Soil fertility Status, Management, and research in East Africa

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ABSTRACT

This study reviews and synthesizes the soil fertility status, management among smallholder farmers and research in the three countries of east Africa, namely Kenya, Tanzania and Uganda. We observe that many studies note the declining soil fertility, mainly due to soil fertility mining, putting crop production in an unsustainable path. Studies have shown that the current soil fertility management practices of recycling crop residue; biomass transfer; short fallow and other organic practices appear to be inadequate to replenish the nutrient outflow. Consequently, a number of case studies have shown crop yield decline in the region.

Soil fertility research in east Africa has concentrated on producing recommendation for monocrop systems while most smallholder farmers plant crops in complex intercropping and mixed cropping systems. Additionally even though agricultural prices and soil characteristics are dynamic, recommendations are always based on static input-output price ratio and soil conditions. This research approach and assumptions render many recommendations irrelevant to smallholder farmers. Consequently, adoption of soil fertility technologies in the region is low, even though many farmers appreciate the benefits of these technologies. The need to revise the current soil fertility recommendation such that they take into account the dynamic nature of soils and agricultural prices is apparent.

Keywords: Soil fertility, fertilizer recommendations, fertilizer trials, nutrient mining, fertilizer use, and East Africa

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Introduction

Sub-Saharan Africa faces problems of food security because of decreasing per-capita food production. Extreme poverty, widespread malnutrition and alarming environmental degradation are, in part, consequences of a farming environment that results in large-scale nutrient mining from generally old and nutrient-poor soils. Nutrient mining in East Africa is among the highest in Sub-Saharan Africa, with an estimated annual nutrient depletion rate of 41 kg nitrogen (N), 4 kg phosphorus (P) and 31 kg potassium (K) per hectare. These figures represent the balance between nutrient inputs as fertiliser, manure, atmospheric deposition, biological nitrogen fixation, and sedimentation, and nutrient outputs as harvested products, crop residue removals, leaching, gaseous losses, surface runoff and erosion. The figures, therefore, are evidence that nutrient inputs are limited, and the basis of argument that the future growth in agriculture in the region will depend primarily on improved land management.

This study reviews and synthesizes the soil fertility status and management among smallholder farmers in the three countries of East Africa. The study also appraises soil fertility research and recommendations in the region. The contribution of this study is the synthesis and comparison of soil fertility status, management and research across the three countries of East Africa. This synthesis would be useful to both biophysical and socio-economic researchers, policy makers and other stakeholders working to improve land management in east Africa. The study raises some important research questions and draws conclusions and their implications that may assist in developing policies for sustainable agricultural production in the region.

The rest of this paper is organized in four sections. The next section discusses the status of soil fertility in East Africa followed by a section on soil fertility management. The paper then discusses the fertilizer recommendations and trials. The last section concludes the paper and offers some policy recommendations of this study.

The status of soil fertility in East Africa

Soil fertility is dynamic; its direction (accumulation or depletion) is determined by the interplay between chemical, biological, physical and anthropogenic processes. This paper dwells more on soil fertility determined by the chemical processes. Tropical soils, including those of East Africa, are commonly described as being acid, infertile and often incapable of sustained agricultural production (Sanchez and Logan, 1989). This is not universally true because of the diversity in terms of the environmental and soil-forming factors (Eswaran et al, 1989), and there is proof of some successful sustained soil management systems in many ecosystems of the tropics (Sanchez et al, 1987). Table 1 shows the diversity of soils in Uganda supporting different types of farming systems. However, a considerable proportion of the soils are highly weathered, have low nutrient reserves and therefore limited capacity to supply phosphorus, potassium, calcium, magnesium and sulphur. Some have sufficiently strong soil acidity for soluble Aluminium to be toxic for most crop species. Such include the Ferralsols and Acrisols which form more than 70% of the soils in Uganda on which most of the farming is practised (Zake, 1992); Cambisols, Ferralsols and Vertisols which cover more than 52% of soils in Tanzania (de Pauw, 1984). In order for farmers to realize acceptable yields and returns to their scarce resources under these soil conditions, they require to use improved soil fertility management that they always find unaffordable. Hence even though soil fertility in most areas of east Africa is low, farmers have not been able to redress the downward spiral of soil fertility.

To evaluate the soil fertility status in East Africa, we use realistic indicators, namely, crop yield levels, chemical analysis, limiting nutrients and nutrient balances data that have been collected in the region over time.

Crop yields. Average crop yields in East Africa (Table 2) are alarmingly below potential yields (values obtained at national research stations). This may be a result of complex interactions between several factors including soil fertility, pests, diseases, climate and management. While there exists no data to apportion the contribution of each factor to the low yields, evidence from long term trials, like the one at Kabete, Kenya, shows that continuous tillage of land results in soil fertility and consequent yield decline (Bekunda et al, 1997). Thus the general trends in crop yield decline in the east African countries are likely related to soil fertility decline (for example banana yields in Uganda declined from 8.4 t ha^{-1} in the 1970s to 5 t ha^{-1} in the 1980s; Gold et al., 1999), and low crop yields (Table 2) are likely an indicator of poor soil fertility.

Table 1. Dominant soils in the major farming systems of Uganda

Major farming system	**Dominant soils**
Intensive banana-coffee lake shore system	Nitisols
Medium altitude intensive banana-coffee system	Nitisols, Ferralsols
Western banana-coffee system	Andosols, Nitisols, Ferralsols and Acrisols; scattered Leptosols and Fluvisols
Banana-millet-cotton system	Ferralsols and scattered Fluvisol; Plinthosols abundant in Tororo and Pallisa Districts and also in northern Bugiri and north and eastern Kamuli
Annual cropping and cattle Teso system	Plinthisols, light textured Ferralsols; Vertisols in drier areas of Katakwi district
Annual cropping and cattle west Nile system	Ferralsols, Vertisols, Leptosols, and Plinthosols Ferralsols and Alisols dominate the northern moist farmlands
Annual cropping and cattle Northern system	Ferralsols, Alisols and Plinthosols
Pastoral and some annual crop system	Vertisols, Cambisols, Luvisols and Plinthosols
Montane system	Mt. Elgon system: Nitisols, Phaezems and Ferralsols Southwestern: Andosols, Ferralsols and Acrisols Rwenzori system: Phaezems and Ferralsols

Table 2. A comparison of potential and on-farm yields of selected staple and cash crops grown in East Africa.

Crop	Units	Potential Yield[1]	On-farm yield		
			Uganda[1]	Kenya[2]	Tanzania[3]
Banana	t $ha^{-1}yr^{-1}$	40-60	5.7	--	6.4
Maize	t ha^{-1}	5-7	1.6	1.8	--
Beans	t ha^{-1}	2.5	0.8	--	0.6
Cassava	t ha^{-1}	50	8.5	--	--
Coffee	t $ha^{-1}yr^{-1}$	2	0.5	2.9	0.4

Source: [1]Bekunda, 1999; [2]Van den Bosch, 1998 (data for 3 districts); [3]Baijukya and Piters, 1998 (data for North West Tanzania).

Soil analytical indicators: The few soil analysis laboratories in the region rely on established, but sometimes laboratory or soil specific indices of soil chemical properties, often termed *critical soil nutrient levels*. Soil organic carbon has been used as an index of sustainable land management in East Africa. Foster (1973) for example reported 6% organic matter as the critical level above which response to N is unlikely. The average value of organic matter content for Uganda's soils sampled from cotton fields (with sample size of 1781 sites) in the 1960s was 3.9% (range 1.0 – 9.1) (Ssali, 2002), implying that most of the soils could respond to nitrogen application. The use of total organic matter as an index for soil nitrogen is questionable given that the organic matter fraction relating to crop response has not been clearly established.

For phosphorus, 5 mg P kg^{-1} of soil (modified Olsen; Jama, 1999) is considered the soil level below which maize performance in Kenya is sub-optimal. Using this value, it is estimated that 80% of the smallholder land used for maize in western Kenya is P-limited. Nyandat (1981) found potassium to be adequate in most of the 181 top soil samples collected from various parts of Kenya, although an earlier study by Anderson (1973) indicated striking responses of different crops to K fertiliser on sandy and on moderately to strongly acid soils in East Africa.

In Uganda, the more readily available basic soil data sets are those of the country-wide reconnaissance soil surveys conducted in the 1950s and 1960s (Ollie, 1959; Ollier and Harrop, 1959, Harrop, 1960) and used to classify Ugandan soils (Anon, 1973). Even then, most of the soils showed one or more limiting nutrients although a majority of the sampled soils had not been subjected to cultivation. Phosphorus was particularly low in 64% of the 262 soil samples analysed countrywide. This trend has not changed and appears to increase. Recent analyses of soil samples from Eastern, Central, south-western Uganda also showed P to be very low (0- 8.5 mg kg^{-1}; Bray I) in 70% of the sampling sites; pH and nitrogen were also a problematic. In Tanzania, soil analyses and related research activities have identified N, P, K, Calcium (Ca), Magnesium (Mg) and, to a lesser extent, sulphur (S) as the major constraining elements to crop production exacerbated by soil acidification and salinisation.

The major constraint to soil tests is that they are of limited use unless they are calibrated to crop response in field trials. Clearly, these tests do not relate to the whole spectrum of crops grown in East Africa.

Limiting nutrients**:** This procedure of characterising soil fertility is being popularised as it is simple to conduct, is crop specific and the results have immediate impact on farmers' decision making toward effective utilisation of nutrient resources available to them. In south western Uganda on soils dominated by Haplic Ferralsols, this test showed that 80% of the test sites had nitrogen as the limiting nutrient, 50% are limited by potassium and 40% by phosphorus (Siriri, 2000). In eastern Uganda where soils are mainly light textured Ferralsols, 90% of the soils were limited by nitrogen, 50% by phosphorus and 10% by potassium. These values show that in some cases, more than one nutrient was limiting.

In Kenya, maize module results obtained from work done by the Kenya Agricultural Research Institute (KARI) staff together with extension staff in the Ministry of Agriculture and Rural Development suggested that the study area (31 districts in Kenya) could be differentiated into six zone-specific fertiliser areas (Nandwa, 1991; KARI, 1994):

1. N, P, Ca and Mg deficiency parts of Uashin Gishu, Keiyo Marakwet, Nyeri and Embu Districts
2. P deficiency parts of Kisii, Nandi, Kericho, Nakuru, Nyandarua, Narok and Kiambu
3. N and S deficiency areas along Lake Victoria shores and coastal strip including parts of Siaya, Bungoma, and Machakos.
4. N, P and K deficient areas around Kerugoya and Embu
5. N and P deficiency areas covering the remaining parts of the country.

Nutrient balances. Nutrient budgeting as a tool for soil productivity assessment has been prominent since 1990 (Lynam et al, 1998) and has since been significantly enhanced and extended to better characterise and analyse nutrient management, particularly in African farming systems. Simply put, it involves computation of nutrient inflows and outflows of a farming system, resulting in a net flow figure, the nutrient balance. A negative balance is an indicator of nutrient mining. One of the most comprehensive studies on nutrient balances was conducted on 26 farms in three districts in Kenya (van den Bosch et al, 1998), and it showed net negative nitrogen balances for all crops, including the cash crops which are favoured in terms of fertiliser allocation (Figure 1), some positive phosphorus balances only in the cash crops (coffee and tea) and slight positive balance for potassium only in coffee. Phosphorus is a less mobile nutrient in soils, causing it to accumulate more in soils of the cash crops where mineral fertilisers are applied. Several other studies have been conducted with different crops and at different levels in the three countries. At the national level, Stoorvogel et al's (1993) calculations indicate that East African countries experience high nutrient depletion rates (Table 3), a result of high population density, continuous cultivation, hilly and mountainous terrain and, in some cases, soils still being relatively fertile, hence having a lot to lose. What is alarming is what the continuous annual depletion spells for the region.

Table 3. Calculated nutrient balances of N, P and K (kg $ha^{-1}year^{-1}$) of the arable land for some Eastern Africa countries.

Country	N		P		K	
	1982-84	2000	1982-84	2000	1982-84	2000
Kenya	-41	-47	-6	-7	-29	-36
Tanzania	-27	-32	-4	-5	-18	-21
Rwanda	-54	-60	-9	-11	-47	-61

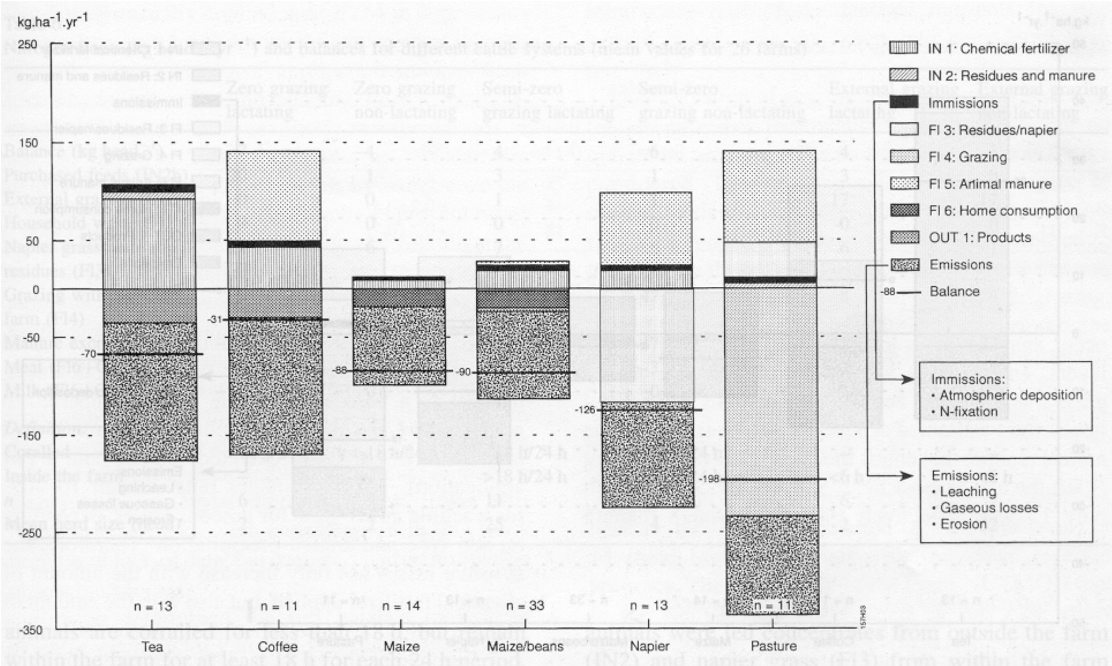

Figure 1. Nitrogen flows and balances for tea, coffee, maize, maize/beans, napier grass and pastures. Figures are means for fields on 26 farms from three districts in Kenya. Number of fields considered in parenthesis. Source: Van den Bosch et al, 1998.

The case study of maize production in eastern Uganda confirms the severe fertility mining in east Africa. Table 4 shows that only 5% of households had positive total NPK balances, with N and K being the most deficient nutrients. N had the lowest percent of households having positive balances. P had the highest percentage of farmers with positive balances and the smallest mean negative balance. If the inorganic fertilizer were used to replace the negative balances, the total value of mined nutrients/ha would be 17.7% of household income, which is about US$793/household per year. This underscores the heavy reliance of subsistence cereal farmers on soil fertility mining to provide for their subsistence in eastern Uganda.

The message form from all indicators of soil fertility described above, despite their shortfalls, it is clear that soil fertility in East Africa is at stake! It is either low or progressively getting low in the present farming conditions. The next section provides evidence and extent of use of resources available in the region for soil fertility management. We review the biological and chemical fertility management practices in the region.

Table 4. Nutrient Balances in Farm Plots, Eastern Uganda.

	Nitrogen	Phosphorus	Potassium	NPK
% with positive balances	12.07	39.66	34.48	5.17
Mean nutrient balances (g/ha) Std deviation (kg/ha)	-48.02 48.20	-10.80 18.24	-51.09 82.40	-100.01 122.79
Mean value nutrient balance (US$)	44.66	11.23	116.49	140.01
Value of mined nutrient per hectare as % of household income *	5.6	1.4	14.69	17.66
Sample size	58	58	58	58

* The average household income in Uganda is estimated to be US$793/year and the average farm size is 2.25 ha (Nkonya, et al., 2002).

Source: Nkonya and Kaizzi, 2002.

Status of soil fertility management

Biological fertility management

The principal means of managing soil fertility on agricultural land in most of East Africa is through recycling of crop residues, transfer of plant materials from non-cropped areas to arable land, from biological nitrogen fixation through leguminous crops, utilisation of animal manure, and occasional application of inorganic fertilisers. We provide one case study from Uganda as an example. In a study on organic resource management in banana-based cropping systems of the Lake Victoria Basin that involved 510 farm families (Bekunda and Woomer, 1996), 13.9% of these farmers recycled banana residues only as the only soil fertility management practice (Table 5). But more farmers recognised that alone, banana residues did not provide sufficient mulch for both moisture conservation and nutrient replenishment, and supplemented these with other organic inputs. Indeed, banana bunch weight was about 7kg heavier on farms utilising cattle manure than those from farms using banana residues only. But this required large grazing areas from which the nutrients were “imported”.

Table 5. Organic resource utilisation and factors that underlie soil fertility management strategies in banana-farming systems in the Lake Victoria Basin, Uganda.

Resource management Category	Frequency of practice (%)	Regulatory factors
Banana residues (BR) only	13.9	low population density, large farm sizes
BR + field crop residues (FCR)	39.2	bean & maize intercropping introduced
BR + FCR +cattle manure	23.1	large land holdings, cattle raised on farms
BR + FCR + small livestock manures	7.4	reduced land availability, poultry & small ruminants raised on farm
BR + FCR + composts	16.4	small farm sizes, efficient recycling of domestic wastes

Source: Bekunda and Woomer, 1996.

The types of other supplements indicate a shift toward greater integration of farm resources brought about by increased population growth and diminishing farm sizes. Clearly farmers recognised the problem of nutrient depletion, were familiar with and practised a range of soil fertility management strategies using inputs within their reach, and were able to move between strategies as conditions warranted. But these strategies did not suffice to sustain soil fertility as indicated by the low banana yields (12-17kg per bunch) yet only 4% of the farm households reported ever using mineral fertilisers. Perhaps their use was not feasible in this particular setting. A study by Nkonya, et al. (2002) in Uganda also showed that farmers with smaller plots used more intensive fertility management methods than those with larger plots though yields of several crops were lower on small farms. This indicates that the intensification did not overcome the outflow of nutrients.

With respect to biological nitrogen fixation (BNF), the International Center for Research in Agroforestry (ICRAF), Kenya Agricultural Research Institute (KARI) and Kenya Forestry Research Institute (KEFRI) have piloted development projects in high population densities in western Kenya (Niang et al, 1998), promoting effective use of improved fallows. Most of the farmers establish the fallows in an existing crop to save on land preparation and weeding. Improved fallows alone more than double yields compared to continuous cropping and more than quadruple when mixed with Minjingu phosphate rock (Wamuongo and Jama, 2000). These BNF strategies have some biophysical limits. Leguminous fallows do not work well in shallow soils, poorly drained soils, P-limited soils and in Vertisols. Their effectiveness depends on their quality parameters. Use of mineral inorganic fertilisers appears necessary as a supplement to this technology.

Evidence of mineral fertiliser use

The countries of East Africa rely on imports to meet most of their fertiliser needs. Therefore, a major indicator of fertiliser use is the amount of the fertilisers that the countries import. Fertiliser imports into Kenya in 1996 were approximately 226000 MT of which 35 - 40% was used by the smallholder farmers (Allgood and Kilungo, 1996).[1] The World Bank (1995) estimated the potential consumption of fertilisers in Kenya to be about 1041000 MT assuming that commercial crops (wheat, sugarcane, coffee and tea) are fertilised at 100% and smallholder crops (maize, sorghum, beans and potatoes) are fertilised at 50% of their recommended doses, respectively. With this estimate, the imports of fertilisers into Kenya in 1996 account for just 21% of the fertiliser needs.

Fertiliser use in Uganda has traditionally been extremely low (Figure 2), being drastically affected by the disruptive politics during the 1970s and 1980s. Beginning with the 1990s, increased emphasis on agriculture and particularly the renewed interest in cash crop production for export have contributed to a general recovery in the use of agricultural

[1] A study by Nyoro, et al., 2002 shows that fertilizer consumption in Kenya was 254,000 Metric tons in 1996 and 352, 000 Metric tons in 2000.

inputs. There has been an increasing awareness in recent years of the need to restore soil fertility through improved use of fertilizer. Still, the present estimated use of 12,000 MT of fertilizer products per year is extremely low.

Like in Kenya, most of the fertilizer imported into Uganda is applied to cash crops; the difference lies in magnitude. It is estimated that of the total fertilizer use in Uganda, 95% is applied to cash crops (tobacco, tea, flowers, and sugarcane) grown on large estates or by outgrowers. For example, Kakira Sugar Works has about 9000 ha of sugar cane and uses between 85-90 MT of TSP and about 100 MT of Urea per month (M. Foster, pers. commun.). Nkonya and Kaizzi (2002) have suggested that adoption of inorganic fertilizer use in Uganda may require more intensive training of farmers who were not familiar with the technology. They observed that because of their access to the relatively advanced Kenyan input market, farmers in eastern Uganda had a high adoption rate for inorganic fertilizer use.

It is estimated that only 15% of farmers in Tanzania use fertiliser. The average fertilizer use in 1991 was 7kg of NPK per ha (Turuka and Kilasara, 2002). The percent of farmers using fertiliser and amount applied decreased after withdrawal of input subsidy in 1990s, with subsequent decline in fertiliser use (Figure 3). Other factors that contributed to decline of fertiliser use were lack of credit for input dealers who lacked capital to buy and distribute fertiliser; devaluation of the Tanzanian shilling that made fertiliser more expensive in the domestic market; fall in producer price for the export crops, etc (MAC et al., 2000).

As is the case for Kenya and Uganda, fertilizer use among crops and regions in Tanzania is skewed. Tobacco and maize receive most of the fertilizer used while the Southern Highlands regions and Tabora region account for the lion’s share of fertilizer consumption (World Bank, 1994). These regions are leading producers of maize and tobacco.

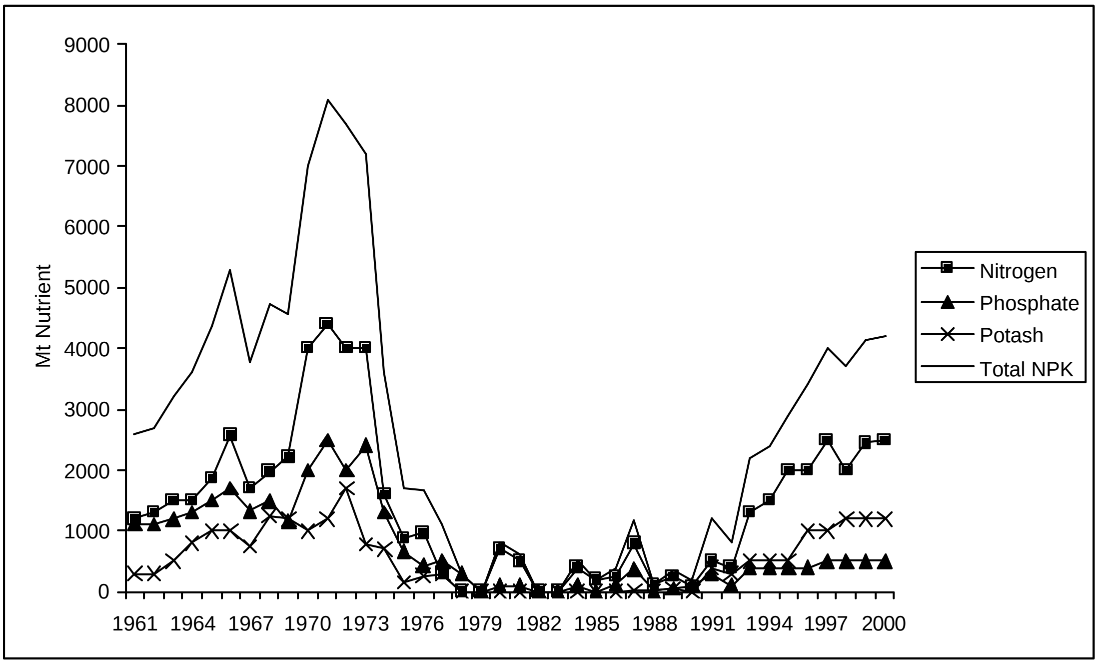

Figure 2. Fertiliser consumption values for Uganda, 1961-2000, based on commercial and donor imports (FAO, 2001).

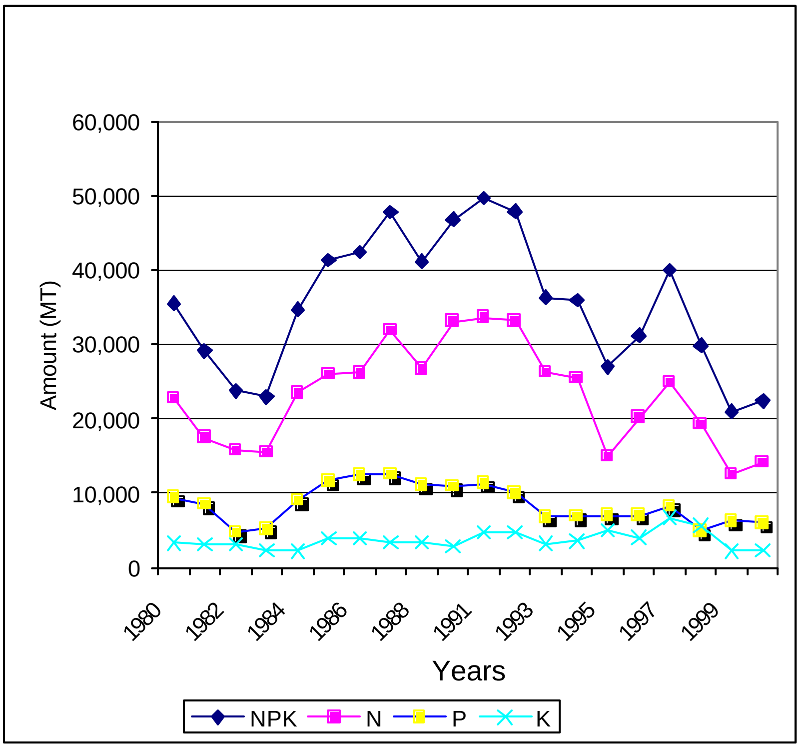

Figure 3. Fertiliser demand trend in Tanzania (FAOSTAT, 2000)

Fertiliser use recommendations

The most comprehensive studies aimed at establishing fertiliser use recommendations were conducted in Kenya under the Fertiliser Use Recommendation Project (FURP) which was initiated in 1986. It was to develop crop, soil, and agro-ecological zone specific fertiliser recommendations for major food crops based on smallholder farming scenarios (Nandwa, 1991; KARI, 1994; Muriuki and Quareshi, 2001). Fertiliser trials were conducted in 31 districts with a total of 71 sites of which 74.3% were located on farmers' fields. Recommendations were made for about 15 cropping systems (mono or inter crops), ranging between 0 – 75kg ha^{-1} of N, P or both, published district-wise, and distributed to extension staff in the Ministry of Agriculture and Rural Development in 1994 (Nandwa, 1991; KARI, 1994). The FURP recommendations were then extrapolated to areas of similar representation but this required verification, a task that was well carried out by the Ministry of Agriculture and Rural Development through the Fertiliser Extension Project (1994-1999) (Muriuki and Quareshi, 2001).

The fertiliser recommendations for Tanzania are based on farming systems and agroecological zones (Table 6). The rates are slightly higher than the Kenyan ones but are still much lower than those applied in the developed countries.

Some constraints may affect application of these recommendations. First, the recommended fertiliser rates were based on static economic considerations. For instance the recommendation rates for maize in Kenya were based on a price input/output ratio (N or P/maize) of 10. The economically optimum fertiliser rates for smallholder farmers were calculated with a value/cost-ratio of 2, i.e. for every shilling invested in fertiliser, the farmer should have obtained an additional income of 2 shillings; 1 shilling to pay for the fertiliser plus additional shilling to cover his/her risks and to give him/her some benefit (KARI, 1994). Unfortunately, prices of inputs and outputs do not always change in a fixed ratio as prices change over time. Secondly, and as mentioned before, soil fertility is dynamic and some applied fertilisers may have a residual effect that may necessitate lower rates in subsequent applications. Where nutrients have not been applied in any form for some time but cultivation has continually been practised, recommendation rates may have to be revised upwards, up to replenishment levels in some cases (Sanchez et al, 1997). This calls for continual studies to keep updating the recommendation rates. It is for these reasons that fertiliser recommendations developed for Uganda based on experiments of the 1950s and 60s are not considered applicable presently, unless they have been verified.

Table 6: Selected fertilizer recommendations for the main crops in Tanzania.

Crop	Area/AEZ	N rates Kgha^{-1}	Prates Kgha^{-1}
Maize	Eastern Zone	40-90	20
	Northern Zone	45-112	No recommendation due to high soil test levels
	Southern Zone Southern Highlands	50 80-120	12-22 (average 17) 20
Rice	Eastern Zone Southern Zone	60-120 40-60	10-20 10-20
Wheat	Northern Zone Southern Zone	30-60 60	45 20
Coffee Tea	Northern Zone Usambara Highlands	80-160 200-375 in 2 splits	80 10-20 kg P/ha * K rates 40-188 kg K/ha (extremely variable)
Tobacco	Western Zone and Iringa Region	60	100 kg P/ha with * 75 kg K/ha
Cotton	Western Zone	Variable depending on soil texture 20-60	15-30
Sisal	Eastern zone	100 in 4 splits	13-25 kg P/ha with *250 kg K/ha in 10 splits

Fertiliser trials in East Africa

There is ample literature on fertiliser research in East Africa, dating back to the colonial days. According to Bekunda et al (1997), most of it has been quality research supporting fertiliser (organic and inorganic) use in improved crop production and maximising nutrient-use efficiency. The limited adoption of mineral fertiliser use was viewed as a symptom of deficiencies in many research trials[2]: (i) most trials were conducted on-station and do not represent farmers' conditions, (ii) they involved single crops or simple season rotations of a few crops in contrast to the intercropping frequently favoured by farmers, (iii) presented insufficient information on optimum use of small amounts of fertilisers to supplement nutrients contained in organic residues available on farms, and (iv) results were not demonstrated to the farmers to increase knowledge of fertiliser use efficiency and benefits.

This section of the paper refers more to the last point; demonstration and participatory trials on fertiliser use, which have recently gained widespread support from government and non-governmental organisations (NGOs). One such NGO is the Sasakawa-Global 2000 (SG 2000) which begun its agricultural projects in Africa in 1986 (Quinones et al, 1997), and operate in Uganda and Tanzania. The core of the SG 2000 projects are dynamic field testing and demonstration of programmes for food crops in which improved technology exists but for various reasons was not being adequately extended to farmers. SG 2000 works with farmers (participation in demonstrations is voluntary) but under the leadership of the national extension departments of the relevant ministries of agriculture. The technology packages taken to farmers by frontline extension staff, with support from SG 2000, are derived from national and international research systems and are upgraded as new research information become available. Farmers pay 50 –100% of the costs of inputs to help ensure that they become stakeholders to the trials which are installed on large size demonstration plots that allow farmers make more realistic appraisal of the recommended technologies, including the economic returns on their labour and capital. Technology packages are not purely fertiliser based; inclusion of other technologies, like best available commercial cultivars of hybrids may act as appropriate entry points for fertiliser popularisation. In Tanzania, average maize yield in demonstration plots increased 208% over farmers' plots during the period 1989-1994 (Quinones, 1997).

Simultaneous with the field demonstrations SG 2000 strives to get attention of the policy makers so that they too pick up lessons from the demonstrations and use these to make

[2] Socio-economic factors are also responsible for the low fertiliser adoption. However, analysis of the socio-economic factors is beyond the scope of this paper

decisions regarding their country's development strategies. We believe this to be a wholesome approach to conducting fertiliser trials and consequent scaling up of appropriate technologies as it involves all stakeholders.

Kenya has benefited from the proximity to some CGIAR centres, which conduct participatory research activities within the country. The Soil, Water and Nutrient Management Programme (SWNMP), a System wide Programme of the Consultative Group of International Agricultural Research Centres (CGIAR), focuses on four research themes: Combating Nutrient Depletion, Managing Acid Soils, Optimising Soil Water Use, and Managing Soil Erosion. Tropical Soil Fertility and Biology Programme (TSBF) and Kenya Agricultural Research Institute (KARI) co-convene the Combating Nutrient Depletion theme in Kenya. The major research objectives of Combating Nutrient Depletion Theme are: 1) Integrating nutrient management practices that redress nutrient imbalances and environmental degradation, 2) Enhancing policies for combating nutrient depletion, and, 3) Assisting farmers to adopt improved nutrient management practices. The governments of Germany, the United Kingdom, the Netherlands, Switzerland and Norway fund SWNM. Combating Nutrient Depletion activities in East Africa are conducted through individual projects as well as network trials. Several network trials addressing integrated nutrient management have been developed and promoted by SWNM-AfNet throughout the country. Examples of such trials are:

? Nitrogen 1: (A). Nitrogen fertiliser equivalencies based on organic input quality, and (B). Optimal combinations of organic and inorganic N sources
? Nitrogen 2: Overcoming the negative effects of low quality organic inputs
? Nitrogen 3: Determining the *in situ* fertiliser equivalency values of best bet leguminous technologies
? Phosphorus 1: Optimal combinations of organic and inorganic P sources
? Phosphorus 4: Residual effects following different rates of P application

Most of the SWNM activities in East Africa are conducted in collaboration with the African Highlands Ecoregional Programme (AHI).

Other fertiliser trials by KARI in conjunction with the Ministry of Agriculture and Rural Development include (Kabete, Muguga, Kitale, Kakamega, Kisii, Embu, Katumani, Mtwapa, Njoro, and Molo) (KARI, 1994a; 1996; 1997; 1998; 2000). Some fertiliser trials are being done by the Universities (Nairobi, Kenyatta, Moi, Egerton and Jomo Kenyatta) and other tertiary colleges (KARI, 1998; 2000) and also by individual researchers. Once the information is gathered from the various trials, the researchers write papers, which are presented in conferences and seminars. Pamphlets, like the *Fertiliser Use Recommendation Pamphlets*, are developed for, and distributed to the intended users - farmers (KARI, 1994).

In Tanzania, fertiliser trials are carried out in all the Agroecological Zones (AEZ) under the different administrative research zones (Eastern Zone, Northern Zone, Western Zone, West Lake Zone, Central Zone, Southern Highlands Zone, Southern Zone and Sokoine University of Agriculture Zone). Both on station and on farm trials are conducted. Results are discussed in different fora. The Department of Research and Development (DRD) of the Ministry of Agriculture and Food Security conducts workshops in the different zones and these are compiled. Dissemination of fertiliser recommendations from the various meetings to the farmers is through the extension services, but has not been very effective especially for on station trials. However with on-farm trials, farmers get the information, as they are part of the process. There is a lot to be done in terms of coordination, compilation of the results and dissemination to the stakeholders.

Some commodity crops like coffee, tea and tobacco are under the umbrella of organized research in their crop authorities. Here research information is disseminated to the farmers (mostly large scale farmers) and outgrowers as soon as possible.

Conclusions and recommendations

In this paper we note that soil fertility in eastern Africa is declining at an alarming rate due to soil fertility mining. This puts crop production in an unsustainable path since a considerable proportion of soils in the region are highly weathered with low reserves of the macronutrients to support nutrient mining. The current soil fertility management practices that small farmers use, namely recycling crop residues, biomass transfer, short fallow and other organic practices appear to be inadequate to counter the nutrient outflows. Consequently, a number of case studies have shown that crop yields are declining. Given that population is increasing, this poses a big challenge for policy makers to address the downward soil fertility trend in the region.

Fertilizer trials and the consequent recommendations conducted in East Africa emphasise the need for greater use of inorganic (and organic) fertilisers to remedy the nutrient deficiencies. Many factors lead to the low adoption of fertilizer use in the region. However, One such factor, which is within the scope of this paper, is inappropriate fertilizer recommendations. The recommendations are based on mono-crop systems while most of the cropping systems in the region are complex intercrops and mixed cropping. Additionally, the recommendations do not take into account the dynamic nature of the agricultural input and output prices and other economic changes. This has made many recommendations irrelevant to farmers, and hence their low adoption, even among those who appreciate the benefit of fertilizer application. Even farmers who have adopted fertilizer use apply doses that are well below the recommended rates. We therefore consider that there is a need for a new approach to bear on replenishing soil fertility in eastern Africa.

Our findings suggest the need to revise the current fertilizer recommendations such that they take into account the cropping systems and the profitability of fertilizer use inputs. This suggests the need to conduct on-farm fertilizer trials in different cropping systems and to collect and analyze soil samples in order to better understand the soil fertility status. Unfortunately, research funding in the region has been falling in the past decade, severely limiting agricultural research. Hence, a need to increase research funding is apparent. This will allow researchers and extension agents to design spatially explicit and appropriate recommendations. Since such strategy is likely to be costly, innovative methods may be used to encourage farmers to conduct soil productivity experiments with the help of researchers. For example the participatory learning and action research approach helps farmers to identify, test and adopt different soil fertility management options suitable in their areas. This also implies a need to adopt integrated fertility nutrient management methods, rather than relying on inorganic fertilizer only to replenish nutrient outflows.

The east African governments also need to create conducive environment for the private sector to have an economic incentive to market fertilizer and other inputs. The current policies are heavily influenced by donors and lending agencies and by crisis management. This has led to inconsistent policies and interventions that have sent wrong signals to both private sector and farmers.

There is also a need to consolidate fertilizer imports in order to gain from the economies of scale of large imports. The east African community is likely to be the relevant vehicle to facilitate the input marketing consolidation process. Scientists in the region also need to strengthen their information exchange mechanisms in order to reduce research costs and increase the quality of the research products.

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