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Background Papers

African Soils: Their Productivity and Profitability of Fertilizer Use

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African Soils: Their Productivity and Profitability of Fertilizer Use

Background Paper Prepared for the African Fertilizer Summit

June 9-13, 2006
Abuja, Nigeria

by

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Acronyms and Abbreviations

AEZ	Agro-ecological zones
AWHC	Available water-holding capacities
BC	Broadcast
C	Carbon
Ca	Calcium
CEC	Cation exchange capacity
DRC	Democratic Republic of Congo
FAO	Food and Agriculture Organization of the United Nations
ha	Hectare
HP	Hill placed
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFDC	International Fertilizer Development Center (an International Center for Soil Fertility and Agricultural Development)
IITA	International Institute of Tropical Agriculture
INRM	Integrated Natural Resource Management
ISFM	Integrated Soil Fertility Management
KCl	Potassium chloride
LEISA	Low External Input Sustainable Agriculture
LGP	Length of growing period
Mg	Magnesium
PR	Phosphate rock
PUE	P use efficiency
RFN	Recovery of fertilizer N
RFP	Recovery of fertilizer P
SSA	Sub-Saharan Africa
SSP	Single superphosphate
TSP	Triple superphosphate
WUE	Water use efficiency

African Soils: Their Productivity and Profitability of Fertilizer Use

Executive Summary

Africa covers an area of about 3,010 × 10^6 hectares (ha), of which about 230 × 10^6 ha is water. The continent has a wide range of soils and climatic conditions. Soils range from stony and shallow with poor life-sustaining capabilities to deeply weathered soils that recycle and support large amounts of biomass. African soils have an inherently poor fertility because they are very old and lack volcanic rejuvenation. Inappropriate land use, poor management and lack of inputs have led to a decline in productivity, soil erosion, salinization, and loss of vegetation. More than half of all African people are affected by land degradation, making it one of the continent's urgent development issues with significant costs—Africa is burdened with a US $9.3 billion annual cost of desertification. An estimated US $42 billion in income and 6 million ha of productive land are lost every year due to land degradation and declining agricultural productivity. Globally, Africa suffered a net loss of forests exceeding 4 million ha/year between 2000 and 2005. This was mainly due to conversion of forest lands to agriculture. Forest cover declined from 656 million ha to 635 million ha between 2000 and 2005.

About 16% of Africa's land is considered high quality, 13% as medium quality, 16% of low potential, whereas 55% of the land is unsuitable for cultivated agriculture but supports nomadic grazing. About 900 million ha of high and medium quality soils support 400 million people or about 45% of the African population; about 30% of the population (or about 250 million) are living or are dependent on the low potential land resources. Numerous studies have shown that soil nutrient balances of most African soils are negative indicating that farmers continue to mine the soil.

Large yield increases can be obtained when inorganic fertilizers are used as demonstrated in many field experiments. Maize yield increase due to NPK fertilizer application can be as high as 150%, but when the soil is amended with lime and manure, yield responses of 184% are obtained. Higher yield improvements have been observed in east and southern African countries. Despite the documented response to fertilizer application, there are great on-farm soil fertility gradients and variations can be large.

Despite the costs of inorganic fertilizers, there is ample evidence that the use of fertilizers can be highly profitable. Whereas in the developed world, excess applications of fertilizer and manure have damaged the environment, the low use of inorganic fertilizer is one of the main causes for environmental degradation in Africa. In addition to increased productivity, increased inorganic fertilizer use benefits the environment by reducing the pressure to convert forests and other fragile lands to agricultural uses and, by increasing biomass production, helps increase soil organic carbon content.

African Soils: Their Productivity and Profitability of Fertilizer Use

I. Introduction

Africa covers an area of about 3,010 × 10^6 hectares (ha), out of which about 230 × 10^6 ha represents natural water resources (FAO, 1978). Most soils of Africa are poor compared to most other parts of the world. Lack of volcanic rejuvenation has caused the continent to undergo various cycles of weathering, erosion, and leaching, leaving soils poor in nutrients (Smaling, 1995). Uncultivated soils have a natural fertility determined by soil-forming factors such as parent material, climate, and hydrology. For soils under natural vegetation, there is a virtual equilibrium, but as soon the land is altered through clearing of the natural forest or savannah, this equilibrium is broken and soil fertility declines at a rate depending on the intensity of cropping and replacement of nutrient loss in the systems (Smaling, 1995). In addition to low inherent fertility, African soil nutrient balances are often negative indicating that farmers mine their soils. During the last 30 years, soil fertility depletion has been estimated at an average of 660 kg N/ha, 75 kg P/ha, and 450 kg K/ha from about 200 million ha of cultivated land in 37 African countries. Africa loses $4 billion per year due to soil nutrient mining (Smaling, 1993). Between 1994 and 1995, farmers in Africa used only 3.5 million tons of plant nutrients on nearly 170 million ha of arable land. Five countries (Egypt, Morocco, Nigeria, South Africa, and Zimbabwe) accounted for 72% of this total. The average rate of use in Africa was 21 kg/ha. In sub-Saharan Africa (SSA), excluding South Africa, however, it was only 10 kg/ha (Henao and Baanante, 1999a). Only four countries (Egypt, South Africa, Swaziland, and Zimbabwe) used more than 50 kg/ha, and 31 countries used less than 10 kg/ha (IFDC, 1996). There is therefore a need to understand how some of these countries have been able to increase their fertilizer use. Whereas in the developed world, excess applications of fertilizer and manure have damaged the environment, the low use of inorganic fertilizer is one of the main causes for environmental degradation in Africa. Increased inorganic fertilizer use benefits the environment by reducing the pressure to convert forests and other fragile lands to agricultural uses and, by increasing biomass production, helps increase soil organic matter + content (Wallace and Knausenberger, 1997).

As a result of the inherent low fertility of African soils and subsequent land degradation, only 16% of the land has soil of high quality and about 13% has soil of medium quality. About 9 million km^2 of high and medium quality soils support about 400 million people or about 45% of the African population. In Africa, 55% of the land is unsuitable for any kind of cultivated agriculture except nomadic grazing (Eswaran et al., 1996). These are largely the deserts, which include salt flats, dunes and rock lands, and the steep to very steep lands. About 30% of the population (or about 250 million) is living or dependent on these land resources.

During the past three decades, the paradigms underlying the use of fertilizers and soil fertility management research and development efforts have undergone substantial change due to experiences gained with specific approaches and changes in the overall social, economic, and political environment (Sanchez, 1994). During the 1960s and 1970s, an external input paradigm was driving the research and development agenda. The appropriate use of external inputs, namely fertilizers, lime, or irrigation water, was believed to be able to alleviate any constraint to crop production. Following this paradigm together with the use of improved cereal germplasm, the “Green Revolution” boosted agricultural production in Asia and Latin America. However, the application of the “Green Revolution” strategy in Africa resulted in minor achievements only due to a variety of reasons (IITA, 1992). One of the reasons is the abolition of the fertilizer subsidies in Africa imposed by structural adjustment programs (Smaling, 1993). In the 1980s, the balance shifted from mineral inputs only to Low External Input Sustainable Agriculture (LEISA) where organic resources were believed to enable sustainable agricultural production. After several years of investment in research activities evaluating the potential of LEISA technologies, such as alley cropping or live-mulch systems, several constraints were identified both at the technical (e.g., lack of sufficient organic resources) and the socio-economic level (e.g., labor-intensive technologies) (Vanlauwe, 2004).

In this context, Sanchez (1994) revised his earlier statement by formulating the Second Paradigm for tropical soil fertility research: “Rely more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use.” This paradigm recognized the need for both mineral and organic inputs to sustain crop production, and emphasized the efficient use of all inputs. The need for organic and mineral inputs was advocated: (1) both resources fulfill different functions to maintain plant growth, (2) under most small-scale farming conditions, neither of them is available or affordable in sufficient quantities to be applied alone, and (3) several hypotheses could be formulated leading to added benefits when applying both inputs in combination. The second paradigm also highlighted the need for improved germplasm; as in earlier days, more emphasis was put on the nutrient supply side without worrying too much about the soil demand for these nutrients. Obviously, optimal synchrony or use efficiency requires both supply and demand to function optimally.

More recently, the shift in paradigm was towards the Integrated Natural Resource Management (INRM), which combined organic and mineral inputs accompanied by a shift in approaches toward involvement of the various stakeholders in the research and development process. One of the important lessons learned was that the farmers’ decision-making process was not merely driven by the soil and climate but by a whole set of factors cutting across the biophysical, socio-economic, and political domain (Izac, 2000). Currently, soil fertility research and strategy focus on the new paradigm of Integrated Soil Fertility Management (ISFM), which is a holistic approach in soil fertility research that embraces the full range of driving factors and consequences of soil degradation—biological, chemical, physical, social, economic, health, nutrition, and political.

This paper discusses the agro-ecological zones (AEZ) and main soil types in Africa followed by a section on the extent, effects, and costs of land degradation including issues of soil productivity and profitability associated with fertilizer use in Africa.

II. Agro-Ecological Zones and Main Soil Types

1. Concepts and Definitions

Parameters used in the definition of AEZ focus on climatic and edaphic crop requirements and on the management systems under which crops are grown. Each zone has a similar combination of constraints and potentials and serves as a focus for the targeting of recommendations designed to improve existing land use through increasing production or by limiting land degradation.

2. African Agro-Ecological Zones

With regard to climatic factors it is important to note that a large proportion of Africa receives less than 200 mm of rainfall per year; the Congo Basin receives over 2,000 mm of rain per year (Figure 1).

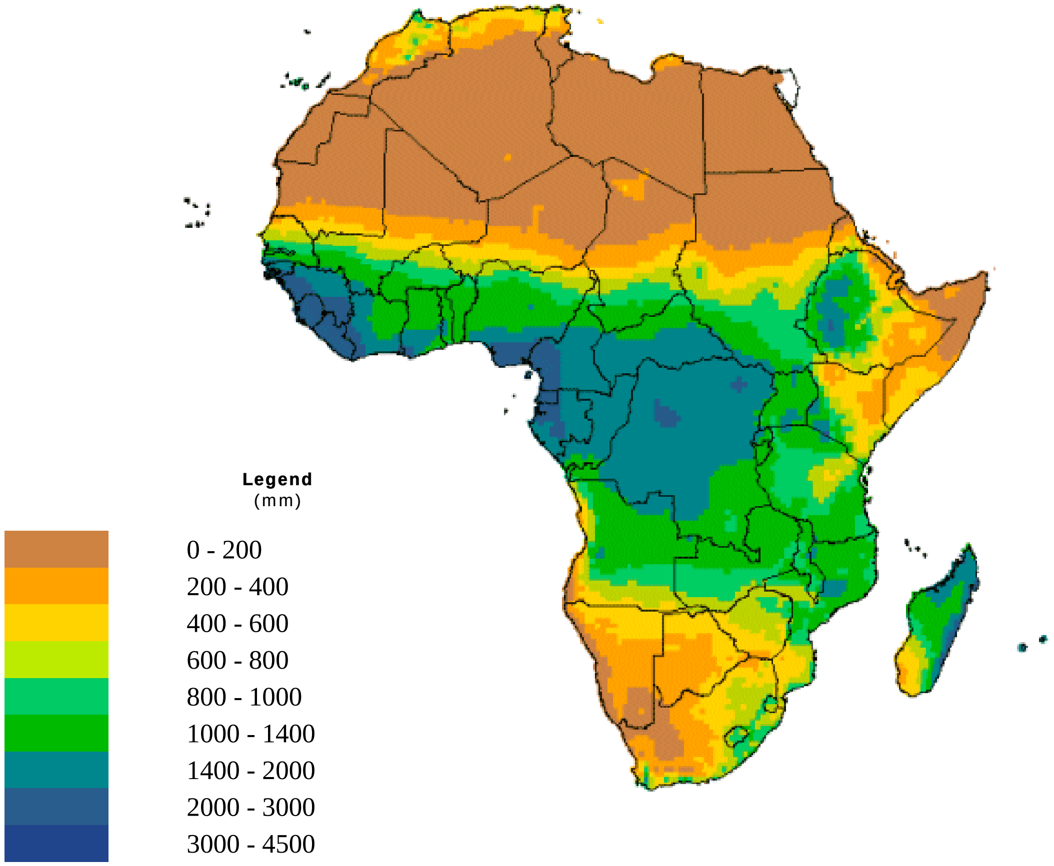

Figure 1. Major Rainfall Zones of Africa

By differentiating areas of varying moisture conditions in Africa, Dudal (1980) identified five major AEZ on the basis of the length of growing period (LGP) (Figure 2). The LGP is defined in terms of the number of days when both moisture and temperature permit rainfed crop production.

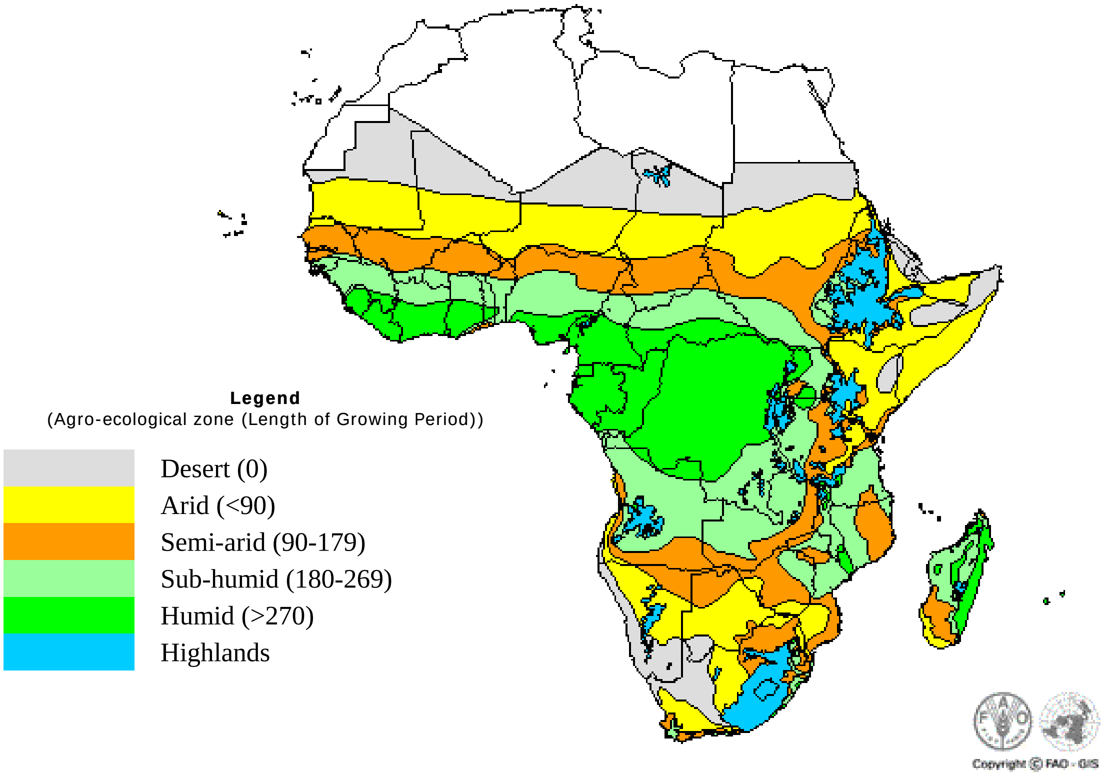

Figure 2. Major Agro-Ecological Zones Based on the Length of the Growing Period

The Humid Zone

This zone stretches from West to Central and East Africa where the rainfall exceeds a mean of 1,500 mm/year, temperatures ranging between an average of 24° and 28°C with a growing period of more than 270 days. In places, relief gives an increased rainfall. For example, Mount Cameroon rises 4,070 m above the neighboring warm sea and receives the full force of the humid air, thus giving the highest rainfall of the continent (averaging 10,000 mm annually at Debundja).

The Sub-Humid Zone

The humid to sub-humid wooded savannah zone covers areas between latitudes 5 to 15° North and 5 to 15° South in central, western, and southern Africa. Areas with one or two rainy seasons of varying lengths are located within this zone. This zone has a growing period of 180-269 days.

The Semi-Arid Zone

This zone covers areas between the sub-humid wooded savannah zone and the arid zone between latitudes 15° and 20°N and 15° to 25°S where the average rainfall ranges from 200 to 800 mm. The Sahel is part of this AEZ and has a growing period of 75–179 days.

The Arid Zone

The arid savannah zone of Africa covers extensive areas north of latitude 20°N and south of 20°S where the average annual rainfall is less than 200 mm. The zone includes the vast Sahara desert and the Namibia, Kalahari, and Karroo deserts. The arid zone has a growing period of <90 days.

The Mediterranean Zone

This zone embraces the extreme northern and southern parts of Africa, especially the coastal areas of Algeria, Egypt, Libya, Morocco and Tunisia. Climatic conditions are quite different from tropical Africa.

3. Soil Types and Constraints

The soil patterns in the five major AEZ of Africa are determined by differences in age, parent material, 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, dominant soils are Ferralsols and the Acrisols. Less important in this zone are Arenosols, Nitosols, and Lixisols. The sub-humid zone is characterized by the dominance of Ferralsols and Lixisols and to a lesser extent Acrisols, Arenosols, and Nitosols. In the semi-arid zone, Lixisols have the larger share followed by sandy Arenosols and Vertisols (Deckers 1993). The next section provides a brief description of the characteristics and potential environmental problems with respect to plant nutrition of some of the dominant soils of Africa. A map showing the distribution of major soils in Africa is shown in Figure 3.

Legend

🟩 Andosol and Nitosols
🟥 Cambisols, Luvisols, Kastanozems, Phaeozems and Planosols
🟪 Vertisols
🟧 Ferrasols and Acrisols
🟦 Fluvisols, Gleysols and Histosols
🟫 Ferric and Plintic Luvisols
⬜ Regosols, Arenosols and Podzols
🟨 Lithosols, Xerosols, Yermosols, Solonchaks, Solonetz and Miscellaneous land units
🟦 Inland water bodies

Figure 3. Major Soil Types in Africa

Ferralsols (Similar to Oxisols in USDA Soil Taxonomy)

Ferralsols occupy a considerable part of Central Africa—The Democratic Republic of Congo (DRC), Angola, Zambia, Rwanda, Burundi, Uganda, South Sudan, Central African Republic, and Cameroon. In West Africa, large tracts of Ferralsols occur in Liberia and Sierra Leone (Deckers, 1993). The eastern part of Madagascar is also largely characterized by Ferralsol associations. A notable characteristic of Ferralsols is their advanced weathering (Deckers 1993). The capacity to supply nutrients to plants and the capacity to retain nutrients (cation exchange capacities [CEC]) are both low. From a soil fertility point of view, this low-retention capacity has marked consequences for fertilizer management. Inorganic fertilizers, especially nitrogen, should be applied in small amounts to avoid leaching because these soils occur in high rainfall regions. Phosphate fertilizers are fixed by free iron and aluminum oxides. There is a need to apply high rates of P fertilizers. Other constraints of Ferralsols include: deficiency in bases (Ca, Mg, K), which requires lime application and incapability to retain bases applied as fertilizers or by other means; presence of aluminum in Ferralsols with low pH (<5.2)—this element is toxic for many plant species and highly active in the fixation of phosphates; presence of free manganese in acid Ferralsols, likewise toxic for a number of species; deficiency of molybdenum, especially required for the growth of legumes—hazards of iron and manganese toxicity in paddy-rice. Physically Ferralsols are excellent soils, well-drained, with a good structure, and deep profile. Rooting depth is almost unlimited and this makes up for their relatively low water-holding capacity (Van Wembeke, 1974).

Acrisols (Similar to Ultisols in USDA Soil Taxonomy)

Acrisols occur in the southern part of the sub-humid zone of West Africa and in southern Guinea, most of Côte d'Ivoire, southern Ghana, Togo, Benin and Nigeria and central Cameroon. In East Africa Acrisols occur in the humid parts of Tanzania (Deckers, 1993). Acrisols have a high water-holding capacity, but the higher density of the second horizon may limit the biological activity and root penetration (Deckers, 1993). Although Acrisols are less weathered than Ferralsols, mineral reserves are low. Leaching is a problem in these soils and boron and manganese are often deficient. High aluminum contents may lead to phosphate fixation. The structure of the surface soil of Acrisols is weak and internal drainage may be hampered by the compact textural B horizon. Special care is therefore needed to protect Acrisols from soil erosion. The addition of lime and organic matter may be needed to ensure sustained production.

Nitosols (Similar to Plaeudults, Paleustults, Plaeudalfs, Paleustalfs in Soil Taxonomy)

The Nitosols are limited in Africa; they occur in Ethiopia, Kenya, Tanzania, and east DRC and in areas of volcanic activity in the Rift Valley Zone (Deckers, 1993). Nitosols have a clay-rich subsoil, which is characterized by a good soil structure, and they have a higher fertility level than Acrisols (Deckers, 1993). The key to the high fertility of the Nitosols is the clay in the subsoil, which can retain considerable amounts of plant nutrients. Phosphate fixation is common and manganese toxicity may be a problem in the more acid Nitosols. The water-holding capacity of Nitosols is favorable because of the high clay content in the subsoil, and these soils have a typically open structure that allows crop roots to penetrate very deeply into the profile.

Lixisols (Similar to Alfisols, Oxic Kandiudalfs in Soil Taxonomy)

Lixisols form a belt in West Africa between the Acrisols and the Arenosols. Other important areas of occurrence include southeast Africa and Madagascar (Deckers, 1993). Lixisols, like Acrisols and Nitosols, have a clay accumulation horizon with a low capacity to store plant nutrients but are well-saturated with cations. The soil-pH of Lixisols is therefore medium to high, and aluminum toxicity does not occur. Because of the low storage capacity for cations, Lixisols may become depleted quickly under agricultural use, though their physical characteristics are generally better than those of Acrisols.

Arenosols (Similar to Psamments in Soil Taxonomy)

Arenosols form an almost continuous belt in West Africa, stretching from northern Senegal, Mauritania, central Mali, and southern Niger, through Chad to eastern Sudan. Other important Arenosol areas include parts of Botswana, Angola and southwest DRC (Deckers, 1993). These soils are also dominant in the North African countries. The soil material of Arenosols is mainly composed of quartz, with a low water-holding capacity, low nutrient content, low nutrient-retention capacity and deficiency of minor nutrient elements including zinc, manganese, copper, and iron (Deckers, 1993). Deficiency of sulfur and potassium is common in Arenosols while fertilizer efficiency is hampered by severe leaching, especially of nitrogen and potassium. Arenosols tend to be weakly structured, which explains compaction of the subsoil and water/wind erosion of the topsoil. In dry areas, Arenosols contain more bases, but the poor water-holding capacity places a severe limit on crop growth and performance.

Vertisols (Vertisols in Soil Taxonomy)

The largest extent of Vertisols occurs in the semi-arid and sub-humid zones of Sudan and Ethiopia, and in Tanzania close to Lake Victoria (Deckers, 1993). Vertisols are characterized by a high content of shrinking and swelling clays (Deckers, 1993). During the rainy season, they expand and surface flooding becomes a problem. In the dry season, the clay shrinks and large deep cracks develop. Tillage is hampered by stickiness when wet and hardness when dry. A very narrow range exists between moisture stress and water excess. The permeability is low when moist, making them sensitive to erosion in the absence of vegetative cover. The physical condition of Vertisols is greatly influenced by the level of soluble salts and/or adsorbed sodium. Phosphorus availability is generally low. Due to the flooding in the rainy season, the efficiency of nitrogen fertilizer applications may be very low due to high nitrogen losses under waterlogged conditions.

Gleysols and Fluvisols (Similar to Aquic Suborders and Fluvents in Soil Taxonomy)

Gleysols are found in equatorial Africa and inland valleys across Africa. These are soils with signs of excess wetness. The parent material is characterized by a wide range of unconsolidated materials, mainly fluvial, marine, and lacustrine sediments with basic to acidic mineralogy. These soils occur mainly in depressional areas and low landscape positions with shallow groundwater. The main obstacle to Gleysols is the necessity to install a drainage system designed to either lower the groundwater table or intercept seepage or surface runoff water. Drained Gleysols can be used for arable cropping, dairy farming, or horticulture. Soil structure will be destroyed for a long time if wet soils are cultivated. Gleysols in (depression) areas with unsatisfactory drainage possibilities are therefore best kept under a permanent grass cover or (swamp) forest. Gleysols can be put under tree crops only after the water table has been lowered with deep drainage ditches. Gleysols in the tropics and subtropics are widely planted in rice.

Soils in the Mediterranean Region

The soils in the Mediterranean region are unique. These are Rendzinas, Phaeozems, Cambisols, Kastanozems, Arenosols, and Solonchaks, and they result from the combination of dry summer seasons and the prevalence of calcareous material. These soils are dominated by carbonates and are often clayey and rich in organic matter and calcium. They have good structure, are well drained, and have adequate available water capacity. Leached soils such as Ferralsols are rare. The main impediments of Mediterranean soils are excessive limestone and disproportionate soluble salts, in addition to the scarcity of water, particularly in arid and semi-arid areas. From an agricultural standpoint, Mediterranean soils are fertile.

Table 1 summarizes the extent of the main soil types, constraints, and countries covered.

Table 1. Main Soil Types, Extent, Constraints and Countries Covered

Soil Type	Hectare (ha)	Percentage of Total Land (%)	Main Constraints	Main Countries Covered
Andosol and Nitosols	117,123,121	3.8	Fertile (volcanic ash), high P-fixation, Mn toxicity, medium water and nutrient retention	Rift valley (Ethiopia, Kenya, Tanzania, Zaire)
Cambisols, Luvisols, Kastanozems, Phaeozems and Planosols	211,348,146	6.8	Low-to-moderate nutrient content	Mediterranean countries
Vertisols	98,985,811	3.2	Heavy soils, medium mineral reserves, erodibility and flooding	Sudan, Ethiopia, South Africa, Lesotho
Ferrasols and Acrisols	500,910,947	16.2	Low nutrient content, weathered, Al and Mn toxicity, high P-fixation, low nutrient and water retention, susceptible to erosion	DRC, Angola, Zambia, Rwanda, Burundi, Uganda, Sudan, Central African Republic, Cameroon, Liberia, Sierra Leone and Madagascar Sub-humid zone of West Africa
Fluvisols, Gleysols and Histosols	132,037,611	4.3	Poor to moderate drainage	West, Central and southern Africa
Ferric and Plintic Luvisols	179,786,479	5.8	Low nutrient content	Western and southern Africa
Regosols, Arenosols and Podzols	579,101,963	18.7	Mainly quartz, low water and nutrient holding capacity, wind erosion, poor soils with nutrient leaching	West Africa/Sahel, Sudan, Botswana, Angola and DRC, North Africa
Lithosols, Xerosols, Yermosols, Solonchaks, Solonetz and Miscellaneous land units	1,244,513,150	40.3	Shallow soils Soils subject to drought Presence of salt	North African countries, South Africa, Namibia, Somalia, Sahel
Inland water bodies	27,230,091	0.9	Flood zones	
TOTAL	**3,091,037,319**	**100**		

III. Land Degradation and Soil Productivity

1. Land Degradation

Land degradation is defined by FAO (2002) as the loss of production capacity of land in terms of loss of soil fertility, soil bio-diversity, and degradation of natural resources. Land degradation is a widespread problem that affects soils, landscapes, and human welfare (Thiombiano, 2000). At least 485 million Africans are affected by land degradation, making it one of the continent's urgent development issues with significant costs: Africa is burdened with a $9.3 billion annual cost because of desertification. While the cumulative loss of crop productivity from land degradation worldwide between 1945 and 1990 has been estimated at 5%, as much as 6.2% of productivity has been lost in SSA. An estimated $42 billion in income and 6 million ha of productive land are lost every year due to land degradation and declining agricultural productivity (UNDP/GEF, 2004). Globally, Africa suffered a net loss of forests exceeding 4 million ha/year between 2000 and 2005, according to FAO. This was mainly due to conversion of forest lands to agriculture. Forest cover went from 656 million ha to 635 million ha during this period.

Causes for land degradation are: human population growth, poor soil management, deforestation, insecurity in land tenure, variation of climatic conditions, and intrinsic characteristics of fragile soils in diverse AEZ. Various agricultural and non-agricultural uses of soils are pointed out to have a negative impact on African lands, due to the lack of appropriate land use planning and to the mismanagement of natural resources by land users, particularly by resource-poor farmers.

Land degradation is the most serious threat to food production, food security, and natural resource conservation in Africa. The population is trapped in a vicious cycle between land degradation and poverty, and the lack of resources and knowledge to generate adequate income and opportunities to overcome the degradation. Scientists have reported that soil loss through erosion could be about 10 times greater than the rate of natural formation, while the rate of deforestation is 30 times higher than that of planned reforestation. Wind and water erosion are significant causes of degradation, but soil fertility decline (largely invisible and a gradual process) is also notable.

Land degradation is caused by soil water erosion (46%), wind erosion (36%), loss of nutrients (9%), physical deterioration (4%), and salinization (3%). Overgrazing (49%) followed by agricultural activities (24%), deforestation (14%), and overexploitation of vegetative cover (13%) constitute the primary causes of land degradation in rural areas (Dunstan et al., 2004). This degradation reduces the capacity to increase food production. Yield losses due to land degradation in Africa range from a 2% decline over several decades to a catastrophic 50% (Scherr, 1999). Crop yield loss due to erosion in 1989 was 8% for Africa as a whole, which makes the fight against land degradation a fight against poverty.

Worldwide, the area of degraded soils is extensive (Table 2) and the effects of degradation are evident in many parts of the continent with degradation-prone soils, and unsustainable intensification in many of the densely populated zones (Scherr, 1999). The situation is especially dire in Africa, where millions of people are threatened by hunger (UNDP/GEF, 2004). Of the African drylands, 73% is degraded and 51% is severely degraded (Dregne and Chou, 1992). It is estimated that since the 1950s, Africa has lost about 20% of its soil productivity irreversibly due to degradation (Dregne, 1990).

Table 2. Global Estimates of Agricultural Land Degradation by Region

	Total Land (m ha)	Degraded Land (m ha)	Percent Degraded
Africa	187	121	65
Asia	536	206	38
South America	142	64	45
Central America	38	28	74
North America	236	63	26
Europe	287	72	25
Oceania	49	8	16
World	1,475	562	38

Source: Scherr, 1999; Oldeman et al., 1992.

Soil-fertility depletion in smallholder farms is a fundamental biophysical root cause of the declining per capita food production; it has largely contributed to poverty and food insecurity. Over 132 million tons of N, 15 million tons of P, and 90 million tons of K have been lost from cultivated land in 37 African countries in 30 years (Smaling, 1993). Nutrient loss is estimated to be 4.4 million tons of N, 0.5 million tons of P, and 3 million tons of K every year from the cultivated land (Sanchez et al., 1997). These rates are several times higher than Africa's annual fertilizer consumption (excluding South Africa) of 0.8 million tons of N, 0.26 million tons of P, and 0.2 million tons of K. The loss is equivalent to 1,400 kg/ha of urea, 375 kg/ha of triple superphosphate (TSP) and 896 kg/ha of KCl during the last three decades. Figure 4 shows the annual average nutrient depletion in Africa measured in kilograms per hectare per year between 1993 and 1995.

Soil organic carbon is a depletable natural resource capital, and like the negative nutrient balances, its decline threatens soil productivity. The concentration of organic carbon in the top soil is reported to average 12 mg/kg for the humid zone, 7 mg/kg for the sub-humid zone, 4 mg/kg in the semi-arid zone and 2 mg/kg for the drier semi-arid zone (Windmeijer and Andriesse, 1993). Most African soils are inherently low in organic carbon (<20 to 30 mg/kg). This is due to the low root growth of crops and natural vegetation but also the rapid turnover rates of organic materials with high soil temperature and microfauna, particularly termites (Bationo et al., 2003). There is much evidence for rapid decline of soil organic C levels with continuous cultivation of crops in Africa (Bationo et al., 1995). For the sandy soils, average annual losses in soil organic C may be as high as 5%, whereas reported losses for sandy loam soils seem much lower, with an average of 2% (Pieri, 1989). Results from long-term soil fertility trials indicate that losses of up to 0.69 tons of carbon/ha/year in the soil surface layers are common in Africa even with high levels of organic inputs (Nandwa, 2003).

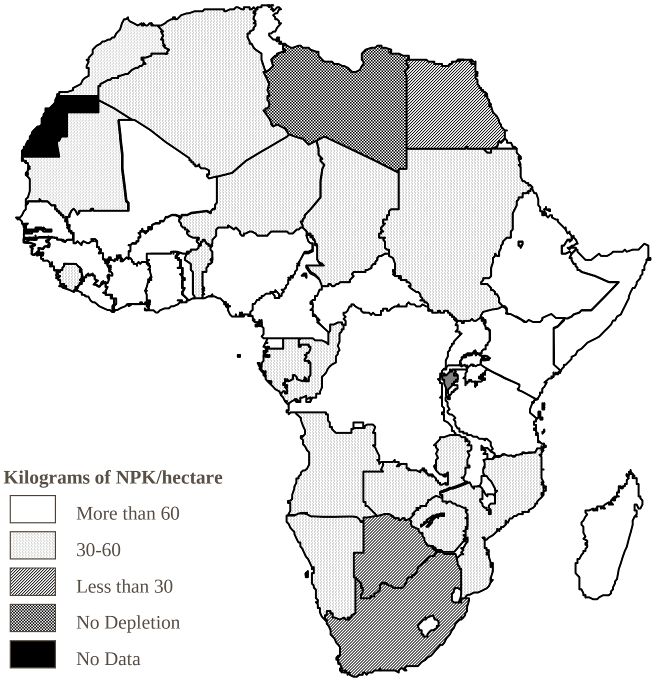

Figure 4. Average Annual Nutrient Depletion (NPK) in Africa Between 1993 and 1995 (Source: Henao and Baanante, 1999b.)

2. Soil Productivity

Soil Moisture

Soil moisture stress is perhaps the overriding constraint to food production in much of Africa. Only about 14% of Africa is relatively free of moisture stress. The incidence of drought since 1975 has increased nearly fourfold (UNDP/GEF, 2004). Moisture stress is not only a function of the low and erratic precipitation but also of the ability of the soil to hold and release moisture. About 10% of the soils in Africa have high to very high available water-holding capacities (AWHC). These are mainly Vertisols and other clayey soils. The 29% of soils with medium AWHC are mainly Lixisols and Ferralsols and some loamy Inceptisols and Entisols. The low AWHC class soils are the Ferralsols and other sandy loam soils. Despite their clayey textures, Ferralsols have low AWHC. The very low AWHC class soils are sandy soils such as Arenosols and other sandy and sandy loam soils. The development of conservation agriculture technologies with soil permanent cover will be of importance for the conservation of soil moisture, as shown in various FAO projects.

Productivity Zones

Soil properties, including soil climate, provide some preliminary information to address soil quality and to classify land according to its potential for productivity. Land can be classified as prime, high, medium, and low potential lands, and the unsuitable class of lands. Figure 5 gives the agricultural potential of African soils. Prime land comprises those soils with deep, permeable layers, an adequate supply of nutrients, and generally do not have significant periods of moisture stress. The soils are deep, without impermeable layers, textures are loamy to clayey with good tilth characteristics, and the land is generally level to gently undulating. They occupy about 9.6% of Africa and they occupy significant areas in West Africa south of the Sahel, in East Africa mainly in Tanzania, and in the southern African countries of Zambia, Zimbabwe, South Africa, and Mozambique.

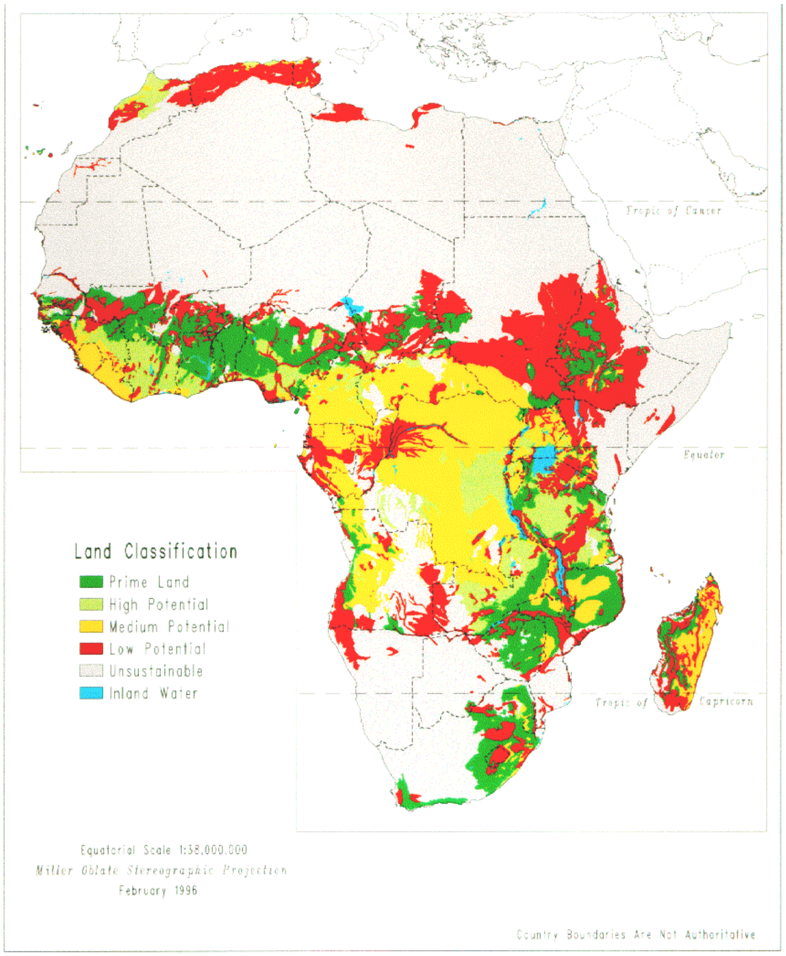

Figure 5. Land Classification of African Soils

High potential soils are similar to the prime soils but have some minor limitations such as an extended period of moisture stress, sandy or gravelly materials, or with root-restricting layers in the soil. The high potential lands occupy an area of about 6.7%.

Medium- and low-potential lands, which occupy 28.3% of the surface, have major constraints for low-input agriculture. These lands have a major soil constraint and one or more minor constraints, which can be corrected. Constraints include adverse soil physical properties including surface soil crusting, impermeable layers, soil acidity and specifically subsoil acidity, salinity and alkalinity, and high risks of wind and water erosion. The large contiguous areas of central and West Africa are considered as medium potential, due to the presence of acid soils and soils that fix high amounts of P. With an inherently low soil quality, low-input agriculture can be equated to potential soil degradation. These are some of the priority areas for technical assistance and the implementation of appropriate soil management technologies.

The unsustainable class of lands are those that are considered to be fragile, easily degraded through bad management, and in general are not productive or do not respond well to management. These occupy about 55% of the African continent. They are generally erodible and require high investments.

IV. Profitability of the Use of Fertilizers in African Agro-Ecosystems

There is ample evidence that increased use of inorganic fertilizers has been responsible for an important share of worldwide agricultural productivity growth. Fertilizer was as important as seed in the Green Revolution contributing as much as 50% of the yield growth in Asia (Hopper, 1993). Several studies have found that one-third of the cereal production worldwide is due to the use of fertilizer and related factors of production (Bumb, 1995, citing FAO). Van Keulen and Breman (1990) and Breman (1990) stated that the only real cure against land hunger in the West African Sahel lay in increased productivity of the arable land through the use of external inputs, mainly inorganic fertilizers. Pieri (1989) reporting on fertilizer research conducted from 1960 to 1985 confirmed that inorganic fertilizers, in combination with other intensification practices, had tripled cotton yields in West Africa from 310 to 970 kg/ha. There are numerous cases of strong fertilizer response for maize in East and southern Africa (Byerlee and Eicher, 1997).

The data in Table 3 summarize multi-site response to soil fertility improvement and clearly demonstrate the importance of fertilizers in maize yield improvement in different AEZ and soil types in Africa. Maize yield increase over the control due to NPK fertilizer application from six AEZ and averaged over 4 years was 149%; when the soil was amended with lime and manure, yield response over the control increased to 184% (Mokwunye et al., 1996). Similarly, higher yield improvements have been observed in East (Qureish, 1987) and southern (Mtambanengwe and Mapfumo, 2005) African countries.

Table 3. Maize Response to Organic and Inorganic Fertilizer Application in Selected Sites in East, West, and Southern Africa

Site	Treatment	Yield	Yield Increase
		(tons/ha)	(%)
West Africa (Multisites, 3-6 year average)[a]	Control	1.51	–
	TSP+N+K	3.172	110
	N+K	2.319	54
	P+K	2.426	61
	P+N+K	3.765	149
	P+N+K+lime (500 kg/ha every 3 years)	3.794	151
	Crop residue (CR)	1.999	32
	Manure (10 tons/ha every 3 years)	2.497	65
	P+N+K+Mg+Zn	3.880	157
	P+N+K+Mg+Zn+Lime	4.006	165
	P+N+K+Mg+Zn+CR	4.083	170
	P+N+K+Mg+Zn+Manure+Lime	4.289	184
East Africa (1981-1985)[b]	Control	1.9	–
	Crop residues	2.5	32
	Manure (5 tons)	3.5	84
	Fertilizer 60 kg N, 25 kg P)	4.1	116
	Manure (10 tons)	4	111
	Fertilizer 120 kg N, 50 kg P)	4.6	142
	Manure 5 tons + Fertilizer 60 kg N, 25 kg P)	5.2	174
Southern Africa[c]	Control	0.729	–
	N+P+K	2.194	201
	Termitaria+N+P	2.229	206
	Cattle manure+N+P	2.644	262
	Maize stover+N+P	1.575	116
	Fresh litter+N+P	2.553	250
	Crotalaria juncea+N+P	2.496	242

a. Mokwunye et al. (1996)—Results from six different AEZs in Togo.
b. Qureish (1987)—Results from Kabete, Kenya.
c. Mtambanengwe and Mapfumo (2005)—Results from Chinyika, Zimbabwe.

Despite the above response to fertilizer application, studies have shown that there are great on-farm soil fertility gradients, and the yields are bound to vary greatly even on the same production unit. Prudencio (1993) observed such fertility gradients between the fields closest to the homestead (home gardens/infields) and those furthest (bush fields/outfields). Soil organic carbon contents of between 11 and 22 g/kg have been observed in home gardens compared with 2-5 g/kg soil in the bush fields. Similarly, higher total organic nitrogen, available phosphorus, and exchangeable potassium have also been observed in the home gardens compared with the bush fields. Fofana et al. (2006), in a study in West Africa, observed that grain yields across years and fertilizer treatment averaged 0.8 tons/ha on outfields and 1.36 tons/ha on infields (home gardens). Recovery of fertilizer N (RFN) applied varied considerably among the treatments and ranged from 17% to 23% on outfields and 34% to 37% on infields. Similarly, average recovery of fertilizer P (RFP) applied across treatments was 31% in the infields compared with 18% in the outfields over the 3-year mono cropping period. These results indicate higher inherent soil fertility and nutrient use efficiency in the infields compared with the outfields and underlines the importance of soil organic carbon in improving fertilizer use efficiency. Once soils are degraded and poor in organic matter, the response to fertilizer is less and the recovery of applied fertilizers is very low.

Despite the fact that deficiency of P is acute on the soils of Africa, local farmers use very low P fertilizers because of high cost and problems with availability. The use of locally available phosphate rock (PR) could be an alternative to imported P fertilizers. For example, Bationo et al. (1987) showed that direct application of local PR may be more economical than imported water-soluble P fertilizers. Bationo et al. (1990) showed that Tahoua PR from Niger is suitable for direct application, but Parc-W from Burkina Faso has less potential for direct application. The effectiveness of local PR depends on its chemical and mineralogical composition (Chien and Hammond, 1978). Phosphate rocks can be used as a soil amendment and the use of water-soluble P can be more profitable.

Phosphorus placement can drastically increase P use efficiency as shown with pearl millet and cowpea in an experiment involving broadcast (BC) and/or hill placed (HP) of different P sources. For pearl millet grain, P use efficiency (PUE) for broadcasting single superphosphate (SSP) at 13 kg P/ha was 23 kg/kg but hill placement of SSP at 4 kg P/ha gave a PUE of 83 kg/kg P. The PUE of 15-15-15 broadcast was 29 kg grain/kg P, whereas the value increased to 71 kg/kg P when additional SSP was applied as hill placed at 4 kg P/ha and 102 when only HP of 4 kg P/ha of 15-15-15 was used. Hill placement of small quantities (4 kg/ha) of P attains the highest use efficiency with the efficiency decreasing with increasing quantity of P.

Farm-level fertilizer prices in Africa are among the highest in the world. The cost of 1 ton of urea, for example, is about US $90 in Europe, US $500 in Western Kenya, and US $700 in Malawi. These high prices can be attributed to the removal of subsidies, transaction costs, poor infrastructure, poor market development, inadequate access to foreign exchange and credit facilities, and lack of training to promote and utilize fertilizers. For example, it costs about $15, $30, and $100 to move 1 ton of fertilizer 1,000 km in the United States, India, and SSA, respectively (Sanchez, 2005; Sachs, 2005—Seminar Presentations at ICRAF).

Contrary to conventional wisdom, there are examples of evidence of fertilizer response and profitability in Africa that compare favorably to those in other parts of the world. Yanngen et al. (1998), in a comprehensive study of fertilizer profitability in Africa, found out that, among the cereal crops covered, maize and irrigated rice exhibited the strongest incentives to fertilizer application. The yield response and the profit incentives for rice and maize have been observed to be equal or higher than what was obtained in Latin America and Asia, respectively (Yanngen et al., 1998) (Table 4). For maize and rice, maximum value costs of 26 and 4 have been obtained, respectively, and this is far higher than the benefit/cost ratio of 2 required to ensure farmers' willingness to invest in fertilizer use. These results and other numerous responses from site-specific studies are clear evidence that the use of inorganic fertilizer could indeed be a profitable investment.

Table 4. Fertilizer Incentives: Summary of Key Indicators by Crop and Region, Adapted From Yanngen et al. (1998)

Type of Crop	Region	Kilogram of Output Per Kilogram of Nutrient Use (Efficiency)			Profit Incentives (Value/Cost Ratio)	
		Typical	Minimum	Maximum	Minimum	Maximum
Maize	East and Southern Africa	17.0	2.0	52.0	1.0	15.0
	West Africa	15.0	0	54.0	0.69	26.0
	Latin America	10.0	5.0	18.0	1.2	5.3
Cotton	East and Southern Africa	5.8	0	7.0	0.00	3.1
	West Africa	5.0	2.0	12.0	0.61	3.7
Rice (irrigated)	West Africa	12.0	7.0	16.0	1.6	3.97
	Asia	11.0	7.7	33.6	1.5	3.1
Sorghum	East and Southern Africa	10.0	4.0	21.0	1.5	2.6
	West Africa	7.0	3.0	14.0	1.0	18.0
	Latin America	7.0	2.8	21.0		

A significant problem to effective utilization of fertilizers has been "pan-territorial/blanket" recommendations that fail to take into account differences in resource endowment (soil type, labor capacity, climate risk, etc.). The situation is exacerbated by the failure to revise recommendations following dramatic changes in the input/output price ratios due to subsidy removal and devaluation of currencies. Farmers using inorganic fertilizers experiment with different rates and methods of application. In West Africa, for example, farmers have adopted the "micro-dose" technology that involves strategic application of small doses of fertilizer (4 kg P/ha) and seed (Tabo et al., 2006). This rate of fertilizer application is only one-third of the recommended rates for the areas. In all the project study sites in the three West African countries (Burkina Faso, Mali, and Niger), grain yields of millet and sorghum increases were up to 43%-120% when using fertilizer "micro-dosing." The incomes of farmers using fertilizer micro-dosing and inventory credit system or "warrantage" increased by 52%-134%. Small amounts are more affordable for farmers, give an economically optimum (though not biologically maximum) response, and if placed in the root zone of these widely spaced crops rather than uniformly distributed, result in more efficient uptake (Bationo and Buerkert, 2001). The successful experience has shown that adoption of micro-dose technology requires supportive and complementary institutional innovation and market linkage. Organized farmer groups provide access to post-harvest credit provided on the basis of storage of grain as collateral (warrantage), enabling farmers to sell crops later in the season for higher prices and higher profits. They also provide greater access to fertilizer, leading to higher sustained yields and income.

Variability of rainfall is a critical factor in efficiency of fertilizers and in determining risk-aversion strategies of farmers in Africa. The tendency of African rainfall to be both spatially and temporally concentrated has important implications for fertilizer use. A survey of available data found African levels of available water from rainfall at 12.7 cm/year compared with North America at 25.8, South America at 64.8 and the world average at 24.9 (Brady, 1990). Fertilizer is commonly thought to increase risk in dryland farming, but in some situations it may be risk-neutral or even risk-reducing. Phosphorus and shorter-duration millet varieties in Niger, for example, cause crops to grow hardier and mature earlier, reducing damage from and exposure to drought (ICRISAT, 1985-88; Shapiro and Sanders, 1998). A key constraint, however, is the unavailability of fertilizer and the lack of incentive for adopting fertility-enhancing crop rotations in these zones (Thomas et al., 2004).

In the dry land of the Sahel, several scientists have reported that where the rainfall is more than 300 mm, the most limiting factors to crop production are nutrients and not water. At Sadore where the annual average rainfall is 560 mm, the nonuse of fertilizers resulted in a harvest of 1.24 kg of pearl millet grain/mm of water, but the use of fertilizers resulted in the harvest of 4.14 kg of millet grain/mm of water (Table 5).

Table 5. Water Use, Grain Yield, and Water Use Efficiency (WUE) for Millet at Sadore and Dasso (Niger)

Treatment	Sadore			Dosso		
	Water Use	Yield	WUE	Water Use	Yield	WUE
	(mm)	(kg/ha)		(mm)	(kg/ha)	
Fertilizer	382	1,570	4.14	400	1,700	4.25
Without fertilizer	373	460	1.24	381	780	20.4

Source: ICRISAT (1985).

Many development projects have invested billions of dollars in soil and water conservation. For the most part, these did not include soil fertility improvement and the water harvested in this manner is not reaching its full potential for productivity improvement. It is well known that fertilizers are a key to improved water use efficiency because water harvesting can also improve the fertilizer use efficiency. The Zai system is widely used in West Africa for water harvesting and soil conservation. The data in Table 6 indicate that the use of Zai alone will improve the productivity very little (only 200 kg/ha of sorghum grain); but when the Zai is associated with manure and fertilizer, large crop yield increases can be obtained (1,700 kg/ha of sorghum grain) (Table 6).

Table 6. Effect of “Zai” on Sorghum Yields

Technology	Sorghum Yield (kg/ha)	Yield Increase (%)
Only planting pits (Zai)	200	–
Zai + Cattle manure	700	250
Zai + Mineral fertilizers	1,400	600
Zai + Cattle manure and fertilizers	1,700	750

Source: Reij et al. (1996).

V. Conclusions

Africa has an extremely wide range of soils and climatic conditions. The soils range from stony shallow ones with meager life-sustaining capabilities to deeply weathered profiles that recycle and support large biomass. In many parts of Africa, inappropriate land use, poor management and lack of inputs have led to a decline in productivity, soil erosion, salinization and loss of vegetation. African soils are at risk, undergoing degradation since the traditional methods used by farmers (shifting cultivation, nomadic grazing) cannot cope with the increasing needs of the ever-expanding human and livestock populations. Conservation action to halt and reverse degradation needs to be planned in detail for each land type and socio-economic circumstance. Positive developments also occur, but so far seem to be drops in an ocean of land degradation.

The very low use of inorganic fertilizer has greater negative environmental consequences than excess use of inorganic fertilizers. Organic sources are not sufficient to replace nutrients lost or removed from the soils. Increased inorganic fertilizer use would benefit the environment by reducing the pressure to convert forests and other fragile lands to agricultural uses and, by increasing biomass production, helps increase the soil organic matter content. This organic material supplies and helps retain soil nutrients.

The present farming systems are unsustainable. Intensification is needed to feed growing populations, but it must be done in a way that uses soil nutrient and water resources efficiently, and relieves pressure on forests and other fragile lands. Technologies need to be adapted to the specific biophysical and socio-economic circumstances of small-scale farmers in Africa. For efficient nutrient utilization, inorganic fertilizer must be combined with organic matter, water harvesting, conservation agriculture, and controlling soil erosion in site-specific integrated soil fertility management strategies. These complementary activities help ensure that maximum benefits are derived from each component practice.

Although significant progress has been made in research in developing methodologies and technologies for combating soil fertility depletion, the low adoption rate is a reason for the large difference between farmers’ yields and potential yields. The costs of fertilizers can be 2 to 4 times higher in Africa than in the developed countries. Without a set of conducive policies, it will be hard to raise fertilizer use levels outside traditional user countries such as Egypt and

South Africa. There is a need to focus more on increasing fertilizer use efficiency to become more profitable. Another way to get fertilizer prices affordable for the small-scale farmers is the development of the local fertilizer sector. There is a need for feasibility studies for the development of the fertilizer sector mainly using indigenous phosphate rocks. There is also a need to develop tools for the scaling up of success stories such as the use of Zai technique, micro-dosing, small-scale water harvesting, and tree regrowth for soil mulch.

Macro-policy changes were executed without much understanding of the likely consequences at micro-level and the hidden effects on continued erosion of the natural resource base. Structural adjustment policies resulted in the reduction of the use of external inputs, extensification of agriculture, further encroachment on land under natural vegetation, and the reduction of farmers’ potential to invest in soil fertility restoration. Future research needs to look for ways and means to reverse these trends.

Interest in the quality and health of soil has grown with the recognition that soil is vital not only for production of food and fiber, but also for other ecosystem services than those directly providing tangible benefits for human welfare. Research on inorganic fertilizer should consider its effect on aspects of climate change such as greenhouse gas emissions and carbon sequestration, water quality, and interaction with pests and diseases. The challenge is to establish and quantify the global benefits resulting from sustainable land management. The use of decision-support tools can help predict and unravel some of these challenges facing integrated sustainable management of natural resources.

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