	5.4-10.2

Fertility aspects

Ca:	8.4-40
Mg:	4.5-9.8
K:	0.08-0.96
P:	12-150 but mostly above 20 ppm
Mn:	0.2-1.08
%N:	0.06-0.32

Kenyan Vertisols are quite fertile though some may be deficient in nitrogen. Beans do well in vertisols if drainage is improved. Calcareous vertisols have better structure and drainage than non-calcareous ones.

Table 1: Summary of soil constraints to bean productivity in Kenya

Soil type	Constraint to bean production	Control measures
Nitosols	None	may require fertilization for maximum yield
Acrisols	deficiency in both N and P	require fertilization
Ferralsols	highly deficent in both N and P; poor management of cultivated land may render these soils susceptible to soil erosion	require fertilization; good soil conservation measures
Luvisols	deficient in N; susceptible to erosion	supply N; good soil conservation measures
Cambisols	None	
Andosols	highly susceptible to erosion	soil conservation measures
Phaeozems	deficient in both P and N	require fertilization
Planosols	deficient in P and Ca and also N in some cases; poor soil drainage	require fertilization; improve drainage
Vertisols	poor soil drainage	improve drainage

The Grain Legume Project carried out trials from 1977 on farmers' fields in some of the major bean-growing areas in Kenya. The objective of the trials was to study the response of beans to the application of fertilizers, taking into account the large variation that exists between soils and soil conditions of various areas (Machakos, Embu, Kisii, Kakamega Districts and the area around Thika).

In total, 200 fields yielded useful and reliable information. The experiments were carried out with pure bean crop, planted at a density of 200,000 plants per ha. The gross plot size was $10.5m^2$. Experiments were planted in one replication per farmer. The treatments changed little over the seasons. In the earlier trials three treatments were included, namely an unfertilized control, a TSP and a DAP treatment. Later on, a CAN treatment was added, and in the trials of the last seasons, different rates were also studied, bringing the total number of treatments to six. The conclusions and recommendations of these experiments are given in Table 3. Table 2 gives the soil and climatic factors of the experimental areas.

Table 2: Soil and climatic factors of experimental areas

District/area	Soil type(s)	r/Eo	Description	Average annual rainfall (r) in mm	Average annual evaporation (Eo) in mm
Machakos	Acrisols, Luvisols, Cambisols and Ferralsols	0.40	semi-humid to semi-arid	718	1790
Embu	*humic/eutric Nitosols, **Acrisols Luvisols and Ferralsols	0.68	sub-humid	1238	1810
Kisii	Nitosols or Luvic Phaeozems	1.11	humid	1957	1768
Hamisi/Vihiga	Acrisols	0.88	humid	1845	2097
Ikolomani	mollic Nitosols	0.88	humid	1845	2097
Thika area	Ferralsols	0.58	semi-humid	1020	1822

*Coffee zone, highly fertile **Cotton zone, less fertile

Table 3: Response to nitrogen

District/area	Response to N (kg bean/kg N)	Average %N in soil
Machakos	7.5	0.10
Embu	4.8	0.20
Kisii	1.9	0.26
Hamisi/Vihiga	7.3	0.17
Ikolomani	3.0	0.22
Thika	9.0	0.16

Response to P was not very clear. In Kisii the beans responded well to its application, but in Embu and Thika only in the presence of nitrogen. In Western Province, although the soil P-values are low, the response to the applications were disappointly low. Deficiencies of other nutrients may play a role in this.

N and P are the most limiting soil constraints to bean productivity in Kenya. Other nutrients are generally sufficiently supplied in most soils.

Table 4: Response of beans to phosphorus in various areas in Kenya

District/area	Response to P (kg bean kg P)	Average P mg/kg soil)
Machakos	3.7	over 20
Embu	8.9-10.4	-
Kisii	6.4-24.1	22
Hamisi/Vihiga	7.8	16
Ikolomani	2.5	12
Thika area	1.5	12
*FAO-central plots	12.9-16.4	

*FAO demonstration plots 1969-1972, applied was 60 kg P_2O_5/ha

Table 5: New fertilizer recommendations for pure bean

District/area	Recommedation	Exceptions
Machakos	138Kg CAN/ha, top dressed 4 weeks after germination	Not in dry seasons Erratic responses when: %N Over 0.10
Embu (also coffee zones in central province)	200Kg DAP/ha, at planting	low responses when: -N% over 0.32 -K deficiency -Al toxicity
cotton zone	200Kg TSP or 180 Kg 20:20:0 at planting	low responses when: -K deficiency -Al toxicity -%N lower than 0.12(?)
Kisii	78kg TSP/ha, at planting	low responses when: -P over 25mg/kg -pH-H_2O over 5.9
Hamisi/Vihiga	138kg CAN/ha, top dressed 4 weeks after germination	low responses when: -K deficiency -high soil pH-H_2O (>5.8
Ikolomani	No recommendation yet	
*Thika	at planting 100kg DAP+70kg CAN/ha plus at flowering: 70 kg CAN.	

*Fertilizer recommendations for the Nitosols, found in the coffee/tea and main coffee zones are the same as those described under Embu District. For the Kisii area bean yield on unfertilized plots were found to follow the equation.

Bean yield (kg/ha) = 1363pH - 6224; r = 0.85***, df = 18

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A Review of Fertilizer Requirement for Dry Bean Production in Kenya

John G.N. Muthamia

National Horticultural Research Centre, Thika, Kenya

Introduction

In Kenya, approximately 400,000 hectares of beans are grown per year. Beans are mostly grown by small-scale farmers over a wide range of soil types and agro-ecological zones. The yields are low, averaging about 800 kg/ha. Beans are the main source of protein for a large proportion of the Kenyan population, but they are not considered a main crop by farmers. Beans are generally grown in mixed stands with maize or are planted to fill up spaces between other crops; monocrop beans are rare. The importance of beans to Kenyans is evident when one considers the harsh environments - poor soils, droughts in some areas, low market prices, destruction by insect pests and diseases - which result in low bean yields and yet the farmers don't give up growing them.

Though dry beans have been found to respond to fertilizers, the response is not as striking as in other crops such as maize, potatoes, cabbage, etc. Most small-scale farmers find it economical to apply fertilizer to other crops such as cereals and cash-crops grown in association with beans; thus beans benefit indirectly (Zoebl, 1984). The small-scale farmers are not interested in maximum yield because the inputs required to reach this are beyond their capability. The aim is high returns on money invested (Zoebl, 1984).

With the selection and breeding of higher yielding lines, greater response to fertilizers is greatly influenced by available soil moisture, and in cases of low rainfall (200-250 mm) the response to fertilizer is absent or even negative (GLP 20, 1982). The optimum rainfall for growing a bean crop is 350-400 mm, if well distributed over the growing season (Floor, 1984) Yield response due to fertilizer application has been established in most of the representative bean-growing areas of Kenya (Zoebl, 1984).

The recommended practice of planting and fertilizing in furrows is rather labour-demanding if furrowing is done with a hoe (32 man-days). A special furrow opener takes about 25 man-days (Zoebl, 1984).

Fertilizers and Manures

Beans appear not to respond well to fertilizers, and when they do the response is not as striking as in other crops

(GLP 20, 1982; Zoebl, 1984). Application of fertilizers significantly increases plant height, leaf area, total dry weight, number of pods per plant and number of primary branches (Mahehema and Ndunguru, 1984; Mbugua, 1983). In Kisii it was also reported that the bean plants that received fertilizers withstood beanfly attack better than those that did not receive any fertilizer (GLP 20, 1982).

Yield responses due to fertilizer application have been established in most of the representative bean-growing areas of Kenya. These results were arrived at after over 200 field trials planted with improved GLP varieties in pure stand (GLP 19, 1981). When rainfall is low and distribution poor, the response to any type of fertilizer is low and uneconomical and may even be negative (Floor, 1982, GLP 20; 1982).

Manures - both poultry and farmyard - have been used with some positive response. In Kenya an application rate of 10 tons per hectare gives a fair yield under moist conditions. Under dry conditions farmyard manure applied on the furrow was reported harmful to plants due to direct contact with seed. In Kakamega (GLP 18, 1981, GLP 19, 1981) a 2-week pre-application on the planting furrow was most beneficial.

It has also been reported from other countries that highest grain yields are obtained by using a combination of manure and inorganic fertilizers - 7.5 tons manure + 10 kg P+25 kg N/ha (Rweyemau and Ndunguru, 1984).

Phosphorus

Phosphorus is limiting in the highlands and in western Kenya and it is in those soils that response to phosphates is dramatic (Zoebl, 1984). Response to triple superphosphate (TSP) has been found to be erratic in dry areas of Machakos. Positive response is only achieved when pH is over 6, %N over 0.12 and P is 25-35 (GLP 21, 1982). When positive response to phosphates were reported, it was observed that phosphates increased leaf area index, plant growth rates, pods per plant, seeds per pod and 100 seed weight (GLP 19; Mbugua, 1983). In the coffee areas represented by Embu, response to phosphorus is relatively high (Floor, 1984), but absent in dry areas.

Nitrogen

The response of beans to nitrogen is related to the percentage organic nitrogen in the soil as can be seen below.

%N in Soil	Response to N in kg bean/kg N added	Area
0.10	7.5	Machakos
0.16	9.0	Thika
0.17	7.3	Hamisi/Vihiga
0.20	4.8	Embu
0.22	3.0	Ikolomani
0.26	1.9	Kisii

It has also been observed in Embu that response to nitrogenous fertilizer is low if the soil has low natural phosphorus (Floor, 1984). Indeed, calcium ammonium nitrate (CAN) alone in these areas is uneconomical, but in the presence of phosphorus as 20:20:0 or diammonium phsphate (DAP) 18:46:0, nitrogen is beneficial. In Kisii, nitrogen response was found to be low even in the presence of phosphorus. In these areas the high amounts of organic matter make it unnecessary to use nitrogenous fertilizers on beans (Floor, 1984). In the drier areas of eastern Kenya, nitrogen is generally in short supply (Floor, 1984; Zoebl, 1984) and response to nitrogen is positive.

Nitrogen fixation

Beans are leguminous plants, and like other legumes they can fix atmospheric nitrogen through symbiotic association with rhizobia. The efficiency of nitrogen fixation varies with bean varieties, rhizobia strains and abiotic factors. Leakey and Day (1977) have enumerated the probable reasons for failure of effective inoculation. One factor is high seedbed temperatures. The level of available nitrogen in the rhizosphere may be sufficiently high to inhibit nodulation. The host cultivar may be a poor nodulator, or there might be insufficient or excess macro and micro-nutrients. They observed that Mo, Zn, Bo and Cu are required for effective nodulation while Mn and Al excesses limit nodulation.

The University of Nairobi MIRCEN project is producing, processing, packaging and marketing Rhizobia with usage instructions on the package.

Floor (1984) observed that addition of phosphorus had a highly significant effect on nodulation. He concluded that phosphorus availability in the soil may determine the magnitude of nodulation and that beans need more phosphorus when they depend upon atmospheric nitrogen fixation than when grown with combined nitrogen. The amount of fixed nitrogen can benefit the successive crop. Yields of maize following cowpeas and beans are significantly higher than a continous sole crop of maize (Nadar and Faught, 1984).

Conclusion

Experiments over the years have indicated that beans don't respond well to fertilizers and are better integrated in the farm system as an intercrop with a cereal or a cash-crop whereby the cash-crop receives the fertilizer and the bean benefit indirectly. The small-scale farmer is not interested in maximum yields because the inputs required to reach the maximum yields are beyond his capability. The aim is high returns per money invested.

Where beans are planted as a monocrop, application of fertilizers can boost yields, but the question is whether it is economical for the farmer to apply fertilizers. Where the bean farm gate prices are high, it is worthwhile using fertilizers. The results from various areas over the years have helped to establish fertilizer recommendations as:

Dry regions - Use CAN at 138 kg/ha top dressed 4 weeks after germination.
Coffee cotton zone - Use DAP at 200 kg/ha at planting.
Kisii and Western - Use TSP at 78 kg/ha at planting.

The recommended planting/fertilizing in furrows has been found to be rather labour-demanding. Application of DAP in the planting furrow resulted in reductions of 5-43% in emergence. This loss can be avoided if thorough mixing of soil with fertiliser is done prior to seed placement to avoid contact between fertilizer and seed.

Where intercropping with maize is done, the maize receives all the fertilizer, and the beans receive one-half of that applied in pure cropping bean stands.

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Soils and Bean Production in Angola

J.A. Sereno, J.A.S.C. Melo and F. Girao Monteiro

Institute de Investigacao, Agronomia, Angola

Introduction

Bean crop (*Phaseolus vulgaris* L.) is the most important legume in Angola, although other legumes like groundnuts and cowpeas are of considerable importance for the diet of the population. As a food crop it ranks third after maize and cassava. However, in certain regions, as in the Central Plateau, it comes second. Beans are mainly grown at the peasant farm level usually under some kind of intercropping farming. From North to South the dominant crops in the farming systems are respectively, cassava, maize and sorghum.

Data on soil fertility concerning bean production systems are not known. Soil fertility research before 1975 focused on identifying general chemical constraints to crop growth and on divising remedies within the scope of a high energy input agriculture. Neither bean crop research was seen as an important issue, nor was soil fertility management in bean-cropping systems at the small farm level. Following independence, the war has caused a major disruption in traditional patterns and farming systems of peasant agriculture, making it impossible to survey and monitor the trends in the bean production. Finally, social instability and a severe shortage of manpower, among other factors, have prevented any consistent research work.

In 1987, under the influence of the Regional Bean Research Programme a major step took place with the establishment of a National Bean Research Programme sponsered by the Faculty of Agriculture with the collaboration of the Agronomic Research Institute.

In this report an attempt is made to put together some information which hopefully can be of some help for the regional programme in assisting national experts on strategies and methodology to follow in bean research in Angola.

Principal zones of bean production and soils

The two main bean production zones are shown in the map. These were drawn from an enquiry carried out in 1970/71 by the government. Table 1 shows data concerning the analysis of bean production in those zones.

Several important aspects are revealed in Table 1. The total bean production of zone 1 was approximately four times greater than that of zone 2; the number of small farms that used to grow beans in zone 1 was almost double that in zone 2; most of the production in both areas was achieved under some sort of intercropping systems; productivity in zone 1 was almost twice that of zone 2.

Soils in both zones were grouped according to the MPAM classification system, a system developed by Portuguese soil scientists and similar to the French classification system. A short description follows along with a tentative correlation with the Soil Taxonomy System.

Generally speaking, most of the soils have an udic moisture regime. The exceptions are those ocurring along the western strip of both zones and in the southern strip of zone 2. The annual rainfall in those areas amounts to approximately 1000 mm, and, as a result, soils have a ustic moisture regime. Almost all the tropical ferralitic soils mentioned later only occur in these strips.

The dominant soils in the area of bean production are slightly ferralitic and very often associated with paraferralitic soils. They account for as much as 55% and 65% of the total area of zones 1 and 2, respectively. Some of them can tentatively be considered as Ultisols; others are intergrades between Ultisols and Oxisols. They are very deep soils, fine to medium texture and without structure except in the upper horizons. The mineral reserve is very low or virtually non-existent. Nutrients are in short supply and both CEC and pH are low. Its productivity is low and depends on the degree of preservation of the upper layers. Their main physical constraint is the low moisture-holding capacity.

The psammo-ferralitic soils rank second in terms of area of distribution. They can be considered as Entisols (Quartzipsaments) and very often occur with other psammitic soils lower in iron. They account for about 25% of the areaof each zone. They were derived from quartose materials. Some important characteristics are a sandy or sandy loam texture, almost without structure, excessive permeability, low moisture-holding capacity, low CEC and no mineral reserve. They are the least productive of the soils referred to.

Tropical ferralitic soils come third and can be seen as being Alfisols, mainly Ustalfs. They account for about 10% of the area of zone 1 and a much less proportion of the area of zone 2. Important characteristics are a fine or medium texture, reasonable mineral reserve and CEC, and low pH. Their profiles are not deep. Some physical characteristics enhance susceptibility to erosion. When not occuring in hilly areas, they are very important in terms of crop productivity.

Para-ferralitic soils follow. They can be correlated to Udults and Ustults. Usually they occur in hilly landscapes associated with rock outcrops. Their characteristics are similar to those of the slightly-ferralitic soils. However, they are comparatively less deep and with a better structure, higher base saturation and better mineral reserve. They account for about 5% of the area of each zone.

Calsiallitic soils are only found in zone 1 where they occur frequently in conjuction with other soils with an aquic moisture regime. They account for less tha 4% of the area and constitute a very peculiar kind of soil possibly correlated to Udalfs and Tropepts. Some important characteristics are a medium to fine texture, kaolinite and micaceous minerals well represented in the clay fraction, high CEC and base saturation and a pH close to neutrality.

Finally we have the group of the typical ferralitic soils which can be correlated to Oxisols (Ustox, Orthox). They have similar characteristics and occur associated with the slightly ferralitic soils. However they are still less productive as a result of higher degree of alteration. They account for less than 1% of the area of the two zones.

Soil Constraints for Food Crops Agriculture

The level of soil fertility in Angola is generally low. Research was carried out before 1975 mainly to detect nutrient deficiencies and chemical imbalances. Aspects of soil physics were given little attention. Most of these results and findings were not published since the studies were not completed in 1975.

A considerable amount of research has also been carried out by other Portuguese institutions in Portugal. However, the gathering of that information has proved to be very difficult in part because the library at the Agronomic Research Institute is no longer working properly.

What follows is a summary of the information taken from Moreira et al. (1963) relating to nutrient deficiencies in ferralitic soils with fine texture and psammitic sandy soils, both being the most widespread groups in the country (50%).

In ferralitic and psammitic soils the N, P and S deficiencies were found to be very frequent. Erosion seems to increase N and S deficiency. Some soils with K in short supply were noticed. Psammitic soils were low in B and sometimes in Ca. In very acid soils some evidence of Al and/or Mn toxicities was found.

Subsequent studies focused on the use of mineral fertilizers for maximizing the yields of some crops grown in the Central Plateau, the most densely-populated area of the country. Again the preliminary findings were not published.

One exception to the approach of using high-energy inputs consisted of a study aiming at evaluation of cheap local raw materials such as phosphate rocks and limestones for direct use in peasant agriculture. Apart from some generic documents, no detailed results were published.

After 1975, the production of main crops decreased, owing initially to the disruption of the internal trade network. Then as a consequence of the war the majority of the peasant people moved into protected villages provoking more pressure on the nearby land. As a result dramatic effects on soil fertility are expected, mainly in areas of flat landscape where soils were already very poor. In this respect the data of an unpublished survey covering 26 locations at Huambo province can illustrate the situation (Appendix 4). Soil samples were collected by staff of the International Red Cross Organisation. Soil analyses have revealed that in addition to N, both soil P and K were in short supply, whereas chemical imbalances can be anticipated because the soils have low base saturation. Since fertilizer transportation and trade have virtually stopped, crop yields will tend to decrease still further in those areas unless tolerant varieties are made available to peasants.

Bean Yield Data from Field Experiments

Field experiments to screen for better varieties have been carried out at the Agronomic Research Institute. However, soils at the Institute's headquarters (Huambo) are not representative of the soils in the area. In addition, fertilizers have been applied for a long time, and although pH is low and Mn is high, P stress is not likely to occur. Furthermore, experiment fertilizer application rates have been comparatively higher than those used by small farmers. Neverthless the results may constitute important estimates of potential yields. Appendix 2 and 3 show some bean yield data.

Existing Facilities

The Department of Soils and Climate was practically closed between 1975 and 1982. In 1982 conditions allowed for the begining of its rehabilitation, and in 1984 a FAO/UNDP project considerably strenghtened its working capacity. Neverthless, the main constraint for more efficient activity still remains in the severe shortage of skilled people. Facilities at the Department can be considered good. They include well equipped labs for routine soil and plant analysis, rooms and equipment for soil cartography, a technician's room, separate laboratories for the preparation of glasshouse and field experiments, offices etc. Technical staff include two postgraduates, two graduates and four students of the Faculty of Agriculture.

The main activities of the Department are soil survey for land-use planning; evaluation of phosphate rocks for direct use in agriculture; collaboration with the Early Warning System Project; collaboration with classes at the Faculty of Agriculture; collaboration with the National Bean Research Project. The Department still keeps a routine soil analysis service which is unique in the country.

Perspectives for the near future include extention of the FAO project aimed at carrying out soil cartography and soil fertility studies; establishment of an agreement with specialized Portuguese institutions to allow for general and specific work in particular areas; strenghtening of links with the Regional Inventory Agricultural Resource Base project; strengthening of links with the Early Warning System project and the beginning of contacts with the World Meteorological Organisation; a closer collaboration with the National Bean Research project.

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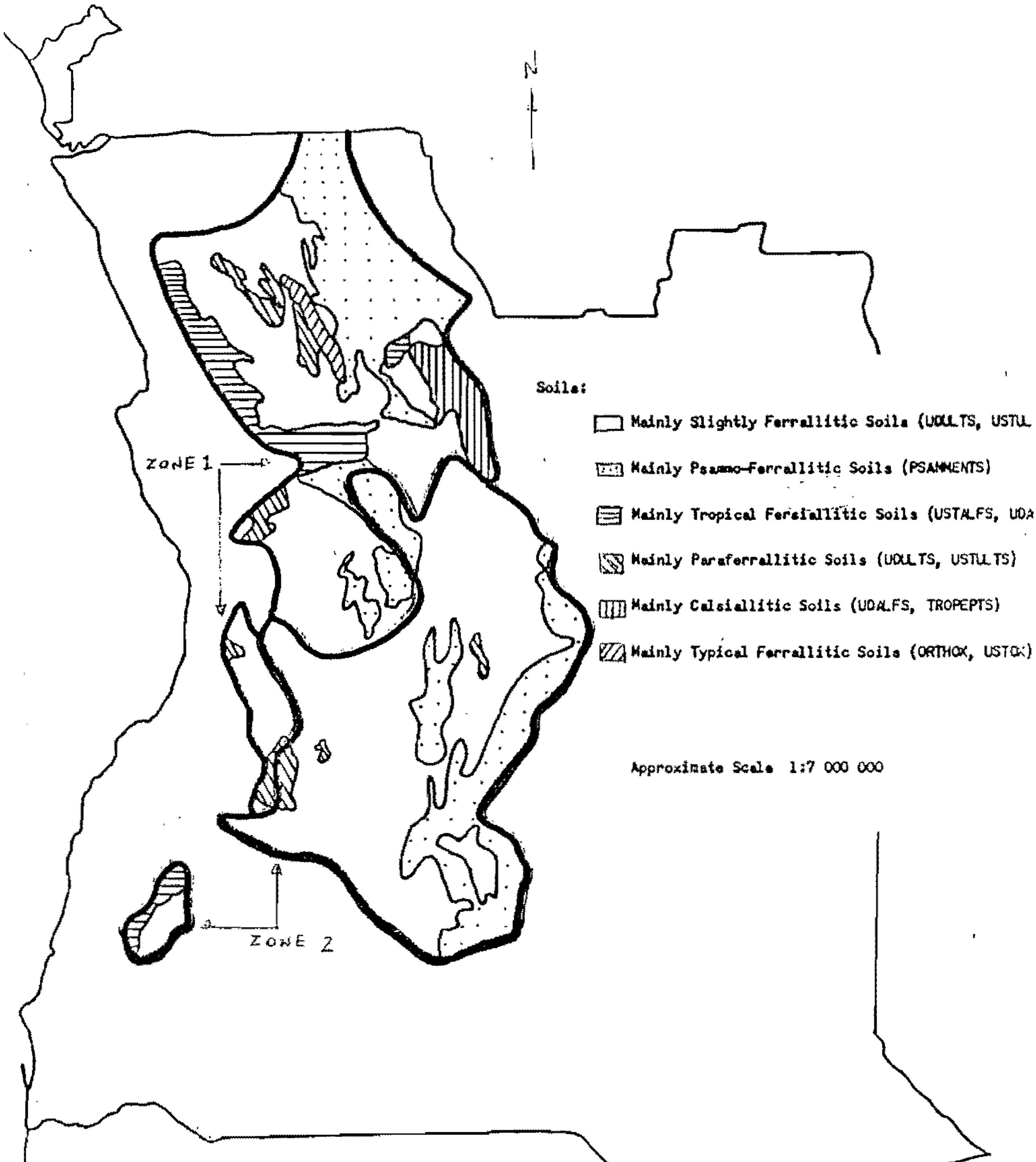
SOILS IN THE PRINCIPAL BEAN PRODUCTION ZONES



TYPICAL FERRALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-10	10-25	25-45	50-85	90-125	135-175
> 2 mm %	0	0	0	0	0	0
Na fracção < 2 mm						
Anál. granulométrica %:						
2 — 0,2 mm	12,1	5,6	10,6	8,3	5,4	10,9
0,2 — 0,02 mm	56,2	63,5	57,3	59,8	60,7	55,6
0,02 — 0,002 mm	3,5	5,0	3,0	6,8	5,9	5,9
< 0,002 mm	24,9	24,6	27,7	22,6	26,3	25,7
$CaCO_3$ %	0,0	0,0	0,0	0,0	0,0	0,0
Matéria orgânica %	5,0	2,8	2,1	1,6	—	—
pH (H_2O)	5,3	5,0	5,0	5,0	5,2	5,3
pH (*KCl*)	4,3	4,2	4,2	4,3	4,4	4,5
T m. e./100 g	11,31	8,98	7,40	6,06	—	—
Bases permut. m. e./100 g:						
Ca	1,24	0,94	0,77	0,81	—	—
Mg	0,00	0,00	0,00	0,00	—	—
K	0,15	0,07	0,06	0,05	—	—
Na	0,04	0,04	0,06	0,07	—	—
V %	12,6	11,7	12,0	15,4	—	—
C orgânico %	2,87	1,64	1,19	0,92	—	—
N total %	0,106	0,083	0,060	0,043	—	—
C/N	27,1	19,8	19,8	21,4	—	—
Fe_2O_3 livre %	0,43	1,88	1,98	2,03	2,09	2,32
Na fracção < 0,002 mm						
Relações moleculares:						
SiO_2/Al_2O_3	—	—	—	—	0,95	—
SiO_2/R_2O_3	—	—	—	—	0,83	—
Fe_2O_3 total %	—	—	—	—	9,42	—
T (*pH* 7) m. e./100 g	—	—	—	—	3,67	—
Composição mineralógica	—	—	—	—	$K_1Gb_2Go_3$	—

CALSIALLITIC SOIL OF SUBHUMID AND HUMID REGIONS

Dados analíticos:

Profundidade (cm)	0-16	16-31	31-55	55-82	82-111	111-160
> 2 mm %	0	0	0	0	0	0
Na fracção < 2 mm						
Análise granulométrica %:						
2 — 0,2 mm	6,8	7,5	4,7	2,1	0,4	0,5
0,2 — 0,02 mm	62,7	68,8	54,5	48,8	49,8	52,1
0,02 — 0,002 mm	11,1	10,0	11,2	19,4	22,4	22,4
< 0,002 mm	18,1	15,0	27,5	29,5	29,7	26,3
$CaCO_3$ %	0,0	0,0	Vest.	0,4	0,3	0,3
Matéria orgânica %	1,8	1,4	1,0	0,3	—	—
pH (H_2O)	5,8	5,8	6,5	9,0	8,8	8,9
pH (*KCl*)	4,6	4,1	4,9	6,6	6,4	6,6
C orgânico %	1,05	0,80	0,56	0,15	—	—
N total %	0,081	0,072	0,058	0,027	—	—
C/N	13,0	11,1	9,7	5,6	—	—
P_2O_5 total %	0,07	0,06	0,06	0,07	—	—

PSAMMO-FERRALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-10	10-33	33-65	65-100	100-140	140-180
> 2 mm %	0	0	0	0	0	0
Na fracção < 2 mm						
Análise granulométrica %:						
2 — 0,2 mm	39,1	39,2	45,0	39,0	35,7	35,4
0,2 — 0,02 mm	55,4	53,5	48,0	54,1	54,9	55,7
0,02 — 0,002 mm	0,2	0,6	1,1	1,4	1,2	1,5
< 0,002 mm	4,4	6,6	6,2	5,9	8,5	7,8
$CaCO_3$ %	0,0	0,0	0,0	0,0	0,0	0,0
Matéria orgânica %	0,9	0,5	0,3	0,2	—	—
pH (H_2O)	5,9	5,8	5,5	5,4	5,5	5,4
pH (KCl)	5,3	4,7	4,5	4,5	4,6	4,7
T m. e./100 g	2,12	1,56	1,37	1,50	—	—
Bases permutáveis m. e./100 g:						
Ca	0,81	0,13	0,09	0,09	—	—
Mg	0,13	0,13	0,00	0,00	—	—
K	0,05	0,05	0,07	0,04	—	—
Na	0,00	0,02	0,04	0,02	—	—
V %	46,7	21,2	14,6	10,0	—	—
C orgânico %	0,50	0,27	0,16	0,10	—	—
N total %	0,022	0,012	0,006	0,005	—	—
C/N	22,7	22,5	26,7	20,0	—	—
Fe_2O_3 livre %	0,21	0,31	0,31	0,31	0,38	0,42
P_2O_5 total %	0,04	0,04	0,03	0,03	—	—
Na fracção < 0,002 mm						
Relações moleculares:						
SiO_2/Al_2O_3	—	—	—	2,00	—	—
SiO_2/R_2O_3	—	—	—	1,85	—	—
Fe_2O_3 total %	—	—	—	4,60	—	—
T (pH 7) m. e./100 g	—	—	—	6,31	—	—

TYPO-FERSIALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-15	15-30	30-45	45-77	77-115
> 2 mm %	1	3	2	5	7
Na fracção < 2 mm					
Análise granulométrica %:					
2 — 0,2 mm	62,6	57,2	55,0	57,5	44,7
0,2 — 0,02 mm	21,2	22,5	20,5	14,5	19,6
0,02 — 0,002 mm	5,8	7,7	4,0	5,2	6,3
< 0,002 mm	9,1	10,8	19,4	22,3	28,0
$CaCO_3$ %	0,0	0,0	0,0	0,0	0,0
Matéria orgânica %	1,3	0,7	0,6	0,6	—
pH (H_2O)	5,7	6,0	5,7	5,5	5,6
pH (KCl)	4,6	4,4	4,1	4,0	4,8
T m. e./100 g	5,05	4,31	4,81	5,58	—
Bases permutáveis m. e./100 g:					
Ca	1,10	0,70	0,62	1,32	—
Mg	1,20	1,41	1,40	1,04	—
K	0,27	0,10	0,07	0,10	—
Na	0,03	0,08	0,07	0,18	—
V %	51,5	53,1	44,7	47,3	—
C orgânico %	0,75	0,41	0,36	0,32	—
N total %	0,051	0,050	0,045	0,039	—
C/N	14,7	8,2	8,0	8,2	—
Fe_2O_3 livre %	0,46	0,50	0,70	0,91	0,96
P_2O_5 total %	0,06	0,07	0,06	0,05	—
Na fracção < 0,002 mm					
Relações moleculares:					
SiO_2/Al_2O_3	—	—	—	2,27	—
SiO_2/R_2O_3	—	—	—	2,01	—
Fe_2O_3 total %	—	—	—	6,28	—
T (pH 7) m. e./100 g	—	—	—	18,36	—

Dados analíticos:

Profundidade (cm)	0-11	11-40	40-75	75-105
> 2 mm %	1	0	1	1
Na fracção < 2 mm				
Análise granulométrica %:				
2 — 0,2 mm	6,0	6,3	4,0	3,8
0,2 — 0,02 mm	41,2	34,7	30,8	28,3
0,02 — 0,002 mm	17,3	18,9	19,6	18,1
< 0,002 mm	34,9	39,7	47,1	50,6
$CaCO_3$ %	0,0	0,0	0,0	0,0
Matéria orgânica %	2,0	1,0	0,7	—
pH (H_2O)	5,0	5,2	5,2	5,1
pH (KCl)	4,2	4,4	4,1	4,3
T m. e./100 g	9,07	7,49	8,65	—
Bases permutáveis m. e./100 g:				
Ca	0,65	0,57	0,48	—
Mg	0,26	0,00	0,00	—
K	0,16	0,05	0,08	—
Na	0,09	0,15	0,23	—
V %	12,6	10,3	9,1	—
C orgânico %	1,18	0,60	0,42	—
N total %	0,087	0,053	0,056	—
C/N	13,6	11,3	7,5	—
Fe_2O_3 livre %	2,03	2,79	3,17	3,68
Na fracção < 0,002 mm				
T (*pH* 7) m. e./100 g	—	—	13,56	—
Composição mineralógica	—	—	K_1Mi_2	—

APPENDIX 2: Production data of bean variety field experiments Zone 2 (IIA-Chianga 1983)

Meteorological data

	Rainfall (mm)	Temperature °C (mean)	Relative Humidity (%)
February	244.9	20.8	79
March	182.1	20.7	76
April	45.6	20.2	68
May	19.3	19.2	57

Fertilizer	Kg/ha
Ammonium nitrate	185
Superphosphate (triple)	218
Potassium chloride	100
Kieserite	100

Soil analysis (Ferralitic soil)	
Sand (%) 2 - 0.2	13.25
Fine sand (%) 0.2 - 0.02	16.26
Silt (%) 0.02 - 0.002	15.66
Clay (%)<0.002	54.25
Organic Matter (%)	2.41
Total N (%)	0.10
C/N Ratio	14
P (Bray I) ug/g	12
pH (H_2O)	5.4
pH (KCl)	4.7
pH ($CaCI_2$)	4.8
Exct. Bases - Ca	2.02
me/100 g - Mg	0.16
- K	0.37
- Na	0.11
Effective CTC me/100 g	3.46
Base Saturation (V) %	76.9
Al + H (me/100 g)	0.8
Al (me/100 g)	0.4

PSAMMO-FERRALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-10	10-33	33-65	65-100	100-140	140-180
> 2 mm %	0	0	0	0	0	0
Na fracção < 2 mm						
Análise granulométrica %:						
2 — 0,2 mm	39,1	39,2	45,0	39,0	35,7	35,4
0,2 — 0,02 mm	55,4	53,5	48,0	54,1	54,9	55,7
0,02 — 0,002 mm	0,2	0,6	1,1	1,4	1,2	1,5
< 0,002 mm	4,4	6,6	6,2	5,9	8,5	7,8
$CaCO_3$ %	0,0	0,0	0,0	0,0	0,0	0,0
Matéria orgânica %	0,9	0,5	0,3	0,2	—	—
pH (H_2O)	5,9	5,8	5,5	5,4	5,5	5,4
pH (*KCl*)	5,3	4,7	4,5	4,5	4,6	4,7
T m. e./100 g	2,12	1,56	1,37	1,50	—	—
Bases permutáveis m. e./100 g:						
Ca	0,81	0,13	0,09	0,09	—	—
Mg	0,13	0,13	0,00	0,00	—	—
K	0,05	0,05	0,07	0,04	—	—
Na	0,00	0,02	0,04	0,02	—	—
V %	46,7	21,2	14,6	10,0	—	—
C orgânico %	0,50	0,27	0,16	0,10	—	—
N total %	0,022	0,012	0,006	0,005	—	—
C/N	22,7	22,5	26,7	20,0	—	—
Fe_2O_3 livre %	0,21	0,31	0,31	0,31	0,38	0,42
P_2O_5 total %	0,04	0,04	0,03	0,03	—	—
Na fracção < 0,002 mm						
Relações moleculares:						
SiO_2/Al_2O_3	—	—	—	2,00	—	—
SiO_2/R_2O_3	—	—	—	1,85	—	—
Fe_2O_3 total %	—	—	—	4,60	—	—
T (*pH* 7) m. e./100 g	—	—	—	6,31	—	—

TYPO-FERSIALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-15	15-30	30-45	45-77	77-115
> 2 mm %	1	3	2	5	7
Na fracção < 2 mm					
Análise granulométrica %:					
2 — 0,2 mm	62,6	57,2	55,0	57,5	44,7
0,2 — 0,02 mm	21,2	22,5	20,5	14,5	19,6
0,02 — 0,002 mm	5,8	7,7	4,0	5,2	6,3
< 0,002 mm	9,1	10,8	19,4	22,3	28,0
$CaCO_3$ %	0,0	0,0	0,0	0,0	0,0
Matéria orgânica %	1,3	0,7	0,6	0,6	—
pH (H_2O)	5,7	6,0	5,7	5,5	5,6
pH (*KCl*)	4,6	4,4	4,1	4,0	4,8
T m. e./100 g	5,05	4,31	4,81	5,58	—
Bases permutáveis m. e./100 g:					
Ca	1,10	0,70	0,62	1,32	—
Mg	1,20	1,41	1,40	1,04	—
K	0,27	0,10	0,07	0,10	—
Na	0,03	0,08	0,07	0,18	—
V %	51,5	53,1	44,7	47,3	—
C orgânico %	0,75	0,41	0,36	0,32	—
N total %	0,051	0,050	0,045	0,039	—
C/N	14,7	8,2	8,0	8,2	—
Fe_2O_3 livre %	0,46	0,50	0,70	0,91	0,96
P_2O_5 total %	0,06	0,07	0,06	0,05	—
Na fracção < 0,002 mm					
Relações moleculares:					
SiO_2/Al_2O_3	—	—	—	2,27	—
SiO_2/R_2O_3	—	—	—	2,01	—
Fe_2O_3 total %	—	—	—	6,28	—
T (*pH* 7) m. e./100 g	—	—	—	18,36	—

PARA FERRALLITIC SOIL

Dados analíticos:

Profundidade (cm)	0-11	11-40	40-75	75-105
> 2 mm %	1	0	1	1
Na fracção < 2 mm				
Análise granulométrica %:				
2 — 0,2 mm	6,0	6,3	4,0	3,8
0,2 — 0,02 mm	41,2	34,7	30,8	28,3
0,02 — 0,002 mm	17,3	18,9	19,6	18,1
< 0,002 mm	34,9	39,7	47,1	50,6
$CaCO_3$ %	0,0	0,0	0,0	0,0
Matéria orgânica %	2,0	1,0	0,7	—
pH (H_2O)	5,0	5,2	5,2	5,1
pH (*KCl*)	4,2	4,4	4,1	4,3
T m. e./100 g	9,07	7,49	8,65	—
Bases permutáveis m. e./100 g:				
Ca	0,65	0,57	0,48	—
Mg	0,25	0,00	0,00	—
K	0,15	0,05	0,08	—
Na	0,09	0,15	0,23	—
V %	12,6	10,3	9,1	—
C orgânico %	1,18	0,60	0,42	—
N total %	0,087	0,053	0,056	—
C/N	13,6	11,3	7,5	—
Fe_2O_3 livre %	2,03	2,79	3,17	3,68
Na fracção < 0,002 mm				
T (*pH* 7) m. e./100 g	—	—	13,56	—
Composição mineralógica	—	—	K_1Ml_2	—

IBYAN 27551 A (Bush types)

Variety	Origin	Yield (Kg /ha)	(1)
FA 114	IIA-Angola	1188	a
FE 74	IIA-Angola	842	b
LINSA 23	ICA-Colombia	833	b
LINSA 22	" "	831	b
BAT 1249	CIAT	792	b
BAT 1275	CIAT	719	b
BAT 1250	CIAT	701	b
LINSA 24	ICA-Colombia	251	c

IBYAN 57041 A (Bush typy)

Variety	Origin	Yield (Kg /ha)	(1)
A 81	CIAT	1569	a
CENA 164-1	BRASIL	1473	a b
A 83	CIAT	1440	a b
A 90	CIAT	1410	a b
EC 4	IIA-Angola	1366	a b
IAPAR-RAI-54	BRASIL	1335	a b
BAT 874	CIAT	1294	a b
BAT 561	CIAT	1215	a b
FC 25	IIA-Angola	1070	b c
FC 1	IIA-Angola	788	c d
CARIOCA	BRASIL	742	c d
BAT 160	CIAT	551	d

(1) Means followed the same letter are not significantly different at the 5% level

IBYAN 3703 (Bush types)

Variety	Origin	Yield (Kg/ha)	(1)
FB 109	IIA-Angola	1370	a
BAT 1281	CIAT	1317	a b
FB 108	IIA-Angola	1292	a b
BAT 1198	CIAT	1225	a b c
BAT 1280	CIAT	1185	a b c
BAT 1257	CIAT	1076	a b c
BAC 38	CIAT	956	b c
EX-RICO 23	CIAT	919	c
78-0374	EUA	876	c

VIRAF 73055 (Climbing Types)

Variety	Origin	Yield (Kg/ha)	(1)
PI 311998	MEXICO	1021	a
FR 95	IIA-Angola	920	a b
ATICA	HONDURAS	887	a b
V-4213-22	CIAT	847	a b c
PI 312052	MEXICO	831	-
V-4190-21	CIAT	829	a b c
V-4213-23	CIAT	747	a b c
TURRIALBA 612-25	COSTA RICA	724	a b c
S 412 4 R	EL SALVADOR	665	b c
V-2959-CM(10-0)-15	CIAT	550	c

(1) Means followed by the same letter are not significantly different at the 5% level

APPENDIX 3: Intercropping bean-maize experiment Zone 2 (IIA-Chianga 1987)

Soil analysis (Ferralitic soil)	
Sand (%) 2 - 0.2 mm	21.22
Fine sand (%) 0.2 - 0.02	16.59
Silt (%) 0.02 - 0.002	14.25
Clay (%)<0.002	46.84
Organic Matter (%)	2.78
Total N (%)	0.12
P (Bray 1) ug/g	6
pH (H_2O)	5.4
($CaCl_2$)	4.7
Exctr. bases - Ca	2.14
me/100 g - Mg	0.36
- K	0.79
- Na	0.04
(Al + H) (KCI) me/100 g	0.49
Effective CEC	3.81
Base saturation (%)	87
Mn (Ammonium acetate) ug/g	9

Maize and beans mean yields at different treament combinations.

(Maize/bean intercropping exploratory trial)

Treat. no	Maize variety		Bean variety	Maize yield (Kg/ha)	Bean yield (Kg/ha)
1	SAM3	x	Sondeombua	5025	83
2	BR	x	Sondeombua	4870	132
3	BR	x	Manteiga	3594	293
4	SAM3	x	Ervilha	5234	192
5	SAM3	x	Manteiga	5718	294
6	SAM3	x	Sachinongue	4291	171
7	BR	x	Sachinongue	3529	178
8	BR	x	Erivilha	4419	169
9	SAM3	x	Branco Egito	5962	240
10	BR	x	Branco Egito	4147	221
LSD 5%				2247	122

Crop Populations: Maize = 40 400 pl/ha

Bush Beans = 121 212 pl/ha

Table 1: Bean production analysis

Zones	Total number of farmers	Farms that grow beans (%)	Average farm size (ha)	Average yield Kg/ha	Average yield/ farm	Auto-consumption: Total (TON)	Auto-consumption: % of total production	Auto-consumption: Average per farm (Kg)	Number of farms that grow beans.	Production area (ha): Sole crop	Production area (ha): Intercropping	Total produc tion (TON)
Zone 1	410 779	66 8	0 5	361.2	174 0	18578	38 9	67 7	274 538	26 747	291 927	47 75
Zone 2	295 194	52 4	0.4	195.4	79 4	6855	55 7	44 3	154 832	9 080	204 783	12 298

Source:

Recommendations of Working Groups

Recommendations on the Improvement of Traditional Bean Cropping Systems

The group recommends following the subsequent research approaches:

- Farmer-based problem indentification
- Long term experiments to evaluate system sustainability
- Exploit possibilities of systems transfer for short term benefits for farmers
- Develop various options for improvement rather than single solutions
- Involve farmers in all research steps
- Respect an extensive set of criteria to evaluate systems including agronomic, economic and socio-economic parameters.

The following potential collaborative research projects should be studied by national and regional programmes in their various aspects:

- Banana/bean/coffee system
- Bean/maize; and bean/sorgum system
- Improvement of *in situ* composting
- Collaboration with ICRAF for the development of agroforestry/bean systems

Recommendations on Soil Fertility Research in Bean-based Cropping Systems in Africa

A. For NARS

1. More attention is required, in planning soil fertility research, to the likelihood of adoption of results by small farmers.

2. Increased efforts are required, both by research and extension agencies, to increasing productivity through improvements to the supply, conservation and utilization of organic materials.

3. Research is needed on the judicious use of inorganic fertilizers to supplement efficiently used organic materials.

4. Long term research on soil fertility is needed to assess residual effects of treatments, which may be at least as important for sustainability as their immediate effects. This will include assessments of soil physical characteristics and microbiological processes.

5. Teamwork, involving soil scientists, microbiologists and agronomists, is indispensable in the implementation of the above strategies.

B. For CIAT

For the many situations in Africa where small bean producers are not expected to have adequate access to soil amendments, the genetic approach of breeding for tolerance to specific soil constraints is an appropriate new strategy. Initially, CIAT should concentrate upon screening bean germplasm for tolerance to the Al/Mn toxicity problem of acid soils and make results available in appropriate forms for use by NARS.

Recommendations on the Diagnosis of Soil Fertility Constraints in Bean-based Cropping Systems in Africa

A. A bean map for Africa should be developed immediately which delineates the bean growing areas for the purpose of evaluation of edaphic and climatic constraints on bean production.

1) CIAT should provide national programmes with guidelines for supplying required information to the CIAT Agroecological Unit.

2) The CIAT Agroecological Unit should evaluate and compile this information, and determine the needs for additional information.

3) CIAT should take the necessary steps, in collaboration with national programmes, to collect other needed information for the development of the bean map.

B. The major soils in the bean growing areas of Africa should be identified and characterized.

1) The CIAT Agroecological Unit should collect existing information on the major soils.

2) Benchmark sites should be identified by a soil fertility working group together with the respective national programmes, and these should be characterized in collaboration with IBSNAT.

3) One or more students should do MSc thesis research on the Fertility Capability Classification (FCC) system to determine its utility on Africa soils and to translate soil survey results to FCC.

C. The capacity of the NARO's to diagnose soil fertility constraints of beans should be improved.

1) Short course training in diagnostic techniques including the use of soil and plant tissue analysis, nutritional screening trials, and use of visual symptoms should be provided.

2) Soil and plant tissue analytical procedures should be standardized.

3) MSc training should be provided in soil fertility and plant nutrition.

4) Norms of the Diagnosis and Recommendation Integrated System (DRIS) for the interpretation of bean plant tissue analysis results should be developed for Africa soils. This should be the subject of MSc thesis research or a regional sub-project.

5) CIAT should prepare audio-tutorial units, in French and English, on nutritional disorders in beans.

D. Soils fertility research on beans should receive more emphasis.

1) A soil fertility working group consisting of two people from each of the CIAT Regions should be formed. This group would be responsible for coordinating soil fertility research activities, indentifying bench-mark sites, etc.

E. A standard set of genotypes should be assembled for use in soil fertility research.

1) National and regional bean breeders should identify 25 broadly adapted varieties with variable tolerance to soil fertility stress. These varieties should be identified at the bean breeders workshop in January, 1990.

2) These varieties should be evaluated and characterized under soil fertility stress conditions.

3) These varieties should be used in future soil fertility and plant nutrition research.

Closing Remarks

Tamirie Hawando

Soil Scientist/Deputy Head,
Economic and Social Affairs Department
Worders Party for Ethiopia

It is a pleasure for me to have been invited by the organising committee of this workshop to make some brief remarks during this closing session. The subject of this workshop was very important and timely because it clearly identified the bean production needs of the countries in the region. It reviewed areas of strength and weakness on bean research activities in order to determine future research directions and work out a realistic, clear and goal-oriented strategy on tackling soil-related constraints to productivity of beans in the bean-cropping systems.

As stated in the brochure of the workshop, the purpose was to document and assess past research, to identify needs and priorities for future research programmes, to review research methods with a view to standardising the approaches within the region and to devise strategies for regional collaboration in central, eastern and southern African Countries.

In this connection, it is very important to note that as a starting point a national strategy should be clearly established for each country based on needs, goals and priorities before any research programme is executed. These national research strategies will be used as a base to work out a sound regional strategy. In many developing countries, need-based, goal-oriented and clearly stated national research strategies do not exist. The absence of such strategies has been the major hinderance in the judicious utilization of existing agricultural research results within a country. Likewise, this allows for little transfer of appropriate technologies developed in other countries on similar climatic and soil conditions.

In this workshop, several important aspects of soil-related constraints have been discussed. Traditional forms of soil fertility maintenance practices in many central, eastern and southern African countries have been in use for centuries. Some of these traditional methods are the shifting cultivation or bush fallow cropping system, where the land rather than the crop is rotated, a traditional system that assumes abundance of land. The soil burning system called *guie* in Ethiopia, mound cultivation in southern Africa, the *ngoro* land-use system in Tanzania; *mafuku* in Zaire, multiple-cropping and alley-cropping are all traditional systems of increasing soil fertility status. These have all been fairly well discussed during this workshop.

In the paper dealing with the role of agro-forestry in bean-based cropping system of sub-saharan Africa, the authors have clearly brought out two important points:

- Agroforestry is not a new system in Africa; farmers have been using it for centuries to increase their agricultural productivity.

- Participation of farmers in decision-making processes becomes important for the successful dissemination of improved techniques in agro-forestry.

On the subject of diagnostic survey techniques for soil, this workshop has discussed the importance of using a systems approach to understand general soil-related problems. The paper on this subject emphasized the need to learn from the time-tested traditional cropping systems and to incorporate what farmers have to say about new methods. Because the end-product-user is the farmer himself, it is therefore important to encourage him to participate in the decision-making process.

The papers on soil organic matter and use of green manures bring out three essential points.

These are:

- It is important to maintain soil organic matter in the crop production schemes in traditional as well as modern systems of agriculture practices.

- The role of organic matter is important in terms of nutritional contributions as well as physical and biological factors in improving soil fertility status.

- Green manure and mulches are highly beneficial to soil fertility.

This workshop has also reviewed research on bean responses to fertilizers in some African countries and has also discussed bean genotypes that are adapted to low phosphorus availability. Selection of genotypes that are relatively tolerant to nutrient stresses should be given due emphasis.

In my assessment, this workshop has been very successful in that important interactions among the scientists have taken place, and I sincerely hope that this will pave the way for more regional cooperation among scientists and national bean research programmes of the participating countries.

It is important to note that this workshop has taken place at a time when the world food supply situation, particularly that of developing countries, is worsening. The International Food Policy Research Institute in 1977 projected that production of cereals, the major food grain in developing countries, will show a deficit of 121 to 143 million tonnes between supply and demand by 1990 and this deficit will jump to 171 million tonnes by the year 2000. This will be further aggravated by climatic constraints which will hinder optimal utilization of soil resources. The core of the food deficit lies in low-income countries which contain around 70% of the world's population. Most of these countries are in Africa, Asia and Latin America. It is not only productivity of land that is low in these countries but also the use of productivity-increasing inputs such as high-yieling seeds, fertilizer, water and energy; efficiency and use of these inputs is very low.

In the 1960s and 1970s 90% and 70% of the increase in grain output came from increased productivity. Only in 1950s did the major increase in crop production output come from area expansion. Therefore, there is a need for evolving strategies aimed at increasing intensity of cropping, enhancing productivity and improving the efficiency of agricultural inputs.

Nutrient deficiency is the major limiting factor for crop production in most of the world's soil resources. The phenomenal increase in crop production output in the last two decades is attributed to the removal of nutrient stress through use of fertilizers. Whether the strategy for increasing food production is based on bringing new lands under cultivation or through intensive cropping with improved technology of already-cultivated lands, both need a constant watch on nutrient supply in the soil because both lead to the decline of soil fertility.

In many countries, inadequate attention is being paid to organic wastes and recycling of crop residues. It is reported that in developing countries nearly 500 million tonnes of dung and crop residues badly needed for improving the soil are being burnt. The figure for Ethiopia stands at 13.7 million tonnes of dung and crop residue burnt every year.

Soil-related factors are among the most significant constraints on crop production in the developing countries. Thus, use of improved, modern technologies and agricultural inputs assumes highest priority in all tropical regions.

There are many challenges for the soil scientists and agronomists in the decade ahead. Out of these challenges, the three can be considered most important: improving the productivity of the land that is already under cultivation and developing new lands with rational land-use planning so that every hectare of land is used according to its capability; and increasing the efficiency of productive inputs which are necessary in order to optimize crop production and to sustain soil productivity for generations to come. I hope the participants of this workshop will take note of these challenges in their future research programmes.

I have been told that during your stay here in Ethiopia, you have had a chance to see the country-side, done some sight-seeing of historical places in and around Addis Ababa, talked to people, tasted *njera* and *wat* (Ethiopian national dishes) and enjoyed some cultural exchanges. I would like to congratulate the organizing institutions of this workshop, CIAT and the Institute of Agricultural Research (IAR), for bringing together the regional scientists and the organizing committee for doing an excellent job in looking after the actual workshop activities. I wish you all a happy journey back to your respective countries. Finally, I declare this workshop closed.

APPENDIX

Participants: Workshop On Soil Fertility Research For Bean Cropping Systems In Africa

Name	Discipline/Focus	Address
Angola		
J.A. Sereno C.Melo	Soil Chemistry & Fertility	Instituto Investigacao Agronomica, Depto.de Solos e Clima, C.P.406,HUAMBO
Burundi		
Wakana Matthias	On-Farm Agronomy	Institut des Sciences Agronomiques du Burundi (ISABU), B.P.795, BUJUMBURA.
Ethiopia		
Kidane Georgis	Agronomy	Institute of Agricultural Research, Melkassa Research Center, P.O. Box 436, NAZRETH
Teshome Regassa	FSR Agronomy	" " "
Tekalign Mammo	Soil Chemistry & Fertility	Alemaya University of Agriculture, Agricultural Research Center, P.O.Box 32, DEBRE ZEIT
Tenaw Workayehu	Agronomy/Physiology	Institute for Agricultral Research, Awassa Research Center, P.O.Box 6, AWASSA
Kenya		
P.T.Kamoni	Soil Science (surveys)	Kenya Soil Survey, National Agricultural Laboratories , P.O.Box 14733,NAIROBI
John G.Muthamia	Agronomy	National Horticultural Research Station, P.O.Box 220,THIKA
Malawi		
Spider K.Mughogho	Soil Chemistry & Fertility	University of Malawi, Bunda College of Agriculture, P.O. Box 219, LILONGWE

Rwanda		
Rubaduka Enoch	Agronomy/Breeding	Institut des Sciences Agronomiques du Rwanda (ISAR), Rwerere, B.P.73, RUHENGERI
Andre Sebahutu	Soil Chemistry & Fertility	ISAR, B.P.138 BUTARE
Tanzania		
K.L.Haule	Soils & Fertilizer	Tanzania Agricultural Research Organization (TARO), Mlingano, P.Bag Ngomeni, TANGA (Telex: 45095 TACORD TZ)
Cosmos M.Mayona	Legume Agronomy	Uyole Agricultural Centre, P.O. Box 400, MBEYA
Patrick A.Ndakidemi	Agronomy	TARO Lyamungu, P.O.Box 3004 MOSHI
Johnson M.R.Semoka	Soil Fertility & Plant Nutrition	Sokoine University of Agriculture, Dept. Of Soil Science P.O. Box 3008, MOROGORO (Telex:55308 UNIVMO TZ)
Uganda		
Michael U.Adrogu	FSR Agronomy	Kawanda Research Station P.O. Box 7065, KAMPALA
John B.K.Kavuma	Soil Fertility	" "
Zaire		
Lunze Lubanga	Soil Chemistry & Fertility	Institut National pour l'Etude et la Recherche Agronomiques (INERA), Station de Mulungu, D.S BUKAVU.
Zambia		
Godfrey A.Mitti	FSR Agronomy	Dept.of Agriculture, Msekera Regional Research Station, P.O. Box 510089, CHIPATA (Telex: 06304 EPADP ZA)
Zimbawe		
Melvyn Piha	Agronomy/Soil Fertility	Dept. of Soil Science & Agric. Engineering, University of Zimbabwe, P.O. Box MP 167, Mount Pleasant, HARARE

Enos Shumba	Agronomy	Dept. of Research & Specialist Services, P.O. Box 8100, Causeway, HARARE
Others		
G.B.Singh	Agronomy	Zonal Coordinator, International Council for Research in Agroforestry (ICRAF), P.O. Box 30677, Nairobi, KENYA
O.Todo Edje	Agronomy	SADCC/CIAT Regional Programm on Beans in Southern Africa P.O. Box 2704, Arusha, TANZANIA Telex 42106 CANWHT TZ
Willi Graf	Agronomy	CIAT Regional Bean Programme for Great Lakes B.P. 259 Butare, RWANDA (Telex:604 PUB BTE RW, attn CIAT BP 259. Fax: 250-30599)
Roger A.Kirkby	Agronomy	CIAT Regional Bean Programme for Eastern Africa, P.O. Box 67, Debre Zeit, ETHIOPIA (Telex: 21207 ILCA ET)
Charles Wortmann	Agronomy	CIAT Regional Bean Programme for Eastern Africa, P.O. Box 6247, Kampala, UGANDA (Telex: 61406 RAYMA UGA attn Hemu for CIAT)
Jonathan Lynch	Plant Nutrition	CIAT, A.A. 6713, Cali, COLOMBIA (Telex: 05769 CIAT CO)