KENYA NATURAL RESOURCES MANAGEMENT ASSESSMENT

Volume 3

Agroforestry, Soil Conservation, and the Sustainability of Agriculture

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EXECUTIVE SUMMARY

Analysis

Agriculture is the mainstay of the economy of Kenya. However, declining yields from unsustainable agricultural systems on the Kenyan Highlands, combined with continuing very rapid population growth, is resulting in the in a mass movement of people off of the Highlands into the much more fragile arid and semi-arid lands (ASAL). Rainfed agriculture in the ASAL is inherently of much higher risk with lower potential yields. The development of sustainable production systems in the ASAL is much more difficult than in the medium to high potential zones of the Highlands. The ASAL is ecologically much better suited to range and wildlife management. Extensification of agriculture threatens to degrade or to destroy the natural resource base for Kenya's national parks, its wildlife, its rangelands and much of its irrigation and hydroelectric potential.

Kenya has done an exceptional job overall with physical soil conservation measures for controlling erosion on farmlands. Border plantings, hedgerows, contours grass strips and contour plowing all reduce erosion and are very common throughout the Highlands. The widespread application of physical soil conservation practices in the Machakos District in the semi-arid zone southeast of Nairobi may be the most successful example of soil conservation in sub-Saharan Africa. SIDA has a long-standing soil and water conservation extension program covering the whole country, and consider it to be one of their most successful programs anywhere. Soil erosion still remains a problem, but the trends seem to be positive.

Agroforestry in the form of on-farm tree planting for both farmers' wood needs and for the commercial sale of wood products has had quite phenomenal success in Kenya. Large areas of the Highlands that have been converted from open grasslands to croplands in the past 20 years, now appear quite heavily forested when traversing the countryside. This success has been due to the private ownership of farm land, the lack of restrictions on farmer harvest and sale of wood products, the efforts of at least three government extension agencies, the work of numerous NGOs and the development of hundreds of private nurseries throughout Kenya. Agroforestry techniques for soil fertility maintenance or improvement have enjoyed relatively little success to date in comparison. Early work focused on alley cropping; this technique is proving to have little potential in the ASAL and the Highlands.

Sustainable agriculture depends upon farmers' ability to maintain the fertility of their soils. Soil fertility maintenance requires the replacement of nutrients that are lost over time through erosion, leaching and through the harvest of crops and crop residues. The most critical nutrient in Kenya, as in most of Africa, is phosphorous (P). Most Kenyan soils are low in P. Furthermore, P is highly concentrated by crops in the grain that is removed

through harvest. Continuous cropping without replacement of P over periods of 20+ years leads to depletion of the capital stock of P in the soil.

Most farmers who raise cash crops purchase fertilizers and generally do a relatively good job of maintaining soil fertility on the fields where cash crops are grown. However, soil fertility decline, especially P deficiency, has become the principal constraint to agricultural production on fields where food crops are grown for local consumption rather than for sale. The problem is especially severe for near-subsistence smallholders. These farmers use little or no fertilizers on their maize and other food crops. The problem is the most widespread and acute in the Western Highlands where population densities are highest, farm size is smallest and the fewest cash crops are grown. It is a growing problem on croplands in the Central Highlands and in the ASAL. The ASAL are especially problematic over the long term due to their low potential and high risk of crop failure due to drought. These factors greatly limit farmers ability to purchase inputs.

The problem of P depletion and declining soil fertility associated with unsustainable agricultural systems is a widespread concern amongst soil fertility specialists and the scientific community, but has little recognition amongst Kenyan decision makers. No one has conducted an overall study of the severity, the geographical extent or the number of people affected by declining soil fertility and declining yields.

Soil fertility scientists at ICRAF believe the Maseno area northwest of Kisumo to be representative of large areas of the Western Highlands where farmers have been drawing on the capital stock of P in the soil for several decades without replenishing it. Surveys have revealed a widespread perception by farmers that yields have decreased substantially during this time. Actual yields are a small fraction of the potential. Most farms within a 20 km radius of Maseno are less than 1.2 has in size with maize yields of less than 0.5 tons/ha/season because of P deficiency. Yield potentials under intensive management run 5-10 tons/ha/season for the same zone. Small applications of commercial phosphate have relatively small, short-lasting effects because most of the P is quickly bound up in the high iron soils of the region. Restoring the capital stock of phosphate in the soil would require the addition of quantities that far exceed the means of the vast majority of smallholders in the area.

Approximately half of Kenya's population of 26,000,000 is in the Western Highlands. 49% of the population is 14 years of age or younger. Most of these young people will be starting new families over the next 20 years and will be seeking employment in agriculture or elsewhere. If viable strategies cannot be developed to intensify agricultural production in the Highlands and to greatly increase employment opportunities, then ever growing numbers of people will be forced to move off of the Highlands to start farms in the fragile arid and semi-arid lands. That movement, which is already accelerating, will have drastic environmental consequences and will greatly accentuate the already stressed ethnic tensions over land rights in Kenya.

Programming Options for USAID

A range of programming options have been identified under which USAID could contribute to the task of enhancing agricultural sustainability and, concomitantly, food security and environmental stability in Kenya. Furthermore, the problems described above are not unique to Kenya but are largely held in common with the other countries of the Greater Horn of Africa. Regional approaches should be pursued as feasible. Also, strategies developed in Kenya may find applicability throughout the region. In overall strategy development, the Agriculture, Population and Health and the Small Enterprise Development Offices of the Mission should work in concert to assure the highest impact and the most efficient use of resources.

Programming options include the following:

1. Support for Research on Sustainable Agriculture No overview of the problem of sustainability has been conducted and the biophysical and socioeconomic requirement for sustainable production systems have not been defined. The first option for USAID is to provide support to Kenya Agricultural Research Institute (KARI), the International Center for Research in Agroforestry (ICRAF) and the Kenya Forestry Research Institute (KEFRI) to conduct this review, to identify research gaps, to conduct research as needed, and to define the conditions for sustainable agricultural production systems. The results of this review and the definition of conditions should be critical for defining policy and institutional reforms that will be needed for achieving sustainability.

2. Support for Agroforestry Research Contributing to Sustainable Agriculture Agroforesty holds significant potential for increasing the efficiency of use of both the soils capital stock of nutrients and of purchased inputs, of organically fixing Nitrogen from the air, of diversifying production systems and reducing risk, and of increasing cash incomes from a variety of tree products. A second programming option would be to provide support to ICRAF/KARI/KEFRI to conduct strategic research on the interactions between trees and crops for nutrients, water and light and to identify high value agroforestry species that can be integrated into agricultural production systems. ICRAF has identified this as their greatest unfunded research needs.

3. Support for a Regional Phosphate Initiative The phosphate deficiency constraint will be extremely difficult to overcome if regional sources of phosphate cannot be developed at prices that are significantly less than the high cost of imported phosphate fertilizers. The countries of the Greater Horn of Africa are fortunate to have a number of undeveloped or partially developed reserves. The Minjingu reserve near Arusha, Tanzania compares favorably in quality with the best phosphate rock in the world. A regional study of opportunities for development and use of these reserves should be conducted. The study should include economic analyses of the production and transport costs of the different forms of fertilizer that could be produced from each reserve, analyses of the agronomic potential of these different forms, and the development of regional strategies

for addressing the constraint of phosphate deficiencies, especially the socio-economic constraints for smallholder farmers. USAID/Kenya could be a catalyst for this regional study and could fund part or all of the Kenya specific components.

4. Phosphate Rock Pilot Project in the Western Highlands Over 10 million hectares of unproductive, phosphate deficient soils in the Cerrado region of Brazil were restored to self-sustaining agricultural productivity in the 1970's and 80's through a one-time, highly subsidized application of phosphate rock to replenish the soil's capital stock of phosphorous. ICRAF scientists believe there is a strong potential that the same approach could work in the Western Highlands of Kenya using finely ground phosphate rock from the Minjingu deposits. It is strongly recommended that USAID fund a study through KARI/ICRAF/KEFRI to determine the biophysical and socio-economic feasibility of this strategy. The study should include on-farm trials to determine agronomic response and farmer acceptance. If the results are positive, USAID should then develop a Phase II operational pilot project to test the strategy on a watershed catchment, preferably of several thousand hectares in size. The project should include a strong applied research and extension component to assist smallholders to make the conversion from near-subsistence productions systems to self-sustaining commercial production systems.

5 Development of a Future Options Model The linkages between demographic growth, agricultural intensification versus extensification, creation of off-farm employment and the environment are poorly understood by politicians, decision makers, the general public, donors and development organizations. The development and wide diffusion of a professionally produced, graphically illustrated model illustrating the linkages and impacts of different policy options/development scenarios could have a strong impact on these stakeholders. Professionals in the fields of demography, agricultural development, industrialization/off-farm employment creation and in natural resources/environment should develop two or three realistic hypothesis of future trends in each field. A model of future scenarios should be developed based on these hypotheses. Finally, communication professionals should package the results in easily understood, graphic presentations for wide diffusion.

"Hardly anything is as destructive in terms of maintaining a balanced environment as the expansion of impoverished smallhollder farming producing unfertilized arable crops on depleted soils in a tropical setting."
Ruthenberg 1980

1 INTRODUCTION

1.1. Purpose

This review of agroforestry, soil conservation and the sustainability of agriculture in Kenya was done as part of the Kenya Natural Resources Management (NRM) Assessment done for the USAID Mission in Kenya. The NRM Assessment was undertaken by the Mission as an early step in the preparation of the their new Country Program Strategic Plan (CPSP) for the period 1996-2000. The NRM Assessment was undertaken to review the natural resources management sector in Kenya and to recommend NRM programming options in to the Mission for possible inclusion in the new CPSP.

The current CPSP emphasizes sustained and broad-based economic growth with the following three strategic objectives:

- Reduce fertility and the incidence of sexually transmitted HIV/AIDS....
- Increase level and productivity of private investment and employment.....
- Increase agricultural productivity and farm incomes....

This paper shall argue that all three of these strategic objectives are critical to the natural resources and environment of Kenya, but none of them have been developed with explicit linkages to NRM and the environment. High fertility and demographic growth rates pose the single greatest threat to sustainable natural resources management in Kenya. Increasing off-farm employment opportunities in the private sector is critical to providing alternative means of livelihood of the rapidly growing, 80% rural population. Increasing the agricultural productivity of arable lands is critical if extensification of agricultural into marginal lands is to be minimized. Improving linkages within the existing portfolio of the Mission and explicitly linking them to environment and natural resources could provide the framework for a powerful program addressing Kenya's most critical needs.

This paper assesses the sustainability of current agricultural production systems and the contributions of agroforestry and soil conservation to sustainability, all within the context of these larger issues. It then presents a range of programming options for the USAID Mission. All or most of them could be integrated into the Agricultural Office's program. The level of effort and choice of options, of course, will depend on levels of funding and the relative priorities assigned by the Mission as a whole.

1.2. Methodology

The methodology followed the general methodology of the NRM Team. The Team began work on February 1 with the initial week dedicated to meeting in Nairobi and review of relevant documents. A particular emphasis in the first week was placed on seeking meetings, not always with success, with individuals who could provide a "big picture overview" of NRM issues in Kenya. The second week (plus three days on weekends) were dedicated to field trips with other team members that covered representative areas of all the principal agricultural zones in the Highlands and the drylands farming areas with the exception of the coastal zone. The team was obliged to begin drafting their reports on the third week while continuing to schedule further meetings in Nairobi. The author participated in a formal briefing to USAID/Kenya and REDSO on March 2 and a senior staff review of the NRM Assessment synthesis draft on March 9 This report was completed by March 10, 1995.

2. THE NATURAL RESOURCE BASE FOR AGRICULTURE

2.1. Socioeconomic Importance

Agriculture is the mainstay of the economy of Kenya and is dependent on the sustainable use of natural resources, agricultural soils in particular. Agriculture generates 60% of Kenya's foreign exchange and contributes about 30% of gross domestic product. The principal export crops are coffee and tea. Others include pyrethrum and sisal. Horticultural crops including cut flowers and vegetables are a rapidly growing export. This is concentrated around Lake Naivasha. Other important cash crops are sugar cane, wheat and hybrid maize.

Kenya's population of 26 million people is 80% rural and nearly all rural employment is based on agriculture. The agricultural sectors includes productions units varying from highly commercial enterprises of over 10,000 has. in size down to near-subsistence smallholders on farms of less than a hectare. Most off-farm employment is based on agriculture. Sustainable agriculture is critical to the national economy, to food security and to the health and nutrition of Kenya's population.

2.2. Land Cover/Land Use in Kenya

The most recent data on land use and vegetation cover for Kenya is provided by the 1992 Water Master Plan as follows:

VEGETATION UNIT	AREA in Ha.
Forest	1,230,000
Woodland	2,140,000
Bushland	24,750,000
Wooded Grassland	10,700,000
Grassland	1,200,000
Desert	7,890,000
Plantation (intensive forestry)	170,000
Farmland and Urban Development	9,540,000
Mangroves	64,000

Categories are based on the following definitions:

-*Forest*:.....a continuous stand of trees at least 10m tall, their crowns interlocking.
-*Woodland*:.....an open stand of trees, at least 8m tall, with a canopy cover of 40% or more.
-*Bushland*:..... .an open stand of bushes and climbers, usually between 3 and 7m tall, with a canopy cover of 40% or more.
-*Wooded Grassland*:.land covered with grasses and other herbs, with woody plants covering between 10 and 40% of the ground.

The present area of farmland has been converted in the distant or recent past from forest, woodland, grassland, wooded grassland and shrubland cover types.

Changes in land use/land cover is difficult to quantify over time. The country has not been mapped in detail used the same land use/land cover classification scheme at different points in time. Even if this were done, the error margins for the classification of individual cover type classes would often exceed the actual change in land cover. Much of this report presents qualitative information on changes in land use by agroecological zone.

2.3. Agroecological Zones

General land suitability for agriculture and livestock production is generally classified by agroecological zones (AEZ). The most critical factor is the reliability of adequate rainfall for crop, pasture and range production. Agroecological zones are based on the ratio of annual rainfall to evapotranspiration. Most of Kenya is characterized by a distinctly bimodal rainfall pattern which renders the classifications of lands into homogeneous AEZs relatively difficult. However, the country is commonly divided into 6 or 7 AEZs

depending on the particular system classification used. Table 1 presents the surface area by AEZ for one of these systems (From Table 10 of Njoka et al, 1988)

TABLE 1 AGROECOLOGICAL ZONES OF KENYA

	ZONE	AREA	% OF TOTAL
I	Afro-Alpine	800 km2	0.1%
II	High Potential	53,000	9.3%
III	Medium Potential	53,000	9.3%
IV	Semi-Arid	48,200	8.5%
V	Arid	300,000	52.9%
VI	Very Arid	112,000	19.8%

The only two zones that are well suited to rainfed agriculture are the medium to high potential zones. This is also the area where the majority of export and cash crops are produced. Most of the medium to high potential zones are in the Central and Western Highlands of Kenya where temperatures are cool, evapotranspiration is low, and soils are of medium to high natural fertility. The distribution of soil types is a complex mosaic. Most soils in the Highlands are of volcanic origin or are derived from well-weathered basement complex rocks. Soils are generally deep, well-drained and easily workable. They are good agricultural soils.

With two growing seasons per year, the Central Highlands (east of the Rift Valley) and Western Highlands (west of the Rift Valley) of Kenya are an exceptional resource base for agricultural development in Eastern Africa. However, they only cover about 18% of the country. Furthermore, not all of this land is dedicated to agriculture. This 18% also includes forest and nature reserves and nearly all of the country's productive forest plantations.

Figure 1 depicts what ICRAF refers to as the Bimodal Highlands of Kenya. It includes all of the high, and most of the medium, potential AEZs of the Highlands. The Bimodal Highlands are over 1000 meters in elevation and have over 1000 mm. annual rainfall. Most of Kenya's population is also very strongly concentrated in the medium and high potential zones of the Highland as shown in the population distribution map in Figure 2. The Western Highlands by themselves support about half of the people of Kenya.

AREAS ABOVE 1000m. AND 1000mm. RAINFALL — KENYA

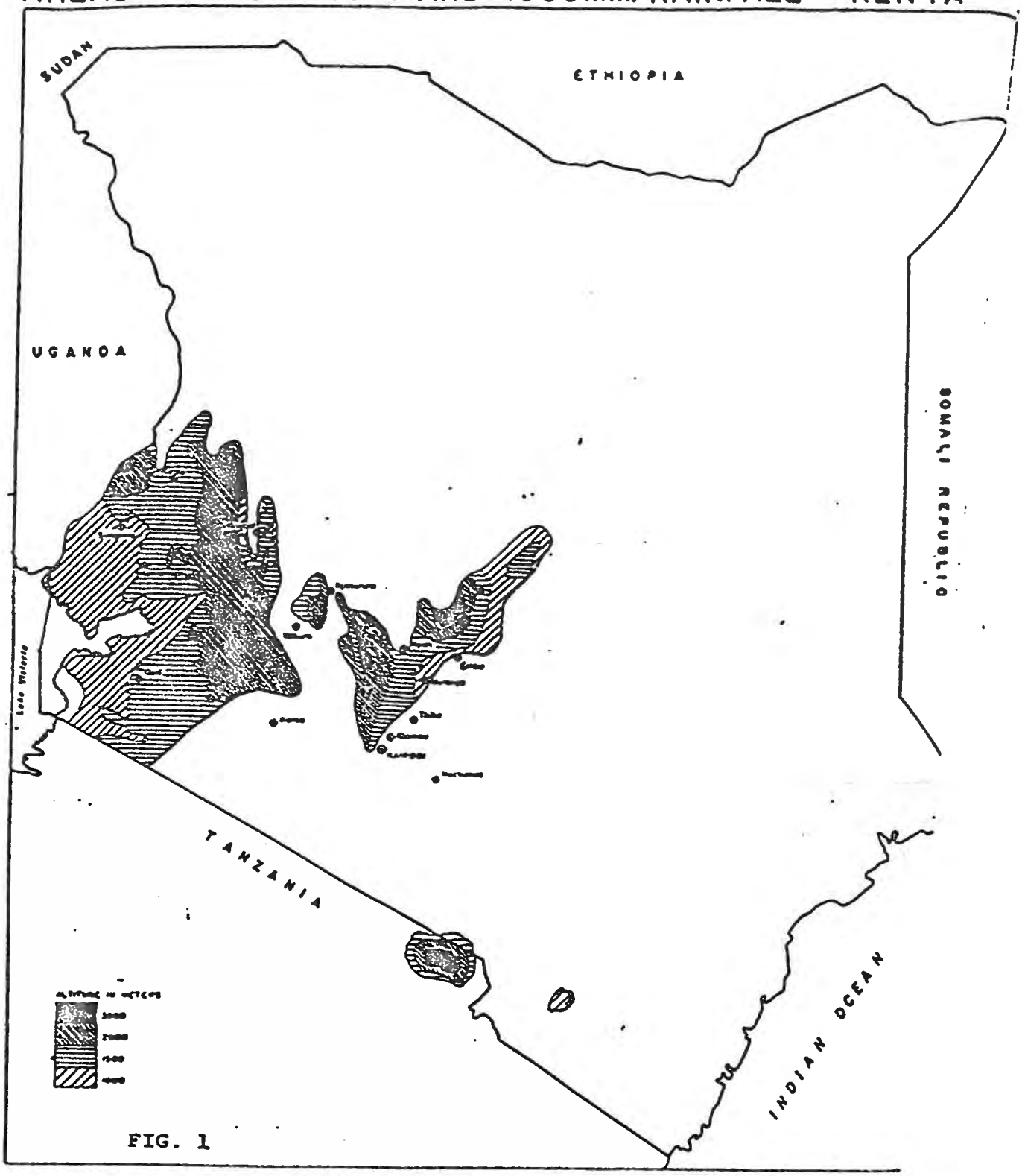

FIG. 1

NYA POPULATION DISTRIBUTION - 1979 Census

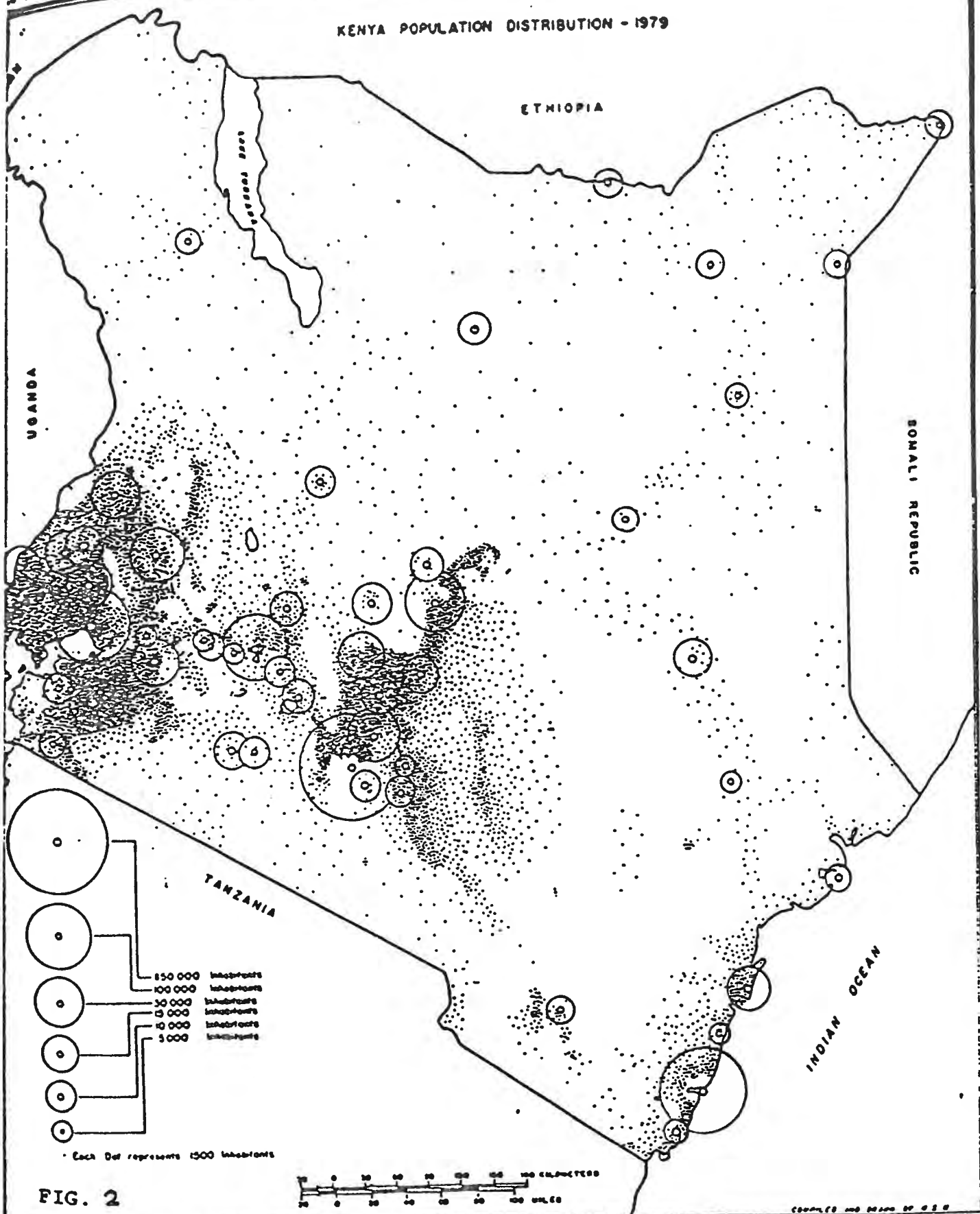

FIG. 2

Large-scale commercial farms in the Highlands include the following:

- Coffee estates
- Tea estates
- Large mixed dairy - maize farms
- Sugar plantations
- Large mixed dairy - maize - wheat farms
- Large mixed dairy - wheat - sheep farms
- Intensive/commercial systems of vegetables, fruit, flowers for export, swine, and poultry

The outputs of these commercial farms are large, but the portion of the population involved is small.

ICRAF (1988) categorizes the principal land use systems in the Bimodal Highlands as follows:

- Coffee-based system
- Tea-based system
- Maize-based system
- Sugar-based system
- Potato-based system
- Food crops based system

All except the last are based on a cash crop. Due to the historical geographical pattern of white settlement and post-independence investments in agriculture, most of the higher value cash crops are found in the Central Highlands. Throughout the Highlands, nearly all purchased inputs are used for the cash crops rather than food crops. All systems have important food crop components grown primarily for farmers' subsistence needs. Dairy is an important element in a number of the systems.

A full 80% of Kenya lies in the Semi-Arid to Very Arid AEZs. These are commonly referred to as the arid and semi-arid lands or ASAL. Soils tend to have a sandy loam texture and have moderate to low fertility. Suitability for rainfed agriculture decreases rapidly with increasing aridity. At least half of Kenya is arid to very arid and highly unsuitable for rainfed agriculture. These are the very sparsely populated areas shown in Figure 2. The arid and very arid AEZs are best suited to extensive livestock and/or wildlife production. Water is a critical limiting factor for livestock and for most wildlife species.

The areas of intermediate population densities in Figure 2 correspond, in general, to the semi-arid AEZ. Depending on which classification system is used, the semi-arid lands of Kenya cover between 8 and 20% of the country. Most of the semi-arid lands were used for traditional pasture lands through the middle of this century. Parts of the semi-

arid AEZ, such as the Machakos District southeast of Nairobi, have been almost completely converted to dryland (rainfed) agriculture. Other areas are very rapidly being converted. The semi-arid lands are the principal agricultural frontier in Kenya. Conflicts between traditional pastoralists and agriculturalists over land rights are common and widespread and are currently a major political issue in Kenya.

Unlike the medium to high potential zones of the Highlands, rainfall is commonly the principal constraint to agriculture in the semi-arid AEZ. Drought is a frequent, naturally occurring phenomenon, and the semi-arid AEZ is characterized by frequent drought-induced crop failures. Rainfed agriculture is characterized by lower potential yields and much higher risk. Few cash crops are grown, and agriculture here is primarily characterized by near-subsistence agriculture. Large scale commercial wheat farms have been developed in some parts of the semi-arid AEZ.

3. SUSTAINABILITY AND LINKAGES

3.1. Regional and Sub-Saharan Context

The Bimodal Highlands of Kenya share many characteristics in common with the East African Highlands of Uganda, Rwanda, Burundi, Zaire, Tanzania and parts of Ethiopia. The semi-arid AEZ in Kenya share many characteristics in common with many of the semi-arid lands throughout Africa. Most of the bio-physical and socio-economic constraints to agricultural sustainability in these zones in Kenya can find clear counterparts in the analogous zones elsewhere in Africa. Few of the constraints are unique to Kenya.

The ecological sustainability of agriculture is based primarily on the question of soil fertility maintenance. If one can sustain the ability of a soil to produce a given level of crop yields over time at a given level of agricultural technology and under similar weather conditions, then one can argue that the agricultural system is ecologically sustainable at the level of the farm unit (Although they should never be ignored, we will not deal here with the questions of regional or world-wide exploitation of non-renewable fossil fuels, phosphate deposits, etc., that may be required to sustain the farm unit). Agricultural technologies and weather patterns are anything but static, however, and long term declines in soil fertility may sometimes be masked or difficult to detect. The introduction of early maturing varieties in semi-arid zones, for example, may increase yields, at least temporarily, while soil fertility continues to decline. Also, there are few cases where crop yields or nutrient budgets have been monitored over time in a way that permits quantification of long term changes.

The development of sustainable agricultural systems in the tropics is, in general, inherently a much more difficult proposition than in temperate zones. Tropical soils are often much older and almost always more highly weathered. The mineral component of tropical soils generally has a much lower ability to hold onto nutrients essential for plant

growth than their temperate zone counterparts. This makes the organic component of tropical soils of much greater relative importance for maintaining soil fertility. However, in the heat of the tropics, organic matter decomposes much more rapidly than in cool temperate climates. The higher the temperature and rainfall, the more quickly organic matter breaks down. As the organic matter is lost, nutrients are lost through leaching or are become bound up in unusable form through complex chemical changes in the mineral content. Soil structure, permeability and water holding capacity are likewise degraded.

Soil erosion is another key factor in soil fertility maintenance. Organic matter and nutrients in tropical soils are generally highly concentrated in the relatively thin upper soil horizon that is the first layer to be lost through erosion. Mineral subsoils are generally very low in nutrient content. Soil exposure through cultivation or overgrazing invariably leads to higher levels of soil erosion with partial or total loss of the most fertile layer of the soil. Accelerated erosion on shallow soils over bedrock may lead to the permanent loss of all agricultural potential of these soils.

Traditional systems of tropical agriculture relied primarily on fallowing, often for extended periods of time, to restore soil fertility. Slash-and-burn agriculture is a common result of farmers' inability to maintain soil fertility. In the humid, lowland tropics, soils can often only support one or two cycles of mono-cropping before the land needs to be fallowed. This problem is less severe in more arid regions where lower rainfall reduces leaching and the rate of organic matter decomposition. It is generally much less severe in tropical highlands where the cooler (more temperate) climate has led to the development of soils with higher levels of organic matter that decompose more slowly.

No soils, temperate or tropical, can be intensively cropped indefinitely without replenishment of nutrients essential to the growth of all crops and other plants. Crops vary widely in their nutrient demands and nutrient content. Nutrients are lost through erosion, leaching and the removal of crops and crops residues. Three nutrients, nitrogen - N, phosphorous - P and potassium - K, are essential to all plant growth. K is concentrated in the non-grain biomass of crops and can be efficiently recycled with good crop residue management. N is highly mobile in the soil and can be fixed organically from the air by trees and crop or forage legumes and can also be fixed by lightning and added through rainfall. P is the nutrient that is the most often critically deficient in African soils.

Phosphorous is an essential nutrient for all forms of life. African soils in general have exceptionally low levels of usable phosphorous. "Eighty-eight percent of soils in Africa are deficient in P to the extent that, without additional P, no other input will bear effect" "World Bank et al, 1994). The problem is especially acute in the high potential soils that were originally fertile and on sandy soils in semi-arid lands. "This situation is typical in the high-potential areas of eastern and southern Africa, particularly in Kenya, Uganda, Ethiopia, Rwanda, Burundi, eastern Zaire, Tanzania, Malawi, Zambia and Madagascar. The Lake Victoria basin is especially affected" (same reference).

Phosphorous is highly immobile in the soil and is not readily leached. About 80% of P taken up by crops is concentrated in the grain of cereal and grain legume crops and is lost to the system when these grains are harvested in much higher proportions than are N and K. Many high potential soils start with a appreciable "capital stock" of P, and continuous cropping of several decades may sometimes be possible before phosphorous deficiency becomes a serious problem. Once the soil's reserves are depleted, however, the only effective way to replenish it is "out of a bag" (Pedro Sanchez, personal communication). The long term sustainability of agriculture relies on external inputs of phosphate fertilizer to a greater extent than for any other nutrient.

The soil chemistry of phosphorous is very complex and strongly affected by the type and amount of clay, by iron and aluminum oxides, by soil pH and by organic matter. P in the soil can be categorized as "agricultural P", "capital P" and "inert P". Agricultural P is that portion that is available to crops during a cropping season. Capital P is that portion that will become available over a 10 year period. Inert P is not available for crops within this time frame.

3.2. Soil Fertility and Agriculture in Kenya

Agricultural sustainability has not, historically, been recognized as a significant problem in Kenya and is not widely recognized today by policy makers and donors as a major problem today. Nearly all of the researchers and other professionals that deal with issues of soil fertility and that were interviewed by the NRM Team, however, are very concerned that sustainability is becoming a critical problem for huge numbers of smallholder farmers and that the problem may get much worse over the next one or two decades. This is of critical importance to Kenya, because agricultural sustainability is critical to food security, political stability, the economy and nearly all of the natural resource base of Kenya.

Agricultural sustainability has not historically been a major problem for the following reasons:

- Population densities and the corresponding intensity of agricultural pressures on the land in the recent past were nothing like those of today. The population of Kenya is three times greater than it was thirty years ago. There is no historical precedent for such an increase. The subdivision of farms into smaller and smaller units, the reduction and then abandonment of fallows are recent phenomenon.

- Population and agriculture have been strongly concentrated in the Highlands, especially in the high potential AEZ, where the cool, relatively temperate climate and fertile soils present some of the most ecologically favorable conditions for agriculture in sub-Saharan Africa. It takes longer to deplete the natural fertility of these soils than for most other sub-Saharan soils.

- The agricultural sector in the Highlands has been relatively dynamic and progressive. Farm ownership is almost completely privatized. Technological advances have been rapid, agricultural research and extension function relatively well, and cash crops are grown by many of the smallholders. There has also been a major extensification of agriculture within the Highlands, especially into the medium potential AEZ, in the last 30 years. This has served to relieve some of the pressures on the land.

Indicators of unsustainability

Although there have been no comprehensive surveys on soil fertility maintenance and farm-level nutrient budgets in Kenya, there are many indicators of a growing, widespread problem of sustainability. These include the following:

- A National Task Force led by ICRAF conducted a characterization and review of all the major agricultural land use systems of the Bimodal Highlands in Kenya in 1988 (ICRAF 1988). The coffee, tea, maize, potato, sugar and food crop based systems all include large acreages of land dedicated to food crops for local consumption. The Task Force found a significant problem of declining soil fertility and declining yields on lands dedicated to food crops for farmers own needs in all the land use systems throughout the Bimodal Highlands. While fertilizers are used widely on cash crops, the amounts used on their food crops are totally inadequate for maintaining soil fertility. This report, however, does not quantify the extent of the problem.

- The Maseno area northwest of Kisumu is typical of the population densities (600-1000/sq. km) of much of the Western Highlands; ICRAF scientists believe that the soil fertility problems are also representative of much of the area. Over half the farms are less than 1.2 has. in size. Over half the farmers are getting maize yields of less than 0.5 tons/ha/season. On-farm trials have clearly demonstrated that P deficiency is clearly the limiting factor. Adding P alone often increase yields over five-fold. On-station yields with a balanced fertilizer application and appropriate varieties have given yields of 8-10 ton/ha/season.

- A 15 year soil fertility study done by KARI at their Nairobi headquarters has shown that yields on excellent soils declined from 4 tons/ha to 1 ton/ha on the control plots over this period where no chemical or organic inputs were made. Furthermore, soil organic matter continues to decline on all treatments even where crop residues, manure and chemical fertilizers are routinely added.
- Surveys around Mount Elgon show that farmers perceive their yields to be falling dramatically.

- The problem is not limited to the Highlands. ICRAF has found that P deficiency becomes a serious problem after about 40 seasons (20 years) of maize cropping in the Machakos District (semi-arid AEZ). Probert and Okalebo (1992) reported, "It is now

apparent that phosphorous deficiency is likely to be a limitation to crop growth on much of the croplands of the semi-arid areas of eastern Kenya."

Contributing factors

Sustainable agriculture seems to be particularly problematic in areas with the following characteristics:

- High population densities and very small farms.
- Subsistence agriculture with minimal cash crops or other sources of cash income.
- Lands dedicated to food crops for farmers own needs, even when cash crops are grown on other lands within the same household production units.
- Soils with high levels of phosphorous-binding clays and iron oxides.
- Semi-arid and arid AEZs where continuous cropping is practiced, especially with maize.
- Zones of low elevations and high temperatures.

The most severe problems of soil fertility maintenance seem to be closely associated with poverty and near-subsistence agriculture. In the medium to high potential AEZs, the most affected area seems to lie between Kisii and Kakamega in the Western Highlands. This is the area of highest population density with 600-1000 people/km2. Average farm size is around 1 ha. and continually getting smaller as the population grows. Cash crops are not nearly as important as in the Central Highlands and have gone downhill, partially due to sectoral mismanagement. Soils are generally high in iron and highly depleted in P. Very few farmers use anywhere close to the levels of fertilizers needed to maintain soil nutrients levels, especially of P. Small amounts of soluble phosphate fertilizers are quickly bound up with iron and have relatively short-lived residual effect on crop yields. Most farmers highest priority use of their limited expendable cash is for school fees rather than agricultural inputs.

Farms below one hectare in size are often considered to be "poverty traps". It is argued that below this approximate threshold, most families dedicate nearly all their land and resources just to produce the crops and bare necessities needed for their subsistence. The average farm near Maseno has one hectare of fields yielding 400-900 kg of maize per season. For a family of 10, this is 80 to 180 kg. of maize per capita per year. Such farmers have little opportunity to make needed investments to restore fertility and to convert to higher value cash crops, even if ecological and markets conditions would permit.

Such near-subsistence farmers are also caught in an ecological trap. With no possibility of purchasing fertilizers to replace depleted soil reserves of phosphate or other nutrients from their soils, crop yields continue to decline. Crop biomass production also declines, yielding less residue for livestock and soil organic matter maintenance. Less crop residue favors higher soil erosion. Erosion and lower soil organic matter leads to still lower soil

Table 2 SUMMARY OF MAJOR CONSTRAINTS IN KENYA LAND USE SYSTEMS

	COFFEE	TEA	MAIZE	SUGAR	POTATO	FOOD
Declining wood supplies	X	X	X	X	X	X
Erosion of cropland	X	X	X	X	X	X
Erosion of coffee plot	X	X				X
Erosion of pasture land		X	X	X	X	X
Erosion under newly established tea		X				
Declining soil fertility in cropland	X	X	X	X	X	X
Declining soil fertility in pasture		X	X	X	X	X
Declining soil fertility in coffee plots	X	X				X
Low quantity and quality of fodder	X	X	X	X	X	X
Soil moisture deficit in dry season	X	X				
Inadequate mulch material (coffee plots)	X	X				X
Inadequate planting materials of MPTS	X	X		X		
Labour scarcity	X	X	X	X		X
Inadequate cash income	X			X		X
Hail damage	X	X				
Reliance on unimproved crop varieties						X
Low crop yields						
Frost damage					X	
Poor fruit and vegetable market		X			X	
Poor weed control				X		

fertility. Lower fertility leads to greater poverty. A high percentage of farms in the Western Highlands are too small to be economically viable units. Half of the farms around Maseno are under 1.2 has. A significant portion of the population will be forced to leave the farms or else be supported through food relief.

In the semi-arid areas like most of the Machakos District, nearly all farms are primarily subsistence. Few cash crops are grown in the semi-arid regions, especially at the smallholder level. Crop failures occur at high frequencies; this frequency is inversely proportional to average rainfall. Frequent crop failure makes use of chemical fertilizer a very high risk investment, and very little chemical fertilizer is used. There is generally less problem in the semi-arid AEZ with high iron soils, but P levels are characteristically low. Phosphate deficiency in addition to drought becomes increasingly a limiting factor to crop production over time. Twenty years or more of cropping may be possible before this becomes a major constraint.

The semi-arid soils generally have lower initial levels of organic matter. The organic matter decomposes under cultivation; this occurs more rapidly the higher the ambient temperature. Agriculture generally becomes an increasingly high risk, unsustainable undertaking with increasing aridity and higher temperatures.

The Machakos District of dryland farming has recently gained wide acclaim as the most successful case of soil conservation in Africa. The 1994 book, "More People, Less Erosion" (Tiffen, et al) argues that rapid population growth in Machakos has led to better land husbandry and overall environmental improvement, that rapid population growth has, indeed, been the cause of environmental recovery.

This conclusion is contrary to most literature and conventional wisdom on dryland farming in Africa and is being strongly contested by key individuals who have worked intensively in the Machakos District. The debate centers on the sustainability of agriculture and grazing in the Machakos District and on the question of soil fertility maintenance. Even Tiffen states, "the only area where improvement in resources is in doubt is in the maintenance of soil fertility levels." The book presents only a cursory analysis of the problem of soil fertility maintenance, but their own information presented on pages 114-117 of the book would indicate a significant downward trend in soil fertility with time on soils under cultivation. Dr. Bob McCown (1995, in draft) uses the books own data to show that average food crop production per hectare has been declining since about 1960 in Machakos District, despite the fact that much of the currently cultivated lands has only been converted to agriculture in the last two decades.

3.3. The Sustainability of Rangeland Management

As cited previously, over 70% of Kenya is arid to very arid. Most of this land is highly unsuitable-suitable for rainfed agriculture. It includes many of Kenya's magnificent national parks. Most of the semi-arid regions were originally used for traditional pastoral

rangelands. Nearly all of the arid and very arid regions are still used for extensive livestock production of cattle, goats, and other livestock. Access to water is critical for both wildlife and livestock throughout the ASAL. Large portions of the arid northeast are politically insecure with little presence of the technical ministries or of development organizations. Some areas have been under little government control since independence.

Range management and game ranching can be sustainable land use systems in these areas if properly done. Many of Kenya's rangelands are badly overgrazed, however. Large portions of these areas have been seriously degraded through overgrazing. Much of the degradation began during the colonial period when closure of the dry season pastures in the Highlands and other restrictions on movements of pastoralists and their herds lead to overgrazing in the ASAL, especially around permanent water sources like Lake Baringo. A 1981 study estimated that the resulting accelerated erosion around Lake Baringo had deposited 64 million cubic meters of silt in the lake in the previous 12 years and had reduced the average lake depth by 0.4 meters (Peter de Groot et al, 1992). The entire lake may become a large marsh.

Most of the livestock production in the ASAL is still in the hands of traditional pastoralists (such as the Maasai) who continue to place a high cultural value on the total number of livestock owned by each family unit. Overgrazing is a common result. The NRM Team witnessed this directly around Lake Baringo, throughout the Narok area north of the Maasai Mara and in other areas as well. The very arid lands from northern Tsavo north to Ethiopia west to Lake Turkana are reported to be severely degraded from overgrazing. Most of this area is not accessible without armed escort due to widespread security problems. Very arid lands generally are the slowest to recover once severely degraded.

Most of the soil organic matter and soil nutrients are usually concentrated in the upper 10 centimeters of soil. Wherever overgrazing has resulted in loss by erosion of all or much of this critical layer, the potential productivity of the rangelands has probably been permanently reduced.

Much of the semi-arid lands have been subdivided into Maasai group ranches. Some of these are severely overgrazed, as witnessed north of Maasai Mara. Others are in much better shape, as in the Laikipia area.

3.4. Demography, Agriculture, Employment and Natural Resources

Population growth combined with the problem of agricultural sustainability together pose the greatest threat to natural resources in Kenya. Kenya has experienced an exponential demographic growth rate since independence that is almost without parallel in the world. The population has increased from under nine million in 1963 to the current population of 26 million. Statistics are disputed, but it appears that demographic growth peaked at around 4% in 1989 and has recently decreased sharply to about around 3%. Half the

population is 15 years old or younger; most of these 13 million young people will be entering the work force and starting new families over the next two decades. About half these young people are in the Western Highlands.

Where will these 13 million people go? About 80 % of them live in rural areas. Their options seem limited to staying where they are through inheritance/subdivision of existing farms, to seeking off-farm employment in cities and towns, to supplementing farm income through small enterprises or to starting new farms where land is still available and accessible/affordable. This is primarily in the ASAL.

There will be an average of over a half a million new job-seekers per year from now to the end of the century. About 270,000 new jobs are created annually, but many of them do not represent not full time employment. 98.6% of new enterprises in Kenya have 10 employees of fewer. 73% of people employed work in these micro-enterprises, but a large portion of these people do not have full-time jobs. Medium and small enterprises employ a total of 2 million people. 78% of employment is in rural areas (including villages of less than 2000 people).

The rate of creation of new, full-time equivalent jobs, is probably far below the rate of entry of new job-seekers. One may hope that macroeconomic reforms and liberalization will turn this around, but almost no one expects off-farm employment to absorb more than a fraction of these people. One may expect the following trends:

- Farms will continue to be subdivided through inheritance leading to higher population densities in rural areas, smaller farm size and more people caught in the poverty trap of economically and ecologically unviable farm units.

- Large numbers of people will be forced to leave the most densely populated rural areas as yields fall and farms become too small to meet subsistence needs. Some will swell the ranks of the unemployed or the marginally employed in the urban centers.

- There will be tremendous pressures to bring new lands under cultivation.

> **It is this pressure to clear new lands for agriculture that poses the greatest threat to the natural resource base of Kenya for it threatens the centers of biodiversity, the wildlife and national parks, the most productive forest lands and the fragile semi-arid and arid lands rangelands.**

Nearly all non-forest land in the Highlands is already under private ownership and land prices are high. Although there is still a surprising amount (reputed to be 30%) of privately owned, uncultivated land in the medium and high potential AEZs, it may be

that few of the migrants will be able to afford to purchase such lands. Land pressure on the Highlands may take the following forms:

- Pressures to degazette or to illegally occupy government-owned forest plantations will increase. Most forest plantations lie on rich soils of high agricultural potential. Plantations are especially vulnerable to "squatters" following final harvest and before a new crop of trees can be established. These plantations are a major economic resource of Kenya.

- Pressure to degazette or to illegally clear natural forest reserves and the national parks in the Highlands will increase. Remaining natural forests like Kakamega are the principal remaining centers of terrestrial biodiversity in Kenya.

As these forested areas are small in area and do receive varying levels of government protection, the principal rural-rural movements can be expected to be off of the Highlands onto increasingly arid lands at ever lower elevations with higher temperatures and ecologically more and more fragile conditions for rainfed agriculture. Extensification of agriculture onto these lands is already taking place and the movement is almost certainly accelerating. Indeed, some people have compared the rush to acquire control of lands in Kenya to that of the American West in the 1800's.

Extensification is not at all homogeneous by AEZ. Machakos District runs from a sub-humid 1000 mm per year down to an arid 500 mm per year. Nearly all of this District is already occupied by farmers and the agricultural frontier is now east of the District. On the other hand, the most rapid area of agricultural expansion in Kenya at present is probably the forest clearing southwest of the Mau Escarpment in the largest remaining block of subhumid forest in Kenya. There has been a general movement into the Rift Valley, one of the areas that is currently the object of hotly contested ethnic land claims.

Laikipia District is another area of rapid subdivision and conversion to agriculture. It is reputed that land development companies obtain large blocks of land and bring potential buyers from the Western Highlands during the peak of the rainy season when the ASAL are lush and green. They offer land at what seems incredibly low prices compared to prices in the medium and high potential zones. Migrants commonly try to directly transplant their agricultural technologies, often with very disappointing results.

The ultimate extent of agricultural extensification will ultimately depend on how desperate people become. This will depend on the extent of continuing demographic growth, on the availability of other economic alternatives and on the sustainability of present and future agricultural systems. In some places in the Sahel such as the Tahoua Department of Niger, desperate subsistence farmers have cleared virtually all lands down to the 200 mm average annual rainfall and below. This is roughly equivalent to 400 mm of annual rainfall with a bimodal distribution at low elevations in Kenya. If this were to occur, it

would be an ecological disaster for Kenya's wildlife, national parks, its rangelands, its water resources and its people.

This grim scenario could happen in Kenya but it can be averted through the concerted action of government, NGOs, private sector and donors. Averting this disaster will require a three pronged strategy:

- Continued, major emphasis on family planning and decreased demographic growth to reduce pressures on the land over the mid to long term.

- Continuation of macro-economic reform and liberalization with the objective of massively increasing off-farm employment opportunities.

- Identification, development and extension of sustainable, intensified agricultural production systems in both the medium to high potential and the semi-arid AEZs wherever these systems do not exist.

3.5. The Role of Agroforestry in Sustaining Agriculture

Agroforestry can play a key role in enhancing the sustainability of agriculture in the Highlands and in the semi-arid AEZ, but will not provide any miraculous solutions to the problem.

On-farm tree planting Agroforestry can be simply defined as the planting of trees on farms. Overall, the integration of trees into smallholder farming systems in Kenya has been remarkably successful. The most densely populated areas of Kenya, the Central and Western Highlands, are much more heavily forested today than they were three decades ago. Nearly all rural areas seem to be largely self sufficient in woodfuels. Trees are an important cash crop, an interest-bearing capital investment that farmers manage, save and harvest at critical times to meet their needs.

The most significant plantings on smallholder farms are typically border plantings of trees that attain pole or sawtimber size. In the Central Highlands the major species planted is Grevillea robusta; in the Western Highlands, it is eucalyptus. Cypress (Cupressus lusitanica) is also common in both areas. Although these plantings result in net decreases in crop yields, at least in the short term, their overall net benefit to the farm family economy is clearly perceived to be positive.

The standing volume of planted trees in farmlands in the Highlands is estimated at over 40 million cubic meters. This is greater than the estimated standing volume of industrial forest plantations. Furthermore, standing wood volumes are directly correlated with rural population density. The increase in standing volume of planted trees on farms has been

estimated to have increased at the rate of 4.7%/yr between 1986 and 1992 (P. Holmgren et al, 1994).

Key factors that have contributed to the widespread success of smallholder agroforestry plantings in Kenya are the following:

- Private ownership of smallholder farms, secure land tenure and minimal practice of share-cropping or lease-holder cropping.

- Minimal government restrictions on farmers' rights to freely harvest and market wood products from trees they have planted on their own farms.

- Three separate government extension services promoting on-farm tree planting, active NGO involvement and large numbers of private and government owned tree nurseries.

Agroforestry and soil fertility maintenance

Perhaps the most exciting promise that agroforestry held for the tropics in the early 1980's was the prospect of continuous cropping at moderately high yields with no additions of chemical fertilizers through the intimate association of woody plants with agricultural crops. The principal agroforestry technique that was specifically designed to assure soil fertility maintenance is commonly called alley cropping or hedgerow intercropping. Hedgerows of fast-growing, Nitrogen-fixing woody species are planted in parallel bands a few meters apart and crops are planted in the "alleys" in between. It is based on the following principles:

- The root systems of the hedgerows fully exploit the soil of the cropped alleys and capture and recycle any free nutrients that would otherwise be lost to leaching, especially before early in the cropping season before the crops root systems are well established.

- The deep roots of the woody hedgerows bring nutrients up from the subsoil that are beyond the reach of shallow-rooted crops.

- Nitrogen-fixing hedgerow species add Nitrogen to the system.

- The hedgerows are clipped several times a year with the clippings returned to the soil to maintain soil organic matter and soil nutrients.

Alley cropping has enjoyed very limited acceptance by farmers in Kenya, as it has elsewhere, for the following reasons:

- The hedgerows also compete with the crops for moisture, nutrients and sunlight, and the net effect on crops is too often negative.

- Clipping the hedgerows is very labor intensive and often competes with scarce labor at critical times.

- The deep roots of woody plants can't "recycle" what isn't present in the subsoil. Most tropical subsoils are extremely poor in essential nutrients.

Current thinking at the International Center for Research on Agroforestry (ICRAF) is that competition for soil moisture will probably make alley cropping impractical in any zone with less than 700 mm rainfall per cropping season. This makes it impractical for all of the semi-arid AEZ and part of the more humid zones. It seems to hold little more promise in the high rainfall zones. Even at Maseno in the Western Highlands with 1800 mm/yr., the acceptance of alley cropping in on-farm trials with 50 farmers between 1988 and '93 was very poor. The main problem was considered to be competition for sunlight.

Promising Aspects of Current Agroforestry Research

Although alley cropping itself may have little potential in Kenya, other tree/crop configurations hold potential for increasing the sustainability of soil fertility maintenance and of agricultural systems. Indeed, most on-farm trees probably contribute to some degree. The challenge is to find the best species in the optimal tree/crop management regime for the different ecological conditions and farming systems. Promising species/techniques include the following:

Identification and integration of high value woody species into farming systems

ICRAF scientists believe there is a large potential for greatly increasing the value of multi-purpose tree species planted on farms. This includes improved germplasm for species already planted, domestication, diversification and varietal improvement of fruit trees and completely new species. One proposal that presents a strong revenue making potential is the domestication of *Prunus africana*, a tree native to tropical montane areas in many parts of Africa. The bark of this tree is used to produce a pharmaceutical for treating cancer of the prostrate. The overall market value of the trade in the bark of this tree is estimated at $US 150,000,000 per annum. The tree shows good potential to be grown as an agroforestry species.

Grevillea intercropping Grevillea robusta is planted widely by farmers in the Eastern Highlands and increasingly in semi-arid Machakos District. It is proving to be a tree of remarkable compatibility with food crops. It has two very special characteristics:

1. Most of its roots go deep below the rooting zone of maize and other crops. Its sparse network of shallow roots do not compete strongly for soil moisture.

2. Grevillea has a unique ability to access phosphorous that is bound to iron oxides and that is otherwise unusable to most plants. The phosphorous may be made available to crops, although this has not yet been quantified.

Farmers have learned on their own that they can minimize water competition with food crops during drought by cutting all branches off the Grevillea. The tree will grow new branches. Grevillea also has a thin crown that allows adequate sunlight to pass through for maize. Maize can be grown beneath a nearly closed stand. The tree produces firewood and valuable sawtimber and can be treated for post and poles. Although not common as yet in the Western Highlands on high iron soils, Grevillea may have a potential in this region for accessing bound phosphate and inputting it into the cropping system.

Phosphorous "pumping" by woody species

ICRAF researchers at the Maseno Station observed an unexpected, very marked increase in maize yields on plots where hedgerows from alley cropping trials had just been removed. Although the trial was not designed to test the effects of the removal of hedgerows on soil fertility, the yield increase is attributed to iron-complexed phosphate that was accessed by the hedgerow species, and released in an available form when the root systems decomposed. This fortuitous result presents the prospect of identifying appropriate species for improved, short duration woody fallows to increase available phosphate levels, soil organic matter and improved soil fertility.

Melia volkensii

This is an indigenous species native to the semi-arid areas of Kenya and has just been identified as a very promising agroforestry species. It is much faster growing than most semi-arid species and loses its leaves twice per year. It appears very promising for intercropping in dryland systems, but tests have not yet begun. Its leaves contain a strong pesticide.

Agroforestry species as Striga "traps"

The flowering parasitic plant Striga is a major and growing problem on maize and other food crops. It the Western Highlands, it is second to phosphorous deficiency as the principal constraint to crop production. Recent observations by ICRAF indicate that certain woody species can serve as a biological trap that can trigger the germination of Striga seeds in the soil at a time when no crops are present. The seeds die after germination for lack of a host.

Practical Techniques for Studying Evapotranspiration and Water and Nutrient Budgets for Woody Plants

Competition for water and nutrients between woody perennials and agricultural plants in agroforestry systems has been one of the most critical and one of the most difficult phenomena to study and to quantify. ICRAF scientists appear to have recently made a major breakthrough in developing relatively simple and inexpensive instrumentation to study these interactions. Not only can total water demands on individual trees be monitored throughout the day, but also the relative supply of water from shallow roots that compete with crop plants and that of deep roots that do not, can also be quantified. Furthermore, sampling of the nutrient content of the sap of shallow roots will permit quantification of nutrient competition with agricultural crops. Sampling the nutrient flow from deep roots will permit quantification of the nutrient input that comes from the subsoil beyond the reach of shallow-rooted annual crops. This should permit much more rapid and effective analysis of tree-crop compatibility.

3.5. The Role of Soil Conservation in Sustaining Agriculture

Kenya has done an exceptional job overall with physical soil conservation measures for controlling erosion. Border plantings, hedgerows, contours grass strips and contour plowing all reduce erosion and are very common throughout the Highlands. The widespread application of physical soil conservation practices in the Machakos District in the semi-arid zone southeast of Nairobi may be the most successful examples of soil conservation in sub-Saharan Africa.

Physical soil conservation measures have been the most successful in the Highlands. Land tenure is deeded and secure. High population densities and land fragmentation have favored soil conservation. Border plantings are extremely common, and very often form vegetation strips that prevent soil from being lost from one farm to the next. Contour strips of forage grasses (especially napier grass) and hedgerows are less common, but still widespread. If maintained over time, they will lead to the formation of terraces as they capture soil moved downslope by cultivation and water transport. Inadequate attention has been given to their spacing, however. They are generally too widely spaced; most of them would eventually lead to the formation of terraces with headwalls of over 2 meters. This will lead to deep burial of the best topsoil and increase the risk of failure of the headwalls during exceptional rainfall events.

The Swedish International Development Agency (SIDA) has a long-standing soil and water conservation extension program that started in 1974. They support the extension service of the Ministry of Agriculture. The project now covers the whole country and has reached 1.4 million farmers. SIDA considers it to be one of their most successful programs anywhere. The main soil conservation techniques extended have been the following:

- "Fanja ju" or near-contour, large, widely spaced, infiltration ditches in which fruit trees are planted
- Contour grass strips
- Contour trash lines
- Woody perennial hedgerows
- Diversion ditches

Although trends are positive, there are probably few areas where soil erosion has been reduced to sustainable levels. It was cited as a significant constraint in all the agricultural production systems in the Bimodal Highlands by ICRAF (1988) The problem risks becoming more severe in areas where soil fertility continues to decline due to less ground cover from crops and lower infiltration rates resulting from less organic matter.

4. CONSTRAINTS AND OPPORTUNITIES

Principal constraints that have been identified are the following:

- 1. Lack of a comprehensive understanding of the nature and extent of the problem of agricultural sustainability in Kenya and of its future implications.

- 2. Lack of recognition of the severity of the problem on the part of high-level government officials, policy makers, the general public and the donor community and the lack of simple, graphically illustrated materials for presentation to these different stakeholders.

- 3. Lack of focused research leading to the definition of sustainable agricultural systems for the different agroecological niches in Kenya.

- 4. Lack of appropriate policies and institutional frameworks to guide the transition to sustainable systems.

4.1. Incomplete Understanding of the Problem

Constraint Although there is widespread agreement amongst nearly all scientists who deal with soil fertility maintenance and different aspects of sustainable agriculture in Kenya that Kenya is facing a serious problem with the sustainability of its agricultural systems, there is no overall grasp of the severity, the geographical extent, the numbers of people affected, the rate of change and the future implications of the problem.

Opportunity An in depth, multi-disciplinary study should to be undertaken to define the nature, severity and implications of the problem. The analysis should include the following:

- Analysis of the sustainability of the present agricultural systems in Kenya.
- Definition of the technical and socio-economic factors affecting sustainability by agroecological zone and by agricultural system.
- Analysis of the "state-of-the-art" knowledge of what is needed to achieve sustainability of those systems that are not.
- Review/inventory of the land resources available for the extensification of agriculture in Kenya. The review should include present land use/land cover, land tenure and analysis of the sustainability of agricultural development of these lands. This component should make strong use of existing digital geo-referenced data bases and GIS capabilities in Kenya.
- Geographical analysis of the dynamics of the on-going extensification of agriculture.

Analysis of the implications of the problem should project future trends over the next 20 to 50 years based on a range of scenarios. Key factors should include the following:

- Future demographic growth.
- Future off-farm employment opportunities
- Future potential for intensifying agricultural production systems.
- Future policy options.

Each scenario should project future socio-economic and environmental impacts.

This study could be Kenya specific or part of a general study for the Horn of Africa or the East African countries with highland agriculture. The study should culminate in a technical conference to present and debate the nature of the problem and to define strategies and policy options.

4.2. Lack of Awareness of the Problem.

Constraint Outside of the scientific community, there is little awareness of the severity and implications of the problems of agricultural extensification and sustainability. Government officials, policy makers, the private sector, the general public and the donor community need to know what Kenya's options are and the implications of each option in order to make informed decisions.

Opportunity If the study proposed in 4.1. is realized, it would be a simple step to convert its results into a range of simple, graphically illustrated materials targeted for the different stakeholder groups. Such materials should be prepared by communications media professionals. A particularly powerful tool are the computer-aided graphics presentations prepared by the Futures Group under the centrally-funded RAPID Project for countries such as Rwanda and Madagascar. Such models can dramatically illustrate the environmental/natural resources impacts of demographic growth, off-farm employment creation and extensification of agriculture.

Once such materials are prepared, they need to be followed by a program of broad dissemination to the different groups concerned.

4.3. Research on Sustainable Agricultural Systems

Constraint Although a wide range of research has been and is being done on different aspects of soil fertility maintenance and agricultural sustainability, no one seems to be able to define at present the appropriate mix of technical and socio-economic factors needed to assure sustainable agricultural systems in the different agro-ecological zones of Kenya.

Opportunity A subcomponent or a natural follow-on to the study proposed in 4.1. would be the design of a coordinated research program with the objective of defining sustainable agricultural systems. Such a research program should also define the conditions under which rainfed agriculture cannot be sustained given present or foreseeable agricultural technologies and socio-economic conditions. The definition of sustainable systems must include the following critical issues:

- Soil fertility maintenance. How can one avoid short to long-term nutrient depletion of soils. Closely associated with this is the issue of soil organic matter maintenance.
- Socio-economic size and characteristics of the farm unit. Most, if not all, agricultural systems will require periodic outside inputs of purchased fertilizers to replace net losses from the farm nutrient budgets. This will generally necessitate some portion of the farm being dedicated to cash crops or some other source of non-farm income.

Definition of sustainable systems will need to integrate research from the following disciplines:

- Soils mapping
- Soil chemistry/soil fertility (especially on P)
- Soil organic matter management
- Fertilizer use (NPK, liming, etc.)
- Socio-economic research
- Agroforestry
- Tillage
- Soil conservation (erosion control)
- Water and soil moisture management

Sustainable systems will generally require a higher level of farm management and will require a higher level of diagnostic capability on the part of extension agents.

4.4. Institutions and Policies

Constraints Policies and institutions are not focused on sustainability of agricultural systems. Government policies support the idea that agricultural land is still a relatively unlimited resource, that every Kenyan should have the right to own a piece of land. Distribution of tracts of land to the landless are highly publicized in the media. The resulting perception of land as an unlimited resource does not favor family planning: the perception of limited resources is increasingly recognized as an important condition leading to smaller family size. The constitution and laws give the private landowner almost free reign to use or abuse his land as he pleases.

The Kenya Agricultural Research Institute (KARI) includes soil fertility research in its programs, but does not focus on sustainable agricultural systems. The socio-economic unit at KARI is relatively new and weak. Most socio-economists assigned to KARI's regional centers are relatively junior and not well integrated. KARI needs to improve its systems for priority setting and for integrating the geographic focus of each regional center with KARI's national research programs. Adaptive research at the local level needs to be strengthened. On-farm trials do not receive the emphasis needed.

Agricultural research is not linked nearly as closely to agricultural extension as it should be. The Training and Visitation (T&V) extension system supported by the World Bank may not be the optimal system for Kenya. It is very time intensive for KARI scientists, it is very costly and manpower intensive and is strongly focused on NPK and improved varieties.

Opportunities Kenya now has a multi-party system with a basically free press and relative freedom of speech. There is opportunity, however imperfect, for organizations and individuals to affect natural resource policies.

Kenya benefits greatly from the presence of the international headquarters of the International Center for Research in Agroforestry (ICRAF). ICRAF is well integrated with the two Kenyan national research programs of KARI and the Kenya Forestry Research Institute (KEFRI). ICRAF's one and only self-managed agroforestry research center is located in the dryland farming zone at Machakos. Soil fertility maintenance is a strong component of ICRAF research.

KARI is the second largest national agricultural research center in sub-Saharan Africa outside of South Africa and the most competent in East Africa. While not without its problems, it is a functioning center capable of doing credible research.

4.5. Soil Nutrient Balance and Fertilizer Use

Constraint: The use of fertilizers needed to maintain the nutrient status of crop soils is inadequate because of high costs, inappropriate recommendations on types and rates of

application and inappropriate marketing. Until 1994, the Ministry of Agriculture had only three fertilizer recommendations for the country -- one for the Western Highlands, one for the Central Highlands and one for the coastal area -- this despite the mosaic of soil types, crops and farming systems that characterize Kenyan agriculture. Government extension agents are reported to be very poorly trained in the calculation of applications rates for farmers. Even officers supervising entire districts often need to be retrained in this area. Virtually no soil testing services exist for small farmers.

A more intractable constraint is the high cost of fertilizers and the low purchasing power of farmers, especially for fertilizer use on food crops. Nearly all fertilizers used in Kenya are imported. Overland transport costs from the coast greatly add substantially to their costs. One exception is a small plant in Thika that produces about 5000 tons of simple superphosphate fertilizer per year from rock phosphate imported from the Minjingu deposits in Tanzania.

Opportunities Rapid progress has recently been made on making fertilizer recommendations much more specific. This has been done through the Fertilizer Use and Recommendations Project (FURP) that works through KARI. Soil testing was done throughout the Highlands and brochures with fertilizer recommendations by more localized zone are currently being printed. Extension officers are being retrained, sometimes with considerable resistance in areas where the new recommendations differ strongly from the old. The data from the soil testing is being entered into a geo-referenced data base.

The principal opportunity for reducing costs of fertilizers is in the development of local and regional reserves of phosphate rock. As shown in Figure 3, there are several deposits in and near Kenya. The highest quality deposit near Kenya is the Minjingu deposit near Arusha, Tanzania. Minjingu phosphate rock "has a high relative agronomic potential and compares favorably with the best PR in the world." (IFDC, 1990). The Minjingu deposit and others present a real opportunity for Kenya and other countries in the region to address the widespread occurrence of phosphate deficiencies on crop soils.

Another phosphate rock deposit is located at Tororo in Uganda right next to the Kenya border with the Western Highlands where phosphate deficiencies are the most acute. Commercial development of the Tororo deposits was undertaken in the past, was abandoned during the period of civil unrest and may be restarted in the near future. As phosphate rock can be processed and applied in many different forms, the agronomic and economic potentials of these local phosphate rock deposits need to be fully evaluated and developed as appropriate.

Costs of phosphate fertilizers were collected as part of a regional data base on phosphate rock prepared by the Tropical Soils and Biology and Fertility (TSBF) office in Nairobi. Cost per kilogram of elemental P of phosphate fertilizers sold in Kenya in 1994 were $4.50/kg of P for the simple super phosphate produced at the Thika plant, $2.50/kg for

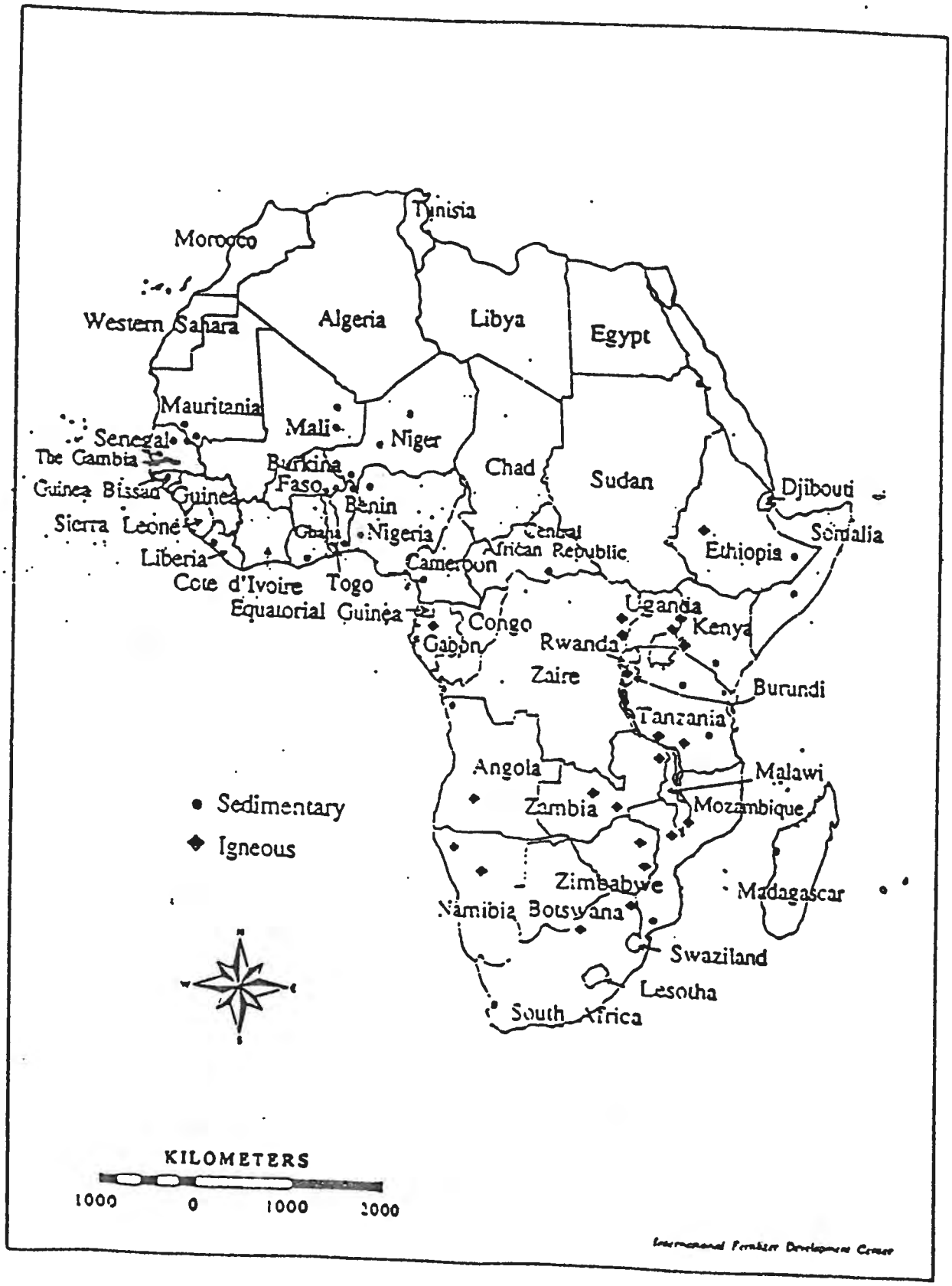

Figure 3 Phosphate Deposits in Sub-Saharan Africa.

commercial fertilizers brought in by donors and $0.47/kg for finely ground, bagged phosphate rock from the Minjingu deposits.

The solubility of phosphate rock and the corresponding agronomic response is strongly affected by soil acidity. The more acid the soil, the more quickly the phosphate rock is converted to a soluble form usable for plant growth. Studies at Sokoine University in Tanzania compared the agronomic effectiveness (RAE) of the Minjingu phosphate rock to that of triple superphosphate as a function of soil pH. The RAE was low (24%) for soils with a pH of 6.6 or greater; medium (49%) for soils with a pH around 5.2; and high (125%) for very acid soils with a pH around 4.6. The pH of crop soils in the Western Highlands runs about 5.0 to 6.5 with an average around 5.7.

Even if costs of phosphate fertilizer can be significantly reduced, the costs of replenishing the soils capital stock of phosphate will probably be beyond the means of most smallholders. ICRAF scientists estimate that an average of approximately 250 kg of elemental phosphate per hectare may be needed in the Western Highlands. The GOK and their donors partners need to develop strategies for addressing this problem. Strategy options should include the possibility of a one-time subsidy with the goal of aiding near-subsistence farmers to make the transition to commercially and ecologically viable production units.

5. USAID PROGRAMMING OPPORTUNITIES

A range of programming options have been identified under which USAID could contribute to the task of enhancing agricultural sustainability and, concomitantly, food security and environmental stability in Kenya. Furthermore, the problems described above are not unique to Kenya but are largely held in common with the other countries of the Greater Horn of Africa. Regional approaches should be pursued as feasible. Strategies developed in Kenya may find applicability throughout the region. There is also considerable opportunity for integrating Mission programs in agriculture, population and health and in small enterprise development.

Programming options include the following:

5.1 Support for Research on Sustainable Farming Systems

5.1.1. Situation There is general recognition within the scientific community that Kenya faces a significant problem of unsustainability in many of its agricultural production systems, but no one has defined the geographical extent of the problem, the number of people affected, the severity of the problem and the overall trends. Furthermore, KARI, ICRAF and KEFRI are all doing research on different components of sustainable agricultural systems, but no one seems to be synthesizing this research to define the overall technical and socio-economic components or minimum requirements for sustainable agriculture in the different agro-ecological zones of Kenya. This is necessary

for developing and implementing policy reforms that will be needed to make the transition to sustainable systems.

5.1.2. Objectives:

- Preparation of an overview of agricultural sustainability in Kenya

- Definition of the minimum requirements for sustainable agricultural systems in the principal agro-ecological zones of Kenya.

- Definition of the policy and institutional reforms needed to make the transition to sustainable agricultural production systems.

5.1.3. Strategies:

- Characterize the agricultural production systems of Kenya by biophysical and socio-economic parameters, analyze the sustainability of these systems, quantify the nature of the problem and the trends, estimate the number of people affected and prepare an overview report.
- Develop models for sustainable agricultural systems. These first two steps may be expected to require 2-3 years.
- Identify key gaps where additional research is needed, and feed this into KARI's evolving system for prioritization of research needs. The greatest emphasis will be on defining the socio-economic conditions (integration of cash crops, farm size, etc.) necessary for the purchase of inputs needed to achieving sustainability at present and foreseeable levels of technology development.
- Reorient research programs and conduct additional research as needed. The project could supply a pot of money for research needed to fill in such gaps.
- Analyze the differences between existing agricultural systems by AEZ, and what is needed to achieve sustainability.
- Analyze the policy and institutional reforms needed to achieve sustainability by AEZ.

5.1.4. Implementing Agencies:

KARI, ICRAF and perhaps KEFRI would be the principal implementing agencies. Their existing structure needs to be analyzed to best define where this function should be placed. ICRAF may have the greatest capacity to play the lead role in the development of the models.

5.1.5. Indicators

- Overview report completed
- Agricultural sustainability models developed
- Research gaps/needs identified

- Research program amended accordingly
- Needed policy and institutional reforms defined

5.2. Agroforestry Research Contribution to Sustainable Agriculture

5.2.1 Situation

Agroforestry holds great potential for contributing to sustainable agriculture in the following areas:

- Supply of nitrogen through N-fixing woody species.
- More efficient recycling of nitrogen, phosphorous and other elements.
- Soil organic matter maintenance
- Increased cash income to farmers through production and sale of high value wood and non wood products from trees and shrubs. This income can contribute to the economic viability of farm units and enhance farmers ability to purchase needed fertilizer and other inputs needed for sustainability.

The major constraint to realizing the potential of agroforestry is lack of funds for strategic component interactions research. This involves research on the interactions between agroforestry species and agricultural crops in the supply of, and competition for, light, nutrients and water. Recent technological advances have made research on the interactions for water and nutrients much more easily studied. This should allow for much more rapid screening of potential agroforestry species.

It has recently been discovered that their are huge reserves of nitrates is highland subsoils at depths of 50-200 cm beyond the rooting zone of most agricultural crops but easily tapped by many tree species. Efficient agroforestry species and techniques for tapping these reserves and making the nitrate available for crop growth need to be tested.

Another new area of emphasis in agroforesty research is on the identification and integration of exceptionally high value species into farmers systems. This sometimes involves the domestication of species that produce especially high value products for sale.

Research is needed to screen candidate species and to develop techniques for integrating their cultivation into farming systems.

5.2.2 Objective Enhance the contribution of agroforestry to the sustainability of agricultural production systems Kenya

5.2.3. Strategies

- Support strategic research on tree - crop interactions in order to speed the screening of potential agroforestry species.

- Support research to screen and identify high-value multi-purpose tree species for integration into agroforestry systems in Kenya.
- Concentrate both types of research in areas characterized by declining soil fertility, P deficiency and near-subsistence smallholder agriculture.

5.2.4. Implementing agencies ICRAF should be the lead agency for this research but should also include their partners of KARI and KEFRI. The strategic research should be conducted at Machakos, Mareno and Embu research stations as appropriate. The screening for high value species should be concentrated at Mareno and Embu in the Highlands.

5.2.5. Indicators

- More efficient techniques for screening potential agroforestry species based on tree - crop interactions defined.
- Effective agroforestry species and techniques identified for enhancing the sustainability of soil fertility
- High value agroforestry species identified and integrated into farming systems.

5.3. Greater Horn of Africa Regional Phosphate Initiative

5.3.1. Existing Situation

Most of the agricultural systems in Kenya and in much of the Greater Horn of Africa is characterized by long term depletion of phosphate in the soils. This is the most critical factor in the unsustainability of present systems. The principal sources of phosphate fertilizer available on the market are imported, and are prohibitively expensive for most farmers. The cost per kilogram of elemental P in commercial fertilizers sold in Kenya in 1994 was 5 to 9 times that of finely ground and bagged phosphate rock.

Inability to develop more economical sources of phosphate will negatively impact on food security, economic development and the intensification of agriculture. It will accelerate the extensification of agriculture into fragile lands that will lead to the further degradation/destruction of the natural resource base of the region. Phosphate supply may be viewed as strategic to the security of the region.

The development of sustainable agricultural systems in Kenya and in the Greater Horn of Africa will probably depend on the development of local sources of phosphate reserves at affordable prices. Potentially exploitable reserves exist in Kenya, Tanzania, Uganda, Burundi, Zaire, Ethiopia and Somalia (Figure x) The two reserves in Uganda are just across the border from the Western Highlands, and rock phosphate is already imported from reserves in the Arusha area of Tanzania. A regional effort is required to assess, test and develop these reserves in an economically viable fashion.

5.3.2. Objectives:

- Assessment of the opportunities for development of the regional reserves of phosphate rock within the Greater Horn of Africa.
- Development of regional strategies for overcoming the constraint of phosphorous-deficient soils in the region, especially on smallholder farms.
- Assist in the development of reserves as appropriate.

5.3.3. Strategy

The regional strategy should include the following components:

- Review and complete the existing information base on phosphate rock reserves in the region. Assess the quality and extent of these reserves.
- Determine the potential forms of phosphate fertilizer that could be developed from each reserve and their suitability for the soils and agricultural systems for the region. Processing options include ground phosphate rock, very finely ground, partially acidulated phosphate rock (PAPR), compacted, and soluble phosphorous fertilizers (diammonium phosphate, monoammonium phosphate, triple-super phosphate, etc.)
- Perform an economic analysis of the costs of production of phosphate fertilizers from the known reserves and the transport costs to the different agricultural zones.
- Conduct agronomic trials (on-farm and on-station) as needed of locally produced phosphate fertilizers stratified by agroecological zone and agricultural system.
- Proceed to industrial-scale development of regional phosphate reserves as investment opportunities are shown to be viable.

5.3.4. Institutions:

The World Bank is promoting the concept of a phosphate initiative for sub-Saharan Africa. A draft paper analyzing the issues related to investment in soil nutrient capital (phosphate) to improve agricultural productivity and natural resource management is in draft (World Bank, et al, Nov. 1994) USAID Kenya and the USAID Africa Bureau should lobby the Bank to include Kenya and the Greater Horn of Africa within one of the proposed pilot zones to test this approach. Although the Bank is presently thinking of individual countries for pilot studies, it would seem highly appropriate to study the regional potential for the Greater Horn. Funding of the initiative should be multi-donor and include USAID and the World Bank. USAID Kenya should fund part or all of the Kenya specific portion of this regional initiative.

Implementing agencies should include the International Fertilizer Development Center, the IARCs active in the region and the NARCs. Based in Nairobi, ICRAF may be best indicated to be the lead amongst the IARCs. KARI has the greatest institutional capacity amongst the NARCs of the region and should play a key role. KEFRI should also be involved in field trials in Kenya.

5.3.5. Indicators

- Assessment completed identifying the optimal sources, forms and means of applications of phosphate fertilizers
- Strategies developing for overcoming smallholder financial constraints to phosphate use and restoration of the capital stock of P in the soil
- Pilot projects developed to promote production and use
- Quantities of phosphate fertilizer produced in the region and quantities applied
- Effects on yields and soil nutrient budgets

5.4. Restoration of Sustainable Agriculture in the Western Highlands

5.4.1. Existing Situation:

- Soils throughout much of the Western Highlands are highly depleted in phosphorous. Existing agricultural systems are ecologically unsustainable in that they are characterized by continued declines in crop yields and soil fertility. They are economically unsustainable in that they do not produce enough of a surplus to permit purchase of agricultural inputs, especially phosphate fertilizers, needed to maintain productivity.
- Soil fertility and agricultural productivity cannot be restored without inputs of phosphate fertilizer.
- Over 10,000,000 has. of similar, unproductive, phosphate deficient soils in the Cerrado region of Brazil were restored to self-sustaining agricultural productivity in the 1970's and 80's through a one-time, highly subsidized application of phosphate rock to replenish the soil's capital stock of P. Subsequent maintenance applications were paid for by the farmers.
- The per kilogram cost of elemental P in bagged, finely ground phosphate rock from the Minjingu deposit near Arusha was selling in Kenya for one fifth the cost of that in imported, commercial, soluble phosphate fertilizers in Kenya in late 1994. The relative agronomic effectiveness of the Minjingu phosphate compared to triple superphosphate is reported to be low (24%) for high pH soils (greater than 6.6), medium (49%) for soils with a pH around 5.2, and high (125%) for acid soils around pH 4.6 (IFDC 1990). The pH of soils in the Western Highlands generally run between pH 5.0 to 6.5 with an average of pH 5.7 (Keith Shepherd, ICRAF, pers. com)
- An approach similar to the one in Brazil could potentially help a large proportion of near-subsistence farmers in the Western Highlands make the transition to self-sustaining commercial enterprises and could reduce the migration of people off the Highlands to the marginal ASAL.

5.4.2. Objectives:

- Assessment of the potential of the Brazilian approach to the Western Highlands.
- If the assessment proves positive, test the approach on an operational scale on a suitable site.
- Assist near-subsistence farmers to make the transition to self-sustaining commercial production units
- Reduce migration from the Highlands to the ASAL.

5.4.3. Strategies

- Two phases are envisioned. The first phase will assess the feasibility of the approach in the Western Highlands. If the results of Phase I are positive, the second phase would be an operational field test in a watershed of the Western Highlands.
- The project will start from the premise that the investments needed to restore productivity of these depleted soils and to jump-start the economy of the Western Highlands will probably not be within the means of the rural smallholders. The project will define the societal investments needed to reverse the cycle of degradation.
- One of the key strategies will be to test the concept of restoring the soils capital stock of phosphate (phosphate which is bound up in the soil but which becomes available for plant growth over a period of up to 10 years) to a point where other classical investments in agricultural inputs and in sustainability-enhancing practices (fertilizer, improved seed, pest management, organic inputs, etc.) by smallholders will provide positive responses and will begin to reverse the downward spiral of poverty and fertility declines.
- In Phase I, the project will assess/test a range of phosphate fertilizers that are presently or potentially available in the region. This will include both fertilizers that are presently on the market as well as the types that might be produced from reserves in the region. The assessment will cover farmer acceptance, agronomic response by soil type and economic costs and benefits at both the smallholder and societal levels. Agronomic trials will include tests of phosphate fertilizer and organic matter (manure, mulch, residues) interactions. Phase I would include phosphate rock applications on a mini-catchment including approximately 50 smallholders.
- In Phase II, the project would work intensively within one pilot watershed that is sufficiently large to test economies of scale and large enough to test the ecological effects of increased vegetative cover expected to result. Ideally, the catchment should be several thousand hectares in size. The project will provide fertilizers free or at minimal costs on a one-time only basis to participating farmers within a pilot watershed catchment. Farmers will first be required to install soil conservation measures that will prevent phosphate fertilizers from being lost to erosion in order to qualify for their fertilizer allotment.
- Concurrently with the restoration of soil fertility, the project will test and extend a range of agronomic, physical soil conservation and agroforestry techniques for efficient use and recycling of nutrients, for minimizing erosion, for soil organic matter

management, for biological supply of Nitrogen, and for injection of cash incomes through the incorporation of classical and innovative cash crops into the agricultural system.

- It is expected that yields in the pilot catchment will increase dramatically. Farmers will sell their surplus production and will reinvest part of their profits to continue to increase productivity and to convert to more attractive cash crops. Private sector agricultural service businesses will develop as a natural result. Off-farm employment will rise.

5.4.4 Implementing Agencies:

The Phase I assessment and the research component of Phase II will be handled by KARI, KEFRI and ICRAF working in collaboration. They already have experience working under such an arrangement. Linkages (and co-funding) will be pursued with ICRAF's Africa Highlands Initiative and the Greater Horn of Africa Initiative. Extension in Phase II will be handled by the agricultural extension service of the Ministry of Agriculture and by qualified PVOs/NGO's. Fertilizer distribution would probably best be handled by an NGO/PVO.

5.4.5. Indicators

Phase I

- Agronomic response and farmer acceptance of various forms of rock phosphate quantified by production system and soil type.
- Feasibility of operational pilot project determined.

Phase II

- Crop yields
- Farm unit nutrient budgets
- Soil organic matter
- Smallholder income
- Area planted to cash crops
- Smallholder investments in agricultural inputs
- Development of private sector including agricultural inputs and services.
- Creation of off-farm employment
- Demographic growth and fertility rates

5.5. Demography/Agriculture/Employment/Natural Resource Options

5.5.1. Situation: Decision makers, politicians, the private sector, NGOs, the general public and donors have limited awareness of the linkages between demographic growth, agricultural productivity, creation of off-farm employment, the environment and the

natural resource base in Kenya and of the future implications of policy decisions to be made.

5.5.2. Objective: Develop a high quality, professionally produced media presentation for broad diffusion to graphically illustrate the future scenarios that are possible and probable over the next 20-50 years based on realistic assumptions and policy options affecting future demographic growth, agricultural yields and industrialization.

5.5.3. Strategy

The development of the model should start with a review and synthesis by professionals in each field of the present trends in the fields of demography, agriculture, natural resources and industrialization/creation of off-farm employment. Extensive use should be made of existing geographically referenced information bases. A particular emphasis should be made on the review and synthesis (as proposed in 5.1 of this report) of present trends in agricultural sustainability and productivity by agro-ecological zones.

This review should be followed by the elaboration of a range of realistic hypotheses of future options/trends in each field. Again, these hypotheses should be elaborated by specialists in each field. Critical hypotheses in agriculture will concern the options of agricultural extensification into marginal areas versus intensification in the medium to high potential zones. Three hypotheses per field might be appropriate -- one optimistic, one pessimistic and mid-range.

Models should then be developed that illustrate the future scenarios that would result from the different hypothesis in each field and that stress the linkages between sectors.

The next step involves the packaging of these scenarios into high quality graphical presentations by professional communications specialists. Very effective computer-aided graphical presentation have been done for countries like Rwanda and Madagascar.

The final step would be the broad diffusion of the communications package(s) to politicians, decision makers, sectoral ministries, the private sector, NGOs, the general public, donors and development organizations.

5.5.4. Implementing Institutions

The sector reviews and hypotheses development should involve specialists in KARI, KEFRI, ICRAF, the USAID Population Office and the Small Enterprise Development Office with their GOK collaborators and others to be identified. The development of the communications package should be done by a an institution such as the Futures Group or other specialized in this field.

5.5.5. Indicators

- Models developed
- Communications package completed
- Number and types of presentations made
- Professional surveys of beliefs and attitudes of target audiences done prior to, and after, presentation of the communications package
- Media coverage of issues and options

5.6 GIS as a Tool for Improved Natural Resource Management

5.6.1. Situation The use of geographic information systems (GIS) has reached a higher level of development in Kenya than in most other African countries. The topographic base maps and most of the thematic maps available have already been digitized. These geo-referenced data bases permit new types of analyses and new approaches to problem solving that were not possible in the past. The maize data base project that served to reorient KARI's maize research program is an excellent example of the potential of GIS in Kenya. Effective natural resource management relies heavily on the availability and analysis of spatial information. Geographic information systems can be an effective tool in NRM.

The use of GIS in Kenya, however, is constrained by the following factors:

- Lack of an institution charged with gathering and updating geo-referenced data bases.
- Lack of information on data bases available.
- Restriction on user access to data bases.
- Lack of training in GIS systems and applications.
- Difficulties in procurement and maintenance of necessary hardware and software.

These are all constraints that can be addressed by the private sector. Most of them can probably be best addressed by the private sector.

5.6.2. Objective: Promote the role of the private sector in providing services for enhanced use of GIS systems as a tool for natural resources management and related fields.

5.6.3. Strategy:

The overall strategy proposed is to contract with a qualified firm to provide a range of GIS services to government and non-government agencies over a period of approximately five years with the view of developing a client base that would make the provision of services a profit making, private sector function. The company could be local or international but should be one already present in Kenya and with a long term commitment to Kenya.

The contractor would be required to provide the following services:

1. Procurement and maintenance of hardware and software for sectoral ministries and NGOs.
2. GIS training for government and NGO staff.
3. Maintain an up to date library of all publicly available, geo-referenced data bases. Periodically publish and distribute a catalogue of available data bases and reproduce copies at cost for all customers.
4. Provide a wide range of GIS applications using available data bases.

The contract for GIS services should be accompanied by credits to approved sectoral ministries and NGOs for procurement, training and GIS applications. Donors and other private companies should be free to hire the contractor for services 1, 2 and 4 at free market prices.

5.6.4. Implementing agency USAID could directly contract for the above services or provide funding to ICRAF to award and manage such a contract. ICRAF has a GIS unit with a high the level of technical expertise needed to prepare and manage such a contract. This GIS unit is currently swamped with requests for the types of services that would be contracted for under this proposal. A technical review committee should be created to approve or disapprove requests for assistance from sectoral ministries and NGOs.

Channeling funding through ICRAF could have distinct advantages. It would assure that a strong research and development perspective be maintained. ICRAF's GIS unit is currently at the forefront of the development of GIS applications in the region.

Annex 1

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Annex 2

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