TURNING AVAILABLE TECHNOLOGIES FOR IMPROVEMENT OF SOIL FERTILITY MANAGEMENT INTO REAL OPTIONS FOR FARMERS IN SUB-SAHARAN AFRICA

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PROBLEM STATEMENT

More than any other region in the world, Sub-Saharan Africa (SSA) relies heavily on its environmental resource base from both an economical and social perspective. That resource base is at risk because of a number of reasons, including:

- poverty combined with fast population growth,
- urbanization and migration,
- evolution of market economies unsupported by environmental policies and regulations, and
- political transition in a fragmented continent (World Bank, 1996).

Since agriculture is the fundamental economic activity in most African countries, soil, water and nutrients are some of the most essential physical resources that are at stake. Water is becoming an increasingly scarce production factor (FAO, 1996), fertile surface soil is being eroded, and soil nutrients are mined (Stoorvogel and Smaling, 1990). Due to the above mentioned factors, farm households have replaced once stable systems with more intensive systems relying heavily on external inputs, or they have moved into more ecologically fragile areas. Implementation of Structural Adjustment Policies (SAPs) has resulted in increasing prices of external inputs, while price levels of agricultural products have decreased and only a limited growth in productivity has been realized. These developments have forced farm households to exploit essential natural resources. In the short and long-term, these processes will affect the livelihoods of millions of people in rural and urban areas of SSA.

Much technical research has been conducted to address issues of declining natural resource bases in agricultural systems. Scenario studies have shown that there are no technical barriers to producing

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sufficient food for all people in SSA in the coming 50 years (Penning de Vries et al., 1995). However implementation of these technologies and the impact on agricultural production and natural resource management in smallholder agriculture has been limited. At the government level, strategies have been formulated to increase agricultural income, increase cash and food crop output, and improve agricultural employment and development of technologies for sustainable natural resource management. But farmers have not responded to government rhetoric. Effective implementation of these strategies has been lacking, resulting in limited alterations in incentives at the farm level.

In addition, national governments and farmers have been confronted with a fast changing environment beyond their control, which includes world market liberalization with impacts on input and output prices, urbanization resulting in changing consumer markets, breaking of soil nutrient cycles, and increasing distance between market and production.

In this paper, the respective responses from researchers, policy makers and farm households in SSA on the above sketched developments are presented and an analysis is made on why these strategies have had limited impacts in addressing the problems. In the last two sections a number of suggestions are presented to improve the effectiveness of the existing technologies and policy instruments.

RESEARCHERS' RESPONSE: AVAILABLE TECHNOLOGIES

GROUPING OF TECHNOLOGIES

Over the past decades, a wide array of technologies to improve the productive capacity of soils in SSA have been developed. Research institutions, development organizations as well as farmers themselves have addressed the observed problems of soil fertility decline through the development of alternative soil fertility management systems, soil conservation investments, or simply through importing outside resources such as mineral fertilizers. Technologies can be distinguished between those that:

- save nutrients from being lost from the agro-ecosystem such as erosion control, restitution of residues, agroforestry, and recycling of household wastes and animal manure; and
- add nutrients to the agro-ecosystem, such as the application of mineral fertilizers and amendments, concentrates for livestock, organic inputs from outside the farm and leguminous, N-fixation species in wetland;

All the technologies aim at manipulation of one or more nutrient inputs, outputs, or internal flows in the farm (Table 1).

Two recent studies present an overview of existing technologies aiming at maintaining and improving soil fertility: one for West Africa (Mokwunye et al., 1996) and one for a number of countries in East and Southern Africa (Braun et al., 1997). In these studies the following grouping of technologies were suggested:

- Mineral (soluble) fertilizers,
- Mineral soil amendments,
- Organic inputs,
- Improved low-external input systems,
- Soil and water management and conservation,
- Integrated Nutrient Management.

In Tables 1 and 2, a summary of the way these groups of technologies manipulate soil nutrients is presented, and in the following sections, they are reviewed in some more detail, drawing largely on the analysis of the two studies mentioned above.

MINERAL FERTILIZERS

The use of mineral fertilizers has recently been the subject of debate regarding the perceived negative environmental effects (Dudal and Byrnes, 1993; Conway and Pretty, 1991). Nonetheless, pioneering work by C.T. de Wit and his co-workers (Breman and De Wit, 1983) revealed that low soil fertility is at least as important as drought stress with respect to crop and pasture production in West-Africa, even in the Sahel. Meanwhile, it has been proven that the judicious use of N (nitrogen) and P (phosphorous) fertilizers can bring about substantial yield increases in West Africa (Van Reuler and Prins, 1993). Positive responses to K, S, Ca and Mg have also, though less frequently, been observed (Maduakor, 1991).

Farmers' procurement of fertilizers has a short, value cost-based time horizon, i.e., the forthcoming growing season. Applying fertilizers means that (i) farmers get higher yields from a particular plot, (ii) increased biomass production protects the soil surface and may contribute to soil organic matter, (iii) other plots may be left to recuperate as the desired production is realized on the fertilized plot, and (iv) part of the fertilizer remains in the soil and contributes to soil fertility. Negative effects of fertilizer application arise from (i) excessive application of certain types of fertilizer (urea, sulphate of ammonia, di-ammonium phosphate) which may pollute the environment and cause soil acidification (referred to by farmers as 'the devils' salt'), and (ii) the application of a particular fertilizer nutrient which may induce accelerated depletion of other soil nutrients that are not included in the fertilizer. Since vigorously growing crops take up more nutrients than crops grown under low-input conditions. Table 3 shows results from Kenyan fertilizer trials, and clearly illustrates this point. The 'only-P' treatment in the Nitisol increases N and K (potassium) uptake, whereas the 'only-N' treatment in the Vertisol increases P and K uptake. In West Africa, most fertilizers contain both N and P, but straight fertilizers such as SSP, TSP and urea are also common. *Most fertilizers applied to cotton in Mali,* Senegal, Burkina Faso, Benin and Togo are mixtures of N, P, K, S (sulphur) and even B (boron).

Nutrients added in mineral fertilizers follow three pathways, namely (A) plant uptake, (B) loss through leaching, denitrification, and erosion, and (C) stay in the soil. The ideal situation is to maximize pathways A and C. For this to happen, there are factors to be borne in mind. Blanket fertilizer applications, a very common practice in SSA, often results in low fertilizer use efficiency. The type and amount of fertilizer applied must be a reflection of the crop requirements, the soil nutrient stock and its plant-available percentage, which differ largely at all spatial scales. Nutrient imbalance is a major cause of low fertilizer use efficiency. There is little benefit from adding N to a soil with a low P/N ratio, as P will continue to limit the yield of the crop and the added N will be wasted (i.e., follow pathway B). In Kenya, it was observed that P availability is of paramount importance for biological nitrogen fixation and that high application rates of N severely reduced this process (Braun et al., 1997). Increased efficiency is economically attractive and creates a 'win-win' situation for importing governments and traders, practicing farmers ,as well as the environment.

Rainfall characteristics largely determine the successful application of fertilizers, particularly as regards mobile nutrients such as N. Dry spells during the growing season may result in low fertilizer use efficiency and increased drought stress in the case of improved genotypes. Very wet spells result in leaching and erosional losses which may be minimized through split application. Food crops like maize and rice, particularly in the case of improved genotypes, are more responsive to fertilizers than the small grains (millet, sorghum) and the tuber crops (yam, cassava). An important setback, however, is that some improved cultivars produce fewer crop residues, which is an important product for systems that include livestock. This mainly applies to the small grains in the Sudan Savannah and the Sahel.

In East and West Africa, research into fertilizer recommendations has received large-scale attention in the past. Consequent upon this, fertilizer recommendations are being revised from being based on very broad areas to specific recommendations taking into account the agro-ecological zones, soil classifications and crop requirements during growing period. However, a lot of research results remain inaccessible and many studies are too reductionistic to address the complex and dynamic farming systems. Also, some knowledge gaps are still evident, including limited knowledge on phosphorus (e.g., effects of rock phosphates, relation between available P and crop P uptake), and the dynamics of soil acidification.

MINERAL SOIL AMENDMENTS

Phosphate rock. Previous research with West African phosphate rocks (PRs) has focused on their suitability for direct application, as an alternative to costly, high-reactivity P fertilizers (Gerner and Mokwunye, 1995). The potential of PR lies in the fact that it (i) redresses P deficiency, (ii) has a strong residual effect, and (iii) does not acidify the soil. The agronomic effectiveness of PRs depends on its chemical and mineralogical composition, and on soil and plant factors. PRs were successfully tested in Niger, Mali, and Burkina Faso. The researchers concluded that exploitation and use of PR is a viable alternative to the use of high-reactivity imported fertilizers. Clearly, PRs can serve both sustainability (restoring the P stock of West African soils) and productivity goals. In East Africa less research has been conducted on the potentials of PR and the results show only a limited agronomic and economic effectiveness, except for the Minjingu PR from Tanzania, a guano-based rock. PR resources however are available in a number of regions in East Africa (Ethiopia, Kenya, Tanzania, and Uganda).

Although PRs seem crucial to the upgrading of P stocks of West African soils, farmers have not adopted their use yet because of (i) the dusty character of the finely ground material, (ii) the fact that the material only contains one macro-nutrient, and (iii) its slow reactivity. Perhaps extension messages in the past have been too optimistic on the immediate reactivity of PRs.

The efficiency of PRs is related to its chemical reactivity. Therefore, PRs can best serve farmers' needs under the following circumstances; (i) in areas where P is the most limiting plant nutrient, (ii) in areas with relatively high rainfall and rather acid soils, (iii) in areas of wetland rice cultivation, such as irrigation schemes and inland swamps, (iv) by mixing them with organic matter, for example in microbiologically active compost pits, and (v) by applying them to leguminous species, which are able to acidify their own rhizosphere by taking up N_2 (gaseous nitrogen) instead of NO_3^- (nitrate). The high residual effect of PRs has an important bearing on the agronomic and economic evaluation of (rock) P fertilizer use in West Africa which, however, is too often neglected as calculations are made on a growing season basis. Moreover, PRs can be very effective in the drier zones, and in the case of perennial cropping and reforestation efforts, where initial reactivity of the product is less relevant than in the case of annual cropping.

Lime and dolomite. Lime and dolomite deposits are found in many countries and are indispensable in correcting Al (aluminum) and Mn (manganese) toxicity in acid soils. They also improve the Ca- (calcium) and Mg- (magnesium) status of soils. Convincing examples of the dual effects of dolomite in continuous cultivation in Burkina Faso are given by Lompo (1993). Also, positive responses of liming on crop yields have been reported in Kenya and Uganda (Braun et al., 1997). Nonetheless, the use of lime at the farm level is negligible, whereas the extent of acidity problems in Africa is worrying. The product is bulky, costly and involves extra labor for application, but its effect is often rather short-lived (2-4 years). Whereas many West African countries (Benin, Burkina Faso, Ghana, Niger, Nigeria, Mauritania) have liming resources (limestone, marble or dolomite), they are often only used for the production of cement.

ORGANIC INPUTS

Organic fertilizers may originate from the farm itself (crop residues, farm livestock manure), and thus be a nutrient-saving technology, or they can be obtained from other sectors or from products manufactured elsewhere, and as such they constitute a nutrient-adding technology. The major constraint with organic inputs is the large amount required to maintain agricultural production at its current levels. Besides, there is a common misunderstanding that adding organic inputs to tropical soils will easily raise soil organic matter levels. This is only true on continuous application of large quantities (De Ridder and Van Keulen, 1990). In contrast, the role of organic materials in maintaining the physical and biological characteristics of the soil is often underrated.

Crop residue. The direct or indirect return of crop residues to the soil aids in maintaining the nutrient balance. This is true, especially for K, which is relatively abundant in the residues of most crops. The impact of crop residues on soil fertility depends on the way they are applied (e.g., burning, mulching, and incorporation during land preparation), and their quality (C/N (carbon over nitrogen) and C/P (carbon over phosphorous) ratios, content of lignin and polyphenols). It is important to realize that the quality and nutritive value of residues is a reflection of the nutrient stocks of the soil that produced them, so that crop residues originating from depleted soils are unlikely to be effective in restoring soil fertility.

Incorporating crop residues with a high C/N and C/P ratio such as maize or rice stover causes initial immobilization of N and P. However, burning can lead to invasion of *Imperata cylindrica*, which is hard to eradicate (Kang et al., 1990). Other field trials have shown that crop residues applied as a surface mulch protect the soil and improve crop yields (Kamara, 1988). Systems based on no-tillage and residue mulches are effective in soil fertility restoration, but have not been widely adopted because of weed control needs (Greenland et al., 1994).

Crop residues, in the traditional systems of the more arid agro-ecological zones of SSA are first used to cover the needs for fuel, animal feed, housing and fencing material, before the rest is left or burned on the field as a source of nutrient (Bationo et al., 1993). Annual burning of fields and fallow in the dry season is a common practice in the Sudan Sahelian Zone (SSZ) in West Africa. In the absence of farm power, burning is the only way to clear the land for cultivation by hoe. Different negative effects of burning are (i) the considerable loss of carbon and nutrients, (ii) the physical and biochemical deterioration of the soil, and (iii) its considerable contribution (in the form of CO_2 (carbon dioxide)) to the earth's greenhouse gas problem. Positive effects, though short-lived, are the increase of pH and the immediate availability of nutrients to crops from the ashes.

Animal manure from the farm. In Equatorial Forest Zones (EFZ) in West Africa, livestock is not common, and animal manure is not generally valued as a source of nutrients. In the SSZ, however, animal manure is an integral component of soil fertility management. Low rural income, low use of mineral fertilizers, and the relatively high numbers of livestock in the region mean that animal manure is a principal source of nutrients (Breman and Niangado, 1994). In the highlands of East Africa zero-grazing units have become an essential component in soil nutrient management in intensive small-scale farming systems. A survey by McIntire et al. (1992) revealed that in on-station research, applied quantities of manure are in the order of 2.5 to 20 t/ha whereas farmers' actual application levels ranged from 175 to 700 kg/ha. Especially in West Africa there is simply not enough manure to sustain crop yields at even the current levels found in farmers' fields, a problem that is particularly pronounced in post-drought years. The only crops receiving high levels of manure are those grown in the champs de case (Prudencio, 1993) in West Africa and some of the cash crops in East Africa (coffee).

Manure application to cropland takes several forms. Farmers can corral their animals overnight on fields during the dry season or they can gather manure from stalls, transport and hand-spread it on fields (such as in the zero-grazing units in East Africa). Corralling returns both manure and urine to soils and results in greater crop yields than when manure is applied alone. Corralling also requires no labor for manure handling, storage and spreading. Since 40-60 percent of the N excreted by ruminants is in the form of urine, the potential for nutrient loss is greater when animals are kept in stalls since only manure can be collected and spread on cropland. But even in farming systems with zero-grazing units in East Africa relatively high losses in nutrients were found (Van den Bosch, 1998).

Organic inputs obtained from outside the farm. In general in SSA, the use of organic wastes and agro-industrial by-products has slowly increased over the last few years. An IFDC study in Ghana (Owusu-Bennoah and Visker, 1993) and a study by INERA in Burkina Faso (Sédogo et al., unpublished) reported a range of products from municipal wastes, breweries, timber industry, juice factory, cocoa company and slaughterhouses, potentially available as an organic input in agriculture. A preliminary estimate indicated that the nutrient contents are low and highly variable (5.0-8.1 percent N, 0.1-0.9 percent P, 0.3-2.0 percent K), and that they are more costly per kg of nutrient than imported commercial fertilizers. Coffee husks are commonly used in the mulching of banana and pineapple crops in Uganda, and their use has been observed to more than double the fruit yields (Bwamiki et al., 1998; Murekezi, 1998). In general, the transport and labor costs, competitive alternate uses, and difficulties in collection govern the use of off-farm organic inputs.

IMPROVED LOW-EXTERNAL INPUT SYSTEMS

Rotating or intercropping. Intercropping of cereals and grain legumes is often mentioned as having many advantages over monocultures. Some of them are definitely true, but the N input by biological fixation from most tropical intercropping systems is low. In Kenya, sequential maize (long rains) and beans (short rains) systems outyielded intercropping systems (Nadar and Faught, 1984). But in Uganda, concurrent intercropping of bananas and beans reduced bean yields considerably (Wortmann et al., 1992), and use of live mulch (*Mucuna*) reduced banana fruit yields (Zake et al., 1994). Increased use of fertilizers and other inputs upsets the traditional advantages of intercropping systems.

Bationo et al. (1994) showed the beneficial effects of cereal-legume rotations in Niger. Whereas continuous cropping of pearl millet resulted in lower yields across all N rates, millet-cowpea and millet-groundnut associations performed markedly better. The positive effect of rotation on cereal yields has been attributed to both the biologically fixed N from the legumes, their positive effects on soil biological and physical properties and the ability of some legumes to solubilize occluded P and highly insoluble calcium-bound phosphorus by the legumes' root exudates. Other advantages of crop rotation include soil erosion control, organic matter restoration, and pest and disease control.

Green manures, cover crops. In contrast to the role of grain legumes, a green manure legume is grown wholly for use as an organic manure for a subsequent crop. This obviously maximizes the amount of N from the legume available for another crop. Green manure legumes usually contain adequate N to promote mineralization shortly after soil incorporation. Quoted examples are Crotolaria, Mucuna and Sesbania species, in which over 100 kg N/ha was accumulated in the above ground plant parts under favorable soil and climatic conditions (Giller and Wilson, 1991). It is unusual for green manures to be adopted solely for their beneficial effects on soil fertility but where other benefits are also found, such as suppression of weeds, reduction of the incidence of pests, and erosion control, farmers may be persuaded to use them.

Azolla. Good responses by wetland rice to the incorporation of *Azolla* have been reported in several West African countries (Esiobu and Van Hove, 1992). Problems associated with the use of*Azolla* in small farms in West Africa include poor water control, and cultural practices not adapted to involve the use of*Azolla*, e.g., direct sowing of seeds, P deficiency, and insect attacks. Moreover, vaşt amounts of labor are needed while many farmers are not aware of the value of *Azolla*.

Agroforestry and related systems. Agroforestry is a collective name for land use systems in which woody perennials are grown in association with crops or pasture in a spatial arrangement, rotation or both, and in which there are both ecological and economic interactions between the tree and non-tree components of the system. Interest has grown in the development and use of more productive land use technologies involving agroforestry systems (Steppler and Nair, 1987). Two commonly practiced agroforestry technologies are alley cropping for food production and alley farming for both food and animal production (Kang et al., 1990).

In West Africa, agroforestry systems perform best on non-acid soils in the EFZ, and appropriate species are being selected for specific locations. *Enterolobum cyclocarpum*, *Albizia lebbek* and *Gliricidia sepium* combine fast growth with nodulation and high N_2 fixation. *Leucaena leucocephala* reportedly fixes 75-200 kg N/ha and produces up to 40 t/ha of fresh green manure, depending on interrow spacing and number of cuttings (Kang et al., 1990). Kang et al. (1981) showed that *Leucaena* prunings, when incorporated, increase maize yield more than when applied as mulch.

Research on agroforestry in the drier zones of West Africa has shown less promising results. Breman and Kessler (1995) concluded that competition for water and light is highly constraining and largely depends on soil and climatic conditions as well as farm management. A viable option seems to be the combination of trees and the increased use of fertilizer.

Also in East Africa, research on agroforestry has led to a number of promising results. Next to erosion control and benefits of higher amounts of living biomass, deep capture of NO_3 has been shown to be another potential benefit of trees. Mekkonen (1995) and Hartemink (1996) showed that *Sesbania* and weed fallows can explore subsoil N, as well as topsoil N that would otherwise be leached beyond the root zone of annual crops.

Initial high expectations about the contribution to sustainable land use by integrating N fixing trees into agro-silvo-pastoral systems, and in particular alley cropping systems, has of late been put into a more realistic perspective by different researchers (Breman and Kessler, 1995; Sanchez, 1995). Although trees can potentially provide building poles, fuelwood, fodder, fruits, shade, etc., competition for light, water, and nutrients with other system components can be stiff. Nonetheless, agroforestry can provide many economic benefits.

Fodderbanks and improved pastures/fallows. In the Northern GSZ of West Africa, the introduction of forage legumes into the traditional farming and the livestock husbandry systems has been investigated by ILRI staff (e.g., *Stylosanthes spp.*). The initial idea was to provide supplementary feed for ruminants. Fodderbanks, if adequately supplied with phosphorus, also accumulate nitrogen that becomes gradually available for subsequent crops. Penning de Vries and Djiteye (1982) studied the possibilities to improve the productivity of pastures in the Sahel and SSZ. Recently, Coulibaly (1995) compared the two technologies and concluded that fodderbanks can do well even in the northern parts of the Sahel, whereas the scope for improved grazing grounds did not reach further than the southern SSZ.

The beneficial effects of fallow systems are closely linked to soil organic matter levels. Young (1989) estimated that a land use system in the humid tropics must add biomass in the order of 8 tons of dry matter per hectare per year to maintain soil organic matter. For improved fallows on degraded land to have a chance, they may have to be fenced off from animals, which however, does not seem to be a very feasible option in Africa.

SOIL AND WATER MANAGEMENT AND CONSERVATION

Deforestation, burning, permanent cropping, and overstocking are important contributors to the high runoff and erosion problems in Africa. Oldeman et al. (1990) estimated that 72 percent of the African arable soils and 31 percent of pastureland have been degraded as a result of soil erosion.

Roose (1989) reviewed the results of 30 years of research at ORSTOM and CIRAD on water and soil conservation in the SSZ of West Africa and concluded that the major factors in curbing erosion are slope management, cultural practices, and vegetation cover. Quantitative data on runoff and erosion were largely (and unfortunately) obtained from miniplot research. Only occasionally have such results been properly extrapolated to entire catchment areas and river basins. Moreover, the factor erosion in the continental nutrient balance study (*OUT 5* in Figure 3.3; Stoorvogel et al., 1993) proved to be both high and sensitive to the output of the balance model. Unravelling the real impact of erosion as well as soil conservation measures on the nutrient budget in different land use/catchment area combinations is crucial to understanding the most appropriate technologies for different ecosystems.

In the SSZ of West Africa, the prominent soil and water conservation techniques include stone bunds on slopes, contour stone bunds, stone terraces, stone lines, earth bunding, and planting pits. Presently in parts of Burkina Faso, Mali, and Niger traditional stone lines and planting pits are increasingly used to rehabilitate degraded land, using technologies derived from indigenous knowledge. Impressive results have particularly been obtained in the Yatenga area in Burkina Faso, where Vlaar and Wesselink (1990) reported a sorghum yield increase up to 1500 kg/ha due to permeable rock dams. Biological means of reducing erosion are contour-planted trees and fodder grasses, and the application of trash lines of surface mulch and weeds.

Research results with respect to tillage as a means of enhancing water infiltration show large differences. Whereas minimum tillage is advocated in the EFZ of West Africa, it seems that soil tillage does reduce erosion in the drier zones as it enhances water infiltration into the soil profile. Responses to tied ridges were high under all tillage methods at Saria and Kamboinse research stations (Rodriguez, 1987). Klaij and Hoogmoed (1989) found good pearl millet seedling survival rates in Niger due to ridging practices effectively reducing wind erosion.

In East Africa, soil degradation through erosion has received a lot of attention. Major soil conservation techniques include grass and stone bunds, terraces, mulching, contour planting, and tied-ridging. In Ethiopia, the 'fanya juu' system (bunds in which the bank is above the ditch, with the objective of leading to progressive terrace formation) has led to increased yields and biomass production (Abiye Astatke et al., 1989). Also in Ethiopia , the technique of broadbeds and furrows showed promising results, as well improved drainage systems. In Kenya, different soil conditioners to reduce runoff and erosion have been tested (Bryan, 1992).

INTEGRATED NUTRIENT MANAGEMENT

So far, different techniques have been discussed in isolation. It pays, however, to combine different techniques, such as application of mineral fertilizers (*IN 1*) and manure (Table 1). As nutrients in manure are released slowly, one can avoid losses through synchronizing the release of nutrients with momentary crop nutrient demand by manipulating the rate, quality, timing, and placement of organic inputs. Moreover, this can help increase fertilizer use efficiencies, as fertilizer nutrients can complement nutrients released from organic sources. In addition, the acidification risk is reduced when nutrients present in the manure are added to those not present in the fertilizer. Also, applying fertilizers to crops on the lower parts of terraced fields combines inputs (*IN 1*) with relatively good water and organic matter conditions due to erosion control (*OUT 5*). Other examples are combined application of phosphate rock and mineral fertilizers; inocculation of leguminous species in combination with organic manure and mineral fertilizers; as well as fertilizers, organic manure, and lime.

Integrated nutrient management (INM) is a combination of techniques, including both low and higher-external capital and labor input technologies, in a quest for win-win situations. It should be borne in mind that each tract of land has its own "niche", i.e., its own agro-ecological potentials and limitations, and as a consequence, the number of INM options to build productive and sustainable farming systems is highly location-specific. A good example is that of the development of intensive farming system in valley bottoms in West Africa (Windmeyer et al. 1993).

A few long-term data sets in support of the INM strategy are available. At IITA, maize yields declined over 12 years of continuous cropping, but never fell below 4 t/ha. In the absence of fertilizers, however, yields dropped from 4 t/ha to 2 t/ha. Pichot et al. (1981) reported on 20 years of continuous trials on sorghum near Saria, Burkina Faso, and found that manure, in combination with small fertilizer applications improved the soil as opposed to heavy fertilizer doses alone or the mere application of crop residues. Chabalier (1986) at Bouake, Ivory Coast, found that high levels of compost applied during 11 years were not enough to maintain long-term fertility. Results of relatively long-term soil fertility experiments in West Africa have been summarized by Pieri (1989). In East Africa, a number of long-term experiments have been conducted or are still ongoing, trying to give some evidence of the potentials of INM. In Kenya, long-term experiments with manure, fertilizers and mulch on coffee (Jones et al., 1960) and with manure, NP fertilizers, and crop residues on maize show in general the superiority of a combination of technologies on the maintenance and improvement of soil fertility (Swift et al., 1994).

Many INM systems are currently being developed and some examples are presented in greater detail by Reijntjes et al. (1992), Pretty (1995) and the previously cited overview studies in East and West Africa.

SUMMARY

The previous sections of this chapter indicate that a wide array of technologies, either science-based or indigenous, have been developed to address issues of soil degradation of fragile lands. But major knowledge gaps are still evident and include the following:

- Georeferenced baseline data at the exploratory level are many but still incomplete, allowing only partial translation into soil productivity indicators.
- There is no holistic concept yet of INM; in many reports any combination of technologies is referred to as INM.
- Very few studies address particular spatial and temporal scales.
- Most studies are reductionist, addressing only one or a few components of a larger problem; this reduces the relevance for the generally complex and dynamic farming systems and their environment.

- Very limited information is available concerning phosphorus (properties and effects of rock phosphate, relation between available P and crop uptake of P).
- The dynamics of soil acidification are still poorly understood.
- Research on erosion is largely restricted to plot-level studies; very little information exists on catchment and river basin level.
- There is lack of understanding of processes of leaching and gaseous losses.
- A paucity of research data exists on source, quantity and quality of organic inputs and on soil organic matter.
- Results of farming systems research are mostly narrative and hardly surpass the stage of storytelling and listing constraints; much better links among agronomists, soil scientists, economists, and sociologists are required to study differences between successful and less successful soil fertility management practices.

In general it can be concluded that the highest potential can be found in combinations of technologies that are fine-tuned to site specific conditions and which aim at optimizing labor and capital inputs, maximizing use of locally available inputs, and integrating both science-based and local knowledge.

POLICY MAKERS' RESPONSE: CAUGHT BETWEEN CONFLICTING INTERESTS

The limited implementation at field level of many integrated soil management practices can be largely attributed to a number of socio-economic factors such as:

- Short-term orientation and risk aversion of farmers due to low and insecure income levels;
- insecure property rights;
- general top-down, bureaucratic approach to research and rural development leading to inappropriate interventions, absence of incentives for farmers, and not making use of farmers' local knowledge;
- traditional research focus on high value cash crops and commodities instead of a systems approach that accounts for local conditions and farmers' livelihood needs;
- low population densities which hamper investments in rural infrastructure and hinder development of regional markets;
- high degree of political instability; and

- unfavourable terms of trade due to insufficient infrastructure in rural areas (leading to high transportation costs, lack of market information, depressed market prices, no credit facilities), low food prices due to national policies and world market influences (leading to fluctuating prices, competition with industrial substitutes of export products, food aid).

Policy makers' response to address the soil degradation problems through relieving some of the above mentioned constraints has been rather limited, not very well targeted, and implemented with limited success. This can partly be attributed to ignorance of the problem at the national policy level. The long-term impacts of a gradual process of soil degradation have only recently been recognized at the national policy level, mainly due to the absence of quantification of the long-term negative environmental and production impacts in national accounts and project calculations. Another factor is that policy makers have to combine multiple goals such as the realization of rapid income growth, ensuring food security and food price stability, and achieving a desirable income distribution (Pearson, 1995). Facilitating sustainable natural resource management is an objective that is currently being included in national policy documents. Policy instruments available to achieve this objective include macro-economic policies, public investments, commodity specific policies, price stabilization policies, and public regulation. Other papers in these proceedings focus in more detail on the impacts of the various individual policy instruments on soil fertility management.

In addition, national policies have been largely influenced by international level liberal reforms such as the GATT negotiations and the structural adjustment programs (SAPs) supported by the World Bank and the IMF. In SSA, the implementation of these programs at the national level have resulted in (i) a direct and significant rise of farm-gate input prices for agro-chemical inputs (De Jager et al., 1998; Reardon et al., 1997), (ii) only very limited increases in farm-gate prices for food products (Koning et al., 1998), (iii) privatization of input supply resulting in reduced access to inputs in marginal areas, and (iv) declining research and extension capacity.

Generally, it is highly questionable whether this liberalization has had positive impacts on agricultural development and food security in SSA. The agricultural growth realized has been a result of area expansion rather than productivity increases. In several cases these policies have contributed to further soil degradation (Koning et al., 1998). It may even be seriously questioned whether the agricultural sector in SSA can develop under free trade conditions as is currently assumed and implemented, especially when the agricultural sectors in developing countries and in the new industrial countries in East Asia developed under long periods of protection.

From the above, it can be concluded that technology development in the area of soil fertility management needs to be linked closely to policy development in order to ensure large scale impacts. Policy instruments influence the demographic situation, market conditions, institutional factors, information and available technology, public and community investments in land management, and ecological conditions. And these factors determine to a large extent the decision making at the farm household level, including soil fertility management. Policies should aim at creating conditions for economically sound production of food and cash crops by the domestic agricultural sector. Increased opportunities for better economic performance, in combination with sound institutional aspects, are assumed to lead to increased soil and water conservation practices and reduction of soil nutrient mining. In the final section of this paper we attempt an identification of potential policy instruments that could facilitate large-scale development and implementation of the different groups of potential technologies identified.

FARMERS' RESPONSE: INDIGENOUS TECHNOLOGY AND LIMITED ADOPTION OF AVAILABLE TECHNOLOGY

INTRODUCTION

Farm household decisions are taken at various levels (village, household, individual) and concern various types of activities (production, food stocks, consumption, and marketing). A set of these types of decisions form a strategy. Studies in SSA reveal that strategies comprise a mixture of food self-sufficiency, profit or cash maximization, risk aversion, and long-term security of livelihood (de Haen and Runge-Metzger, 1990; Maatman and Schweigman, 1994). Depending on the prevailing conditions, one or more strategies are dominant. For instance, in agricultural marginal areas, strategies are described as the economy of survival, comprising decisions with a short-term planning horizon. The fact that a farm household is at the same time a production as well as a consumption unit has impacts on the decisions processes (Low, 1986). For instance, it is argued that low-income farm households maximize utility with partial disregard to market prices (for basic consumption needs) while the choice of production method usually is very cost-sensitive (Hunt, 1991).

As stated earlier, the conditions in SSA have changed considerably in the past decades due to increasing population density, increased resource degradation, greater integration in the market economy, and increased urbanization (Snrech, 1995). Two distinct responses of smallholder farmers to these developments are the development of indigenous technologies and the limited adoption of existing or newly developed science-based technologies.

INDIGENOUS TECHNOLOGY

Farm households have developed different strategies to cope with the various and changing environments and have increased productivity by developing indigenous technologies. Quite a number of cases have been reported where farmers have managed to increase productivity, income levels, and conservation of the national resource base, such as the use of termite mounds, integration of*Acacia albida* in farming systems, 'zai', valley-bottom cultivation, and composting (Richards, 1985; Reijntjes et al., 1992; Reij et al., 1996).

To some extent, the development of low-input ecological technologies can be seen as a defensive reaction of farmers to adverse economic conditions (Koning et al., 1998). These technologies are relatively efficient at low productivity levels (KIOF, forthcoming), and are favored by farmers when prices of outputs are low, prices of input high and infrastructure underdeveloped. In the long term, however, these technologies alone will not be able to exploit the still unused agronomic potential of soils in SSA and address the need for long-term food security for an increasing population. However, combined and integrated with science-based technology, indigenous technologies play an essential role in addressing the problems of natural resource degradation.

LIMITED ADOPTION OF AVAILABLE TECHNOLOGIES

Adoption of new technology is essentially determined by the characteristics of the household (education, social status, attitude, social influence, estimated skills, resource endowments), its objectives or strategies, together with the characteristics of the technology like the relative advantage of a technology, its profitability, compatibility, complexity, triability and observability (Rogers, 1983). In addition, existing external factors like infrastructure and geophysical conditions will determine the adoption of specific practices. In the process of technology development and dissemination, so far, relatively limited attention is paid to these processes of innovation, adoption-decision behavior, and adaptation of technology to fit local circumstances.

The Value Cost Ratio (VCR) is often used as a simple economic indicator to assess potential adoption of new technology at the farm household level. In order to account for risk, opportunity costs, additional labor costs and possible high fluctuations in values in time and place (depending on external circumstances like output prices, yields, weather circumstances, functioning of delivery systems), a VCR of 2 is considered to be a minimum value whereby farm households are interested in adoption of a certain technology. Recent studies of IFDC-Africa revealed that VCRs of fertilizer use on rainfed foodcrops were well below 2, due mainly to withdrawal of subsidies and devaluation of the local currency in the FCFA zone (Gerner et al., 1995). In general, the added value of investments is rather low in rainfed agriculture in West Africa (Van der Pol, 1993). The influence of higher agricultural prices on implementation of soil conservation measures has led to contrasting views (Lipton, 1987; Barret, 1991). It is argued that with increasing returns farmers are encouraged to invest in soil fertility, while others state that high prices will induce soil mining for quick, big money-earning crops. However, additional aspects to the short-term economic profitability influencing the decision to adopt are that:

- the developed technologies are not appropriate for the specific situation of farm households;
- there are differences in time horizon; farm household often have short-term strategies while restoring soil fertility requires a long-term strategy (higher discount rate for farmers than for society);
- farm households are not accustomed to investing money and in most cases do not have the resources to invest;
- land tenure arrangements prevent long-term investments in the soil;
- perception of the problem is not always very clear at the farm household level; if, for instance, the irregular rainfall pattern is considered as major cause of declining yields instead of soil degradation, it will be extremely difficult to involve the farm household in activities concerning restoration of soil fertility;
- agro-ecological margins in specific areas are often very small due to high risk factors, so that chances of total crop failure are too high to justify investments in tools, equipment or, fertilizers;
- knowledge at farm household level may be insufficient because of limited access to information and research results arising from ineffective functioning of extension services and the virtual absence of effective research-extension-farmer linkages;
- there are limited possibilities of economic development outside agriculture in the region;

- supportive infrastructure (credit, technical support) is insufficient;
- marketing possibilities and market access are limited;
- there are technology conflicts with existing local knowledge, social events, or community structures;
- prices of inputs and agricultural products fluctuate strongly; and
- participation in policy and technology development by farmers is limited and therefore technologies may not fulfill farmers' needs or be appropriate for their circumstances.

If a technology is appropriate and the socio-economic environment is favorable, farmers adopt and develop conservation practices and sustainable nutrient management practices. In the Kitui and Machakos districts of Kenya, farmers adopted 'fanya juu' terraces despite lack of any government support (Pagiola, 1996). In the cotton zones in Mali and Burkina Faso, farmers apply the bulk of productivity enhancing inputs and resource conservation investments for reasons of profitability and due to the vertically coordinated production, providing both access to inputs and credit as well as stable markets for the products (Reardon, 1997). On the other hand most of the measures to combat soil erosion will only pay off with long-term time horizons and low discount rates. Since farmers are expected to apply higher discount rates and largely ignore off-site impacts of land degradation, support from society is required to successfully implement these technologies.

In Table 4 a summary of constraints to adoption of the soil fertility management intervention groups is presented for West Africa (Mokwunye et al., 1996).

CONCLUSIONS

It can be concluded that in order to facilitate implementation of technologies at the farm household level:

- farmers have to become key actors in the technology development process,
- socio-economic and institutional constraints to adoption of conservation practices and sustainable nutrient management practices need to be addressed by policy makers, and
- society should assist the agricultural sector in implementing required investments with long-term benefits.

NEED FOR A COMPREHENSIVE AND INTEGRATED APPROACH

ALTERNATIVE TECHNOLOGY DEVELOPMENT APPROACHES

From the previous sections of this paper, it is obvious that in order to arrive at relevant and appropriate technology options which will be implemented on a wide scale by the small-holder farming community, more information is needed than many current research activities can offer. For research to be effective, it is necessary to integrate different relevant disciplines and scales while disentangling the various issues into a workable set of problem statements for targeting research and development activities. This insight has led to a shift in development paradigms from the classic top-down centralized decision making (science-based technical solutions), via neo-liberal to neo-populist paradigms (bottom-up participation, decentralized, action oriented) (Blaiki et al., 1997, Roling and Wagemakers, 1998). Based upon this change in paradigms, more participatory and multidisciplinary research and development approaches and methodologies have been developed, such as Farming Systems Research, PRA/RRA, Farmers First, Participatory Technology Development (PTD), Farmers Field Schools, and Participatory Learning and Action Research (Reijntjes et al., 1992; Pretty, 1995; Chambers, 1983; Hamilton, 1995). In practice, these research and development methodologies have been implemented with varying degrees of success. In the field of soil fertility and natural resource management, this shift in paradigm also is taking place, but has not yet led to a major shift in the research and development approach. New strategies for an Integrated Nutrient Management approach, following the approaches in Integrated Pest Management, are being proposed (Deugd et al., 1998) and in a number of projects, a more action oriented approach is being adopted (Defoer et al., 1998).

THE NUTMON APPROACH

A concrete example of an integrated, comprehensive, multidisciplinary methodology which targets different actors in the process of managing natural resources in general and plant nutrients in particular, is called NUTMON (De Jager et al., 1998, Van den Bosch et al., 1998). This approach aims to:

- i) determine farm households' perception of soil nutrient depletion and related constraints and potentials;
- ii) acquire a comprehensive knowledge of a farm system and its internal and external nutrient flows in a spatial and temporal context;

iii) quantify nutrient flows and balances of existing farming systems at different spatial scales;
iv) quantify the economic performance of existing farming systems at different spatial scales;
v) identify, on-farm test, and evaluate with stakeholders relevant INM-technology options;
vi) identify and evaluate with stakeholders relevant policy instruments for enabling INM-technology adoption;
vii) formulate development scenarios, research priorities, and policy advice to reduce soil nutrient depletion.

At different stages of the approach, stakeholders' research methods, knowledge, and evaluation criteria and indicators are integrated with science-based methodologies, criteria, and indicators. In this way, a comprehensive and participatory analysis is realized. The NUTMON approach is summarized in Figure 5.1.

The NUTMON approach is currently being implemented in research and development projects addressing soil fertility management in Kenya, Uganda, and Burkina Faso. In the period 1995/1996, a pilot phase with small holder farmers in three districts in Kenya generated first experiences and results with this approach.

The indications of unsustainability of agricultural production at national level in Kenya correspond with the observations at farm household level. A mean of 71 kg N/ha per year and 9 kg K per ha per year were mined, implying that 32 percent of the net farm income was based upon nutrient mining (De Jager et al., 1998; Van den Bosch, 1998). However high variations between Land Use Zones and farms were observed (Figure 2). In addition, 54 percent of farms in the sample realized income levels from farm activities that were below the estimated poverty line. This led to the conclusion that in the current socio-economic environment, a large portion of the farm households were producing in an economically unsustainable situation and that off-farm income was essential for large groups of small-scale farm households to achieve economic viability. The mean partial nutrient balances, consisting of nutrient flows in direct inputs and outputs were positive. This indicates that farmers applied more nutrients through inputs than were exported through sale of products, but factors like leaching and erosion caused the N and K balance to be negative. Cash crops like coffee and tea realized higher gross margins and considerably lower nutrient mining levels than the food crops maize and maize-beans intercrop (Figure 5.3). Apparently for farm households, application of nutrients to cash crops is economically more attractive than to food crops. Unfavorable input/output price ratios apparently lead to low level nutrient application in food crops.

Given declining food production per capita and the threat of further declining productivity due to observed nutrient mining, drastic changes in the economic environment are required to change this trend.

The multi-disciplinary monitoring approach, although still in development, has contributed to the understanding of current farm management systems and to targeting and prioritizing different development options. The observed heterogeneity in physical and socio-economic environments, farm management strategies and objectives, and technical knowledge etc., can be used as a starting point for inducing changes toward increased sustainability.

CONDITIONS FOR TURNING AVAILABLE TECHNOLOGIES INTO REAL OPTIONS

As stated earlier, there exists a wide range of technologies to address soil nutrient depletion, but in many cases adoption of these technologies has been hampered by prevailing socio-economic conditions. Also a comprehensive, integrated rural development agenda, at the system level, is absent. Rural development efforts are often fragmented and ad-hoc in nature, and existing policies favor attainment of short-term goals and are not geared toward long-term, sustainable agricultural development.

Various authors have listed policy recommendations to address these socio-economic constraints (Scherr and Yadav, 1996; Koning et al., 1998) as follows:

- Improve information systems for land management,
- Increase research and technology development, including links with the private sector (seed, fertilizer industry),
- Promote investment in land improvement,
- Modify property rights to encourage long-term investments,
- Develop more flexible and participatory planning systems for sustainable use,
- Support local organisations to manage local resources,
- Develop marketing infrastructure,
- Correct distorted price incentives,
- Encourage rural income growth and diversification,
- Reduce discrimination against marginal regions for public investment,
- Protect regional agricultural markets,
- Increase attention for primary education and higher education,
- Implement participatory extension systems, including private initiatives,

- Create an agricultural policy formation unit, and
- Evolve policies to promote non-farm income options in rural areas.

At the policy level, instruments should be geared towards facilitating increased profitability of the agricultural sector through output and input market development and facilitating long-term investment in soil fertility. Both research and policy interventions require a comprehensive national and regional approach with a high level of participation of all actors. Research and extension services need to be redirected to focus on natural resource management and participatory technology development approaches. The examples of the recently developed IPM-technology in Asia and the biological pest management and organic farming techniques in Europe show the existing, but still untapped potential.

In Table 5, an attempt is made at identifying the potential for further technological development and the necessary policy instruments for turning group technologies into real options for farmers in SSA.

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Table 1: Distinguished types of nutrient flows at farm level (Smaling et al., 1996)

IN flows	Out flows	Internal flows
IN1 Mineral fertilizers	OUT1 Farm products sold	FL1 Animal feeds
IN2 Organic inputs	OUT2 Other organic products	FL2 Household waste
IN3 Atmospheric deposition	OUT3 Leaching	FL3 Crop residues
IN4 Biological nitrogen fixation	OUT4 Gaseous losses	FL4 Grazing of vegetation
IN5 Sedimentation	OUT5 Runoff and erosion	FL5 Animal manure
IN6 Subsoil exploitation	OUT6 Human faeces	FL6 Farm products to household

Table 2: Restoring soil fertility in West-Africa: technical options and their impact on nutrient flows (Smaling et al. 1996)

Technology	Fertility effect (see table 2)	Adding/saving
1. Mineral fertilizers		
- increased use	Increase of IN 1	adding
- more efficient use	Reduction of OUT 3-5	saving
2. Mineral soil amendments		
- rock phosphates	Increase of IN 1 (P)	adding
- lime and dolomites	Increase of pH, IN 1 (Ca, Mg)	adding
3. Organic inputs		
- from within the farm	Reduction of OUT 2	saving
- from outside the farms	Increased recycling FL 1,3,5	mainly saving
	Increase of IN 2	adding
4. Improved low-external inputs Systems		
- rotations, green manures	increase of IN 4, reduction of OUT 2 –5	adding+saving
- fallows, woody species	increase of IN 4,6, reduction of OUT 2-5	adding+saving
5. Soil and water management and conservation	reduction of OUT 3-5	saving
6. Integrated Nutrient Management	combination of IN 1 - OUT 5	adding+saving

Table 3: Yields and NPK uptake of maize on three Kenyan soils as a function of soil type and fertilizer treatment (long rainy season, 1990)

Soil	Treatment (ton/ha)	Yield	Nutrient uptake (kg/ha)		
			N	P	K
Nitisol (red, clayey)	$N_0 P_0$	2.1	42	5	30
	$N_{50} P_0$	2.3	50	6	36
	$N_0 P_{22}$	4.9	79	12	58
Vertisol (black, clayey)	$N_0 P_0$	4.5	63	24	95
	$N_{50} P_0$	6.3	109	35	126
	$N_0 P_{22}$	4.7	70	23	106
Arenosol (brown, sandy)	$N_0 P_0$	2.5	38	7	42
	$N_{50} P_0$	2.2	45	7	47
	$N_0 P_{22}$	2.3	38	11	68
	$N_{50} P_{22}$	3.7	66	16	77

Source: Smaling et al., 1996

Table 4: Major constraints to adoption of groups of technological interventions

Constraints to adoption	Mineral Fertilizers	Mineral Soil Amendments	Organic inputs	Improvement Land Use Systems	Soil conservation	Integrated Nutrient Management
Awareness of technology		■		■		■
Adaptation to farming system		▨				
Research-Extension-Farmers linkage	▨	▨		■	▨	■
Land tenure				▨	▨	▨
Labour			■		■	▨
Capital	■	▨			▨	▨
Institutional support	▨	▨		▨	▨	▨
Gender	▨		▨	▨	▨	
Agronomic performance						■
Output/input prices (profitability)	▨	▨	▨		▨	
National policies	■					
Regional policies						
International policies	▨					
Payback period		■			■	
Riskiness	▨					
Perception		■		▨		▨
Availability		▨	■			▨
Market development agricultural products	■	▨				▨

■ - high constraint

▨ - low/medium constraint

☐ - no constraint

Table 5: Recommended actions to facilitate implementation of technology options to address soil degradation in SSA

Technology	Mineral Fertilizers	Mineral Soil Amendments	Organic Inputs
Constraints to adoption	• Capital, national policies, agricultural market development	• Awareness, perception, pay-back period	• Labour, availability, quality
Promising Technologies	• Fine-tuned fertilizer recommendations for crops, soils and agro-ecological zones • Balanced fertilization • Application according to crop uptake	• Site-specific and targeted phosphate rock application • Lime and dolomite application in acid soils	• Application of crop residues • Application of animal manure • Application of urban and agro-industrial waste
Actions			
Technology Development	• Modelling • Dynamics of soil acidification • Improved P fertilizer recommendations • Further fine-tuning fertilizer recommendations	• Increased efficiency of PR through research, site-specific application and application in combination with other technologies	• Optimising recycling of organic matter from crops residues and animal manure within the farm • Investigation technical options and limitations to application of city and industrial waste in agriculture • Development of appropriate labour-saving application technologies • Development of techniques for green manuring • Improve quality through appropriate composting techniques
Policies/ Institutional	• National policies aiming at supporting agricultural production sector, resulting in higher V/C ratios for fertilizers • Regional policies with mild forms of market protection for most vulnerable food crops • Regional fertilizer procurement and operational market information systems on fertilizers • National policies to support private fertilizer sector • Development of financial support services to farmers (selective rates, credits, group banking) • Policies to support fertilizer infrastructure to reduce farm gate price (transport, storage). • Promote collaboration between research, private fertilizer sectors and farmers groups to make available appropriate types of fertilizers at the right time • Promoting proper function agro-production chains such as cash cropping schemes for cotton in Mali and Burkina Faso • Adopting PTD approach in fertilizer trails	• Implement instruments to change perceptions of PR as long-term capital investment with international donors, policy makers and farmers • National Phosphate and lime investment policies • Regional co-ordination of exploitation of deposits • National policy to facilitate exploitation and distribution • Internalise environmental issues in cost-benefit analysis of PR programmes • (Inter)-national policies to support farm-level investments in PR in P-deficit areas. • Adopting PTD approach and strengthen farmers-extension-research linkages in PR/Lime trials	• Awareness/quantification of international stocks and flows of organic matter and nutrients. • National policies on waste management to facilitate re-use of city/industrial waste • Internalise environmental issues in cost-benefit analysis of waste management programmes • Adopting PTD approach and strengthen farmers-extension-research linkages in trials on organic matter management • Facilitate optimum use of indigenous knowledge

Table 5 continued

Technology	**Improved low-external input systems**	**Soil and water management and conservation**	**Integrated Nutrient Management**
Constraints to adoption	• Awareness, knowledge, lack of participatory approach	• Labour, pay-back period	• Technology, awareness, lack of participatory and integrated approach
Promising Technologies	• Rotation / intercropping • Green manures / cover crops • Agroforestry related systems • Fodderbanks / improved fallow • Variety of techniques such as azolla, double digging, composting, mulching	• Small-scale technologies such as stone and living bunds, various forms of terracing, planting pits, tillage technologies, 'fanya juu', water harvesting techniques	• Developing site-specific, combined low-input, high input and high knowledge intensive technologies, such as fertilizers-organic manure; PR-fertilizers; inoculated leguminous species-organic manure-fertilizers; systems with synchronise nutrient release with crop demand
Actions			
Technology Development	• Increased scientific research efforts in all areas of low-external input technologies • Research-NGO collaboration to mobilise, adapt and improve indigenous knowledge in low-external inputs	• Research-NGO collaboration to mobilise, adapt and improve indigenous knowledge in soil and water conservation measures •	• Research strategy aiming at maximizing use of local resources and optimising external resources • Exploitation of existing heterogeneity in soil fertility management between farms
Policies/ Institutional	• Adjust research policy to incorporate indigenous knowledge and low-external input systems • Research policy shift from commodity to systems approach • Adopting PTD approach and strengthen farmers-extension-research linkages • Regional and national policies to promote natural resource management	• Valuation in project/programme appraisals of unaccounted costs of soil erosion and off-site effects • Formulation and implementation of national soil conservation schemes aimed at providing incentives to farmers' initiatives • Policies to secure land tenure systems • National policies aiming at supporting agricultural production sector, resulting in higher returns to soil conservation measures • Promoting community / water-shed oriented, participative conservation programs • Adopting PTD approach and increased farmers-extension-research linkages in soil and water conservation development	• Integration of indigenous knowledge with scientific knowledge systems • Research strategy focusing on niche differentiation • National policies aiming at supporting agricultural production sector, resulting in higher returns at farm level.

Figure 1:

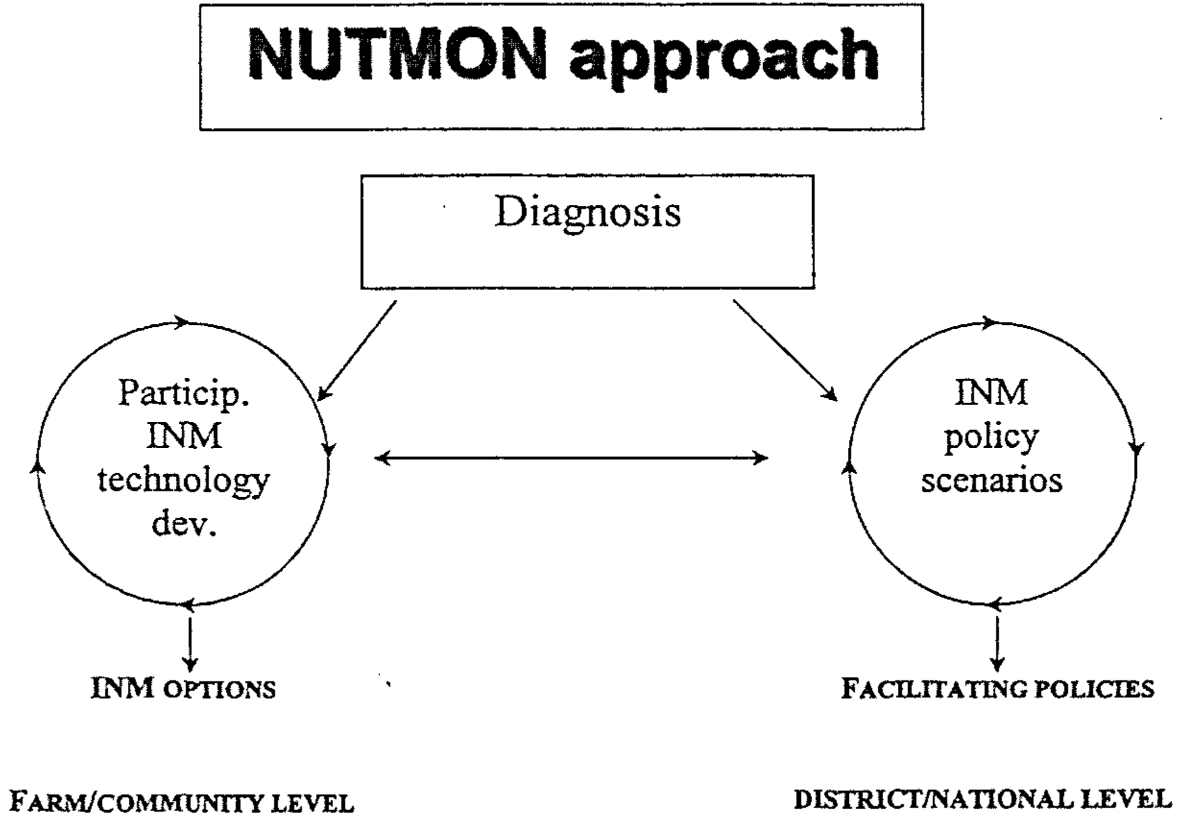
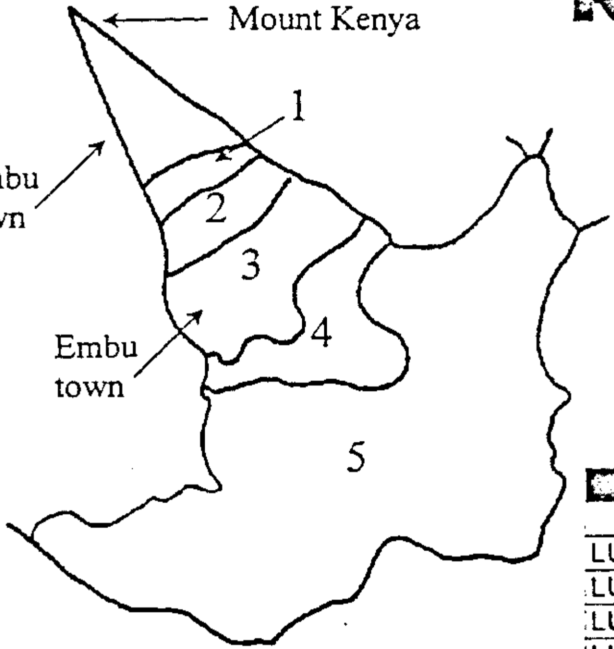

NUTMON approach
Diagnosis
Particip. INM technology dev.
INM policy scenarios
INM OPTIONS
FACILITATING POLICIES
FARM/COMMUNITY LEVEL
DISTRICT/NATIONAL LEVEL

Figure 2: The NUTMON diagnostic results per land use zone in Embu District, Kenya

Results per LUZ Embu



				(US$/y)	
LUZ 1: Tea/dairy	-120	32	-12	1356	0.8
LUZ 2: Tea/coffee/dain	-83	4	-30	868	0.7
LUZ 3: Coffee/maize	-129	-14	-105	2570	0.4
LUZ 4: Tobacco/food	-23	15	-5	709	0.8
LUZ 5: Livestock	44	5	54	1714	1.2

Figure 3: Average N-flows and balances for selected crops in 3 districts in Kenya