Chapter One

Introduction

Current Status of Agriculture in Kenya

Overview

Agriculture, the art and practice of producing food, plays a major role on household well-being and national economies in sub-Saharan Africa (SSA). Thus in Kenya, agricultural sector contributes to 25 per cent of total gross domestic product (GDP) and about 60 per cent of the export earnings in the forms of cash crops such as tea, coffee, pyrethrum and horticultural crops. The sector further accounts for 80 per cent of income for many livelihoods, especially in the rural areas (Wanyama *et al.*, 2006). In spite of this importance of agriculture in SSA as a whole, it is unfortunate that this region has over a long period experienced food shortages as illustrated by continuous food aid which does not seem to end (FAO 1996; World Bank 1996). In other words, food production in SSA has not kept pace with population growth at about 3 per cent annually, while food production is increasing by only 2 per cent. This regions per capita deficit in cereals in among the highest in the world. Net cereal (maize, wheat, rice) imports increased from 1.5 million tons in 1967 to 12 million tons in 1997, and the projections indicators show that the region will require 27 million tons of cereal imports to satisfy demand by 2020 (Ayaga, 2003). These figures reflect the need to reduce cereal import through increased and sustained domestic food production towards food security. Increased food production in SSA is mainly done by expanding the cropland areas, but the constraint of rapid population increases seriously limits land extension.

There is, therefore, a growing need to increase yields per unit area through efficient use of limited land areas. The widely grown food crops in Kenya and most of SSA include the cereals (maize, sorghum, millets, rice) while the grain legumes include common or dry beans, cowpeas, groundnuts, green grams, among others. There is also substantial consumption of both indigenous (amaranth, black night shade, spider plant) and exotic (cabbages, kales, garden peas) vegetables in SSA. Additionally, Kenya has two major cash crops, tea and coffee which are important for the country’s foreign cash earnings.

The Concept of agroecozones (AEZs) in relation to crop production

Variations in altitude, climate and soils largely influence agricultural productivity within and across countries. These variations have been used in the sub-division of arable land into agroecozones (AEZs) for agricultural management purposes. Thus in the eastern Africa region, the demarcation of croplands into AEZs was done in the second half of the 20th century, whereby the ratio of average annual rainfall (r) to evapotranspiration (E_T) was used to assign AEZs in the region (Woodhead, 1968). From this zoning criterion, the high rainfall and cooler areas generally had the $\frac{\gamma}{E_T}$ ratios above 0.60, while the drylands had ratios below 0.35. In Kenya, Jaetzold and Schmidt (1983) incorporated variations in altitude, crops grown and soils in the country as additional attributes for zoning (AEZs). On this basis, Kenya's low maize yields are common on the coastal, medium altitude and moisture stressed light soils, whereas high yields occur on the cooler high altitude regions with heavy soil texture, a high rainfall (Table 1; Fig. 1).

Table 1: Maize growing areas (ha) in Kenya by agroecozones (AEZs, after Ayaga, 2003)

Growing area	**AEZ**	**Altitude (m) a.s.l.**	**Area (x 1000 ha)**	**Mean maize Yield (t/ ha)**
Coastal zone	CL3 / CL4	0-1000	100	1.36
Moisture stressed	UM / LM	1000- 1600	400	1.03
Non-moisture stressed (midaltitudes)	UM / LM / LH	1600 - 1700	400	1.44
High altitude late maturity	UM / UH	1700 – 2030	500	2.91
Very high altitude	UM	2300	100	2.76
Total			1500	

Legend: CL = Coastal lowlands 3 and 4

UM and LM = Upper and Lower Midlands

UH = Upper Highlands

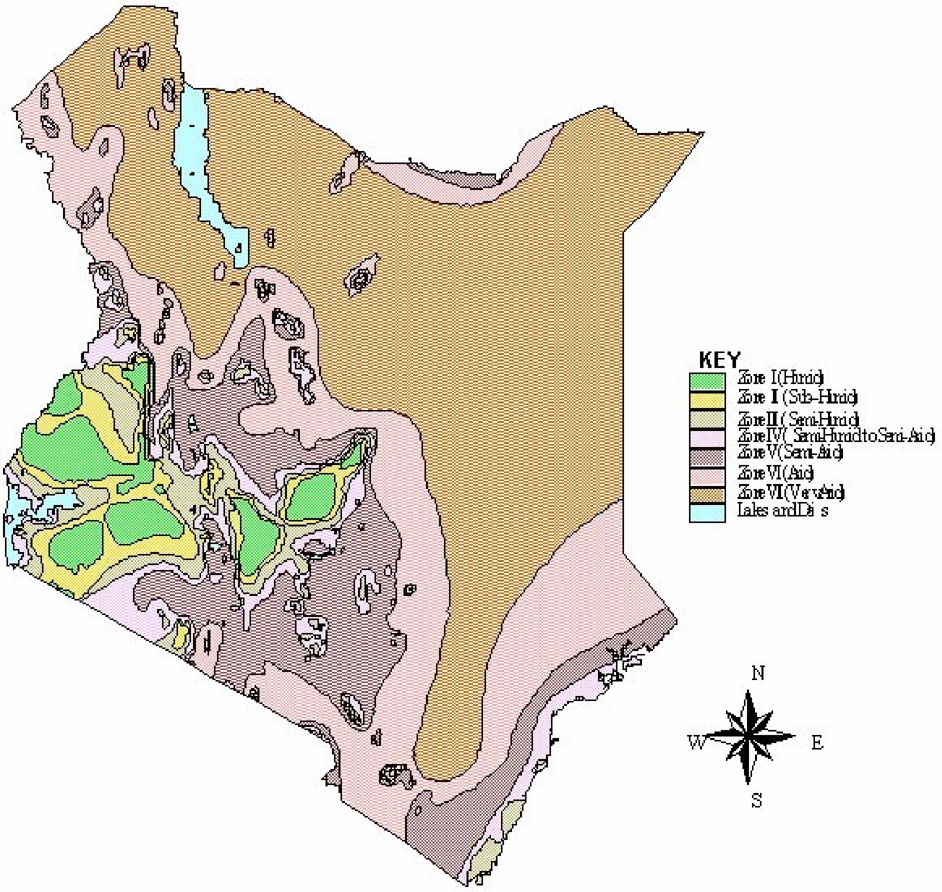


Figure 1: Map of Kenya showing Agroecozones.(After Jaetzold and Schmidt, 1983).

The Problem of Declining Crop Yields

Apart from the impact of AEZ differences on the magnitudes of yields in SSA, crop production in this region is low and declining and hence unsustainable. These findings are reported by numerous researchers in the region. This is particularly so in western Kenya, where average seasonal subsistence maize, beans and cowpeas yields, for example, hardly exceed 1 ton/ha (Sanchez *et al*, Nekesa *et al*, 1999; Ayaga, 2003; Okalebo *et al*., 2005). These poor yields portray hunger in households in this area in periods beyond 3 months after harvests (S.N. Nandwa, *pers*. *comm*.). In addition, the “food basket” Trans Nzoia district, Kenya, declining maize yields over the past 25 years or so (Fig. 2) have been reported by Kariuki (2003). This decline in crop yields reveals food insecurity and hence continuous famine.

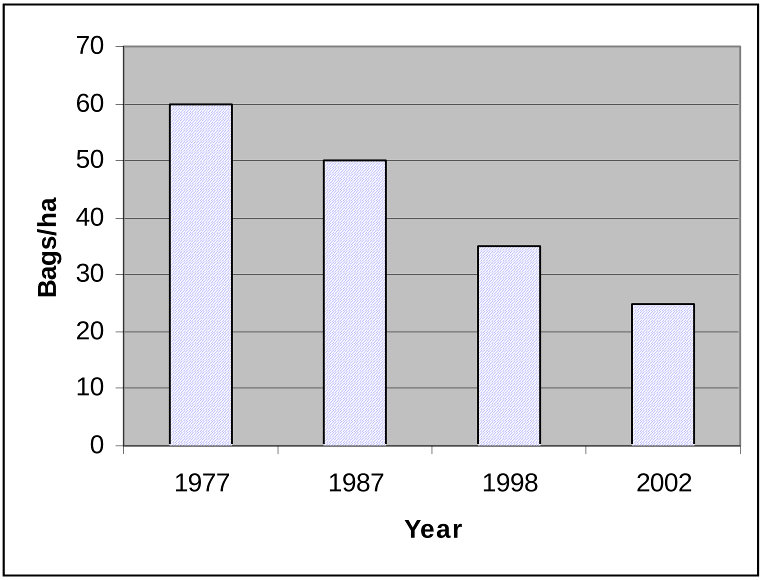


Figure 2: Maize yields in Trans Nzoia district (1977–2002. Source - Rev. Nelson Kariuki (2003), CENART CONSORT NGO, Kitale, Kenya.

NB - One bag weighs 90kg of sun-dried maize grain.

Reasons for the decline in crop yields in SSA are multiple, and include the following:

- frequent/and prolonged droughts leading to crop failures such as those reported for 2 consecutive seasons in eastern and north eastern Kenya in 2008;
- the planting of low quality seed with low yield potential such as the seed from indigenous sources frequently grown by most small scale farmers in SSA;
- widespread poor crop husbandry practices (poor seedbed preparation, late planting along with poor spacing, poor weeding and non-control of diseases and pests etc);
- poor and unstable economies and policies related to acquisition of inputs (quality seed, fertilizers, pesticides and fungicides mainly), value addition and good markets for products;
- post–harvest losses of produce due to poor preservation and storage and transportation of fresh produce, mainly the horticultural products;
- declining soil fertility resulting from continuous cultivation of high nutrient demanding crops (such as maize) on the same pieces of land without or with minimal nutrient returns. This is often referred to as nutrient depletion and constitutes the backbone of this document.

Chapter Two

Soil Fertility Depletion

Soil fertility depletion is embedded within the broader land degradation problem, defined by FAO (2002) as the loss of production capacity of land in terms of loss in soil fertility, soil biodiversity and degradation of natural resources. Thus land degradation is a widespread problem that affects soils, landscapes and human life (Thiombiano, 2000). The cumulative loss of crop productivity from land degradation in SSA between 1945 and 1990 has been estimated at 6.2 per cent of the productivity. In this region about $ 42 billion in income and 6 million hectares of productive land were lost every year due to land degradation and declining crop production (UNDP/GEF, 2004).

Causes for land degradation are intensive land use from human population growth, poor soil management, deforestation, insecurity in land tenure, climatic variations (change) and the characteristics of fragile soils. Hence in Africa, land degradation is a threat to food production, food security and natural resource conservation. Soil loss through erosion could be about 10 times greater than the rate of natural formation. However, water and wind erosion are significant causes of degradation. While soil fertility decline, a gradual and invisible process is also notable. Causes of land degradation have been estimated by Dunstan *et al.* (2004) in rural areas in Africa to consist of: soil water erosion (46 per cent), wind erosion (36 per cent), loss of nutrients (9 per cent), physical deterioration (4 per cent) and Salinisation (3 per cent). Soil erosion is caused by overgrazing (49 per cent) followed by agricultural activities (24 per cent), deforestation (14 per cent) and overexploitation of vegetative cover (13 per cent), all constitute the primary causes of land degradation. Yield losses as a result of land degradation in Africa range from 2 per cent decline over several decades to 50 per cent (Scherr, 1999). Crop yield loss from erosion alone in 1989 was 8 per cent for Africa as a whole.

Globally, the area of degraded soils is very large (Table 2) and the effects of degradation are evident in many areas of Africa, with widespread degradation-prone or fragile soils (described below), which are difficult to bring to productivity, particularly under dense populations (Scherr, 1999). It is estimated that since 1950s, Africa has lost about 20 per cent of its soil productivity irreversibly due to degradation (Dregne, 1990).

Table 2: Worldwide estimates of agricultural land degradation by region

***Source**: (Scherr, 1999; Olderman* et al. *1992).*

In relation to soil fertility decline, Sanchez *et al.* (1997) have stated that soil fertility depletion in smallholder farms is a fundamental biophysical root cause of the declining *per capita* food production, with a resultant significant contribution to poverty and food insecurity. From this observation, these researchers have given estimates of nutrient losses to be 4.4 million tons of nitrogen (N), 0.5 million tons of phosphorus (P) and 3 million tons of potassium (K) every year from cultivated land. In addition, estimates of annual nutrient losses from farming systems in eastern Africa highlands (Stoorvogel, 1993; Smaling *et al.,* 1997) and on farm scales in western Kenya (Shepherd *et al.,* 1996) also exist. These negative nutrient balances are often not corrected in Africa, where fertilizer use, is mainly from 9 to 15 kg/ha annually (Bationo *et al.,* 2006)

An Insight of Soils of Kenya Croplands

In this section, the term "soil" is defined and the characteristics of arable soils in Kenya are summarised and will in later chapters be used to explain differences in crop responses to soil fertility amendments.

A definition of soil may be given from several disciplines or end users, depending on the function of the soil in which one is targeting. Thus the geologist may consider soil to be the decomposed surface part of the rocks. The engineer may focus the physical characteristic of soil, for example its compressibility, its bearing strength, and its permeability to water. For the pedologist, soil is a natural body, occurring in various layers, composed of unconsolidated rock fragments and organic matter. Agronomist defines soil as the unconsolidated cover of the earth, made up of mineral and organic constituents, water and air and capable of supporting plant growth. This is probably the most fitting definition for a farmer, since it includes the most important function of the soil, to grow plants. The growth of most plants is not possible without soil. Human survival depends on the fertility of soil. Therefore, the value of the soil is gauged by its capacity to produce crops. As a medium for plant growth, soil performs four main functions.

- It anchors the plant roots.
- It supplies water to the plant.
- It provides air for the plant roots.
- It furnishes the minerals for plant nutrition.

Apart from the solid (mineral), organic matter, water and air components of soil, millions of microbes live in fertile soil. Without them, soils would be inactive and soon loss their capacity to support plants. Microbes help to bring plant nutrients into available form and they make soil crumbs stable and resistant to erosion. Yield and composition of crops depend largely on the properties of soil. Humans, who eat these crops and the meat from the animals raised on these crops, are truly a product of the soil.

Soils worldwide vary in relation to their physical, chemical and biological properties. These variations result from differences in age, parent material from which they are formed, physiography and present and past climatic conditions. There is a strong correlation between nutrient depletion, the AEZ and dominant soils of each of the AEZ. In the humid zones, the dominant soils (FAO/UNESCO system) are Ferralsols and Acrisols. The sub-humid zone is characterized by prevalent Ferralsols and Lixisols and to a lesser extent the Acrisols, Nitisols and Arenosols. In the semi-arid zone, Lixisols are dominant, followed by the sandy Arenosols and Vertisols (Deckers, 1993).

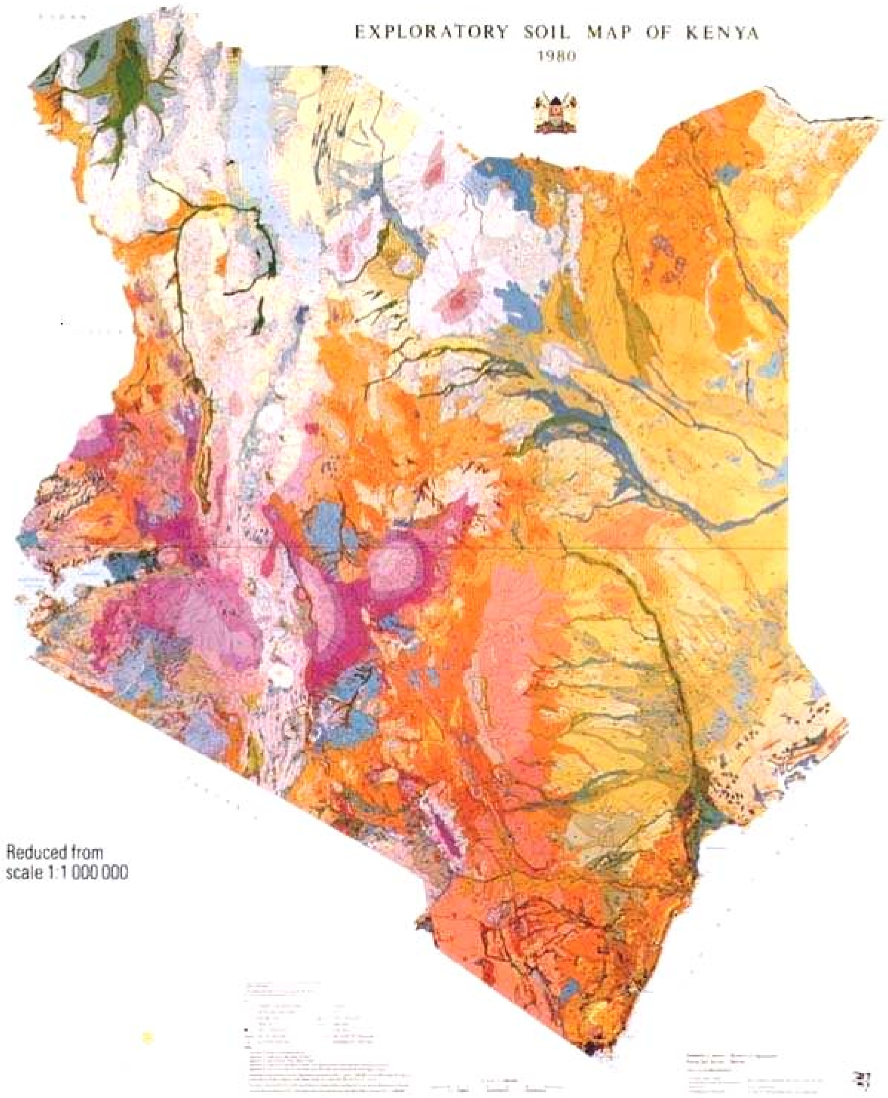


Figure 3: Map showing the soils in Kenya. Source: Survey of Kenya.

A brief description of the characteristics and potential environmental problems in relation to plant nutrition of four dominant soils in Kenya.

a) Ferralsols (similar to Oxisols in USDA Soil Taxonomy)

These are highly weathered soils (Deckers, 1993). They have a low capacity to retain nutrients (cation exchange capacity). This low–retention capacity has marked consequences for fertilizer management. Examples, because of leaching characteristic, the nitrogen fertilizer is to be applied in splits; these soils occur in high rainfall areas. Phosphate fertilizers are fixed by free iron (Fe) and aluminium (Al) oxides; this shows the need to apply large quantities of P fertilizers. Other constraints of Ferralsols include deficiency in bases (Ca, Mg, K), which require lime applications. Toxicities of Al and manganese (Mn) are suggested at pH levels of soils below 5.2. This pH level is associated with molybdenum deficiencies, particularly for legumes. However, Ferralsols are well-drained, with good structure, but have relatively low water holding capacity (Van Wembeke, 1974).

b) Acrisols (similar to Ultisols in USDA Soil (Taxonomy)

Acrisols have high water holding capacity, but the higher density of the second (B) horizon may limit the biological activity and root penetration (Deckers, 1993). Although they are less weathered compared to Ferralsols, mineral reserves are low. Leaching is a problem in these soils and boron (B) and Mn are often deficient. High **Al** contents may lead to **P** fixation. Their surface structure is weak and internal drainage may be reduced by the compact textural B horizon. They should be protected from soil erosion. Addition of lime and organic matter may be needed to ensure sustained production.

c) Nitisols (similar to Plaeudults in USDA Soil Taxonomy)

Nitisols have a clay–rich subsoil, which is characterized by a good soil structure, and have a higher fertility level than the Acrisols (Deckers, 1993). The key to the high fertility of Nitisols is the clay in the subsoil, which can retain considerable amounts of plant nutrients. p–fixation is common and Mn toxicity may be a problem in the more acid Nitisols. Their water holding capacity is favourable because of the high clay content in the B horizon; these soils have an open structure that allows plant roots to penetrate very deeply into the profile.

d) Lixisols (similar to Alfisols in USDA Soil Taxonomy)

Lixisols, like Acrisols and Nitisols, have a clay accumulation horizon with a low capacity to store plant nutrients, but are well saturated with cations low storage capacity for cations. The soil pH is medium to high, and **Al** toxicity does not occur. Because the Lixisols may become depleted quickly under agricultural use, their physical characteristics are generally better than those of the Acrisols.

Chapter Three

Contribution of Soi Stresses to Crop Production

A lot of literature exists regarding the impact of soil based stresses on low and unsustained crop production in SSA. A range of recommendations have been made to restore soil fertility in this region. The current line of thought is to raise the current levels of fertilizers applied (9kg/ha) to 50 kg/ha in Africa by the year 2015 (Bationo *et al.*, 2006; Millennium Development Goals). This intervention on its own may not be sufficient to raise crop yields as the smallholder farmers have yet to find good markets for their produce. Perhaps an approach towards sustainability is to maintain agricultural production operations following the cycle (Fig.4) suggested by John Lynam (*pers. comm*) in which inputs are required to give yields (products), followed by processing or value addition of the products which are likely to fetch good markets and which can also be stored over longer periods after harvests; the income (profits) from good markets may then be used to purchase inputs. However, for inputs, fertilizers will be needed in large quantities to restore the fertility of depleted soils. Farmers will in general need to use efficiently the expensive fertilizers. At this juncture it is pertinent to highlight composition and life functions of plants (Section 3.1) and the roles of specific nutrients (Section 3.2) as they limit production in Kenyan agriculture.

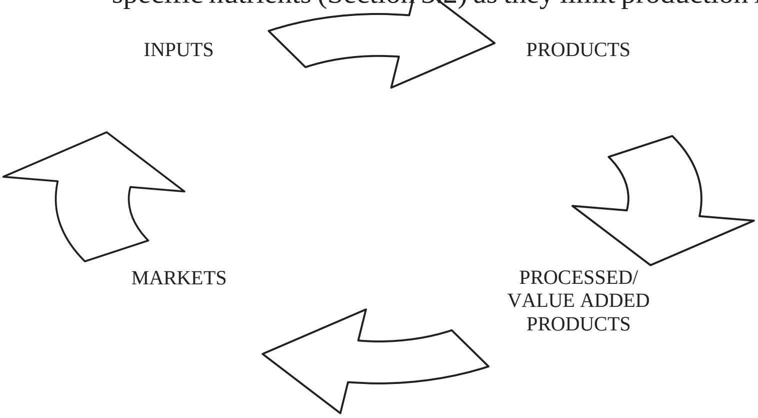


Figure 4: Model of agricultural sustainability. Source J. Lynam pers. comm *2004.*

Composition and Life Functions of Plants

Detailed accounts on the composition and functions of chemical elements on plant growth and nutrition are presented in textbooks and publications on plant physiology and nutrition (e.g. Russell, 1973). It is however, highlighted here that plants are made up of a wide range of chemical elements out of which only 17 are generally known to be essential for plant growth (Table 3). Out of these, the elements Oxygen, Carbon and Hydrogen are obtained directly from the unlimited supplies of the atmospheres and water, while the rest derive from soils, combined in various mineralogical forms (Van Straaten, 2006). In general the following functions are essential to plant life:

- *Absorption of water and nutrients* by the roots and to a limited extent through the leaves.

- *Transpiration* of water from the plants (mostly the leaf stomata) into the atmosphere. Large quantities of water are needed for the plant to take up minerals from soil and to sustain its other functions.

- *Photosynthesis*, the creation of plant material through the chemical combination of carbon dioxide of the atmosphere and water of the soil.

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{Energy obtained}} \underset{\text{(sugar)}}{C_6H_{12}O_6} + 6O_2$$

This synthesis is possible only in the presence of light and with green chlorophyll as the activating agent.

- *Synthesis of complex organic compounds*, carbohydrates, fats, protein, lignin and other compounds are formed from simple sugars, nitrogen compounds and minerals (salts). The energy required for this synthesis is produced in the respiration process.

- *Respiration*, Like all living things, plants breathe. Both their tops and roots inhale O_2 and exhale CO_2. This is the reverse process of photosynthesis.

$$C_6H_{12}O_6 + 6CO_2 \xrightarrow{\text{Energy released}} 6CO_2 + 6H_2O$$

Apart from CO_2 for photosynthesis and O_2 for respiration by the above ground parts, the largest portion of the other plant nutrients enters the plants through the roots and must come from the soil. Table 4 shows the relative amounts of the individual elements in a maize plant.

Table 3: Essential elements for plant growth

Used in large amounts		Used in small amounts
Mostly from air and water	**From soil solids/solution**	**From soil solids/solution**
Oxygen (O)	Nitrogen (N)	Chlorine (Cl)
Carbon (C)	Phosphorus (P)	Iron (Fe)
Hydrogen (H)	Potassium (K)	Manganese (Mn)
	Calcium (Ca)	Boron (B)
	Magnesium (Mg)	Copper (Cu)
	Sulphur (S)	Zinc (Zn)
		Molybdenum (Mo)
		Cobalt (Co)

Source: H. Kohnke and D.P. Franzmeir (1995)

Table 4: Element composition of a maize whole plant.

Element	per cent of total dry weight	Element	per cent of total dry weight
Oxygen	44.5	Phosphorus	0.20
Carbon	43.6	Sulphur	0.14
Hydrogen	6.3	Aluminium	0.10
Nitrogen	1.25	Iron	0.04
Potassium	1.20	Manganese	0.003
Silicon	1.20	Zinc	0.002
Chlorine	0.40	Copper	0.001
Magnesium	0.25	Boron	0.0007
Calcium	0.23	Molybdenum	0.0006

Source : H. Kohnke and D.P. Franzmeier (1995)

Stressing the Roles of Nitrogen and Phosphorus on Plant Nutrition

Cultivated soils are often deficient in the major nutrients Nitrogen and Phosphorus. Evidence regarding these deficiencies are strong for soils in the Kenyan highlands and generally in SSA (see Chapter 4 and 5). In this section only selected details regarding the roles of these two critical nutrients are summarized, particularly as they are important in managing soil fertility for crop production.

Nitrogen

Like Oxygen, Hydrogen and Carbon, Nitrogen is distributed in the atmosphere and lithosphere; the N_2 gas is the main component in the air (about 78 per cent by volume). However, the N_2 gas is not directly accessible to plants. In order for N to be taken up and utilized by plants, it is first converted to NH_4^+ and NO_3^- ions. It is also mentioned here that an additional source of N is through the fixation of N_2 from the air by the legume root nodule–rhizobia bacterium associations. Nitrogen also occurs in soils and the amount of N in the ploughed layer of cultivated soils ranges from 0.02 to 0.40 per cent by weight (Black, 1968). Most of the N in the soil is in organic form. It is generally assumed that organic matter contains about 5 per cent of total N, of which only a fraction becomes available annually for crop uptake and utilization. But the rate at which N becomes available depends on the rate of mineralisation of the organic mater. Therefore, the total N in the soil is not an indication of the amount of this nutrient which is immediately available to a crop, but constitutes a reserve from which N may become available to plants, but not necessarily at a rate that coincides (synchronises) with the requirements of an actively growing crop. Nonetheless, the content of N in the soils tends to remain constant at a level which depends on the nature of the parent material, leaching characteristics of soil (mainly determined by the texture) and on the management systems used (Cooke, 1967)

Nitrogen is essential for several critical biological functions explained in details in the discipline of plant physiology. Plants require N for growth of roots, shoots, fruit and seeds. Adequate N (from reserves or external additions to soils) promotes the formation of chlorophyll. Nitrogen is essential in the process of photosynthesis the primary process that converts inorganic forms of C e.g. CO_2 into organic forms (like sugars/ carbohydrates). Nitrogen is also a building block in the production of proteins and amino acids. It promotes vigorous vegetative growth in plants. Although N plays a crucial role in the nutrition/growth of crops, its requirements for individual crops vary widely. Cereal crops like maize and rice, have a relatively high demand for N to be supplied from soil solution. Different crops and their genotypes also accumulate different levels of total N, ranging from 50 to 150 kg N/ha for different maize genotypes (J.R. Okalebo, KARI Muguga Records of Research 1990–1995). Apart from N uptake and removals by crops, there are also pathways of N losses through volatilization, leaching, denitrification and loss from surface runoff. These contribute to the negative N balances (highlighted earlier in the farming systems in SSA).

Phosphorus

Soil phosphorus (P) is present in the soil as mineral or inorganic (P_i) and organic (P_o) forms, usually in amounts ranging from 0.1 to 0.4 per cent, but values upto 0.7 per cent total P have been found in some arable soils in East Africa (Okalebo, 1987). The total P content in soils also varies considerably, mainly as a result of the influence of the underlying parent materials and climatic variations. The P in soils and plants is ultimately obtained from rocks and minerals released to the soil through the process of weathering. In plant nutrition, the total P in soil is less important than the plant “available” P, the portion of P in soil that can be taken up by plants. Forms of P in soils are given in Table 5. Further, the quantity of P in the soil solution is always small (0.1 to 0.5 mg/kg in most soils). A level of 0.2mg P/kg is usually considered adequate for plant growth (Beckwith, 1965).

Table 5: Predominant forms of P in soils.

Form	**Symbol**	**Formula**	**Found**
P being in rock and mineral fragments	PR	Mostly apatite ($Ca_{10}(PO_4)6F_2$) and secondary phosphates	In soils as apatite and other P minerals of the secondary environment
Organic P	P_o	Complex organic forms	Inorganic complexes in soils such as inositol phosphates, phosphate enters
Inorganic P ions	P_i	HPO_4^-, HPO_4^{--}	In soil solution, plants can use this form

Source *: Van Straaten (2007).*

N.B – In the pH range 4–9, only the orthophosphate species $H_2PO_4^-$ and HPO^{--} will occur in the soil solution.

The main function of P in plants is related to energy transfer and storage. Phosphorus is a key component in the molecules adenosine triphosphate (ATP) and adenosine diphosphate (ADP), which are integral to most energy transport processes in living organisms. P is a vital constituent of chromosomes. P is essential for the formation of proteins and enzymes and is a fundamental component of the cell membrane, as well as dioxyribonucleic acid (DNA). Phospholipids play a vital role in the formation of cell membranes. P is needed by plants for crucial physiological processes, such as photosynthesis and N_2 fixation.

Phosphorus stimulates the development of roots which will proliferate extensively in areas with higher P concentrations. It is needed in the final growth stages of a plant for seed and fruits. The P reserve in seed is concentrated in the form of phytin, the inositol hexaphoshate. Sufficient P will also strengthen the straw in cereals. Phosphorus is relatively mobile in plants and will translocate from older to younger plant tissue (Russell, 1973; Van Straaten, 2007).

As a result of P availability in very small quantities, P deficiencies are widespread in soils and hence P is a commonly deficient nutrient in agricultural production worldwide. In many tropical regions (Kenya included), low P reserves in soils have resulted from long periods of intensive leaching and weathering and the low P status of the parent rocks, such as granite, rhyollite (acidic) . In addition, P in solution has been largely depleted through continuous removal of nutrients through crop harvests and residue removals. This is human – induced P depletion, known to contribute to declining food security (Sanchez *et al*., 1997).

The Decline in Soil Organic Matter from Smallholder Farming Systems

The term soil organic matter (SOM) has a broad meaning because it includes all materials of organic origin present in the soil regardless of their origin and stage of decomposition. Hence the term includes both fresh and highly decomposed crop residues, animal excretions, as well as the decomposing bodies of soil flora, fauna and microbial components of the "microcosm". SOM is not the same in all soils. The type of vegetation, the nature of the soil population, soil aeration, moisture conditions, climate conditions and management practices, all affect the kind and amount of SOM present in the soil. SOM is therefore a product of its environment or AEZ, being high in areas of dense vegetation, forests, usually of high altitude, while the dry lowlands with sparse to no vegetation, are associated with reduced amounts of organic matter in soils.

In a normal productive soil, SOM cannot accumulate because every addition of organic matter will stimulate the activities of microorganism that contribute to decomposition and mineralization of SOM to available nutrient forms (N, P and S nutrients mainly). Some residues and specific constituents of complex residues, decompose more rapidly than others. Simple sugars, amino acids, organic acids, some proteins and many polysaccharides are completely utilized within a few hours to a few days (Behera and Wagner, 1974). Degradation of cellulose, some polysaccharides and chitin may continue for several weeks. The breakdown of the most resistant components, lignin, waxes and the dark, humic substances may require months to years (Haider *et al.*, 1974).

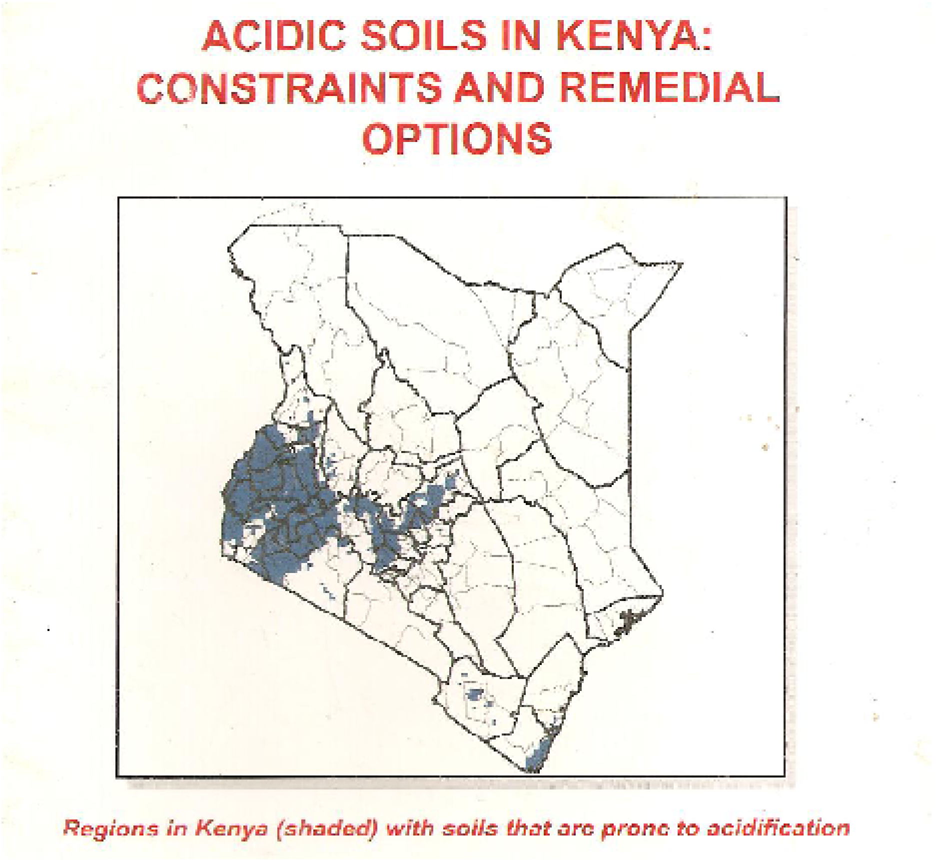
Complete mineralisation of organic matter does not occur; after the processes described above have taken place and the original structure of the organic matter has disappeared, a dark brown to black residue, known as humus, remains. The soil humus generally decomposes at the rate of 2 to 5 per cent annually in temperate climates, but far more rapidly in warm, semi-arid climates (Focht and Martin, 1979). From 60 to 85 per cent of the carbon (C) in most fresh organic mater is likely to be released as CO_2 within a few weeks to about 3 months under favourable environmental conditions. Initially, about half the C consumed by the soil organisms will be utilized for cell and product synthesis to be released after death of the organisms (Focht and Martin, 1979).

The above background information indicates that soil organic carbon (the measure of SOM) is a depletable natural resource capital, and like the negative nutrient balances highlighted above, its decline threatens soil productivity. Most African soils are inherently low in organic carbon (<20 to 30 mg/kg in the top soil). This is due to the low root growth of crops and natural vegetation but also to the rapid turnover rates of organic materials with high soil temperature and microfauna, particularly termites (Bationo *et al.,* 2003). There is evidence for rapid decline of soil organic C levels with continuous cultivation of crops in Africa (Okalebo *et al.,* 1997; Bationo *et al.,* 1995). Results from long-term soil fertility trials at KARI, NARL Nairobi (Kabete) have indicated that losses in organic C upto 0.69 tons/ha /year in the soil surface layers are common in Africa, even with high levels of inputs (Nandwa, 2003).

The Problem of Soil Acidity on Crop Production

Soil acidity is attributed to the abundance of hydrogen (H^+) and aluminium (Al^{3+}) cations in soils, at levels that interfere with normal plant growth. Soil acidity has a negative effect on crop yields mainly through reduced P availability from P fixation in soils whereby the Fe and Al soil components (sesquioxides) fix sizeable quantities of P. Excess Al^{3+} ions, from soil acidity, tend to accumulate in plant roots and thereby prevent P translocation to the tops from the roots, as evidenced by the inhibition of root elongation and overall retarded crop development (Kochian, 1995; Kanyanjua *et al.,* 2002; Ligeyo and Gudu, 2005). The detrimental effect of H^+ ions is not as distinct as that of Al^{3+} cations, but excess H^+ ions in acid soils affect plant root membrane permeability and therefore interfere with ion transport (Ligeyo and Gudu, 2005).

On a global basis, acid soils are known to reduce maize yields on nearly 40 per cent of the arable land (Gudu *et al.,* 2005). However, in Kenya, acid soils occur mainly in the high agricultural potential areas characterized by high altitudes and high rainfall regimes, covering about 7.8 million hectares (13 per cent) of total arable land (Kanyanjua *et al.,* 2002; Fig.5). But in western Kenya, acidic and P_- deficient soils are estimated to cover about 0.9 million hectares of land on which about 5 million people cultivate (Woomer et al., 1997). An indication of widespread soil acidity and P deficiency in this region is given in Table 6, across districts in this region. Overall, the constraints of Al toxicity, P and N deficiencies in Kenya reduce maize grain yields by about 26, 16 and 30 per cent, respectively (Kanyanjua *et al.* 2002).



ACIDIC SOILS IN KENYA:
CONSTRAINTS AND REMEDIAL
OPTIONS

Regions in Kenya (shaded) with soils that are prone to acidification

Figure 5: Map showing areas where acid soils occur in Kenya. (Kanyanjua et al., 2002)

Table 6: Some soil test parameters (0-15 cm depth) across districts in western Kenya (means of 20 farms of each district).

Source: *Department of Soil Science Laboratory, Moi University – soils from Best Bets Fertility Project funded by the Rockefeller Foundation, USA.*

Crops and their genotypes (vegetables included) differ in their tolerances to Al toxicity; the grain legumes (pulses) being more sensitive compared to cereals. Thus in a study which compared the performance of bean varieties on an acid ferralsol of Chepkoilel Campus farm, Moi University, Eldoret, no nodulation was observed in bean crop, reflecting the absence of N–fixation by the crop as a result of soil acidity (pH<5). Similarly, low bean yields (0.3 t /ha) were recorded in this study (Birech *et al.,* 2000). These soils are also characterized by rather high Al levels above 30 per cent saturation.

For cereals, about 80 per cent of maize, sorghum and rice yield reductions from Al toxicity have been recorded in the ferralsols of the tropics (Brenes and Pearson, 1973). Kamprath (1972) however indicated that the Al saturation in soils should be less than 45 per cent for maximum growth of maize. Olmos and Carmago (1976) found that 25 per cent Al saturation in soils reduced maize yields. Decreases in maize yields (magnitudes not reported) due to Al toxicity have been reported in oxisols in Brazil (EMBRAPA, 1980), in Madagascar (Van Wanbeke, 1976) and in oxisols and ultisols of Puerto Rico (Brenes and Pearson, 1973) and for the andosols in Pennsylvania U.S.A. (Fox, 1979).

In western and central Kenya, most soils have more than 27 per cent Al saturation (Obura *et al.,* 2003) contributing to low maize and grain legume yields (<0.5 t/ha/ season) at smallholder farm level. In a separate study, Gudu *et al.,* (2007) delineated maize growing areas including their soil properties in central and western Kenya regions. In the data (not shown here) there was pronounced soil acidity and high levels of exchangeable Al, particularly in the andosols of central Kenya. These researchers found high levels of available P in central Kenya, explained in terms of high P fertilizer doses to cash crops (tea and coffee). Soils from central Kenya are also characterized by high organic matter contents.

Chapter Four

Diagnosis of Nutrient Deficiences in Soils and Plants

Historical Perspective on Plant Nutrition

It is useful to highlight a historical background regarding the development of the current diagnostic procedures used worldwide for nutrient disorders in both soils and plants. Thus, the development of the theory and practice of mineral nutrition of plants and the use of mineral fertilizers in agriculture occurred during the period 1800–1870, known as the "Modern Period" (Russell, 1952; Boulaine, 1994). In this regard, it is perhaps pertinent to recall the concept of Leibig's "Law of the Minimum" developed in the "Modern Period" which incorporates both aspects of deficiency and sufficiency of a nutrient:

1. by the deficiency or absence of one essential nutrient, all others being present, the soil is rendered barren for all these crops to the life of which one constituent is indispensable,
2. with equal supplies of the atmospheric conditions for the growth of plants, the yields are directly proportional to the mineral nutrients applied in the manure,
3. in a soil rich in mineral nutrients, the yields of a field cannot be increased by adding more of the same substances."

In a nutshell, Liebig's Law of the Minimum pinpoints the concept of limiting nutrients and the need for balanced plant nutrition towards sustained crop production. It may also be appropriate to remind ourselves about the production of the first insoluble phosphate fertilizer by Liebig, then from bones and followed by phosphate rock, combined with acid by Lawes and Gilbert, in England (Wild, 1988; Van der Ploeg *et al.*, 1999). Once again, this brief historical perspective reminds us, the origin of our current knowledge on plant nutrition and the practical applications of nutrients in form of fertilizers and manures, to increase and sustain crop production, globally, under diverse differences or variations in soils and environmental conditions.

Soil Tests and Their Related Problems

Commercial fertilizers and manures are increasingly becoming important inputs worldwide. However intensive agriculture is practiced, to correct plant nutrient deficiencies so as to produce satisfactory or economic crop yields. This requirement raises the need to identify limiting nutrients in a field and the quantities to be applied. This leads to the determinations of the plant available forms of nutrients in soils.

Overall, the use of soil analyses to predict a plant's response to fertilizers is based on the correlation between some fraction of a nutrient extracted from a representative soil sample and measured response from fertilizer applications. Soil-analyses–fertilizer–response relationships, apart from those of NO_3-N (mobile in soils), are on the average based on an analysis of plough–layer (0-15 cm) soil samples. This procedure has generally given a reliable basis for predicting a response, provided that adequate and up to date field calibrations data are available (Jackson *et al.*, 1983)

It is not difficult to determine chemically the soil's content of essential elements. However, it is not the amounts of nutrients present in the soil that are significant to crop production, but their availability in the proper proportions throughout the growth period of the plant. This is a function of the soil, the crop and its genotype and its environment and management practices. It is therefore not surprising that no chemical tests have yet been developed that are able to provide an accurate assessment of the amounts of essential elements which are available to the plant in the soil, and hence the exact amounts which need to be added (Osborne, 1974). In spite of these difficulties, by correlating the results of soil tests with the crop responses obtained from fertilizer trials in the field, it has been possible to develop analytical methods which make it possible to predict approximate fertilizer needs.

These tests are however appropriate only to the specific soil types for which they were developed (e.g. Okalebo *et al.*, 2002). Their interpretation requires calibration with fertilizer field experiments, and their reliability depends on the practical experience of the interpreter. Most of the original tests have been developed for the acidic soils of the humid temperate regions, with little focus on arid–regions, dominated by problems of alkalinity.

There are also problems of sampling (variability issue), analysis and interpretation. Results of tests are further complicated by the fact that the availability of soil nutrients is not the same for all crops; different crops are also able to tap nutrients from different soil depths. Hence, the interpretation of soil tests is different for different crops (and their varieties) and will vary according to their positions in the field in the crop rotation schedules. Nitrogen availability in particular is influenced by complex edaphic, climate and biotic factors that frequently make a soil test meaningless. A rise in temperature of the soil may speed up nitrification and thereby release relatively large amounts of N; leaching and denitrification, on the other hand, may cause rapid losses of NO_3–N. Tests for potential N availability (Robinson, 1968) have been developed, but these methods have been adapted to only a very limited extent.

From the above consideration, it is clear that soil analysis cannot provide absolutely reliable data. Mengel and Kirkby (1982) concluded that the relative lack in reliability in no way belittles the importance of soil testing. They point out that they provide a relative indication of soil fertility status that, if carried out over several years, will provide valuable information on whether this fertilizer practice adopted is maintaining, improving or decreasing the levels of available nutrients. However, in Africa the importance of soil testing has arisen mainly from the recognition of soil fertility depletion and the need to bring back the affected soils into production (Smaling *et al.,* 1997). The practice is of great importance to the agricultural, environmental and overall development of communities in the continent. A more ecological approach to nutrient management has also emerged over the past 2 decades known as Integrated Fertility Management (INM). Janssen (1993) defined INM as involving "the combined use of organic and inorganic fertilizers in such away that the required nutrients are applied and the soil organic matter content is maintained.". Others have expanded the principle to include biological nitrogen fixation (Wortmann and Kaizzi; 1997; Woomer *et al.,* 1999). Another recent development is the acceptance by the scientific community that human activities have affected the earth's atmosphere composition and this in turn has altered the climate, often with disastrous impacts. Carbon dioxide and other "greenhouse gases" are causing the earth's temperatures to rise and resulting in less reliable rainfall patterns.

In the past, agriculturalists felt little connection to the future concerns of global atmospheric change, after consideration of fossil fuels (Bouwman, 1990). Other recent developments signal the need to better analyse the chemical compositions of plants and soils. Plant breeders no longer select crops based on yield properties alone, but rather recognize the importance of nutrient use efficiency and tolerance to nutrient stress (DeVries and Toenniessen, 2001; Gudu *et al.,* 2005). Soil biology is now sufficiently developed that litter decomposition and nutrient mineralization operate in a more predictable manner (Woomer and Swift, 1994) allowing these benefits from organic inputs to be better managed (Palm *et al.,* 2001; Giller, 2002). All developments imply the need for soil and plant analysis to support interpretations from specific studies.

Estimating Available Phosphorus With Reference to Kenyan Soils

Due to low inherent soil fertility in the highly weathered and leached tropical soils (Kenya included), the nutrient phosphorus is well-known to be widely deficient in these regions (tropics). Further, applied P fertilizers hardly move beyond the areas/ spots of their application (Russell, 1973). Soil P also exists in both organic and inorganic pools. These observations, and others, have resulted in many methods being developed for testing soils for available P. All of them involve the treatment of soil samples with, and suitable extractants that remove an accessible nutrient fraction. These include the extraction of P from soil by different techniques; water, calcium chloride, sodium hydroxide, anion exchange resins, radioactive isotope and others (Kafkafi 1979; Okalebo, 1987). It is however stressed here that the critical values of available P above which no responses to P fertilizers should be expected vary widely, according to soils, crops and management practices (Hagin and Tucker, 1982) and must therefore be calibrated in each case. Field trials are needed to establish critical levels for different environments and to determine the relationship between the soil test value and yields to levels of P added.

In order to reinforce the impact of available P in the soil, an overview which considers the soil solution component in the soil may be useful. The concentration of mineral nutrients in the soil solution is an indicator of the mobility of the nutrients towards the root surface as well as vertically, and is a measure of the intensity of supply of mineral nutrients. This is an important component of soil fertility. The buffer power of the soil determines the degree and the rate of replenishment of nutrients from the solid phase into the nutrient solution. It therefore represents the capacity of the soil to gradually release plant nutrients; consequently, the exchange complex of the soil can be considered as a reservoir that buffers the ionic supply by soil minerals and fertilizers and the ionic withdrawal by crop uptake and by leaching (Fig. 6). In relation to this, since nitrates are generally not adsorbed on the solid phase, their concentration in the soil solution is not buffered and is subject to considerable fluctuation (Marschner, 1986). In contrast no nitrate, phosphorus interacts strongly with clay minerals and its concentration in the soil is buffered by the soil.

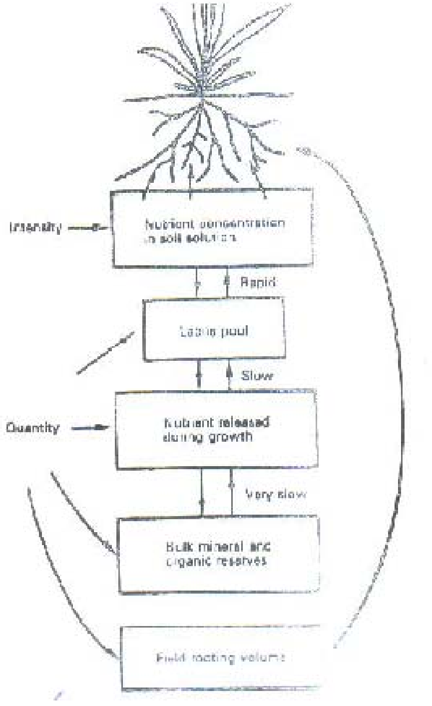


Figure 6: Intensity, quantity, and nutrient sources. After E.G. Williams, from Mengel and Kirkby (1982). By permission of the International Potash Institute

The concentration of P in the soil solution is generally low, and its availability to the crop will therefore depend on the speed with which it is removed from the soil solution and replaced from the soil reserves summarized in Table 7.

Table 7: The functional roles of various P fractions in soils (after Hedley et al., 1982)

Fraction	**Functional role**
Resin Pi	Available
Bicarbonate Pi and Po	Labile
NaOH Pi and Po	Slow
NaOH sonicated Pi and Po	Occluded
HCl Pi	Weatherable
Residual Pi	Passive

Po = organic P fraction or pool

Pi = inorganic P fraction or pool

NB:

Resin–extractable inorganic P (Pi) has been identified as a pool from which plants readily take up P (available P pool).

$NaHCO_3$ extracts labile inorganic (Pi) and organic (Po) P.

NaOH solution extracts moderately labile organic P (Po) and partially dissolves Fe and Al phosphates and dissolves Pi from sesquioxide surfaces, also termed moderately labile Pi.

NaOH–sonicated dissolves moderately labile Pi and Po physically protected by aggregation.

HCl dissolves weatherable mineral P and, or fertilizer reaction products.

Residual P extracted by concentrated H_2SO_4 is strongly retained P, unavailable to plants (Hedley *et al.,* 1982). Organic P (Po) is the difference between total P and inorganic P.

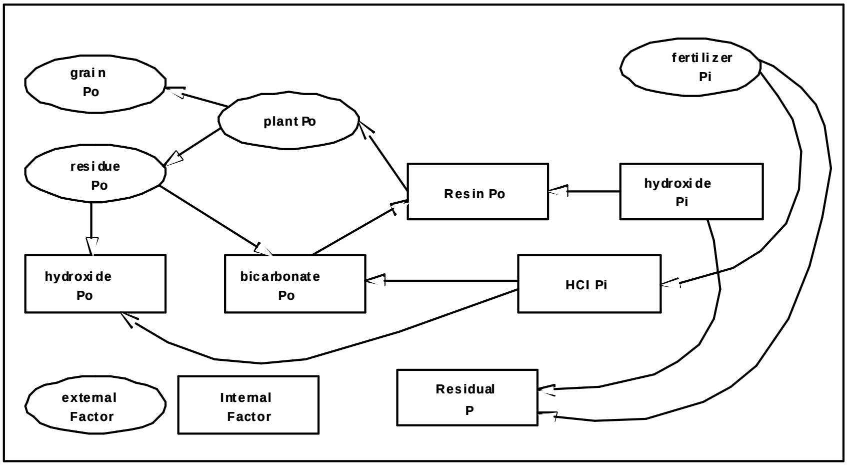


Figure 7: Relationships between the labilie and stable P pools as fabricated by the Hedley et al., *(1982) procedure (after Beck and Sanchez, 1994).*

The complexity in the relationships among P pools in soils is also implied from the existence of multiple reagents to extract available P from cropland soils (mentioned above). However, it is important to note that these multiple reagents are able to extract different levels of available P in soils and they "equally" detect lowest or highest levels of P in soils, in spite of differences in quantities of P. This is illustrated in the significant correlations among extractants (Table 8).

A further demonstration is presented in Table 9 showing differences in levels of available P extracted in different soils using the 3 commonly used reagents for extraction, namely, the ammonium fluoride and hydrochloric acid combination developed by (Bray and Kurtz 1945, the Bray No. 2 method), the sodium bicarbonate extraction (Olsen *et al.*, 1954) and the anion exchange resin (resin bag) method (Amer *et al.*, 1955; Sibbensen, 1978.

Table 8: Correlation coefficients between levels of extractable phosphorus in soils using a range of methods (Okalebo, 1987).

	Total P	Organic P	Muhlich	Bray No. 2	Truog	Egner-Riehm	Dalal Na2OH/NaC03	Olsen	0.01 m CaCl2
Organic P	0.19								
Muhlich	0.90***	-0.25							
Bray No. 2	0.74***	-0.36	0.89***						
Truwg	0.91***	-0.13	0.96***	0.80***					
Egner-Riehm	072***	-0.38	0.87***	0.95***	0.85****				
Dalal Na2OH/NaC03	30.52*	-0.31	0.64**	0.64**	0.73***	0.68**			
Olsen	0.84**	-0.24	0.93***	0.80***	0.98***	0.87***	0.81***		
0.01 m CaCl2	0.84***	-0.26	0.94***	0.87***	0.94***	0.91***	0.73***	0.95***	
Water	0.83***	-0.31	0.96***	0.93***	0.91***	0.92***	0.70***	0.91***	0.97***

Sample size (n) = 24 surface (0-20) soils from Kenya and Uganda.

* Shows significant associations between soil test phosphorus at P=0.05 level

** Shows significant associations between soil test phosphorus at P = 0.01 level

*** Shows significant associations between soils test phosphorus at P=0.001 level

The resin-bag method is dependant on the finding that rate of extraction was dependant on the rate of release of phosphate from the soil into the aqueous medium. In this respect, resin bags behave very similarly to roots and many subsequent trials have shown resin-extractable P to correlate better than chemical extractions, with plant P uptake. In the data of Table 9, the yields of maize tops on control treatment pots are high in soils with high levels of available P from each of the 3 methods of extraction and there are weak but significant correlations between these yields and the levels of soil P from resin bag and Olsen P extractions (Okalebo, 1992 KARI Muguga of Research.

Table 9: Magnitude of maize yields (g/pot, tops) on control treatment and available P from selected tests from pot trials (Source: KARI FURP Experiment (Okalebo, 1992)

The procedures for soil P tests are described in Okalebo *et al.,* (2002). Maize tops (g/pot) were harvested from 2 plants/pot, seven weeks after emergence on control treatment pots. Descriptions of these sites are given in FURP (1994) reports**.**

The Phosphorus Sorption Soil Test

Acid soils have a characteristic of fixing phosphate fertilizer applied to them because of large quantities of Fe, Al (and Mn) in forms of oxides or hydroxides (sesquioxides) which trap P. This property, also known as P sorption/adsorption, contributes to reduced availability of P in the soils, hence reduced P uptake and low crop yields. Recoveries of applied P fertilizers hardly exceed 20 per cent in a season for a wide range of crops and this low recovery is attributed to P sorption. It is therefore important to highlight the impact of P sorption by soils and the relationships between P sorbed and other conventional soil tests mentioned in the previous section, in the overall soil testing programmes.

First, P sorption by soil has been defined by Wild (1950) as the removal of soluble phosphate from solution by a soil or soil constituent, followed by its concentration in the solid phase. It has been shown that P sorption is influenced by soil parameters, such as pH, P status of soil, cation exchange capacity and the clay content (Wild, 1950, Moshi *et al.,* 1974; Juo and Fox, 1977; Dandy and Morrison, 1982). As hinted above, many tropical soils sorb large amounts of added phosphates because of their large contents of hydrated Al and Fe oxides from weathering, which carry positive charges at pH values below mainly 4 and 5. In addition, kaolin, the prevalent clay mineral in most tropical soils, may carry positive charges (Moshi *et al.,* 1974). Mathingly (1975) and Partitt *et al.,* (1975) have proposed the main mechanisms of sorption of P onto hydrous oxide surfaces as being; by non-specific sorption, sorption by hydrated Fe and Al oxides and sorption by ligand exchange or isomorphous substitution.

Phosphate sorption by soil is also temperature dependent, increasing with temperature (Fox and Searle, 1978). Thus, soluble P added to soil adsorbs rapidly at first, but the concentration of P in solution continues to decline slowly over a long period of time. Fox and Kamprath (1970) have therefore restricted the term “P sorption” to the process that approaches a steady state in 7 days. They further suggested that in the P sorption studies, the soil P reaction time should be long enough to permit the initial fast reaction to subside. This observation is often taken up in measurements related to P sorption. An increase in soil temperature activates sorption sites that are normally unreactive, both for P immobilisation and release (Singh and Juo, 1977).

Phosphate sorption has been used to characterize soils in relation to their P sorbing power. The relationship between P in the soil solution and P in the adsorbed state is used to P sorption isotherms and used as a basis for determining sorbed P at the standard supernatant concentration of P, which in turn, is an estimate of relative P needs of soils. Beckwith (1965) chose the standard value of 0.2 mg P/kg on the basis of the assumption that successful growth of plants in soils would require a P concentration of approximately this magnitude in soil. Beckwith also recognized that the critical concentration would almost certainly vary among soils, as well as different crops, but he pointed out that phosphate sorption at the standard P concentration of 0.2 mg P/kg in solution would provide useful information about phosphate fertilizer requirements, an observation which was later confirmed by Jones and Benson (1975). Other workers (e.g. P. A. Sanchez , *pers. comm*) have identified even lower critical standard P concentrations below 0.2 mg P/kg , for different crops.

The phosphorus sorbed by the soil is largely determined from the P sorption isotherms which relate the amounts of P taken from the solution by a soil at the equilibrium concentration of P remaining in the soil; the widely used method of constructing these P sorption isotherms is that of Kamprath and Fox (1970) Modifications in methodology have been made (e.g. Okalebo *et al.*, 2002). The calculations for P sorption parameters are made from the P sorption isotheres using a wide range of adsorption equations, but the commonly used equation is that of Langmuir:

$$c / (x /m) = 1/(kb + c/b)$$

where

c = final supernentant solution P concentration

x/m = P sorbed per nit soil mass (mg P/g soil),

b = adsorption maximum (mg/g soil)

k = a constant related to the energy of the soil for P.

A plot of $c/(x/m)$ against c gives a straight line with slope $1/b$ and intercept $1/kb$, from which k and b are calculated. There have been modifications for this equation by other researchers (e.g. Freundlich & Temkin). It is however noted that the equation that gives the best fit varies between soils even where standard conditions are used in experimentation (Juo and Fox, 1977). P sorption data vary with sites and other soil characteristics within those sites (Table 10).

Table 10: Some P sorption data and corresponding soil tests across soils in East Africa (after Okalebo, 1987)

NB: Negative P sorption implies P release than its sorption by soil, reported in homesteads and new lakes (R.L. Fox, *pers. comm*)

Diagnosis Of Nutrient Deficiencies From Plants

Diagnosis of nutrient limitations using growing plants or their components, is dependent on the relationship between nutrient concentration in plant tissues and yields (Smith, 1962). In essence, miserable-looking plants are expected to grow from nutrient depleted soils which supply low levels of nutrients detected in plant analysis. On this basis, poor growth and resultant low yields of crops have been associated to specific nutrient deficiencies, usually diagnosed from visual deficiency symptoms as the plant grows, growth vigour, by spot tests in the leaf/stem, physiological, biochemical tests and chemical analysis of plat tissues. In soil fertility–plant nutrition investigations, both greenhouse and field experiments have been used extensively worldwide to study specific crop responses to nutrient inputs. Pot tests are associated with confinement of roots within limited soil volume of the containers. Results may also be modified from high temperatures & humidity in the greenhouse hence their applicability may be limited. On the other hand, field tests are usually expensive to run. Nonetheless, the common objective for pot and field tests is to detect specific limitations of nutrients for plant growth and to establish nutrient rates to apply to soil, to obtain high crop yields.

In this presentation, the focus is on several methodologies used to diagnose N and P nutrient deficiencies on growing plants or in their tissues. These two nutrients are widely deficient in Kenyan soils, as indicated earlier.

Visual deficiency symptoms

Nitrogen – Visual deficiency symptoms or signs of N–deficiencies in plants are the paling in which plant leaves become pale yellowish–green and the formation of spindy stalks. A clear sign of N deficiency in maize, for example, is the yellowing of the top and centre of the leaves following the V-shape towards the mid-rib of the leaf.

Phosphorus – Visual deficiency symptoms for phosphorus are stunted growth, restricted root development, delayed maturity and poor seed and fruit development. In acute case of P deficiency, plants, such as maize, show purpling of leaves and stems. Skill or experience is however needed to delineate multiple nutrient deficiencies visually.

Spot test in the plant – Simple spot tests conducted in the field and producing an immediate answer are valuable provided that they are calibrated against real responses and are reliable. An example is the effective spot test kit for P in the plant, developed by Bouma and Dowling (1982). Field kits for a number of elements are now being sold by some chemical suppliers (Smith, 1986). However, research is needed to validate these kits for specific crops of interest and incorporating a wide range of nutrients.

Chemical analysis of plant tissue

The results of chemical analysis of plant tissues have many applications and these include:

- diagnosis of nutrient deficiencies, toxicities or mineral imbalances;
- prediction of nutrient deficiencies in current or succeeding crops;
- establishment of fertilizer recommendations;
- monitoring of the effectiveness of current fertilizer practice;
- assessments of the quantities of key minerals removed in crop residues with an aim to replace them and hence maintaining soil fertility;
- estimation of the overall nutritional status of regions, districts or soil types;
- prediction of crop yields;
- estimation of nutrient levels in diets available to humans and livestock.

Like soil analysis, the plant tissue analytical data have to be interpreted. In this regard, the concept of critical nutrient concentrations forms the basis of most methods for using plant analysis for assessing plant nutrition status. Definitions of the critical nutrient concentration are given by Ulrich (1952), but it is the concentration separating the zone of deficiency from the zone of adequacy. The idea of a range of critical nutrient contents in plants, other than a single value, seems to have support from data from both plant and soil analyses is strongly stressed by many investigators (e.g. Van Straaten, 2006).

Chapter Five

Efforts Made to Restore Soil Fertility in Kenya

This chapter summarises findings on tasks related to soil fertility restoration technology for high and sustained crop yields across some AEZs in Kenya over the past 40 years. The findings include aspects on diagnosis of nutrient deficiencies in cultivated soils including indicators of soil fertility decline and crop responses to a wide range of inorganic and organic inputs. It is envisaged that the data on soil fertility management options will contribute to an insight regarding the choice and possible adoption of technologies. Further, it is hoped that the highlights will also guide researchers and extension agents in their efforts to seek the way forward towards soil fertility amelioration and enhanced food security.

Indigenous knowledge on soil fertility decline

Over 90 per cent of soil fertility experiments in Kenya conducted by the author and his partners over the past 4 decades have focussed on improving the limiting nutrient status in cropland soils belonging to smallholder farmers. Thus the participation of the farmers has been incorporated. The farmers were therefore identified and allocated experimental land after researcher-extension-farmer interactions. Above all, in preliminary or diagnostic surveys, farmers have identified their overall agricultural production constraints whereby the problem of low soil fertility has featured most in the study areas. In relation to this, farmers express the unaffordability of fertilizers required to ameliorate soil fertility. Further, during the problem identification surveys, farmers provided useful information regarding the status of their soils. They know that crop harvests are low on sandy and are high on loamy soils. This kind of information has been confirmed from soil analytical data in the laboratory (e.g. the organic matter and available P in soils) which in most cases confirm farmers' perception of soil fertility, whereby higher crop yields are found on areas in the field considered to be of "good" soil fertility (J. Kamau, unpubl.) Knowledge from farmers has also been used to select fields for soil fertility studies reported in this chapter.

The soils data from diagnostic surveys across farms identified from study areas in Kenya have in addition been used to pinpoint specific nutrient limitations to crop productivity. Several examples from such data are summarised in Table 11, whereby N and mainly P limitations are widespread and responses to N and P fertilizers have been found from areas in question.

Table 11: An overview of nutrient diagnostic studies in Kenya (1992-2001)

Source	*District/Province*	*Limiting nutrients*	*Responses following diagnosis*

In Uasin Gishu district, about 84 per cent of cropland soils have available P levels below 10 mg/kg, the critical level (Fig. 8), reflecting the need for P fertilizers to increase maize and wheat production, the main activity in the district. Farmers in fact apply P fertilizers in this district but largely below the recommended rates.

Figure 8: Frequency distribution of available P (mg/kg) from Olsen et al (1954) extraction from surface (0-20cm) soils in 100 farms in Uasin Gishu district (Lwayo et al., *2001)*

In western Kenya (Table 12), nutrient limitations found from simple field experiments (all minus one nutrient type) have been identified for specific soil orders (FURP, 1994; Woomer and Muchena, 1996). This information is useful in targeting specific nutrient restoration programmes to specific soil types. Table 12 also summarises P and N constraints and soil acidity problem across districts in western Kenya.(see also Table 6).

Table 12: The frequency of nutrient limitation classes in Western Kenya (Sources: (FURP, 1994; Woomer and Muchena 1996).

Limiting nutrient	Frequency (per cent)		FAO Soil Order
	FURP (1994)	Woomer and Muchena (1996)	
Nitrogen (N)	46	38	Acrisols, Ferralsols, Luvisols
Phosphorus (P)	17	22	Nitisols, Acrisols, Ferralsols
N and P	12	16	Acrisols, Nitisols
Not limited	25	24	Nitisols, Acrisols, Ferralsols

Indicators of soil fertility decline

It is generally felt that in the absence of rapid and large losses of soils from erosive forces (such as runoff), the process of decline in soil fertility is slow and even slower when nutrient inputs are returned to soils. The decline in soil fertility is often measured in terms of crop yield reductions over time (see chapter 1) and from changes in soil properties, such as the organic matter (N and C mainly) depletion in soils. Thus efforts to identify parameters or indicators on soil fertility decline have been made, but giving variable results (e.g. Okalebo *et al.*, 1997). Perhaps an illustration may be given from the results of a long-term experiment started in 1989 at KARI, Katumani whereby losses of fragile surface soils are being measured as a result of runoff from intermittent rainfall events with different intensities. This experiment has been installed along the slope of about 7 per cent and also monitors the changes in maize and bean yields as sole and intercrops as affected by soil fertility interactions in the forms of inorganic and organic nutrient inputs. The trial therefore permits a range of measurements to be made every season and the treatment details are given elsewhere (Okwach, 1994), with their summaries appearing in Tables 13 and 14.

In a nutshell, continuous cropping of plots in this trial has shown very little difference on maize yield reductions as shown in mean yield data from treatments taken from the first 6 and 11 seasons of continuous cropping. However, significant ($p<0.05$) yield increases from soil fertility interventions have been found (Table 13). On the other hand, soil loss reflected the amount of runoff. An analysis of the soil lost from traditional sole maize cropping with no fertilizer and no maize stover mulch in the exceptionally wet season of 1992 short rains (776mm rainfall) showed that the 51 kgN/ha was lost as organic N in the 53 t/ha of soil displaced from runoff (Okwach, 1994; Okalebo et al., 1997). This loss of N is sufficient to support a maize crop of at least 1 t/ha.

Table 13: Maize yields under various cropping systems (t/ha) in a long-term experiment at KARI, Katumani, Kenya.

Source: Okalebo et al *(1997)*

NB:

Treatment 1, bare fallow was kept clean or weed-free but no crop planted on it.

1 Difference in yield between the fertilizer treatments (5, 6 and 7) and unfertilized treatments (2, 3 and 4) is highly significant.

2 Proportion of stover from previous crop returned as mulch.

Fractionation of the fresh soils from treatments near harvest time to isolate the fine particulate organic matter in 1995 showed that the amount of organic C and N in the 0.05 – 0.25 mm range was only 11 per cent of the total C and N. This ratio was not significantly affected by treatments. Such evidence suggests that the organic C and N in the stover returned each season to treatments 4, 5 and 7 was dissipated by decomposition and did not accumulate. However, the ‘Ludox’ method for particle or density fractionation showed a quite different pattern. The ‘Ludox’ light and medium density fractions were distinctly larger for treatments 5 and 7 than for the low C input treatments, especially when compared with the bare fallow plot (Table 14). Grain yield for the 1995 long rains maize crop was correlated more closely with amounts of C in the “Ludox” medium fraction (r=0.88) than with amounts in the light (r=0.47) or heavy (r=0.64) fractions, thereby reflecting the impact of the medium fraction on soil fertility management.

Table 14: Soil organic carbon fractions after six years of various cropping systems (sampled in 1995) (mgC kg^{-1} soil)

Treatment	Light (<1.13 gcm^{-3})	Ludox fraction Medium (1.13-1.37 gcm^{-3})	Heavy (>1.37 gcm^{-3})
2. Traditional maize (no fertilizer, no mulch)	0.272	0.090	60.33
4. Improved A (no fertilizer, half stover)	0.316	0.110	60.14
5. Improved B (N+P, extra stover)	0.546	0.312	75.84
7. Improved D (N+P, full stover)	0.408	0.250	74.16
Fallow	0.092	0.108	77.23

Source: Okalebo et al *(1997)*

Mitigating soil moisture and fertility stress in the semi-arid lands

As indicated earlier, soil moisture, N and P limitations mainly result in poor crop production in the drylands. An experiment was carried out at Mutua’s Farm near KARI Katumani in the short rains 1988 to investigate the effects of fertilizer and surface soil management on maize yields. The design was a split plot with 3 surface management practices (flat surface, tied-ridges and mulching with 3 t/ha of maize stover from previous crop) as main plots and fertilizer treatments as sub-plots. There were a control (receiving no N or P) and 3 rates of phosphorus (0, 20 and 40 kg P/ha as TSP) with a uniform N application of 60 kg/haN as CAN (Probert and Okalebo, 1992).

There were highly significant effects of both N and P increasing yields of maize grain and P uptake, with responses being obtained upto the highest rate applied. The main effect of surface management treatments was not significant though there was a marked contrast between the flat treatment and the two conservative treatments (ridging or mulching) at the highest rate of application of P. A similar effect can be seen for the treatments that did not receive fertilizer (Table 15). Though no data was taken in support, it seems highly likely that the mulched or ridged treatments retained more water on the plots, permitting better growth on the treatments without fertilizer and a better response to the higher input of P.

Table15: The effects of surface management and fertilizer on maize yield (kg/ha) at Mutua Farm, Katumani (Source: Probert and Okalebo, 1992).

LSD (P=0.05)

For effect of surface management = 922

For effect of fertilizer = 450

For surface management x fertilizer = 780

Addressing the constraint of soil acidity

The constraint of soil acidity on reducing crop productivity is outlined in chapter 4. The commonly used materials to raise the pH of acid soils include agricultural lime, phosphate rocks and ashes. These materials are considered to be affordable, particularly to the small scale farmers. However, many end users of phosphate rock (PRs) recognise their phosphate benefits, but not the liming effect. Over the past several decades there has been a shift for plant breeders to develop crop genotypes that are tolerant to specific stresses such as drought, P deficiency and Al stresses (from soil acidity) without sacrificing high yields (Gudu et al., 2005). These two aspects of “escaping” soil acidity are discussed in this section.

Thus to delineate the P and liming effects from the reactive Minjingu phosphate rock (MPR) mined from Tanzania, MPR (containing 10-13 per cent P and 38 per cent CaO, diammonium phosphate (DAP) and triplesuperphosphate (TSP), both containing 20 per cent P, were applied at similar rates of 0, 30, 60 and 90 kg P/ha, while agricultural lime (20 per cent CaO) from Koru, Kisumu, Kenya, was added alone or in combination with DAP and TSP to the corresponding levels of CaO applied in MPR, viz., 0, 96, 192 and 288 kg CaO/ha (about 0, 0.5, 1.0, 1.5 t lime/ha). The performance of these treatments was studied in the field at small-scale farm level, with 4 farms selected in Bungoma, Siaya, Trans Nzoia and Uasin Gishu districts in Kenya, all farms having acid soils with low P status (Nekesa, 2007). The sites were also within the areas of active Community Based Organisations (CBOs), an advantage for technology diffusion to the farming communities. Maize with common bean, soybean and groundnut intercrops was planted in this study; following the promising “MBILI” (two) staggered two maize and legume rows (Tungani *et al*, 2002). The experimental field design and laboratory procedures and data analysis are presented in more details elsewhere (Nekesa, 2007). Table 16 shows the mean crop yields for Bungoma, Siaya and Uasin Gishu districts obtained in the long rains 2005, the two sites in Bungoma and Siaya are associated with rapid crop growth due to the effect of lower altitude with higher temperatures and humidity, compared to the higher altitude and cooler Trans Nzoia and Uasin Gishu districts. From the yield data (Table 16), soils amendments gave significant ($p<0.05$) increases in maize and groundnut yields. Maize yields of 4 t/ha/season (see Table 16) are very rare to find in these areas at farm level. Yields obtained by using MPR alone were comparable to those found from DAP, particularly groundnut yields; this is confirmed in the economic analysis of combined crop yield data from intercrops for all four sites in the long rains season in 2005 (Table 17).

Table16: Maize and groundnut intercrop yields (t/ha) as affected by phosphate and lime applications in western Kenya long rains 2005 (Source, Nekesa 2007).

Treatment	**Maize grain yield**			**Groundnut kernel yield**	
	Mabanga	**Sega (Siaya)**	**Kuinet (Uasin Gishu)**	**Mabanga (Bungoma)**	**Sega (Siaya)**
Control	0.58	0.52	1.36	0.22	0.22
MPR	4.54	4.40	5.38	0.59	0.33
DAP alone	4.42	3.90	5.42	0.47	0.40
Lime alone	4.48	2.32	5.36	0.55	0.31
DAP + Lime	5.49	4.52	6.19	0.48	0.40
TSP + Lime	4.62	4.57	5.45	0.58	0.35
Averages	4.45	3.75	5.30	0.52	0.35
SED	0.77	0.42	0.53	0.11	0.08
LSD (p=0.01)	2.10	1.25	1.45	0.30	0.22

MPR = Minjingu Phosphate Rock

DAP = diammonium phosphate

TSP = triplesuperphosphate

Mean yields for treatment levels of 30, 60 and 90 kg P/ha are given for each P source, while mean yields for lime rates of 96, 192 and 288 kg CaO/ha are also given viz 0.5, 1.0 and 1.5t of agricultural lime/ha.

The gross margins of combined yield of maize and groundnuts indicate profitability from use of MPR as a source of both P and lime on acid and low P soils (Table 17).

In this experiment, there was an active participation from CBOs, especially in Bungoma and Siaya districts, whose members are currently reserving land for “MBILI” intercropping technology, along with both P and lime applications.

Table17: Gross margins of the test crops as a result of soil amendments made in 2005 in all experimental sites. Source: Nekesa (2007)

Note: MPR = Minjingu Phosphate Rock

DAP = diammonium phosphate

TSP = triplesuperphosphate

All three P sources were added at 0, 30, 60 and 90 kg/ha each whereas lime was applied at 0, 96, 192 and 288 kg CaO/ha of agricultural lime (20 per cent CaO) from Koru, Kisumu, Kenya, corresponding to 0, 0.5, 1.0 and 1.5 t/ha lime respectively.

For Kuinet site, soybeans generally performed better in the second season (2006 long rains) compared to the first season (2005 long rains). This could be attributed more to the variety than the soil amendment materials. Thus in the first season 2005 long rains, the soybean planting seed was brought from Eldoret market and the actual variety was not known, whereas in the second season (2006 long rains) the improved variety was known TGX14482E). In general, the growing or promotion of soybeans should take care of the variety, cater for its poor germination (the seed does not store too long) and the shattering of pods when dry. Soybean grain yields for Kuinet sites in the 2 consecutive cropping seasons are presented in Fig. 9, again showing the similar effectiveness for MPR (with a liming effect) and DAP + lime. These two treatments are recommended for this area, with availability of MPR and economics related to their use being the deciding factors.

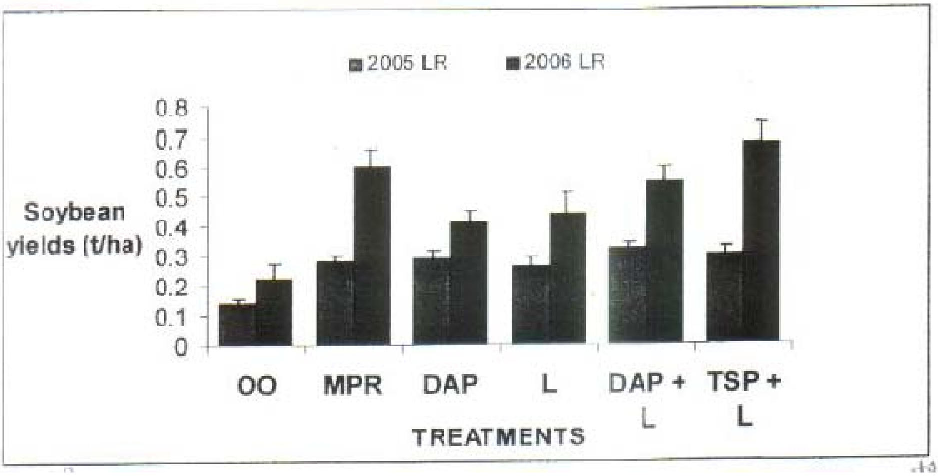


Figure 9: Soybean yields (t/ha) of grain at Kuinet site as affected by lime and P additions to soils.

Maize breeding targeting tolerance to soil acidity related stresses

Importance to lime acid soils to mitigate soil acidity and to breed crops in order to mitigate soil acidity and to breed crops in order to identify genotypes tolerant to soil acidity, has been realised over several decades worldwide. Thus since 2003 the Departments of Botany and Soil Science, Moi University, have studied several aspects of raising the pH of acid soils and breeding maize towards soil acidity tolerance. In the maize breeding programme, funded by the McKnight Foundation U.S.A, under collaboration with EMBRAPA (Brazil), Cornell and Purdue universities, U.S.A. and KARI Kenya, maize genotypes have been screened and bred towards tolerance to Al toxicity and P deficiency in soils (and other nutrients) for adequate maize nutrition and for Al toxicity amelioration. The lime from Koru (4 t/ha) and phosphorus (26 kgP/ha TSP), with a blanket 75 kg N/ha CAN applied to the genotypes, raised maize yields from 0.5 t/ha to 4-6 t/ha, but with genotypes responding differently from lime additions (Obura *et al.,* 2003). In this experiment, the maize yield trends suggest that, irrespective of maize genotypes, external additions of nutrients and liming acid soils are needed to boost the production in the soil fertility depleted acid soils of western Kenya.

In a separate on-going field experiment (established in 2003) at 3 sites (Kuinet in Uasin Gishu, Bumala in Busia and Sega in Siaya), managed by women groups leaders, positive maize responses to initial lime application at 0, 2, 4 and 6 t/h and phosphorus at 0, 26 and 52 kg P/ha have been found upto 6 seasons of consecutive maize cropping (data not shown). It is however highlighted here that in all sites, lime at all rates raised the soil pH and hence the available P in soils resulting in high maize yields reaching 4-6 t/ha (Gudu *et al.,* 2007). However, a decline in soil pH and P availability in soils was observed with consecutive cropping, suggesting the need to repeat lime applications 2-3 years after initial application. Prolonged and better responses have been observed with higher doses of lime application at 4 to 6 t/ha (Gudu *et al.,* 2007).

Towards the development of affordable but effective nutrient replenishment packages to restore soil fertility

It is believed that smallholder farmers will progressively restore the fertility of depleted soils if affordable and effective nutrient materials are available. This reflects the repackaging of the relevant materials into affordable units, such as most commercial products (e.g. sugar) in any shop. From this observation, the task of packing affordable materials was initiated at Moi University in the PREP-PAC package. PREP-PAC stands for “Phosphate Rock Evaluation Project”, whereas PAC stands for package.

Using the PREP-PAC technology to restore the fertility of depleted soils

Following the evidence above and earlier reviews (e.g. Okalebo and Woomer, 1994) on the effectiveness of MPR on acid and low P soils, a package, PREP-PAC was developed at Moi University, Eldoret, Kenya, in 1997, designed to replenish the fertility of soils on seriously depleted patches that are widespread on smallhold farms. PREP-PAC consists of 2 kg MPR, 0.2 kg urea, l20 g food legume seed, rhizobial inoculants (Biofix) packed with lime pellets to raise the pH of the inoculated seed environment and gum Arabic sticker to hold the inoculant onto the surface of the seed and instructions for use written in English, Kiswahili and local dialects. One packet is designed to replenish soil fertility of patches of size 25m^2 (Nekesa *et al.* l999). Since 1997 on-farm trials have been conducted in western Kenya and eastern Uganda to test the effectiveness of PREP-PAC with respect to crop yields and economic considerations; these experiments are:

On-farm testing of PREP-PAC. Through the researcher-NGO-farmer contacts, the target soils for replenishment were:

i) Acrisols with sandy surface horizons and very low soil fertility (common in Siaya and Busia districts, Kenya).

ii) Acrisols with clay surface horizons and low to moderate inherent soil fertility (common in Bungoma and northern Kakamega districts, Kenya).

iii) Acrisols/ferralsols complexes with moderate to high clay contents, but now depleted inherent soil fertility (common in Vihiga and Kakamega districts, Kenya).

PREP-PAC was tested on smallhold maize-legume based intercropping systems in the depleted soils and districts mentioned above in western Kenya and some parts of eastern Uganda. Soils at the study sites had generally low fertility and the farmers considered these the most fertility-depleted areas of their farms (Nekesa *et al* 1999).

PREP-PAC input was provided to 52 farmers in western Kenya and the prescribed application procedure explained. All farm operations, including application, plant disease/ pest control were done by the farmers. Two adjacent plots each measuring 25 m^2 were marked and treatments applied to one plot. Inoculated bean seed and maize were planted immediately. Control plots were beans and maize intercropped with no PREP-PAC inputs.

Treatments were designed to compare economic returns to PREP-PAC with no fertility amendment practices in the bean maize intercrops. In both treatments, farmers planted the same maize variety of farmers' choice and either climbing (cv flora) or bush variety of *phaseoulus vulgaris* contained in the PREP-PAC. Farmers managed the experiment (including the trials in eastern Uganda).

After harvest, sun-dried weights of maize and bean grains from two plots at each farm were taken. Statistical analysis of crop yield and economics data was done on the computer using SYSTAT package and FREELANCE package for the graphics. Maize yields were lowest in the unfertilized (control) plots with a mean farm yield of 0.64 t/ha. PREP-PAC application increased maize yield to a mean of 1.36 t/ha. PREP-PAC application to soils of pH < 5.2 improved bean yield from 25 to 125 kg/ha. This is obviously a very low bean yield. Nonetheless, this low pH level favours the dissolution of phosphate rock in soils. At the pH < 5.2, climbing beans (cv Flora) yielded 200 kg/ ha on the control plots and the PREP-PAC yield was 350 kg/ha. Economically, use of PREP-PAC in soil pH < 5.2 increased financial return on land from Kshs. 8720 to Kshs. 19,920/ha, with a return ratio of 1.27 (Woomer *et al.* 2003a).

Testing the effectiveness of components of PREP-PAC

The performance of PREP-PAC components and their interactions were tested at three on-farm sites with low soil fertility in western Kenya (Oburu *et al* I 99). This region is also characterized by having two cropping seasons annually. Thus a 2 x 2 x 2 factorial arrangement of MPR, urea and inoculant (at 2 levels each) treatments was used in this experiment (with treatments applied in a randomized complete block design with four replications). Plot size was 25m^2, reflecting the target areas for replenishment using one PREP-PAC. Treatments determined the response of maize and N-fixing soybean intercrops to individual components of the pack (MPR, Urea and Biofix) and the interaction of various components of the Pack (rock P + Urea, rock P + Inoculant, Urea + Inoculant, and rock P + urea + Inoculant).

MPR (2 kg) and urea (0.2 kg) were broadcast and incorporated to 0-15 cm seedbed at planting. Soybean seeds (cv Black Hawk) were inoculated for specific treatments for planting. Maize was planted and the standard crop husbandry practices maintained. Maize grain yields for one season (first rains 2001) are presented in Table 18. Thus, the main PREP-PAC components (PR, urea and Biofix) applied individually increased maize yields across the three sites, but particularly so in Kakamega with red soil of a high clay content, where a grain yield increase of 162 per cent above control treatment was found. The complete pack (PR + Urea + Biofix) gave the largest yield increase of 205 per cent above the control in Siaya. Positive economic returns to investment from individual PREP-PAC inputs and their combinations are reported elsewhere (Obura et al. 1999, Woomer *et al*. 2003a).

Table 18: Maize grain yield from three farms in western Kenya under maize-soybean intercrop (Obura, 2001)

Marketing of PREP-PAC

For continuity of acquisition of components of the pack, a marketing study (Mwaura 2002) was conducted whereby the stockists and retailers of agricultural inputs in western Kenya were asked to sell the pack. Selling prices varied widely with farmers able to offer low prices (Figure 10). Economic studies on acquisition of inputs, repackaging, sales and profits need to be continued.

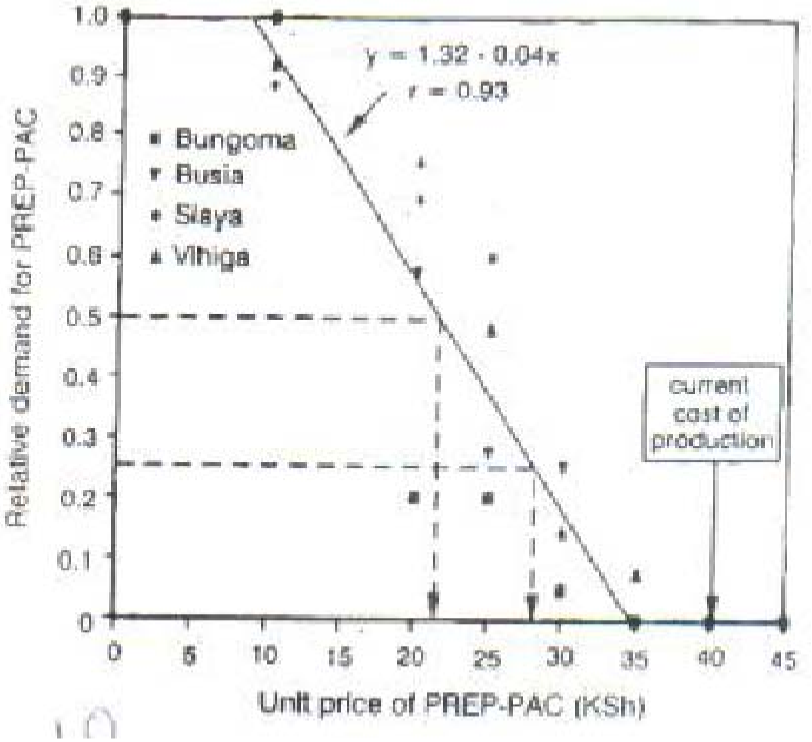


Figure 10: Market testing of PREP-PAC (after Mwaura, 2002)

Extended use of Minjingu phosphate, '(MPR) for soil fertility improvement in Kenya

In the presentation on the use of PREP-PAC, the MPR as its major component was highlighted and stressed, its applicability for amelioration of soil fertility in the worst patches in the fields, focussing the increase in yields of maize-legume intercrops (mainly beans and soybeans). However, as mentioned earlier, MPR is generally effective on acid and low P and Ca soils. Several researches have tested the effectiveness of MPR on a range of crops, including the Agroforestry - short or improved fallows. Thus in a field study by Ndungu *et al* (2003) the use of low cost technology utilizing MPR as a P source to enhance the growth and yield of maize - short fallow intercrops on nutrient depleted soils, also aimed at the provision of low cost N to succeeding maize crops through the N fixed by the legume fallows (crotalaria and tephrosia) and through the fallow biomass. Maize and improved short fallows, all responded to MPR.

Towards the adoption of soil fertility replenishment technology

The case studies presented in this document demonstrated positive effects of soil fertility management technologies mainly in Kenya, using a wide range of inorganic and organic resources and packages, particularly of low cost materials. Monetary gains resulting from use of various technologies have also been reported. But in spite of demonstrations and appreciation of technologies, Africa is faced with a problem of negligible to nil adoption of technologies. The most obvious response is the constraint of expensive agricultural inputs. In one of the attempts to enhance technology adoption, preliminary results of field trials that were conducted in western Kenya under the rare situation of researcher - NGO (Extension) small farmer co-operation, are reported here.

In this endeavour, it was recognized that many existing soil fertility management technologies have been developed on an individual or institutional basis and these technologies have rarely been compared side- by-side on their performance. Thus in 2002, field trials have been installed on 140 smallhold farms across seven districts in western Kenya with varying climate, altitude and soils (Woomer *et al*. 2003b).

The main objective was to compare the effectiveness and the ‘acceptability’ of eight soil fertility - management options across these farms. One NGO (SACRED Africa) led this study with other six NGOs collaborating very closely in the studies. Kenyatta and Moi Universities, Kenya, participated in backstopping (Woomer *et al*. 2003b).

The guiding principle in the study was the need to compare all existing soil fertility amelioration options side-by-side. It is also believed that farmers will accept profitable options that are labour friendly. In the study, the maize-legume widespread intercropping system was adopted, with farmers managing the trials with the advice of the NGOs. The technologies under test consist of the use of organic and inorganic resources applied individually or in combinations, the use of agroforestry short fallow species and the legume cover crops designed to recycle nutrients and the testing of the newly introduced PREP-PAC and MBILI (staggered two maize and two legume spacing) options. The NGOs selected the farmers who participated and executed all field operations.

Treatments/technologies are:

- The absolute control, representing no nutrient inputs from smallhold farmers.
- Farmers’ practice where any form of manure, compost or inorganic fertilizer is applied at varying rates (estimated al 15 kg N + 17 kg P/ha as DAP in Bungoma district, but at 4 t/ha FYM in some districts.
- Organic farming community treatment with biogenic MPR fortified wheat straw or maize stover compost developed at Moi University, Kenya, applied at 2 t/ha (44 kg N + 8.5 kg P/ ha).
- PREP-PAC package (as above), this is an input of 100 kg P/ha + 40 kg N/ha urea + Biofix (rhizobial inoculant), also developed at Moi university).

- Mineral fertilizer, the KARI/FURP (1994) treatment consisting of 75 kg N/ha CAN or urea + 20 kg P/ha TSP (or DAP).
- Mineral fertilizer for MBILI package (staggered row intercropping with inputs of 3I kg N + 20 kg P/ha (DAP at planting but CAN as a topdressing). MBILI = Managing Beneficial Interactions in Legume Intercrops.
- ICRAF's maize-bean-crotalaria short fallow intercropping system designed to supply upto 200 kg N from the biological nitrogen fixation (BNF) process (fixed by crotalaria), through Legume biomass incorporation into soils and nutrient deep root culture.
- Legume cover crop maize cropping, with Lablab (dolichos) incorporated into soils supplying mainly N. No other external inputs were applied to the fallow and to Lablab relay crops.

Maize, beans and groundnuts were planted in the first rains 2002 and the same legumes replanted in the second season 2002. Lablab and crotalaria were also planted about mid way in the first season. Details of experimentation and the low carbon, nitrogen and phosphorus status of soils from 140 test farms are described elsewhere (Woomer *et al* 2003b). However, being on-farm trials, some failure (23 per cent) in recovery of yield data was met. Thus yield data for crops were obtained in 107 farms (Table 19). The overall performance of the intercropping management showed better performance from four technologies out-yielding the no inputs management. The PREP-PAC produced the highest yields (t/ha/year) and the MBILI package produced the greatest annual net return (Kshs/ha/year). This positive effect of MBILI economically is largely due to maize-groundnut intercrop. Groundnut is usually sold for twice the price of beans in most areas of Kenya. Nonetheless, the MBILI management has reduced shading of legumes and an overall yield advantage over conventional intercropping (Woomer *et al* 2003b).

Table 19: Yields (t/ha) of maize and legumes from soil fertility management (Best Bets) in western Kenya during two crop seasons of 2002 (the researcher-NGO-farmer-co-operation; (after Woomer *et al.* 2003b).

Commonly used inorganic fertilizers in the East African Region

It is probably important to summarize information on the commonly used inorganic fertilizers, along with an indication of major nutrient contexts in these materials. This is particularly intended to guide the farmers (Table 20).

Table 20: Commonly used Inorganic fertilizers in East Africa

Fertilizer	Tag/grade on 50kg bag	Nutrients contained
Straight fertilizers		
Sulphate of ammonia (SA)	21-0-0	Nitrogen
Calcium ammonium nitrate (CAN)	26/27-0-0	Nitrogen
Urea	45/46-0-0	Nitrogen
Singe superphosphate (SSP)	0-18/20-0	Phosphorus
Triple superphosphate (TSP)	0-46-0	Phosphorus
Monoammonium phosphate (MAP)	11/13-52-0	Nitrogen and phosphorus
Diammonium phosphate (DAP)	18-46-0	Nitrogen and phosphorus
Muriate of potash (MOP)	0-0-60	Potassium
Minjingu phosphate rock (MPR) – emerging	0-25/30-0	Phosphorus
Compound fertilizers		
MAVUNO (NPK)	10-26-10	Nitrogent, phosphorus, potassium
NPK compound	10-10-5	Nitrogen, phosphorus, potassium
NPK compound	23-23-0	Nitrogen and phosphorus

Although urea is an organic compound, it is converted in soil (catalysed by the urease enzyme) into NH4+ and NO3- ions, absorbable by plant roots just like any other N source, e.g. SA, CAN.

Table21: Information on past fertilizer responses from selected field trials in Kenya

Source	N and P rates	Crop	Major responses
Gathetha (1970)	50-500 KgP/ha SSP	Sorghum, wheat, maize	+ve
Vadiamundi and Thimin	174 kgN CAN + 105 kg P/ha	Maize	+ve
Allan *et al.,* (1972)	170 kgN CAN + 26 kgP/ha	Maize	+ve Economical
Allan *et al.,* (1972)	60 kgN CAN + 26 kgP/ha TSP	Maize	Economical
FURP (1994)	75kgN CAN + 26kgP/ha	Maize	Economical
Probert and Okalebo (1992), ASALS	60 kgN CAN + 20 kgP/ha TSP	Maize	Economical

Note: In the experiments with references given, variation in experimentation sites, N and P sources and rates affected the nature of responses and their economical levels.

The commonly used crop residues and manures vary widely in their nutrient contents. These materials are generally inadequate and of low quality (Table 22). They have to be applied in very large quantities to meet crop demands. They may also be mixed with inorganics of Table 22 to improve effectiveness/efficiency.

Table 22: Nutrient contents of commonly available organic resources among smallholder farmers in Central Kenya (Woomer *et al.*, 1999)

Conclusions and way forward

1. Food insecurity in sub-Saharan Africa is mainly explained in terms of low and declining crop yields. But soil fertility depletion particularly contributes to low and unsustained crop yields.
2. There is strong evidence that yields can be raised through applications of external nutrients and specifically the N and P inputs added individually or in combinations. However, in the ASALs, soil moisture stress will limit the availability and uptake of nutrients, implying the need to conserve water and soil organic matter as the top priority.
3. Phosphate rocks of varying origins, reactivities and agronomic effectiveness are found widely in Africa. Efficient use of these materials needs to be revisited as it reflects a saving on costs associated with importation of refined mineral phosphate fertilizers.
4. Towards the adoption process, soil fertility replenishment options should be evaluated side by-side (or simultaneously) at on-farm level so that the end users and all stakeholders may have an opportunity to give their own assessment and rating of technologies in relation to effectiveness and economic-based information.
5. Extension messages need updating frequently to educate the farmer, particularly on the newly introduced technologies. To this end, short and simple messages in form of brochures are important, as well as other dissemination media.
6. To the DAP farmers, add at least 0.5 t/ha agricultural lime to your DAP each season to reduce soil acidity.

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