

# Science and Technological Innovations for Improving Soil Fertility and Management in Africa:

**A report for the NEPAD Science and Technology Forum**

Louis V. Verchot, Frank Place, Keith D. Shepherd and Bashir Jama



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Louis V. Verchot, Frank Place, Keith D. Shepherd and Bashir Jama,  
World Agroforestry Centre (ICRAF)

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**Key words:** Soil fertility, soil science, land degradation, agricultural productivity

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## Abbreviations

AfNet	African Network for Soil Fertility
ASARECA	Association for Strengthening Agricultural Research in Eastern and Southern Africa
ASTI	Agricultural Science and Technology Indicators
BASIC	Building Africa's Scientific and Institutional Capacity
CAADP	Comprehensive African Agricultural Development Programme
SSA	Sub-Saharan Africa
CGIAR	Consultative Group for Agricultural Research
TSBF	Tropical Centre for Soil fertility
ISFM	Integrated Soil Fertility Management
IARC	international agricultural research centre
NARS	national agricultural research system
SARNET	South Asia Regional Network
USAID	United Nations Agency for International Development
FARA	Forum for Agricultural Research in Africa
NUTNET	Nutrient networking and Stakeholder perceptions
TOFNET	Trees on Farm Network
SWMNET	Soil and Water Management Research Network
KIT	Royal Tropical Institute
CIAT	International Centre for Tropical Agriculture
ICARDA	International Centre for Agricultural Research in the Dry Areas
ACTS	Africa Centre for Technology Studies
NARO	national agricultural research organization
IUFRO	International Union of Forest Organizations
IITA	International Institute of Tropical Agriculture
AHT	African Humid Tropics
IRD	Institute of Research for Development
ISNAR	International Service for National Agricultural Research
IRAD	Institute of Agricultural Research for Development

## Executive summary

Soil fertility degradation has been described as the single most important constraint to food security in Sub-Saharan Africa (SSA). Soil fertility decline is not just a problem of nutrient deficiency. It is one of soil physical and biological degradation, inappropriate crop varieties and cropping system design, and interactions with pests and diseases. This problem relates to the links between poverty and land degradation, and often perverse national and global policies that lack the right incentives and to institutional failures.

Food security in Africa is one of the most pressing problems facing the continent. While the rest of the world has seen significant increases in per capita food availability over the past 45 years, the situation in SSA has only improved slightly, with devastating effects on millions of people on the continent. Malnutrition is widely recognized as an underlying cause of death associated with infectious diseases and projections suggest that undernourishment will worsen in SSA over the next decade. Malnutrition is projected to increase by an average of 32% in Africa (UNDP 2006).

The impact of soil degradation is also devastating for Africa's environment and compromises future development opportunities. Land and soil degradation have serious consequences for other natural resources on which Africa's development depends. For example, degradation of water quality in rivers and lakes due to increased sediment loads affects fisheries and the quality of water sources for humans and animals, which, in turn, impacts health. Land degradation results in the degradation of terrestrial ecosystems and can lead to other negative impacts such as loss of biodiversity. The Global Land Assessment of Degradation (GLASOD), although based on expert opinion rather than direct field data, suggests that about 30 percent of total agricultural, permanent pasture, and forest and woodland areas in Africa are affected by soil degradation.

African leaders have explicitly recognized that science and technology are vital for the transformation of the continent's agriculture and related socio-economic systems. This recognition is embedded in the New Partnership for Africa's Development (NEPAD) – particularly its Comprehensive African Agricultural Development Programme (CAADP) – and in the decisions of the first meeting of the African Ministerial Council for Science and Technology. CAADP and the Council put emphasis on the need to harness and apply science and technology to remove barriers to food and agricultural production. Both underline the role that scientific research and related technological innovations can play in addressing such constraints as poor soil fertility, drought and land degradation.

The NEPAD secretariat, through its Science and Technology Forum, commissioned the World Agroforestry Centre (ICRAF) to undertake a comprehensive background study to identify specific scientific and technological means to improve soil fertility and management in Africa. The findings of the study are presented in this paper, which aims to:

1. Provide a succinct overview of international advances in soil science and related technological innovations for improving soil fertility and management.
2. Identify specific scientific and technological trajectories or pathways that are relevant for the improvement and management and which offer new opportunities.
3. Give an assessment of Africa's capacity (with emphasis on the role and participation of universities in related research and innovation) in science and technology development for improved soil fertility and management.

4. Identify specific areas where capacity building can be better attained through regional and international cooperation.
5. Propose a framework for building capacity in scientific research and technology development to improve soil fertility and management.

ICRAF coordinated a series of four regional consultations with experts in soil fertility issues in Africa to provide answers to key questions on soil fertility issues. Senior soil scientists conducted targeted interviews with professionals in the field in East and Central Africa, Southern Africa, West African Humid Tropics and the Sahel. The opinions of regional experts were summarized in regional reports that are the basis for the conclusions that we draw in this paper. The findings of this report cover both the current state of soil science research in Africa and indications for the way forward.

### **Advances in soil science**

Soil science should be seen within the context of sustainable agricultural systems and sustainable landscape management. The traditional discipline of soil science focused on the biological, chemical and physical dimensions of the soil resource itself. However, sustainable management of soils should be seen in a systems context and embrace a multidisciplinary view of soil resource management.

A number of significant advances have been made over the past decade in both the science and practice of soil fertility management in Africa. The key ones are outlined below:

1. The application of approaches developed by landscape ecologists using new remote sensing and Geographic Information Systems (GIS) tools has led to major breakthroughs in objectively assessing the spatial variation in soil quality and soil degradation. This area will be instrumental in problem diagnosis, but also in better targeting interventions.
2. Significant adoption of a range of improved technologies has been documented across a number of countries in SSA. These technologies include soil and water conservation structures, such as 'zai' pits in the Sahel, organic nutrient management systems such as high quality manuring in intensive dairy systems in Kenya, and more integrated soil management practices. Available evidence shows that these technologies increase productivity in the environments in which they have been adopted and provided farmers with new options.
3. The integration of other scientific disciplines including ecology, economics and participatory social science has helped formulate a more holistic approach to soil fertility management. We recognize that soil fertility management practices need to be more than just technically sound. This integrated approach leads to the development of approaches that are socially and economically acceptable.
4. The impact of recommendations for soil management practices has been enhanced by the emergence of a consensus on guiding principles for Integrated Soil Fertility Management (ISFM). Principles of ISFM have influenced diverse stakeholders in SSA to alter the ways they address soils and their management, at a variety of scales.
5. Substantial progress has been made in developing new tools and applying them in approaches that encompass: participatory approaches, integration of GIS and remote sensing, agroecological and farming systems analysis frameworks, monitoring and



evaluating ecosystem services, rapid spectroscopy techniques of soil analysis, and molecular tools to study soil biodiversity.

### **The state of African agricultural research capacity**

The major challenge is to advance the application of the new tools and integrate them into soil fertility research in national research institutions and universities, which are the major players in soil fertility research on the continent. The private sector accounts for only 2% of all agricultural research, while government-run national agricultural research institutes (NARIs) account for 75%. While universities have grown considerably in enrolments and faculty over the past 20 years, university research still represents a minor percentage of total public agricultural research. This situation is, however, changing in the Eastern Africa where there is strong inter-university research emerging with the support of the Swedish International Development Agency (SIDA).

The trends in agricultural research funding are not encouraging for efforts to tackle the soil fertility problem in Africa. For many countries on the continent, the apex of research system health was during the 1970s, following great expansion in the 1960s, when overall spending levels were high (in real dollars) and spending per scientist at historical highs. Growth in agricultural research expenditure began to diminish in the 1980s and by the 1990s, it had declined to 1% a year.

Just as the case with research expenditures, there is a considerable variation in the number of researchers in NARIs and at universities across the countries. A survey by the Agricultural Science and Technology Indicators (ASTI) project of the International Service for National Agricultural Research (ISNAR) to estimate the number of scientists in different disciplinary fields indicates that between 5-10% of agricultural scientists in the national agricultural research institutes specialize in soils research. The bulk of the researchers in these institutions are engaged in crop-related research. This leads to a logical discrepancy between the nature of the problem of declining soil fertility and allocation of resources to solve it. Yet, as we noted above, soil fertility is widely recognized as the leading constraint to food security in SSA. Without solving this problem, the potential of improved crop varieties is limited.

Research infrastructure is variable between countries. Libraries and access to specialist literature are good in North Africa, and adequate in only a few SSA countries. Scientists posted outside of the capitals generally have poor access to the scientific literature. Universities often do not subscribe to specialist journals, but students and university researchers have access to a few general journals.

Laboratories also are a problem. Many scientists have access to service labs of varying quality. However, research labs are generally lacking and scientists have little opportunity to obtain grants that allow for the purchase of specialized equipment.

### **The way forward**

Progress to date has demonstrated that investing in farmer-centred soil fertility research is integral to successful rural development. Research has allowed us to better understand the diversity of conditions in which existing ISFM options can benefit the rural poor. By taking a pro-poor approach and focusing on the relationships of soil fertility to the overall function of farming systems, international agricultural research has developed the means to achieve

large-scale impacts, responding to the demands of small-scale farmers for improved agricultural production and ecosystem services.

The imperative of soil fertility degradation and the impetus of current success demand urgent and long-term commitment to a comprehensive programme of research and development actions. It is clear from the analysis above that these actions must cover many disciplines, operate across multiple scales and be highly interactive in nature. A programme of work must build on and use methods that have already proved successful. It should also develop and borrow from others where significant gaps in understanding or application occur. Key focal areas for such a programme are:

1. Improved understanding of soil fertility problems and appropriate management options.
2. Managing carbon and nutrient cycles for enhanced agricultural productivity.
3. Managing soils for enhanced ecosystem services.
4. Managing the genetic resources of soil for enhanced productivity and plant health.
5. Empowering farmers to scale up research and results.
6. Methods for and lessons learned from monitoring and impact assessment.
7. Linking advances in ISFM into national soil fertility programmes, development planning, and policies.
8. Communication with policy makers on the importance of improved research capacity in soil fertility.

At the same time, soil fertility needs to be linked more closely to other key concerns of African societies. The links between health and nutrition is often obvious in health-related development programmes, but the connection between sustainable and productive agriculture and health are not always made. Connections also need to be made between urban development and sustainable food production in rural areas.

There is urgent need to strengthen the scientific capacity of scientists in modern approaches. Scientists in Africa often work in isolation. They do not have access journals and ongoing training to stay abreast of new developments in their fields. Many of the new tools available to scientists require sharp quantitative skills to apply properly. Just as important as development of scientific capacity in soils and agricultural research, is the need to strengthen mechanisms and incentives for retention and continuous development of trained personnel.

## **Conclusion**

Solving the soil fertility problem in Africa is the key to food security and to achieving a number of the Millennium Development Goals. Significant gains have been made over the past decades, but, unfortunately, the effort at generating the knowledge to solve the problem pales in comparison to the magnitude of the problem. As Vlek (1995) noted, "Claiming that a rich research data base on soils does exist in Africa borders on recklessness, as it accepts a situation that would be considered utterly unacceptable to the scientific community in the West if it were to deal with an array of problems such as those prevailing in SSA."

If agriculture is to serve as the economic motor that spurs development, as it has elsewhere in the world, the soil fertility problem must be tackled comprehensively. Much remains to be

done. Human and institutional capacity building requires external and internal support. African institutions need to be able to offer attractive employment packages and working conditions that could attract and retain the best. Training should focus on supporting African science catch up with modern approaches to soil science. Capacity building must be implemented in a way that ensures an increase in the number of young scientists capable of undertaking world class science. At the heart of all of this is the question of funding.

Complacency in comprehensively addressing the problem fertility decline will only lead to delays with dire consequences for the people of Africa. As Diamond (2005) has shown, societies have collapsed in the past due to the conjuncture of population growth, environmental damage, changes in trading relationships, and climate change. The message of his book is that many factors interact in different ways and none that no single factor can determine the outcome. However, how a society chooses to respond to the challenges that these changes bring can make all the difference. Globalization of markets, accelerated human induced climate change, land and other natural resource degradation, infectious diseases and population growth all pose serious challenges for Africa. The response to date has not been commensurate with the challenge.

## Soil fertility and African development issues

Soil fertility degradation has been described as the single most important constraint to food security in Sub-Saharan Africa (SSA). Soil fertility decline is not just a problem of nutrient deficiency. It is a problem of soil physical and biological degradation, inappropriate crop varieties and cropping system design, of interactions with pests and diseases. The problem relates the linkage between poverty and land degradation, often perverse national and global policies with respect to incentives, and institutional failures.

Food security in Africa continues to be one of the most pressing problems facing governments and development agencies. While the rest of the world has seen significant increases in per capita food availability over the past 45 years, the situation in SSA has only improved slightly (FAOSTAT, 2005). Elsewhere in the world productivity gains through intensification of agriculture have largely been responsible for eliminating hunger. The Green Revolution produced higher crop yields in Asia through improved varieties of cereal crops, wider use of irrigation and better control of water supplies, widespread use of fertilizers and pesticides, and improvement of farmers' management skills. Unfortunately, SSA has not been able to benefit from the technological advances of the Green Revolution to solve its food insecurity. On the surface, this failure is attributed to the greater complexity of landscapes and farming systems on the continent, but underpinning this is a lack of concerted effort and political will.

Although soil degradation costs accrue to rural land users and society over time, these costs have largely been hidden from land-use decision-making and national policy initiatives. For example, in Kenya the costs of soil erosion at the national scale are equivalent to 3.8% of GDP and equal in magnitude to national electricity production or agricultural exports (Cohen et al, 2005). There is a need for mechanisms that can help internalize the costs of land degradation in development processes.

Tackling soil fertility issues requires a long-term perspective and holistic approach of the kind embodied in the concept of Integrated Natural Resource Management (INRM). Soil fertility problems cannot be isolated from other development problems. Soil fertility degradation is linked with a number of social and environmental problems. For example, malnutrition is a major factor in over 54% of all deaths of children under 5 worldwide (Pelletier, 1993; 1995). The proportion is higher in Sub-Saharan Africa (SSA). Most of these deaths are not due to famine, with 83% of them attributable to mild-to-moderate malnutrition. Malnutrition is widely recognized as an underlying cause of mortality associated with infectious diseases (Villamour et al. 2005; Caulfield *et al.* 2004a, b). Projections suggest that malnutrition will worsen in SSA over the next decade, with the incidence of underweight children in SSA increasing by 9% (de Onis *et al.* 2005). The largest increase is expected in East Africa, where malnutrition incidence is expected to increase by 25%. The impact of worsening food security on Africa's population will be severe.

The impact of soil fertility degradation is also devastating for Africa's environment and compromises future development opportunities. Land and soil degradation have serious consequences for other natural resources upon which Africa's development depends. For example, degradation of water quality in rivers and lakes due to increased sediment loads affects fisheries and the quality of water sources for humans and animals. Lake Victoria, Africa's largest lake, has suffered a serious decline in water quality over the past 50 years due

to increased sediment and nutrient loading. This has promoted the growth of the invasive water hyacinth plant, at great economic costs to the surrounding countries.

As we will see below, farmers in SSA have been dealing with declining soil fertility through conversion of natural ecosystems and clearing more land to meet their needs. Land degradation results in the degradation of terrestrial ecosystems, which can lead to other negative impacts such as loss of biodiversity.

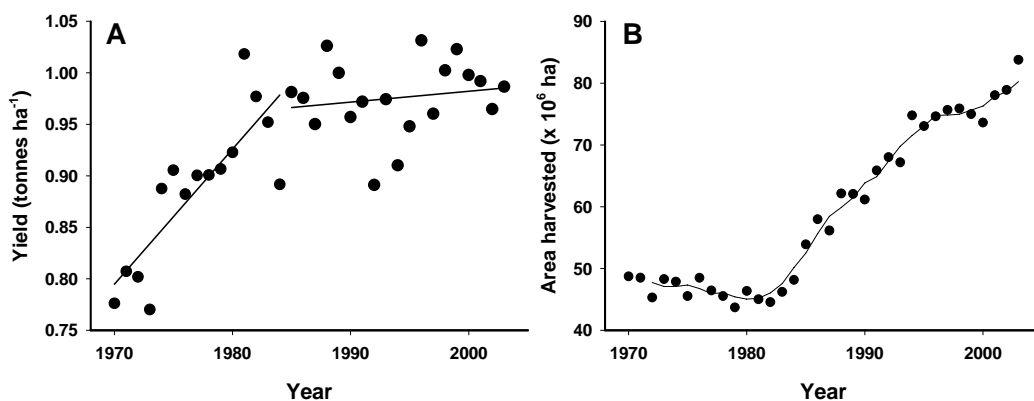
Rural populations, and many urban populations for that matter, rely on products and services of rural ecosystems. For instance, trees and shrubs are important sources of traditional medicines across the continent. Terrestrial ecosystems are also sources of fruits and other food and play important roles in helping people survive droughts. Soil fertility problems are affecting these ecosystem functions and services and the impacts are being felt beyond the farms and farming communities where the problems are occurring. These impacts affect societies in SSA in many ways.

In summary, therefore, tackling the soil fertility problem is fundamental to achieving the Millennium Development Goals of reducing extreme poverty and hunger (Goal 1) and ensuring environmental sustainability (Goal 7).

## The current state of agriculture in Africa: Overview

We will begin this report with a large-scale overview of the current situation of agriculture in SSA. We will construct the current scenario in three dimensions: agricultural productivity, agricultural technology and population food requirements. We will look at ongoing trends in food supply and demand to better understand the nature of the problems we are facing. These trends are good indicators of what we can expect in the short term if no interventions are undertaken.

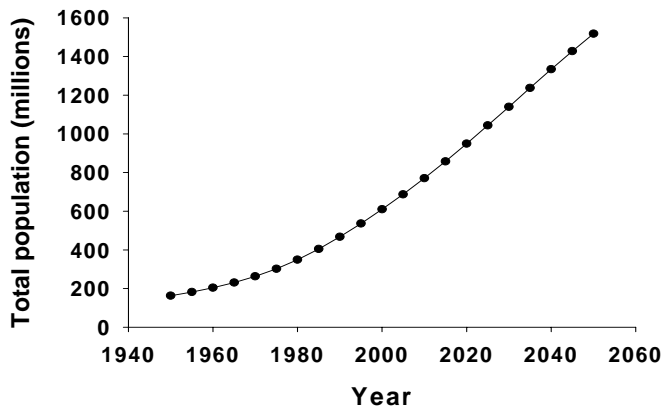
Figure 1: Agricultural statistics for SSA from 1970 to 2003. A: Average cereal yield for all cereals combined with two regression lines showing the rate of change over the periods 1970-1985 and 1985-2003. B: Area harvested expressed in millions of ha with the periodic trend given by the 5-year moving average (solid line). Source: FAOSTAT (2005).



On average, yields of cereal crops in SSA have increased by a meagre  $5.2 \text{ kg ha}^{-1} \text{ y}^{-1}$  over the past 33 years (FAOSTAT). Average cereal yield is still below  $1 \text{ tonne ha}^{-1} \text{ y}^{-1}$  in SSA.

However, a closer look at the figures reveals that there was a period between 1970 and 1985 where yields increased fairly rapidly (Figure 1A). Since 1985, yields have more or less remained constant and Africa has met its food needs by extensification of agriculture (Figure 1B). From 1970 until about 1985, as yields were increasing, the harvested area declined slightly in SSA. Since then, the burgeoning population and stagnation of yields have induced

Figure 2. Population levels since 1950 and projected growth in SSA until 2050. Source: FAOSTAT (2005).



African farmers to open new and often marginal land to cultivation to meet the demands of a growing population.

At the same time, fertilizer use levelled off in SSA as prices increased and subsidies were withdrawn. Between 1970 and 1990, N fertilizer use grew annually by almost 23 thousand tonnes (Figure 2A) and P fertilizer use grew by around 12 thousand tonnes (Figure 2B). Since 1990, N and P fertilizer consumption has grown at only 5000 tonnes a year, each. Yet, as we saw above, the cultivated area has almost doubled.

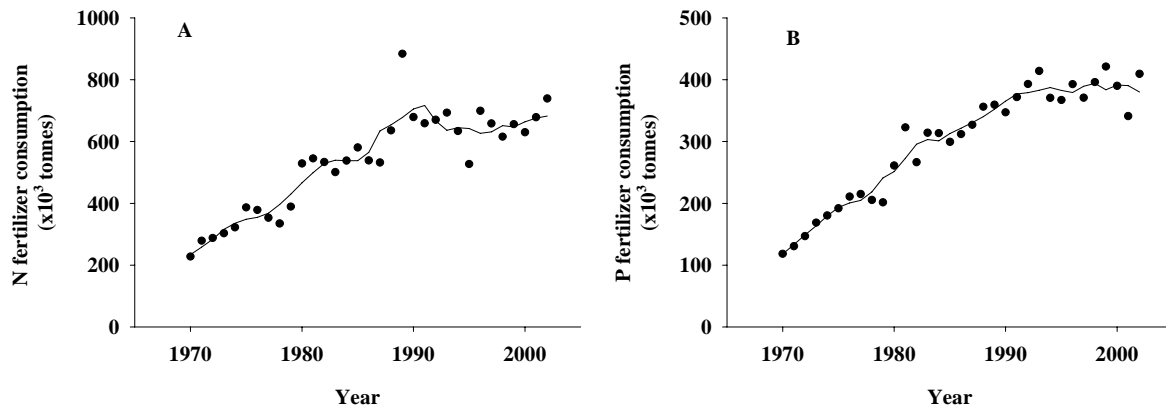
Fertilizer use continent-wide is less than 9 kg N ha<sup>-1</sup> and 6 kg P ha<sup>-1</sup>, which means that farmers are mining their

soils to produce food. On average, farmers are mining 22 kg ha<sup>-1</sup> of nitrogen, 2.5 kg ha<sup>-1</sup> of phosphorus and 15 kg ha<sup>-1</sup> of potassium annually (Smaling, 1993). Thus, increases in agricultural production have largely been met through opening up new land to cultivation and have been obtained at the cost of soil degradation as soils are mined for their nutrients.

In most regions of the world, soil fertility problems have been solved by applying fertilizers to replace nutrients removed by harvested crops and erosion. This has not happened in Africa. Failure to tackle the soil fertility problem limits the possibility for agricultural production to grow and ultimately affects the development of the continent because agriculture is the economic engine that drives development. The effort to raise agricultural production in Africa by developing improved varieties is doomed from the outset because in the absence of proper soil fertility management, improved varieties stand little chance of improving productivity.

Population growth is the final element to consider in the scenario that we are constructing. World population reached 6.5 billion at the end of 2005 and over the next 45 years, an additional 2.5 to 3 billion people will be added to our population. Most of this increase will occur in two regions: SSA and South Asia. By 2050, the population of SSA will likely reach 1.5 billion (Figure 3), with about the population living in rural areas. These people will need to eat and rely to a large extent on land resources for their livelihoods. Unless the problems of soil fertility and agricultural productivity are addressed, environmental degradation will continue, compromising future social and economic development.

Figure 3: Fertilizer consumption statistics for SSA. A: Nitrogen fertilizer consumption with the trend indicated by a 5-year moving average (solid line). B: Phosphorus fertilizer consumption with the trend indicated by a 5-year moving average (solid line). Source: FAOSTAT (2005).



Food security will remain a daunting challenge for SSA in the years to come as the population continues to grow at a high rate. Intensification of agricultural production is required to provide food and incomes for the poor and this cannot occur without investment in soil fertility. Investing in soil fertility management includes rehabilitation of lands that are already degraded and pre-emptive actions on lands at risk of degradation, as well as maintaining the productivity of lands that are currently productive.

## Land degradation in Africa: A large-scale problem

Low-input agricultural systems on land with poor-to-moderate land resource potential is at the root of human-induced soil degradation in Africa. About 55% of Africa's land is desert or marginal land unsuitable for agriculture. Only 11% of the area, spread among many countries, has high quality soil that can be effectively managed to sustain more than double its current population (Eswaran, 1997). Most (63%) of the remaining useable land is of medium and low potential, with major constraints for low-input agriculture. (These lands are at high risk of degradation under low input systems). Soil moisture stress is perhaps the overriding inherent constraint to land productivity, not only because of low and erratic precipitation, but also because of low water holding capacity of soils. Only 14% of the continent is relatively free of moisture stress (Eswaran 1997). Soil phosphorus deficiency is widespread in all regions (see Annex) and remains a major constraint to agricultural productivity.

Soil fertility decline is associated with a number of simultaneous degradation processes that feed back on one another to produce a downward spiral in productivity and environmental quality. For example, as forest is cleared and put into low-input crop production, litter inputs are inevitably reduced. At the same time, tillage and other soil disturbance accelerates decomposition of soil organic matter. These two factors result in the decline of soil organic matter, which not only directly reduces retention of essential plant nutrients, but also results in breakdown in soil physical structure, which, in turn, reduces water infiltration and storage capacity in the soil. Low input levels of nutrient and organic matter and poor crop management contribute to poor crop growth, leaving the soil exposed to wind and water erosion. Finer soil particles, which contain most of the organic matter and nutrients, are then easily mobilized and transported by wind and water erosion to other parts of the landscape and into waterways, where they cause environmental damage. Large and costly inputs are

then required to rehabilitate degraded soils and reverse the environmental damage. Preventing these processes is cheaper than trying to find a cure for the damage they cause.

The Global Land Assessment of Degradation (GLASOD), although based on expert opinion rather than direct field data, suggests that about 30 percent of total agriculture, permanent pasture, and forest and woodland areas in Africa are affected by soil degradation problems. Approximately 65% of agricultural land, 31% of permanent pastures and 19% of forest and woodland are affected (Oldeman 1994). About three-quarters of these degraded lands are in dryland regions, which are also the regions with the highest prevalence of extreme poverty. Desertification processes are believed to affect 46% of Africa, with 55% of that area being at high risk, with worst affected areas being along desert margins, affecting about 485 million people (Reich *et al.* 2001).

Human-induced soil degradation is the most fundamental natural resource management problem threatening Africa's development. Water (46% of area) and wind erosion (38%) are the most important processes, but soil chemical (12%) and physical (4% degradation) are also important (Oldeman 1994). Chemical soil degradation includes loss of nutrients, salinization, pollution, and acidification. Soil fertility degradation, including soil organic matter depletion, in smallholder farms affects 200 million hectares of cultivated land in 37 Africa countries and is becoming increasingly recognized as a primary constraint to agricultural development (Sanchez *et al.* 1997; Conway, 1998). However, as pointed out above, these degradation processes are usually closely inter-linked and must be managed in an integrated way. The large variation in soil fertility in African landscapes -- with the highest variability often being at the smallest scales (within farms) -- poses additional challenges to diagnosing constraints and recommending improvements.

## **Development of soil fertility knowledge**

Understanding of the science of soil fertility in tropical agro-ecosystems has been as much an evolutionary process as has been the development of the national and international institutions that have spearheaded it over the past three to four decades. The current state of knowledge on soil fertility should, therefore, be viewed in the broader context of not only the understanding of soil degradation and rehabilitation processes, but also the development of appropriate methodological approaches for determining these processes and the training of critical numbers of scientists to measure them. For instance, the identification of soil fertility as a biophysical root cause of poor agricultural productivity and the improved understanding of soil degradation processes and rehabilitation principles, based on empirical evidence, has, on its own, been a major achievement that has demonstrated the benefits of a sustained and long-term investment in soil fertility research.

## **NEPAD and agricultural development**

African leaders have explicitly recognized that science and technology are vital for the transformation of the continent's agriculture and related socio-economic systems. This recognition is embedded in the New Partnership for Africa's Development (NEPAD), particularly its Comprehensive African Agricultural Development Programme (CAADP), and in the decisions of the first meeting of the African Ministerial Council for Science and Technology. CAADP and the Council put emphasis on the need to harness and apply science and technology to remove barriers to food and agricultural production. Both put emphasis on the role that scientific research and related technological innovations can play in addressing such constraints as poor soil fertility, drought and land degradation.



The second meeting of the African Ministerial Council for Science and Technology was held in June 2005 to consider a range of new programmes to promote the application of science and technology for sustainable development in Africa, including transformation of agriculture and attainment of food security. One cluster of flagship programmes considered pertained to drought, desertification and land degradation. To inform the design of this cluster, the NEPAD Secretariat through its Science and Technology Forum commissioned the International Centre for Research in Agroforestry (ICRAF, also called the World Agroforestry Centre) to prepare a comprehensive background study that identifies specific scientific and technological means for improving soil fertility and management in Africa. The objectives of this paper, based on the study, are to:

1. Provide a succinct overview of international advances in soil science and related technological innovations for improving soil fertility and its management.
2. Identify specific scientific and technological trajectories or pathways that are relevant for the improvement and management offer new opportunities.
3. Give an assessment of Africa's capacity (with emphasis on the role and participation of universities in related research and innovation) in science and technology development for improved soil fertility and management.
4. Identify specific areas where capacity building can be better attained through regional and international cooperation.
5. Propose a framework for building capacity in scientific research and technology development to improve soil fertility and management.

ICRAF coordinated a series of four regional consultations with experts in soil fertility issues in Africa to provide answers to key questions on these issues. Senior soil scientists conducted targeted interviews with soil science professionals in East and Central Africa, Southern Africa, West African Humid Tropics and the Sahel. The experts' opinions were summarized in regional reports that are the basis for the conclusions that we draw here. This report integrates the findings of the regional consultations, (provided in the annex) and findings from other studies reported in related literature.

The rest of the report is structured according to the terms of reference for the study. The two terms of reference that call for reviewing and assessing the current state of science and capacity – numbers (1) and (3) – are dealt with in the first two sections. The remaining three elements in TOR all relate to the future and are analyzed in an integrative manner in a 'way forward' section. Lastly, we include an annex with the reports from the regional consultations

## **Advances in soil science and technological innovations**

A number of significant advances have been made over the past decade in the science and practice of soil fertility management in Africa. Soil fertility degradation takes place over a long time and recuperation of soil quality can be equally slow. Therefore, lasting impacts of improved management require long-term investment of time and resources. But the impacts of improved management on crop yields are often dramatic even in the short term.

Significant achievements from agricultural research have been demonstrated in improved livelihoods based on the development of soil management principles and in methodological approaches to address the major causes of poverty. The integration of other scientific disciplines, including ecology, economics and participatory social science, has helped formulate a more holistic approach to soil fertility management.

Inability to objectively assess the spatial variation in soil quality and soil degradation has been a major constraint to solving soil degradation problems and managing soil fertility on a large scale. The application of approaches developed by landscape ecologists using new remote sensing and GIS tools has led to major breakthroughs in this area and will be instrumental in problem diagnosis and lead to better targeted interventions.

The impact of recommendations for soil management practices has been enhanced by the emergence of a consensus on guiding principles for Integrated Soil Fertility Management (ISFM). In essence, ISFM is the adoption of a holistic approach to research on soil fertility that embraces the full range of driving factors and consequences of soil degradation – biological, physical, chemical, social, economic and political – as described above. ISFM puts a strong emphasis on research to understand and seek to manage the processes that contribute to change. The emergence of this paradigm, closely related to the wider concepts of Integrated Natural Resource Management (INRM), represents a significant step beyond the earlier narrower, nutrient replenishment approach to soil fertility enhancement.

### **1. Improved problem assessment**

Previous efforts to assess the extent and severity of soil degradation at national, continental and global levels have been based on expert opinion and lack sufficient scientific validity to permit comparisons over space and time. More rigorous quantification is needed for targeting land and water management investments and decision-making on policies.

Land degradation surveillance uses principles adapted from medical diagnostic studies (see <http://www.worldagroforestry.org/sensingsoil/>). Surveillance is the ongoing systematic collection, collation, analysis and interpretation of data and dissemination of the information to stakeholders for action. Surveillance is fundamental for prevention and control of land degradation problems. Key objectives of this approach include to estimate the extent of a soil degradation problem and to provide early warning of soil degradation ‘outbreaks’. Others are to: monitor soil degradation trends, identify management risk factors, monitor progress towards achieving control objectives, evaluate interventions and preventive programmes, and identify research needs.

As Young (1998) noted, “The present unsatisfactory position in knowledge of soil degradation can only be overcome by measurement of changes in soil properties over time ... Soil monitoring should become one of the basic activities of soil survey organizations. It is manifestly desirable for governments to know which land use practices maintain soil fertility and which degrade it”.

Like in medical surveillance, the two primary objectives for soil monitoring are pragmatic: (1) To provide information that can be used to guide resource allocation, and for making land management decisions; and (2) to develop an understanding of cause-and-effect relationships that could subsequently be used for prevention, early detection and outcome management of soil degradation.

Surveillance starts with defining a case, a specific problem that is measurable and repeatable. The basic building blocks of soil monitoring systems are inventory, change detection and risk assessment. Inventories describe the soil condition at a particular point in time and reflect natural variation over an area, as well as the effects of past management. Change detection describes soil condition trends that are indicative of environmental changes and the effects of current management. Risk assessment separates those components of trends over which we have “control” — such as the type of vegetation cover of a site — from those over which we have “little or no control” such as the timing and intensity of rainstorms. A soil monitoring system deploys these building blocks in sequence, as it would obviously be difficult to assess trends in the absence of prior inventories, or to attribute cause-and-effect relationships without considering temporal directionality.

Most previous assessments of soil degradation have not achieved this degree of rigour. Once the problem is measurable, then its prevalence (number of cases per unit area) can be assessed. From measurement of degradation prevalence it is possible to identify putative (tentative) risk factors, which are the keys to managing the problem. These, however, can only be confirmed by measuring the incidence (number of new cases per unit area per unit time) through monitoring programmes (prospective studies).

Surveillance systems should be action-orientated, realistic and timely. Screening tests for rapid and accurate diagnosis of cases is a cornerstone of any surveillance programme. For instance, in modern disease surveillance there is very large investment in standard laboratory methods and laboratory confirmation of priority diseases. Apart from the general lack of case definitions for soil degradation, conventional soil laboratory tests are time consuming and expensive, making it impractical to adequately sample spatial variability. As a result, assessments of large areas are rarely attempted.

A major breakthrough has been the development of infrared spectroscopy, a laboratory-based screening tool for soil condition. Using the technology can be used to diagnose crop and livestock nutritional constraints, so that national laboratories can serve multiple purposes with one instrument without use of chemicals. Infrared spectroscopy allows for large numbers of geo-referenced soil samples to be rapidly characterized. It can therefore be used with in conjunction with satellite imagery to interpolate ground measurements over large areas. Recent developments in GIS and remote sensing have, at the same time, greatly increased capability for digital soil mapping (McBratney 2003).

The fertility capability classification (Sanchez *et al.* 2003) provides a useful framework for assessing soil fertility constraints in the tropics. Developments are underway to provide new soil fertility classification systems based directly on infrared spectral libraries of soils (Brown *et al.* 2005; Shepherd *et al.* 2002).

Since many soil problems are often strongly inter-related (as are multiple diseases) emphasis on an integrated approach to assessing soil degradation is encouraged. The surveillance approach seeks a quantitative understanding of how soil functional capacity (a soil's ability to perform production and environmental functions) is affected by natural processes in the landscape and how human action affects this capacity through mediation of these processes.

New concepts of ecosystem resilience permit systems to evolve from one state to another, provided that key ecological functions, or services, are maintained. Managing ecosystems in a way that maintains their resilience requires an understanding of the interactive effects of the drivers of ecosystem dynamics and threshold effects in these dynamics that result in undesirable changes that are difficult to reverse. Because of our imperfect knowledge of ecosystem behaviour, this understanding can only be built up through purposive experimentation and observation — adaptive management (Gunderson and Pritchard, 2002). The challenge for soil science is to integrate concepts of resilience and adaptive management into soil surveillance systems. For example, there is a need to define threshold points where continued soil degradation will rapidly accelerate a transition into a degraded state from which it is very difficult or expensive to recover.

There has also been much progress in concepts and research methods for trees, crops and soil fertility research (Anderson and Ingram 1993; Schroth and Sinclair 2003), sustainable management of soil organic matter (Rees et al. 2001), modelling below-ground interactions (van Noordwijk *et al.* 2004), and the application of these concepts to integrated plant nutrient management (Soil Science Society of America 2001; Gichuru *et al.* 2003; Vanlauwe *et al.* 2002).

## **2. Improved practices for better management at the field level**

Significant adoption of a range of improved technologies has been documented across a number of countries in SSA. The technologies include soil and water conservation structures, such as ‘zai’ pits in the Sahel, organic nutrient management systems such as high quality manuring in intensive dairy systems in Kenya, and more integrated soil management practices. Available evidence shows that the technologies increase productivity in the environments where they have been adopted. But it is also known that what may work in one site, may not work in another due to differences in soil types, acidity levels, organic matter content, chemical composition of soils, rainfall, slope of land and other factors. Below are a few examples of soil management practices that have been found to significantly improve crop yields.

### *Micro-doses of fertilizer*

Micro-doses of fertilizer have been tested with 160,000 farmers in 2003-04 by ICRISAT in Zimbabwe. As part of a relief programme, farmers were provided with 25 kg of ammonium nitrate and could apply the fertilizer to any cereal crop. Rates averaging about 8 to 10 kg of nitrogen per hectare (approximately 20% of recommended levels) were used.

Virtually all of the farmers applying micro-doses of fertilizer during the 2003/04 cropping season got higher grain yields. Average gains ranged between 30% and 50%, depending on the amount rainfall. Food security in these households improved correspondingly. The 160,000 households taking part in the programme are estimated to have increased their production levels by an average of 250 kg each, achieving a total of 40,000 tonnes. This extra production was valued at more than US\$7 million in food aid imports that were no longer required. The national survey results indicated that the distribution of small doses of fertilizer yielded a 2.5 times larger return from the donor investment than did the distribution of relief seed in the same country (David Rohrbach, personal communication).

### *Organic nitrogen sources*

Because nitrogen is the major limiting nutrient across large areas of the region, there is scope for organic-based nutrients to generate significant impacts on crop production. A range of 'fertilizer tree' and herbaceous legume cover cropping systems has been developed, involving a number of research institutes working in collaboration with farmers and other development organizations. An improved fallow system using a variety of woody legumes has been found to have significant effects on maize in rotations or intercrop systems, producing as much as 150 kg of nitrogen per hectare. Even factoring in lost production due to fallow periods, fallow systems are properly managed (Mafongoya et al 2005). A permanent intercrop system, in which there is no fallow period and crops are grown each season, is more attractive on very small farms where farmers do not practise fallowing, such those as in southern Malawi.

Over 200,000 farmers are testing or using agroforestry fallows or agroforestry intercrops in Malawi, Tanzania, and Zambia. In Eastern Province Zambia, the net annual returns from a fertilizer tree fallow system with an average fallow size of .20 hectares is about \$28 for each household or, in maize production, between 85 and 170 kgs a year, depending on species and performance. Daily maize consumption for adults in Zambia is about 0.75 kg per capita and, therefore, under current practice, the systems generate between 114 and 228 extra person days of maize consumption. In Eastern Province, the total benefits in 2003 were estimated to be about \$1.17 million dollars accruing to approximately 47,000 farmers (Ajayi et al. 2005). It has been estimated that 42,000 farmers planted a fallow in the 2003-2004 season. Thus, by the end of 2006, the economic impacts were expected to have increased to \$2.25 million.

Biomass transfer or mulching with green-leaf manure using foliage of trees and shrubs cut and carried to cropping areas is a traditional practice in many areas. In western Kenya, the naturally occurring shrub *Tithonia diversifolia* is used as a source of nutrients, particularly for vegetable crops. Research has been conducted to improve this traditional system.

Studies have been done on a range of green manure sources and application methods. As many organic materials contain low nutrient concentrations, large amounts of organic material are required to obtain reasonable increases in crop yields. The large amount of labour needed to transport and apply the biomass justifies its use only for high-value crops.

### *Conservation agriculture*

Water is a key constraint to crop performance in many regions of Sub-Saharan Africa. Large areas within the region receive less than 800 mm rain annually in a normal year and are prone to drought periods within the cropping season. Conservation agriculture offers possibilities for better water management and yield enhancement.

Conservation agriculture involves a number of approaches for reducing tillage, which results in higher retention of soil organic matter and improved physical properties of soil, such as water holding capacity, aggregation and infiltration.

In addition to minimum or zero tillage, conservation agriculture involves early land preparation and timely planting, legume rotations, micro-water basins, point seeding and fertilizer application, and covering the soil with biomass (residues and others).

Haggblade and Tembo (2003) found that conservation agriculture practices resulted in an additional 1.1 tonnes of extra maize per hectare in a survey of farmers across Zambia and that these improvements were profitable after subtracting extra costs. It is estimated that about 60,000 farmers in Zambia were employing two or more conservation farming techniques and that farmers' associations were promoting the practice (Haggblade and Tembo 2003).

The major constraint to implementing conservation agriculture practices is the need for greater efforts to control weeds in this system.

### 3. Soil management principles

Principles of ISFM have influenced diverse stakeholders in SSA to alter the ways they manage soils on various scales:

- ISFM approaches are increasingly used by national and international research and development organizations, networks, NGOs and extension agencies.
- A substantial number of short term, degree-related and on-the-job training activities across the continent have helped spread ISFM approaches at national level, including to university curricula.
- Land degradation surveillance approaches for surveying the prevalence of specific soil degradation problems and inherent constraints to crop production, identifying environmental risk factors and monitoring impacts have been developed.

International agricultural research has significantly contributed to the development of sound soil management principles that aim at sustainable crop production without compromising the ecosystem service functions of soil. These include:

- Application of organic resources of animal or plant origin in combination with mineral inputs to maximize input use efficiencies and increase returns to investments.
- Integration of cover crop and multi-purpose, woody and herbaceous legumes into cropping systems to increase the availability of organic resources and consequently increase crop yields and farm profits.
- Enhancing the soil organic carbon pool as an integrator of various soil-based functions related to production and ecosystem services.
- Improved sustainability of nutrient cycles through integration of livestock with arable production.
- Soil conservation methods to control soil loss and improve water capture and use efficiency.

Mineral fertilizers can quickly replenish lost plant nutrients but their continued application without organic matter inputs can lead to declining yields because of other problems such as imbalance or deficiency of certain nutrients, deterioration in soil structure and acidification of the soil. Some studies have found high economic returns to the use of organic nutrients, such as green manures in Kenya (Kipsat *et al.* 2004), and farmyard manure in Zimbabwe (Mutiro and Murwira 2004). However, studies conducted in different parts of SSA show that integration of inorganic and organic nutrient inputs is a better option to increasing fertilizer use efficiency and providing a more balanced supply of nutrients (Mutuo *et al.* 1998; Gachengo *et al.* 1999; Nziguheba *et al.* 2004).

Organic and inorganic inputs cannot be substituted entirely by one another and are both required for sustainable crop production (Vanlauwe *et al.* 2002a; Sanchez and Jama 2002; Place *et al.* 2003). Studies in Kenya and Uganda report a higher maize yield when organic and inorganic inputs are combined than when either of them is applied separately (Jama *et al.* 2000; Delve 2004).

Even in terms of profitability, the combination of inorganic and organics is higher compared to when only one input is added. For example, the combination of integrated biomass transfer and rock phosphate systems on kales and tomatoes in Kenya showed returns from labour of between \$2.14 and \$2.68 a day. These figures were much greater than the \$1.68 a day achieved when only one of the nutrient sources was used (Place *et al.* 2003). In Zimbabwe, the integration of manure and fertilizer on maize resulted in a return from labour of about \$1.35 per day, while the best single fertilizer or manure treatment yielded only \$0.25 (Mekuria and Waddington 2002).

There is need to pay more attention to nutrient recycling beyond the farm scale -- in watersheds, between pastoral and cropping systems, and between urban and agricultural areas. Non-point sources of phosphorus, for instance, dominate the eutrophication of freshwater systems.

#### **4. Tools and methodological innovations**

Due to the complex and interactive nature of the major factors driving poverty, land degradation and soil fertility decline, and the fact that these factors interact on different scales, substantial progress has been made to develop new tools and to apply them in approaches that encompass:

- Participatory approaches that increase the appreciation and use of local knowledge systems in the development of improved soil management interventions and principles.
- Integration of GIS and remote sensing tools in an analytical capacity for large area problem assessment, targeting interventions, and scaling up improved soil management practices.
- Agroecological and farming systems analysis frameworks to understand cause-and-effect relationships on scales ranging from the farm to the agricultural landscape.
- Tools and approaches to integrate processes required for monitoring and evaluating ecosystem services on various scales.
- Rapid spectroscopy and digital mapping techniques to distinguish various soil constraints and properties at plot, farm and landscape scales.
- Molecular tools to study soil biodiversity, response of microbial communities to management and how these responses link to biogeochemical cycles and pest population dynamics.

The major challenge is to advance the application of these new tools and integrate them into soil fertility research in national research institutions and universities. Much research on soil fertility in Africa takes a technology based approach and is carried out in randomized complete-block design experiments. There are examples of application of these methods, but there is a need to use these tools more widely if Africa is going to meet the challenges of the next 10 to 20 years.

##### *Integration of local knowledge of soil management*

Studies coordinated by NUTNET throughout Africa used a participatory approach in numerous countries such as Kenya (Gachimbi *et al.* 2002) and Ethiopia (Corbeels *et al.* 2000). This has led to local successes in innovation and improved soil management. An example of a more widespread indigenous practice is the 'zai' pit water conservation and soil fertility strategy originating in Burkina Faso (Bonkougou 2002). Researchers have helped to disseminate information about this practice and increase productivity through the testing of complementary management strategies and inputs.

### *Application of GIS*

The new Soil Fertility Consortium in Southern Africa (SOFECSA) is combining data on soil nutrient constraints (nitrogen and phosphorus) with poverty maps to identify areas where certain types of mineral fertilizers are appropriate and areas where organic nutrients are likely to work best (areas without severe phosphorus deficiency) and be most suitable (where there are high concentrations of poor people) (Agumya et al. 2005).

### *Infrared spectroscopy*

The use of infrared spectroscopy for rapid analysis of soil quality and organic resources has been a major breakthrough in field diagnostics (Shepherd et al. 2003, 2004). The technology can be combined with (Global Positioning Systems (GPS) and GIS tools to quickly and inexpensively predict how improved crop varieties will respond to fertilizer at a given location. For example, the tool has been used on watershed scale to map soil erosion risk and soil fertility status, and quantify the impact of land use change on soil fertility and carbon stocks, in Kenya, Uganda, and Madagascar (Awiti et al 2005; Cohen et al. 2004; Mulumba 2004; Shepherd et al. 2000; Vågen et al. 2005ab). The technique not only provides a better understanding of the complexity and diversity of local soils, but also serves a tool for monitoring soil quality for environmental protection. It should supply the information governments need to make policy decisions that will help the rural poor boost crop productivity, achieve food security, and protect the environment (<http://www.worldagroforestry.org/sensingsoil/>).

A major advantage of this technology for national programmes is that it can be used to analyse plant materials and liquids, with multiple applications in crop nutrition and livestock nutrition. These include soil engineering tests, plant tissue testing, manure/compost analysis, feed/fodder analysis, livestock faecal profiling, grain/milk/oil analysis, and water quality testing. Thus, laboratories can achieve high sample throughput (400 samples a day) for diverse applications with a single instrument.

The tool is being implemented in a number of projects in SSA, mostly by international organizations. Capacity building with national organizations is needed to develop the knowledge, skill and laboratory facilities to take advantage of the new tool and to extend its usefulness. ICRAF is planning to support a network of infrared spectroscopy laboratories for multiple applications in support of the agricultural green revolution.

### *Application of molecular techniques in microbiological studies*

Several international organizations are using modern methods to study soil microbial communities. The Institut de Recherche pour le Développement is using this approach in the Sahel and in East Africa to look at mycorrhizal and rhizobial relationships in systems using nitrogen-fixing cover crops. ICRAF is using these tools to study the changes in microbial communities as land degrades so as to understand how biological function is lost and the potential for recovery. Washington State University is taking a similar approach in the Sahel, while a few national research organizations are also taking up these tools. For example, the Kenyan Forestry Research Institute is using these techniques for studies of mycorrhiza.

The potential for expanding the application of modern microbiological tools to problems of soil fertility in Africa goes beyond a better understanding of biogeochemical function. The tools have, perhaps, the biggest potential in furthering our understanding of soil-borne plant pathogens.



## Science capacity in soil fertility in Africa

Capacity has at least three elements: physical infrastructure such as experimental sites and laboratories, human resources such as trained researchers or educators, and functional systems in which these elements can generate science. Underpinning these is the level of resources invested in research systems. Each of these topics is discussed in the section that follows, after a general overview of agricultural research in Africa.

This section draws mainly upon research conducted by the International Service for Agricultural Research (ISNAR). ISNAR's Agricultural Science and Technology Indicator (ASTI) project conducted detailed studies of agricultural research systems in many African countries. However, only one (Morocco) is from North Africa. Thus, that region is nearly absent from the quantitative tables and the discussion around them. We supplement these studies with good reviews of North African countries by the International Centre for Research in Dry Areas (ICARDA).

### 1. General state and trends in agricultural research in Africa

Agricultural research systems in Africa differ considerably in terms of their size, scope, organizational structures, and areas of emphasis. Yet there are some similarities or tendencies. Bientema and Stads (2004) note that across Africa, the private sector accounts for only 2% of all agricultural research. Within the public sector, government agricultural research institutes (NARIs) dominate higher education and NGOs in terms of research staff and expenditures. In aggregate, NARIs implement about 75% of agricultural research in Africa.

While universities have grown considerably in enrolments and faculty over the past 20 years, university research still represents a minor percentage of total public agricultural research, as indicated in Table 1. For most countries, the percentage of agricultural research undertaken by universities is below 20%.

The size of agricultural research organizations and expenditures differ widely, with the largest system being in South Africa (over \$280 million annually in 1993 dollars). Nigeria, Ethiopia, and Kenya also spend more than \$50 million annually on agricultural research. In fact, 25% of all spending on research takes place in South Africa (Bientema and Stads 2004). The budgets of some countries are much more modest, such as Burundi, Madagascar, and Niger which, in recent years, are spending just around \$5 million annually. Obviously, some of these differences are explained by the size of the country and the agricultural sector.

Column 2 of Table 1 shows the agricultural research expenditure as a percentage of GDP in 22 SSA countries. Botswana shows the highest investment intensity in research at 7.7%, followed by South Africa and then Kenya. The next tier of countries includes Mali, Morocco, Senegal, Republic of Congo and Malawi. The countries with the lowest ratios of agricultural research expenditure to GDP are Guinea, Madagascar, Niger, and Sudan. It has been estimated (Casas et al 1999) that this percentage averages about 0.5% for North Africa. The Inter-Academy Council recommended that African countries increase their spending on research to at least 1.5% of agricultural GDP, up from the present average 0.7% (IAC 2004).

For many countries in Africa, the apex of research system health was during the 1970s, following great expansion in the 1960s (Muchena and Kiome 1995) when overall spending was high (in real dollars), especially spending per scientist. Growth in agricultural research expenditure began to diminish during the 1980s and by the 1990s, it had declined to 1% a

year (Bientema and Stads 2004). For many countries, there was a net reduction in spending (Table 1).

Agricultural research investment actually declined between 1990 and 2000 in 12 of the 22 countries tabulated. In a few cases, the decline was steep and dramatic — Madagascar, Zambia, Burundi, Niger, Congo, and Sudan. One of the reasons for these shifts is the countries' reliance on donor funding to support agricultural research. As of 2000, 35% of research funds came from donors.

According to Bientema et al. (1998), between 1960 and 1996, the number of African universities increased from 20 to 160 and students from 119,000 to almost two million. However, just under half of the 160 universities are in Sudan, Nigeria and South Africa.

Funding kept pace with university expansion until the 1980s, but spending per student has declined. An earlier study found that spending per student in African universities fell from \$6,300 to \$1,500 during the 1980s (from a World Bank 1994 study). The same Bientema *et al.* (1998) review found that 96 universities in 37 African countries offered some agricultural training, again, about half of them in the Sudan, Nigeria, and South Africa. Forty-two universities offered post-graduate degrees in agricultural sciences. There are no reliable data on the number of degree programmes in soil sciences, but most agricultural graduate programmes include soils as a specialty.

Table 1: Indicators of Agricultural Research Spending in Selected African Countries

Country	Total NARI agriculture spending in 2000 (1993 \$)	Agricultural research as % of agricultural GDP	Annual growth in agriculture research spending (1990 – 2000)	University research as % of total R&D
Botswana	11.0	7.7	3.8	10.2
Burkina Faso	20.2	0.5	-1.2	6.5
Burundi	4.0	0.4	-9.0	23.9
Congo-Brazzaville	1.5	0.8	-6.3	18.1
Cote d'Ivoire	28.4	0.7	-2.2 (a)	12.6
Ethiopia	72.2	0.4	8.5 (b)	10.9
Ghana	40.0	0.4	0.3	16.1
Guinea	6.3	0.2	-5.1	10.0
Kenya	65.0	2.6	1.0	15.6
Madagascar	5.0	0.2	-6.4	3.8
Malawi	7.2	0.8	-4.2	9.5
Mali	24.8	1.0	0.8	10.2
Morocco	107.0	1.0	3.4	36.5
Niger	5.3	0.2	-6.2	15.9
Nigeria	61.0	0.4	3.6	37.7
Senegal	17.5	0.9	-3.0	19.3
South Africa	280.5	3.0	1.3	14.9
Sudan	25.8	0.2	-7.8	28.7

Tanzania	15.0	0.4	25.0 (c)	15.4
Togo	10.5	0.5	-4.2	12.4
Uganda	38.0	0.5	14.5 (d)	20.0
Zambia	6.5	0.6	-6.6	7.9

Source: Compiled from ISNAR reports on Agricultural Science and Technology Indicators in Africa

(a) Annual growth in Cote d'Ivoire is from 1992-2000

(b) Annual growth in Ethiopia from 1993-2000

(c) Annual growth in Tanzania is from 1996-2000

(d) Annual growth in Uganda is from 1995-2000

## 2. Human Resources

Just as the case with research expenditures, there is a considerable variation in the number of researchers in NARIs and at universities across the countries. Table 2 shows the number of full-time equivalent researchers in the NARIs of the 22 African countries. A few countries dominate in total numbers: South Africa, Nigeria, Sudan, Kenya, Ethiopia, and Morocco. Egypt also has a large number of researchers (Casas et al. 1999)

After a period when significant numbers of expatriates were employed in African research systems, almost all scientists in the NARIs and agricultural faculties are African. The only exception appears to be Libya, where 141 of 622 scientists are foreigners.

At the same time, training of scientists has improved. Column 2 of Table 2 shows that the percentage of researchers with post-graduate degrees is above 75% in most countries and indeed that is the average for sub-Saharan Africa (Bientema and Stads 2004). Ethiopia and Guinea are lagging behind in terms of education experience for their researchers. In North Africa, it is estimated that about 70% of NARI researchers and 90% of university staff have post-graduate degrees (Casas et al. 1999). A similar pattern is believed to hold in Sub-Saharan Africa, although figures are not available for all countries.

The percentage of female researchers is well below 50% in all the countries. Table 2 shows that there is quite a variation across countries, with several below 10%. In another group, between 10% and 20% of researchers are women while in several countries the proportion is between 20% and 25%. In Botswana, Madagascar, South Africa, and Sudan, a quarter or more of agricultural research staff are female.

The ASTI surveys attempted to estimate the number of scientists in different disciplinary fields. For many countries, an estimate of the number of researchers who were soil specialists was determined (Table 2, column 4). Results suggest that between 5-10% of agricultural scientists in the NARIs specialize in soils research. The bulk of the researchers in the institutions are engaged in crop-related research. This leads to a logical discrepancy between the nature of the problem and the allocation of resources to solving the problem. As we noted above, soil fertility is widely recognized as the leading constraint to food security in SSA. Without solving this problem, the potential of improved crop varieties is limited.

One of the reasons for this apparent disparity is the continued structuring of research organizations by commodity type. Jones (2004), among many others, urge a change to the compartmentalization of research so that different disciplines can come together to solve the major problems of the continent, such as soil fertility.

It would require a lengthy survey and analysis to assess the quality of soil fertility research capacity in Africa. What is known is that in some countries, this capacity has been lost along

with other scientific capacity because of conflicts. This is the case in Liberia, Sierra Leone, Democratic Republic of Congo (DRC), Rwanda, Burundi, Sudan, Mozambique, Angola, and now Cote d'Ivoire where staff turnover has severely affected institutional knowledge.

The quantity and complexity of research that can be undertaken is limited in countries affected by conflict. For example, many of the countries have few PhD scientists. For instance, in Mozambique there is only one PhD scientist addressing soils in the NARI. In other countries, low salaries are considered to be a major factor in staff retention. Overall, there is a shortage of soil scientist staff throughout Southern Africa (see regional reports in the Annex).

While the preceding paragraphs have discussed the present human resources constraints in the NARIs, it is also important to review the training in the higher education system to predict future levels of agricultural research capacity. In early 1990s, a survey of 19 African countries found that about 11,000 students were enrolled in agricultural departments, with just 387 seeking post-graduate degrees, excluding Nigeria and South Africa where more than 2,000 graduates were enrolled (Bientema et al. 1998). Comparing these numbers to total student enrolment shows that about 4% of university students were in agriculture, but the figures were lower in South Africa (0.9%) and higher in Nigeria (11.0%). One-third of all university students were women, but only 13% in agriculture.

There were about 90,000 African students abroad in major reporting countries (data excluded students in India and Brazil), amounting to about 10% of all African university students. A study in the US, found that 75% of students in agricultural studies were pursuing post-graduate degrees compared to 33% for all foreign students. We do not have data on numbers of graduate students pursuing soils degrees in African universities, but there are some cases, such as Makerere University, where the numbers are shrinking due to perceived lack of employment.

Table 2: Indicators of Human Resource Capacity in Selected Agricultural Research Systems in Africa

Country	Number of NARI Researchers	% with Post-Graduate Degrees	% Female	% Soils (* means NRM Research as a whole)
Botswana	81	67	35	3*
Burkina Faso	244	95	8	15
Burundi	58	74	14	n.a.
Congo-Brazzaville	96	89	12	9.5
Cote d'Ivoire	132	83	8	n.a.
Ethiopia	660	50	7	8.8
Ghana	392	84	17	4
Guinea	242	32	5	1
Kenya	647	85	20	10
Madagascar	178	95	25	11*
Malawi	96	76	8	11*
Mali	270	76	11	3*
Morocco	416	89	18	8.3

Niger	92	89	7	15
Nigeria	839	83	22	4
Senegal	122	99	10	6
South Africa	703	73	33	2.2
Sudan	555	79	28	16*
Tanzania	441	78	19	4.5
Togo	60	96	6	10
Uganda	192	88	21	3
Zambia	148	71	10	10*

Source: Compiled from ISNAR reports on agricultural science and technology indicators in Africa.

### 3. Laboratories and other physical infrastructure

We know of no objective assessment of the adequacy of research infrastructure. We can only offer impressions at this point.

- Our impression of libraries is that they are good in North Africa, and adequate in only a few African countries. Scientists posted outside of capital cities generally have poor access to the scientific literature. Universities often do not subscribe to specialist journals, but students and university researchers have access to a few general journals.
- Many scientists have access to service laboratories of varying quality. However, equipment maintenance, chemical supplies and quality control are common problems, especially outside North Africa and South Africa. Research labs are generally lacking and scientists have little opportunity to obtain grants that allow for the purchase of specialized equipment. This situation has been exacerbated by declining research funding, especially core funds for research.

### 4. Organizational and functional capacity

In terms of the way agricultural research is organized in general, and soils research in particular, several concerns have been noted. First, NARIs tend to be organized around commodities, such as important crops or livestock, because it has been believed that variety and breed improvement is key to agricultural productivity growth. Thus, while NARIs have soil research departments, such departments tend to be relatively small and their work poorly integrated with that of crop scientists. Second, there has tended to be over-centralization of research such that relatively few researchers are posted in rural areas. Even in more advanced countries such as Egypt and Tunisia, most of the agricultural scientists who have a PhD are based in the capital city (Casas et al 1999).

A third observation, related to the one above, is the widely held view that linkages between researchers and development organizations are poor. In the past, research systems have not been held accountable for impact. It was expected that organizations would ensure farmers adopt technologies developed. There are, of course, exceptions to this and across Africa this mode of operation is changing. Morocco has been cited as model of research–development partnerships (Casas et al. 1999), while in East Africa, the Kenya Agricultural Research

Institute has started an innovative programme to improve links between researchers and community based organizations.

The extent to which researchers can become involved with farming communities is limited. The farmer-to-researcher ratio in most countries is extremely high – between 1:10,000 and 1:35,000 (Chema et al. 2003). This may well be ten times greater for soil scientists if they represent only about 10% of agricultural research staff (see Table 2).

A fourth critique is that there is lack of collaboration between NARIs and universities (Michelsen et al. 2003). Universities have largely been regarded as teaching institutions and not contributing to research and development. Policy is changing away from this perception, but in terms of functional capacity, there remain constraints to university faculty becoming more engaged in agricultural research. A key constraint is lack of funding.

However, there are several examples of formal attempts to bring together researchers from different organizations and of networks and consortia within Africa pertaining to soil fertility. NUTNET, an externally initiated network of scientists engaged in related studies coordinated by Wageningen University, is one example. Another is the African Network for Soil Fertility (Afnet). With hundreds of members who are mainly biophysical scientists or development specialists, Afnet is working to improve communication within the scientific and development community. There are also regional networks such as the Soil and Water Management Network in ASARECA.

These networks combine many goals, which include information dissemination, capacity building and generating new research. The ability of these networks to engage in research is heavily dependent on donor funds because although national governments have invested in national research, they do not, as a rule, invest in multi-country research programmes (Chema et al. 2003). Many of the networks in Africa have funded more national adaptive research than they have strategic regional research. A new consortium for soil fertility in Southern Africa (SOFECSA, which grew out of SoilFertNet) is attempting to develop a truly regional research agenda, but is still in its incipiency (see the Southern African regional paper in the Annex).

In terms of functional capacity, one important indicator is the amount of research funds available per scientist. According to Bientema and Stads (2004), agricultural research spending per scientist in Africa was \$130,000 in 2000 (in 1993 dollars), which is just half of the \$260,000 in 1971. This results from ambitious hiring policies by NARIs in the 1980s and early 1990s that was not complemented with increased funding. The range in spending per scientist in 2000 is from a low of \$18,000 in Republic of Congo to a high of \$366,000 in South Africa. However, some countries have improved in recent years. These include Ghana, Tanzania, Uganda, and Botswana.

For the general situation to improve, some authors call for policy change at the top levels to provide for greater collaboration between universities and NARIs (the two are mostly managed from different ministries) and to increase the level of support for research (e.g. Michelsen et al. 2003). The World Bank also recognized this some time ago and attempted to catalyze the formation of National Soil Fertility Plans under their Soil Fertility Initiative (SFI). Soil fertility strategies were established in some countries (Mali, Burkina Faso, Tanzania), but the programme lost momentum.

TerrAfrica is in some ways a successor to the SFI and the World Bank continues to support national strategy development and implementation. For instance, efforts are underway in Ethiopia to develop a major sustainable land management project under TerrAfrica.

In looking towards changes in agricultural and soil sciences for the future, it is important to articulate priority needs of the Forum for Agricultural Research in Africa (FARA) and NEPAD's CAADP (Comprehensive African Agricultural Development Programme). FARA is urging a rethinking of how NARIs conduct research and advocating a shift away from commodity and technology driven organizational structures to those that respond to specific opportunities for smallholder farmers (Jones 2004). The CAADP (2003) research strategy consists of four themes: integrated natural resource management, adaptive management of appropriate germplasm, development of sustainable markets, and formulation of policies for sustainable agriculture.

Soil fertility research is best placed within an integrated natural resource management context where it should link with efforts in crop sciences, agronomy, ecology and social sciences. In order to achieve impact, the CAADP calls for the building of capacity in various institutions, including those that deal with policy and development.

## **The way forward**

### **Maintaining the progress**

It has been demonstrated that investing in farmer-centred soil fertility research is integral to successful rural development. Research has helped us to better understand the diversity of conditions in which existing ISFM options can benefit the rural poor. By taking a pro-poor approach, international agricultural research has developed the means to achieve large-scale impacts, responding to the demands of small-scale farmers for improved agricultural production and ecosystem services.

Many ISFM options are locally profitable, even where land is intensely cultivated and its scarcity places constraints on the ability of farmers' to introduce changes. The knowledge-intensive nature and complexity of the ISFM approach, however, makes it difficult to translate local successes from one area to another, unless favourable factors and those constraining effectiveness and adoption of options are better understood.

Facilitating widespread use and impact of ISFM to solve SSA's soil fertility problems will thus require a tighter linkage and feedback between strategic and adaptive research activities. The iterative process of learning and problem solving builds on indigenous knowledge, improves imperfect technologies, and empowers farmers and institutions. Addressing farmers' problems in a systems context generates management options better suited to their local needs. It also produces policy options appropriate for local institutional realities.

Moving from a nutrient replenishment and technology based approach to a more integrated pro-poor strategy in soil fertility management will allow local approaches to generate global benefits. Future research should aim to create a virtuous cycle (Figure 4) to empower farmers to sustainably manage their soils. To do this, research must increase the range of options available for managing and rehabilitating poor soils in unfavourable social and economic environments.

Increasing our understanding of where ISFM options are working, why and for whom, will address the constraints limiting their wider use. The cost of not engaging in this research is likely to be enormous, in terms of greater poverty, stagnant and declining production, degraded ecosystem services, and loss of intellectual property rights related to the local genetic resources of the soil.

## Enhancing rural livelihoods through ISFM

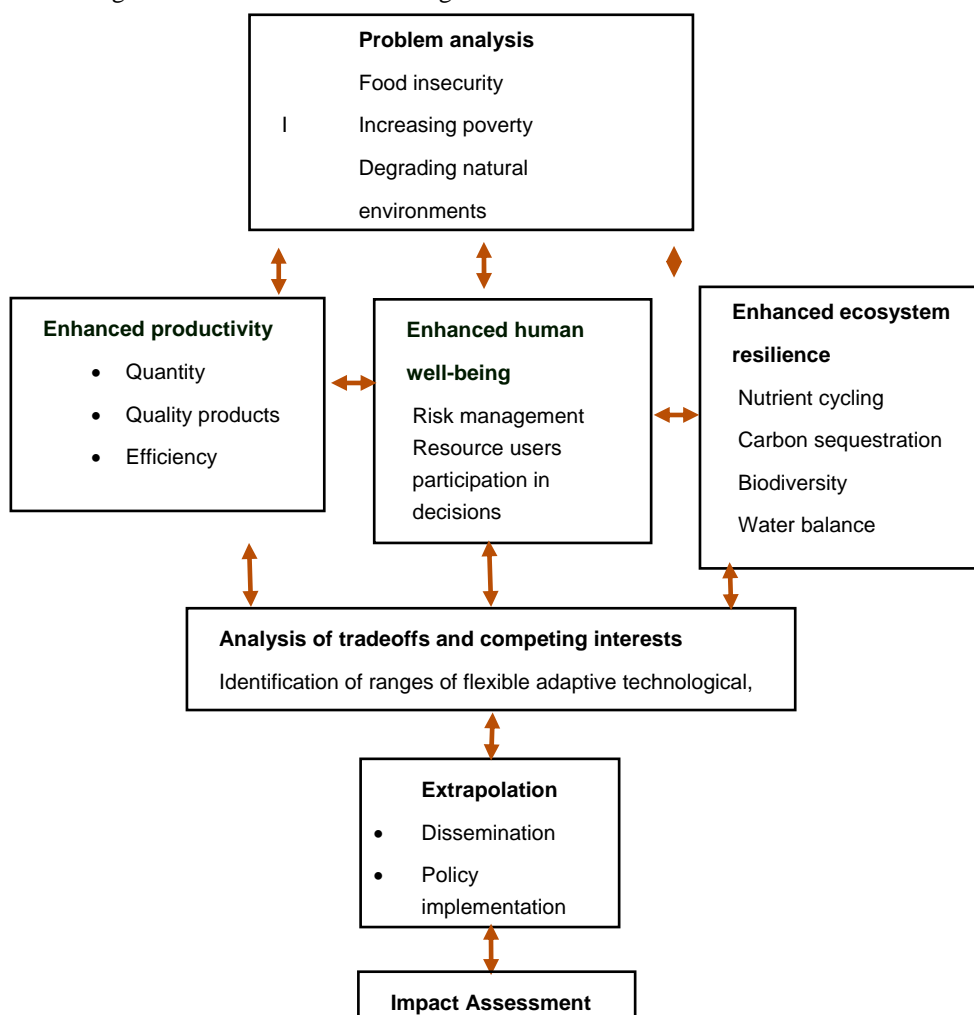
The imperative of soil fertility degradation and the impetus of current success demand urgent and long-term commitment to a comprehensive programme of research and development actions. It is clear from the analysis above that these actions cover many disciplines, operate across multiple scales and are highly interactive. A programme of work must build on and use methods that have already proved successful, besides developing and borrowing approaches where significant gaps in understanding or application occur.

To better organize our recommendations on the way forward, we wish to distinguish between scientific needs and capacity needs. For both, we will identify the key points for organizing the way forward.

## Recommendations for scientific advancement in soil fertility research

In terms of scientific imperatives, we refer to the Integrated Natural Resource Management Framework in Figure 4. The framework embraces problem focused research, one that examines a range of interventions through trade-off analysis, proactively engages in scaling up activities and closes the learning loop through monitoring and impact assessment.

Figure 4: The Integrated Natural Resource Management Framework





There is a need to apply new tools and approaches to improve scientific methods and empirical results in each of these components in the area of soil fertility research:

1. Improved understanding of soil fertility problems.
2. Managing carbon and nutrient cycles for enhanced agricultural productivity.
3. Managing soils for enhanced ecosystem services.
4. Managing soil genetic resources for enhanced biodiversity and pest management.
5. Empowering farmers to scale up research and results.
6. Methods for and lessons learnt from monitoring and impact assessment.

### **1. Improved understanding of soil fertility problems**

The use of infrared spectroscopy for rapid analysis of soil quality and organic resources is a major breakthrough in field diagnostics (Shepherd et al. 2003, 2004). The technology can be used collect data on soil quality and plant nutrition from thousands of locations, geo-reference it, and quickly and inexpensively predict how improved crop varieties will respond to fertilizer at a given location (Vågen et al. 2004; Annex 2).

The technique uses only light for rapid, non-destructive analysis of soil and plant materials. It is similar in many respects to digital photography: reflectance from a sample of material is collected across a range of infrared wavelengths beyond those that can be detected by the human eye. Working from a digital scan, a “reflectance fingerprint” is obtained from which development workers can easily predict the nature of multiple soil properties. A single infrared spectroscopy instrument can provide diagnostic analysis services for a wide range of inputs and products for agriculture, forestry, horticulture, and livestock production. The technique is economical and does not require the purchase of costly chemicals and other consumables normally used in conventional soil analysis.

Field tests have shown that infrared analysis can be used in conjunction with global positioning systems and remote satellite sensing to produce inexpensive maps that pinpoint soil and plant nutritional problems. These tools enable an evidence-based approach, which allows uncertainties in predictions to be quantified, unlike the current approach which is largely based on expert opinion.

Infrared spectroscopy provides a better understanding of the complexity and diversity of local soils. The technique also serves a tool for monitoring soil quality for environmental protection and should supply the information governments need to make policy decisions to help the rural poor boost crop productivity, achieve food security, and protect the environment.

### **2. Managing carbon and nutrient cycles for enhanced agricultural productivity**

Substantial strategic information related to the appropriate management of carbon and nutrients has been obtained, as evident in the soil management principles summarized above. Translating this information into soil management practices that address conditions

experienced by farmers is a challenge that needs to be addressed to achieve large-scale implementation of ISFM practices. Actions to achieve this include:

- Optimise organic and mineral resource use at the farm level in terms of maximal returns to labour and soil amendments by taking into account soil fertility gradients with the farm.
- Identify niches for organic matter production within existing farming systems. The mid-term strategic document of the African Association for Biological Nitrogen Fixation similarly recommends nesting legumes and associated biological nitrogen fixation within improved land management systems.
- Assess the various roles soil organic matter plays in maintaining production and ecosystem service-related soil properties and functions for various biophysical environments.
- Determine trade-offs between the use of organic resources and soil carbon for agricultural productivity and their value for carbon sequestration potential and other ecosystem properties.

### **3. Managing soils for enhanced ecosystem services**

Soils provide a wide range of ecosystem services essential for the well being of agriculture, smallholder farmers, rural communities and society as a whole. These ecosystem services include regulation of nutrient and hydrological cycles, maintenance of the utilitarian functions of biodiversity (medicinal plants, food, fibre, etc.) and participation in carbon sequestration processes. The integrity of the ecosystem needs to be maintained for effective delivery of these services. A recent global assessment has estimated that over 60% of ecosystem services are already threatened or in decline. The assessment emphasizes that future decision-making must consider the value of ecosystem services for poverty alleviation and sustained development (Millennium Ecosystem Assessment, 2005). Therefore, it is important to:

- Develop a methodological approach that integrates plot and watershed-level information related to the target ecosystem services (water quality and quantity, nutrient balance and erosion control, integrated global warming potential).
- Design and test management options to enhance soil-related ecosystem services within food secure land management systems.
- Develop monitoring systems to evaluate the impacts of ISFM options on ecosystem services beyond production.
- Valorise ecosystem services, with initial focus on carbon sequestration, soil conservation, and water quality, for trade-off analysis and policy recommendations.
- Define an appropriate policy and institutional environment that provides incentives to landholders that manage these services sustainably.

National programmes and soil survey departments in particular, have a new and important role to play in soil quality monitoring and land degradation surveillance. Advances in remote sensing, infrared spectroscopy for rapid soil and plant analysis, and GIS make national-level monitoring of soil quality and land degradation feasible on multiple scales at reasonable cost. This new role is important not only for environmental protection, but also for better targeting of technologies to increase crop and livestock productivity.

Essential soil production and environmental functions (e.g. soil nutrient supply, water infiltration) are largely determined by condition of the topsoil and highly dynamic, whereas existing soil resource surveys have used classification systems that are purposely based on intransient subsoil properties. The establishment of reliable baselines for monitoring soil

quality and function using statistically-valid sampling schemes is essential for sound decision-making on sustainable agricultural production and environmental protection.

#### **4. Managing the genetic resources of soil for enhanced productivity and plant health**

Soil biota constitute a major fraction of global terrestrial biodiversity and are responsible for key ecosystem functions. These functions include decomposition; nutrient acquisition, storage and cycling; soil organic matter synthesis and mineralization; soil structural modification; regulation of atmospheric composition; and the biological control of soil-borne pests and diseases. Research on the biological processes of soil lags behind that related to physical and chemical management and so these functions remain largely under-exploited by humans for services and products in agriculture.

However, recent advances in the understanding of soil ecology and in molecular methods for the study of soil have started to reverse this situation. New methods using gene micro-arrays, DNA profiling, DNA and RNA sequencing, and fatty acid analysis constitute powerful approaches to understand the relationship between soil microbial communities and biogeochemical processes equivalent to the genomic revolution in crop improvement. A programme of strategic research is required to realise this potential, but a specific area likely to yield high impact in the short to medium term is the exploitation of the interactions between pest management and soil fertility. Such a strategy would entail a number of components to:

- Develop cultural and bio-control practices to manage the interactions of soil fertility with plant vigour, and the reduction of plant pest problems.
- Develop quantitative techniques for monitoring and manipulating key functional groups of soil biota and their relationship to ecosystem service functions and plant health.
- Develop and validate management practices for key groups of beneficial soil organisms for small-scale farms.
- Link local knowledge about biological indicators of soil quality with scientific knowledge to develop robust soil quality monitoring systems that combine precision and relevance.

#### **5. Empowering farmers to scale up research and results**

There is overwhelming demand for ways to apply knowledge and insights about ISFM over large areas and influence the livelihoods of millions of people. Research to address poverty requires an approach that moves from plot to landscape, from household to community scales. Research activities to achieve these research goals include those that:

- Synthesise and disseminate information on options already adapted for use by different clients.
- Further diversify the range of management options available to small-scale farmers.
- Create a greater understanding of the factors affecting the adoption of ISFM.
- Empower farmers by promoting collective action for innovation and developing cost-effective strategies for building human and social capital at the local level.
- Identify and address policy constraints and options of specific concern to ISFM.

- Develop methods to define and measure impacts of scaling up, including research identifying emergent properties of higher scale systems such as market, pests and diseases, and watershed function impacts.

Much of this research will be more effectively implemented in the context of cross-country research programmes. Indeed, the effects of different policy options can rarely be fully understood in single-country studies. The science of scaling up is an under-developed area of research. How can information be best moved from one community to another? What is the most effective way to build the capacity that is needed to facilitate IFSM at local levels? Hitherto, these issues were left for extension and development organizations, but it is now accepted that these are major research challenges. This entire research area calls for close integration of scientists from different disciplines. It requires great synthesis and communication skills in order to effectively disseminate lessons to policy makers and major development stakeholders.

Quantitative and qualitative research methods will need to be integrated. A key requirement now is for well-planned and systematic field testing of new soil management technologies across a range of environments to develop predictive understanding of what works where and why. Technological advances in remote sensing, GIS and infrared spectroscopy enable efficient sampling schemes and systematic protocols to be applied so that decisions are guided by empirical results rather than expert opinion (e.g. Cohen et al. 2004). Within such a framework, a range of participatory and survey methods will be needed to understand complicated issues such as adoption processes.

## **6. Methods for and lessons learnt from monitoring and impact assessment**

One of the reasons why the science of soil fertility management is not further advanced is due to lack of ongoing monitoring and impact assessment of new management innovations generated by researchers or farmers. Testing and monitoring soil fertility management practices over a wide area would produce a rich source of ideas for improved management systems and provide insights into which options work where and why. Yet national research systems have been built to undertake localized on-station research – they often have ample land resources and other fixed physical structures, but limited logistical support to leave the station and work in communities with farmers. Moreover, scientists have been trained to manage controlled experiments and not to deal with the more complex on-farm situation where numerous factors vary at the same time.

Fortunately, methodological advances now make it possible to undertake complex on-farm research in a scientifically sound manner and at affordable cost. Infrared spectroscopy techniques have been mentioned already. Informed sampling procedures also allow a great deal of variation and much information to be obtained from relatively few samples. Also, statistical techniques are now available to control for many varying factors (such different combinations of soil fertility management practices) and account for contextual factors that vary across sites (through the integration of GIS variables).

Monitoring and impact assessment on farms is the only practical way to understand the socio-economic performance of different systems. Through such assessments it is possible to investigate which systems are profitable and where; which ones are feasible given cash, land, and labour constraints; which ones are readily accepted by the very poor, women, families affected by HIV/AIDS, or other vulnerable groups.

## Capacity building for ISFM research and development

There is an urgent need to strengthen the scientific capacity of scientists in modern scientific approaches, which are rapidly evolving due to technological advances. Scientists in Africa often work in isolation. They do not have access to journals or opportunities for ongoing training to stay abreast of new developments. Yet many of the new tools available require sharp quantitative skills to apply properly. We have identified several key areas for capacity building:

- Systems and evidence-based approaches for planning, targeting and testing soil management technologies, including impact assessment.
- Directing research to meet needs.
- Modern analytical techniques including molecular techniques for soil microbiology, isotope techniques for nutrient cycling studies, infrared spectroscopy and other approaches for rapid soil analysis, GIS, and advanced remote sensing techniques.
- Quantitative skills including advanced statistical methods and numeric modelling to facilitate more complex experimental approaches and extrapolation of experimental results.
- Principles of multi-scale approaches of watershed management and land degradation surveillance, including application of remote sensing, GIS, infrared spectroscopy, and multivariate/spatial statistical methods and modelling.
- Interdisciplinary training to facilitate communication between scientists from different areas and to facilitate greater collaboration on projects.
- Skills to facilitate integration of research findings into and national policy and decision-making, including quantification of ecosystem services and integration of soil and land degradation issues with social and economic decision-making, and using tools such as environmental accounting and environmental service payments.
- Skills to facilitate linkages with the private sector to provide advice and extension services to the smallholder sector.

Just as important as development of scientific capacity in soils and agricultural research, is the need to strengthen mechanisms and incentives to retain and ensure continuous development of trained personnel. Several mechanisms have been put forward in the regional reviews. These include:

- Development of postdoctoral opportunities for regional scientists. Many scientists in the region go directly from PhD training into professional positions without additional mentoring that would allow them to consolidate the knowledge that they have gained from their formal training.
- Investment in research infrastructure and facilities such as GIS/remote sensing and soil laboratories, broadband Internet connectivity, libraries, and stable power supplies. Access to modern research facilities is considered necessary for ISFM and is a powerful incentive for retaining high-calibre staff.
- Greater government investment in national agricultural research and extension services is needed to increase employment and career advancement opportunities. Better links between universities, NARS and the private sector could help to create more job opportunities. Achieving this will also positively feed back into increasing enrolment at universities.
- Fellowships to promote attachment of junior and middle-career scientists to other institutions – such as IARCS, AIR and universities — to strengthen their skills and expose them to the diversity of ISFM approaches.

- Sponsored professorships, where renowned technical experts are funded to work with specific groups at national or regional level over a given timeframe, with the specific aim of developing capacity and imparting skills.
- Sponsored visits by experts over short periods to deliver modular courses (for instance, at universities) as part of a strategy to reinforce MSc and PhD training in the region. For particular skills, the students can then be sent to advanced institutions for limited periods. The objective should be to ultimately enable selected national or regional institutions to offer advanced and high-quality MSc and PhD training.
- Targeted research support to newly established and mid-career scientists in strategic local institutions, coupled with comprehensive involvement of experienced personnel will provide resources to enhance local capacity as well as offer incentives to retain personnel.

All of the regions that we surveyed indicated that capacity for ISFM research in SSA is insufficient, both in terms of the numbers of professional personnel and essential laboratory and library facilities. ISFM is a knowledge-intensive approach to soil management. But professional staff and students alike work in isolation from others in their fields and lack access to up-to-date educational opportunities. Networks run by sub-Regional Organisations (SROs) and Consultative Group on Agricultural Research (CGIAR) Centres, such as the Tropical Soil Biology and Fertility Institute's (TSBF's) African Network for Soil Biology and Fertility (AfNet), and the African Network for Agroforestry Education (ANAFE) provide vehicles of opportunity to correct this situation. Priority actions should aim to:

- Strengthen networking to engage a wide range of stakeholders and enhance the efficiency of ISFM research.
- Develop a high-quality virtual agricultural library that can be accessed via the Internet, and take the steps to ensure that scientists have access to this library. This may involve widespread distribution of Current Contents to remotely posted staff, who could then order specific articles through a centralized service.
- Develop regional research programmes in which scientists can participate in scientific teams working on regional problems. These programmes require adequate funding to facilitate not only project operations, but also communication and scientific discussion within the team.
- In particular, strengthen links between research and extension, including NGOs, using a "learning-by-doing" approach, which incorporates local knowledge and builds on existing networks.
- Develop strategic partnerships in capacity building that identify and utilise the range of comparative expertise.
- Improve the dissemination of knowledge on ISFM through a wide range of methods, including electronic sharing and training of trainers.
- Promote programmatic linkages with universities and other educational institutions to strengthen curricula with appropriate and up-to-date information and teaching materials.
- Raise awareness of ISFM issues with policy and decision makers at all levels.

## Conclusion

Solving the soil fertility problem in Africa is the key to food security and to achieving a number of the Millennium Development Goals. Significant gains have been made over the past decades, but, unfortunately, the effort at generating the knowledge to solve the problem pales in comparison to the magnitude of the task. As Vlek (1995) noted, “Claiming that a rich research database on soils does exist in Africa borders on recklessness, as it accepts a situation that would be considered utterly unacceptable to the scientific community in the West if it were to deal with an array of problems such as those prevailing in SSA”.

If agriculture is to serve as the economic motor that spurs development, as it has elsewhere in the world, the soil fertility problem must be tackled comprehensively. Much remains to be done. Soil fertility research needs to be given a status similar to that of plant breeding in both international and national agricultural research priorities. Human and institutional capacity building requires external and internal support. African scientists lack many of the post-PhD training opportunities available to their international counterparts (continuing education, participation in international seminars, postdoctoral training, sabbatical support, etc.). African institutions also lack the means to offer attractive employment packages and working conditions that could attract and retain the best scientists.

African institutions must overcome the bias that their role is to do adaptive research and that strategic research is for international institutions. This view is patronizing and robs Africa of the opportunity to excel. As a first step, training needs to focus on supporting African science to catch up with modern approaches to soil science (such as use of isotopes, infrared spectroscopy, integration of GIS and remote sensing). Capacity building must be implemented in a way that ensures an increase in the number of young scientists capable of undertaking world class science. This will translate into more African scientists able to take on international scientific leadership as they mature in their careers.

At the heart of all of this is the question of funding. Soil fertility is not glamorous. Many see it as fairly routine. Core funding in international and national research is decreasing and much of the work is done through special projects that often seek to produce impact within their short lifetime of 3-5 years. This is unrealistic for research, which is by nature a long-term endeavour. The dramatic gains of the Green Revolution in Asia and the modest gains in soil fertility work in Africa bear testament to what can be accomplished with adequate investment.

Beyond research, extension services need to function well to facilitate application of scientific advances to solving problems. The extension-research link is generally weak in Africa (Muchena and Kiome 1995), and extension services often lack the means to achieve large-scale impact. The part of the private sector in agricultural research is small, but there is a trend towards increasing this role in provision of extension services. For example, seed companies in eastern Africa are beginning to provide soil, crop and livestock diagnostic and advisory services to farmers' cooperatives, while the tea, coffee, sugar and horticultural sectors often have out-grower schemes that provide extension support to smallholders.

Complacency in comprehensively addressing soil fertility will only lead to delays with dire consequences for the people of Africa. As Jarred Diamond (2005) has shown, societies have collapsed in the past due to the conjuncture of population growth, environmental damage, changes in trading relationships, and climate change. The message of his book is that many factors interact in different ways and that no single factor is determinant of the outcome,

except one: how a society chooses to respond to the challenges that changes bring. Globalization of markets, accelerated human induced climate change, land and other natural resource degradation, infectious diseases and population growth all pose serious challenges for Africa. The response to date is not commensurate with the challenge.



## ANNEX 1: REGIONAL REPORTS

### Report on Southern Africa

The main challenge for agricultural research and development in Southern Africa is to reverse the prevailing negative trends in land productivity in both crop- and livestock-based farming systems. This would lead to increased per capita food production, household incomes and better livelihoods. Declining soil fertility, a root cause for the stagnant *per capita* food production in Sub-Sahara Africa (Sanchez, *et al.* 1997), has not only threatened food security, but also accelerated depletion of natural resource and general land degradation. A major consequence is the loss of ecosystem services, and emergence of socio-political conflicts largely driven by resource scarcity.

Studies have revealed widespread negative balances for major crop nutrients in Southern African states (Smaling, 1993; Smaling *et al.* 1997). Nutrient outputs from the farming systems are exceeding inputs as most farmers cannot obtain the external inputs required to offset nutrients removed in crop products and/or lost from the soil due to natural and human-driven environmental processes.

Unless major steps are taken, severe soil nutrient depletion will continue to occur as practitioners lag behind, grappling to unravel the complexity of the processes driving this phenomenon. The search for lasting solutions to soil fertility problems has often been frustrated by the complex nature in which soil fertility interacts with environmental, cultural and socio-economic factors governing agricultural production and off-farm livelihood sources in predominantly smallholder farming systems (Mapfumo and Giller, 2001).

Based on activities of the various institutions and organizations working in the region, there is a plethora of evidence showing that these interactions occur differently across spatial (e.g. at farm and national levels) and temporal scales (Waddington *et al.* 1998; Gichuru *et al.* 2003; Waddington, 2003). This has clearly demonstrated that soil fertility is a development issue that requires interdisciplinary capacity and multi-institutional involvement. After more than two decades of soil fertility research in Southern Africa, major questions by agricultural research and development investors include:

1. What is the current state of knowledge?
2. What has been the impact of soil fertility initiatives to date, and what has been achieved?
3. Can our current understanding of soil fertility issues take us forward and how?
4. What capacity is there in the region to articulate the soil fertility research and development agenda on a scale that can positively impact on household food security and livelihoods?

This report addresses these pertinent questions. It synthesises the major soil fertility issues arising from years of research and development interventions in Southern Africa, highlighting current gaps and proposing the way forward. We draw from a diversity of documents based

on initiatives undertaken in the region, expert consultation and personal experiences on regional soil fertility issues. Particular attention is given to synthesis reports on integrated soil fertility management produced by the newly established Soil Fertility Consortium for Southern Africa (SOFECSA).

## **Current understanding and knowledge gaps**

The emergence of regional networks such as the Soil Fertility Network for Maize-Based Systems in Southern Africa (SoilFertNet), the African Network (AfNet) of the Tropical Soil Biology and Fertility Institute (TSBF) of International Centre for Tropical Agriculture CIAT, and the recently launched (May 2005) and broader Soil Fertility Consortium for Southern Africa (<sup>1</sup>SOFECSA) bears testimony to how increased understanding and awareness of the importance of soil fertility have transformed the activities of institutions and individuals. The major gains in current understanding of the soil fertility issues in the region can be categorised into bio-physical process issues and socio-economic and policy related matters. These are outlined below.

### **Biophysical process and adaptive issues**

The most dominant soil groups in Southern Africa are characterised by an inherently low nutrient capital (e.g Acrisols, Arenosols, Ferrasols and Lixisols), exhibiting severe deficiencies in phosphorus (P), nitrogen (N) and sulphur (S), particularly under continuous cropping with sub-optimal inputs. In their natural state, the ecosystems are dominated by miombo woodlands (*Julbernardia* and *Brachystegia* species and associated vegetation). Maintenance of soil fertility in the natural ecosystems is achieved through tight nutrient cycling, for which there is a delicate balance between nutrient inputs and outputs (Swift *et al.* 1989; Mtambanengwe and Mapfumo, 1999). The tree components play a critical role in deep nutrient capture and regulation of nutrient release. Land clearance and cultivation breaks this balance and potential crop productivity is lost in a very short time (<5 years). Management efforts to maintain or improve crop production in these miombo-derived agroecosystems should therefore aim to simulate the nutrient cycling patterns exhibited in natural systems. Managing nutrient use efficiency in cropping systems is the key challenge for ISFM research and development.

Soil organic matter (SOM) acts as a sink and source of nutrients in soils (Woomer and Swift, 1994). Soils under smallholder farmer management generally have a relatively poor capacity to store and supply plant nutrients because of low SOM contents, which in most cases are less than 1.5%. In granite-derived sandy soils that predominate in Zimbabwe, for example, organic C is often less than 0.5%. The low SOM can largely be attributed to high turnover rates caused by high tropical temperatures, low annual organic matter inputs and, in case soils with low clay content, poor protection against microbial decomposition. Giller *et al.* (1997) showed that the ability to build SOM stocks under in sandy soil (~ <20% clay) are low compared with clayey soils, particularly under cultivation (Zingore *et al.* 2005) which promotes rapid organic matter decomposition. It is therefore difficult to build soil N stocks.

On-going research on soil fertility by the University of Zimbabwe focuses on establishing SOM thresholds and appropriate organic resource management techniques for enhanced nutrient use efficiency. The impact of applying different quality organic resources annually

<sup>1</sup> SOFECSA is the successor of the SoilFertNet

and in different quantities on build-up of SOM pools and changes in crop productivity over time is also being assessed in a long-term experiments started in 2002 in collaboration with TSBF-CIAT. The objective of this work is to quantify relations between the soil mineral and organic components as they influence nutrient cycling and plant productivity.

The non-nutrient functions of organic matter, such as water holding capacity, structural stability and cation exchange have largely not been quantified. This lack has limited modelling of soil organic matter (van Keulen, 2001), yet simulation modelling continues to play a pivotal role in enhancing our predictive understanding of SOM function. There is need for supporting such comprehensive process work, which should continue to underpin adaptive research and capacity building initiatives for ISFM. The long-term experiments could be strategically located with co-funding from host institutions/organizations.

Mineral fertilizer must be applied in the farming systems of Southern Africa if crop yields are to be increased and sustained at high levels. The inherently low nutrient capital and poor nutrient retention capacity (low clay and SOM contents) for most soils mean that high crop yields are not feasible at the current levels of inputs. Main nutrient loss pathways are crop harvests, leaching and soil erosion. With respect to nitrogen, nitrate leaching has been identified as a single major loss pathway, with N released from mineral fertilizer and high quality organics lost during the first 3-6 weeks after start of the rains (Mapfumo *et al.* 2001; Chikowo *et al.* 2004).

Under sandy soils with ~10% clay, N retention is a critical management problem and efforts should continue through adaptive research to find ways in which organic resources and timing of application can be managed to reduce losses and increase fertilizer use efficiency. Such findings suggest that N is best managed by applying small doses as necessary within a season, and underline the importance of farmers having access to mineral fertilizer throughout the cropping cycle. Variable application of top-dressing N fertilizer conditional on rainfall has already been proved to increase both yields and profits for maize (Piha 1994).

Only mineral fertilizer, nitrogen fixing leguminous plants (through green manuring, legume rotations and intercrops or tree-shrub fallows<sup>2</sup>), and livestock manure have a realistic chance of sustaining crop production in smallholder farming systems of Southern Africa. Most of the locally available organic nutrient sources can only play a complementary role as they are often inadequate in amounts, low in quality, and only accessible by the wealthier groups of farmers (Mtambanengwe and Mapfumo, 2003).

Options for raising enough organic matter for soil fertility management and other uses (e.g. livestock feed) at the farm scale remain limited (Snapp *et al.* 1998) and require innovative solutions. Adaptive research focusing on combining fast growing multipurpose trees and other crop enterprises require evaluation at different scales. Major chemical attributes and conditions determining organic resource quality in relation to nutrient release potential are now known (Palm *et al.* 1997; Mafongoya *et al.* 1998; Vanlauwe, 2005). There has been limited applied work aimed at manipulating organic resource quality at the field scale, and viable technical options are therefore still lacking. However, there is sufficient evidence on the superiority of combined over sole applications of organic and mineral fertilizers although there has been very limited research on optimisation of such combinations in farmers' fields.

Grain legume rotations and intercrops are the most preferred form of legume integration at the farm scale. Applicability of other technologies such as green manures and improved

<sup>2</sup> Green manure and tree fallows often involve foregoing potential harvests of readily harvestable food/cash crops and may not be feasible for land-constrained farmers

fallows is often a function of land and labour availability. Nitrogen-fixing indigenous herbaceous legumes fallows (indifallows) are currently being evaluated as a less management demanding technology (Mapfumo *et al.* 2005). Such innovative ecological approaches to soil fertility management should continue to be explored.

Most of the N<sub>2</sub>-fixing legumes grown in these systems do not require inoculation with appropriate *rhizobium* to form the symbiosis that allows these plants to derive most of their N from N<sub>2</sub>-fixation (Giller, 2001). Soils generally contain a wide diversity of *rhizobium* strains, but limited work has been done to select legume varieties/cultivars and *rhizobium* strains that combine for high N<sub>2</sub>-fixation efficiency. An exception is soybean that requires inoculation and is arguably the most researched grain legume in the region.

While the potential N contribution of legumes is high, the actual amounts are very small due to small areas allocated to legumes on farms (3-15% of annually cropped area, Mapfumo *et al.* 2001). Apart from environmental factors such as soil P deficiency, drought/water-logging and disease, legume production is often limited by lack of appropriate markets and options for home processing and utilization. Work by Africare-Zimbabwe with soybean demonstrated the importance of a direct link between ISFM technologies and human health and nutrition.

Phosphorus is a major nutrient limiting primary productivity in tropical agroecosystems, and savannah-derived agroecosystems of Southern Africa are no exception. In addition to inherently low P levels in soils, continuous cropping has led to severe depletion of this nutrient, even in systems where crop diversity is high. Use of crops that are efficient in soil P mobilization and acquisition through various mechanisms (Smithson and Giller, 2002) has often simply provided the means for efficient depletion of the small soil capital, unless external additions are made. Recycling of organic resources generated from these P-deficient soils will only stagnate yields and should be viewed as a mere “recycling of poverty”.

Even the prospects for harnessing N<sub>2</sub>-fixing legumes to improve the N economy of the agricultural systems will be severely hampered by the widespread deficiency of P in soils. Addition of mineral P fertilizer on a regular basis can result in the build up of P in soils. There should be more efforts to support initiatives for capitalisation of soil P stocks. Apart from mineral fertilizer, technical options for increasing the solubility of rock phosphate, which widely occurs within the region, should continue. This may involve promotion of agro-industrial chemical processing in addition to low-cost partial acidulation efforts (e.g. microbial solubilization).

It is apparent from the foregoing discussion that past investment in soil fertility has assisted in building a critical mass of scientists to spearhead the development of the science of soil fertility management. The knowledge so far gained is sufficient to drive large-scale ISFM development initiatives with the view to make quantifiable impacts on livelihoods. This situation calls for an understanding of the context in which the current body of knowledge is adaptable, and such characterization should be a continuous process.

## **Socio-economic and policy issues**

Overall, one major contribution of the past and current ISFM initiatives is the enhanced understanding and insights, by practitioners, of other agricultural disciplinary issues and how ISFM is related to these and other factors influencing livelihoods in smallholder farming communities. It is the socio-economic and policy components of ISFM research that have generally lagged behind and more attention is required to integrate them with current advances in biophysical research. Understanding the reasons why farmers have not widely adopted many ISFM technologies falls under these disciplines. The reasons for non-adoption

are only beginning to be understood now. Three of the main guiding questions that arise from this realization include:

1. What technologies are there and for which farmers?
2. Have appropriate approaches been used to disseminate available technologies and to what extent?
3. Are appropriate tools available for effective monitoring and assessment of the impact of ISFM technology interventions in a way that enable development of replicable transfer/dissemination models?

Both pessimistic and optimistic views can be entertained when it comes to the impacts of past soil fertility research, depending on whether one takes a development or research perspective, or bases one's arguments on different planning horizons. If current soil fertility research achievements from over 30 years of investment are taken as an end in themselves, then very little has been accomplished positively changing the livelihoods of the predominantly poor farmers. However, if these achievements are considered as a means to an end (goal), then tremendous gains have been made which can be used to leverage broad-based developmental initiatives.

Agricultural production in smallholder farming systems is intricately linked to poverty-driven risk aversion tactics by farmers. Technological change therefore involves breaking the vicious cycle of poverty, and this requires patience and a sustained investment to leverage a giant leap in both attitudes and capacity for resource capture and utilization by farmers. It is with this view that some of the major points on the socio-economic and policy aspects of ISFM technologies given below are made:

Best-bet technologies that include grain-legume rotations and intercropping, green manures, animal manures, mineral fertilizers, combinations of inorganic and organic nutrient sources, and agroforestry-based technologies have been developed. Definition of best-bet technologies was based on the following criteria (Waddington *et al.* 1998):

- Long-term contributions to increased soil fertility.
- Appropriateness for many farmers across important agro-ecologies.
- Small additional cash and/or labour requirements
- Appropriateness in areas with little competition for arable land.
- Resulting ease of adoption by farmers.
- Only a small reduction in maize yields or substitution by production of other crops.
- Compatibility with other components of the farming systems.

However, most of these technologies have been tested at plot-level and, therefore, views about their suitability may reflect how well these technologies link to other integrative elements at the farm scale. The only comprehensive evaluation of best-bet technologies on a nationwide scale was done in Malawi by the Maize Productivity Task Force (Gilbert *et al.* 2002), but analysis was not based on the set criteria for best bets. Recent synthesis work suggests that the limited technology evaluation studies done were conducted in isolation. Phiri *et al.* (2005) reported of fragmented and unpublished studies related to the adoption of soil fertility technologies in Zambia. Many players promoting soil fertility were often located in different areas of the country and pursued different operational objectives with different resource bases. Limited and isolated testing was also done in Zimbabwe and Mozambique.

It is therefore apparent that despite sound and development-oriented criteria, little or no analysis has been done to verify the conformity of the various technologies to the set criteria.

There is need for an appropriate integrated assessment framework for evaluation of these technologies beyond the plot level. Currently there is no basis for measuring the impact of these technologies. For instance, there has been a general consensus on which technologies would be tested but with no recommendations for approaches to be used in transferring them to farmers.

Different approaches have been used to disseminate and scale up of ISFM technologies, ranging from top-down strategies through farming systems research to a variety of farmer participatory methodologies (e.g. farmer field schools and participatory action research). Most of these approaches have not been developed in the context of ISFM technology transfer or scaling up/out. Little is known about which dissemination approaches are suitable for which technologies. The question of methodological approaches for technology transfer is therefore fundamental in taking positive steps towards ISFM technology testing and evaluation. One of the challenges is whether the current science and practice of ISFM can be used to generate new farming systems that are oriented towards enhanced food security and better livelihoods.

According to Rusike et al. (2005) national governments of Malawi, Mozambique, Zambia and Zimbabwe have adopted a common set of agricultural development priorities and now have similar policies that are supportive of ISFM as they endeavour to modernise their smallholder agricultural sector (liberalization of input/output markets, adoption of demand-driven research and development, etc.). This presents an opportunity for a regional approach to ISFM technology development and dissemination, scaling up and impact assessment, in order to promote systems innovation.

There is high social differentiation in adoption and intensity of adoption of ISFM technologies. Most of the adopters are relatively wealthy and experienced farmers who are also active members of extension groups, mostly located in high rainfall areas (Phiri *et al.* 2005). These findings suggest that a minimum threshold of resource endowment is necessary for a farmer to adopt, the technologies and implies a greater developmental challenge for breaking the vicious cycle of poverty.

Support for access to ISFM technologies in farming systems has to date also taken a very narrow perspective, and have been skewed in favour of only mineral fertilizers. Thus, support for adoption of other technologies such as those based on N<sub>2</sub>-fixing grain and tree legumes is required.

Identification of socio-economic domains for targeting of soil fertility technologies remains a grey area. There is also very little known about sequencing of technologies for specific user groups to enhance an incremental build up in farmer capacity to adopt high-value (most profitable) technological combinations.

While there have been significant efforts to transform the approaches for delivery of ISFM technologies to farmers within institutions (e.g. use of participatory approaches), few efforts have focused on changing how these institutions relate to each other. Strong inter-institutional linkages are one of the missing components for soil fertility integration. The fragmented nature of research and development initiatives undertaken by NGOs, and public and private institutions, often results in inconsistent and conflicting messages to farmers. There are several examples of poor linkages between state organs of research and extension and NGOs. Yet soil fertility is a chronic and obscure problem for which a sustained flow of consistent advice is of paramount importance. Adoption is therefore unlikely to be phenomenal under the status quo. Governments and regional networks such as SOFECSA

have a bigger role to play in promoting such linkages without compromising the national and regional priorities.

Use of mineral fertilizer remains technically one of the most viable options for raising agricultural productivity in smallholder systems. However, fertilizers are not readily available and accessible to farmers in the region, greatly undermining their contribution to agricultural production and food security. Despite the increased awareness about the potential of mineral fertilizers among farmers, several studies in the region provide evidence that per capita fertilizer consumption has either remained static or declined (Phiri *et al.* 2003). About 60% of Malawian farmers across eleven districts reported a reduction in the amounts of fertilizer and hybrid maize seed purchased over three consecutive seasons, due to high prices. A significant proportion of those farmers using mineral fertilizer in the region only access fertilizers through free handouts schemes by governments and NGOs, yet sustainability of these schemes is highly questionable. Increasing per capita fertilizer use therefore remains a major challenge for the future of agriculture in Southern Africa and will likely have to be based on developing markets for agricultural products.

Lack of attractive and viable markets has, in recent years, emerged as a major disincentive for farmers to invest in adopting ISFM technology. Little is known about how much development of (or linkage to) competitive markets can drive adoption of ISFM. Research to address this area could usher a new era in finding ways of linking ISFM directly to farm income and livelihoods. The soybean initiative in Zimbabwe (Rusike *et al.* 2000; Mpeperekwi, 2001) provides an example of how an integrated production framework ensuring linkages between a soil fertility technology, through farmer training and input support (e.g. seed and fertilizer) to marketing can improve farmers' livelihoods. Drawing from this case study, development and evaluation of a generic framework applicable to other technologies is required in the region.

Such studies, though limited, suggest that low input to produce price ratios are a major incentive, while soil fertility benefits can accrue as secondary benefit. On the other hand, low profit margins due to low productivity for specific land-based technologies (e.g. some grain legume) against other crops competing for land use have resulted in poor adoption by farmers (Nakhumwa, 2001). Agricultural markets in the region have tended to be unstable and unpredictable, partly because of conflicts between government social welfare concerns, including activities of relief agencies such as free input schemes and food relief, and fundamentals of market liberalization (e.g. emergence of a vibrant and viable private sector through competitive acquisition and delivery of technologies).

Pro-ISFM national policies have been gradually put in place to varying degrees over the years. Historically, soil issues in the region were addressed from a conservation perspective and the concept of soil fertility, and particularly nutrient budgets, was not central. Policies by governments therefore left soil fertility in the periphery. There was also a perceived unsound colonial connotation to the implementation of soil conservation strategies, and this resulted in negative attitudes by farmers. For example, coercive methods were employed to enforce indigenous communities to implement soil conservation measures (Mangisoni, 1999), and this has subsequently militated against diffusion of technologies.

Corrective policies did not emphasize soil fertility per se. A transition to farmer-driven soil conservation action strategies was therefore bound to be a long process, and may explain the slow pace at which the soil fertility agenda has moved. It took a long time to convince farmers and develop a regional capacity in soil fertility, in terms of both development of the science (e.g. biophysical scientific methods), building numbers of competent scientists, and creation of awareness among stakeholders. Increased attention to soil fertility in the

smallholder sector only took root in the 1990's through the actions of government-IARCS-donor partnerships. For instance, the Ministry of Agriculture and Livestock Development of Zambia put in place a policy to prevent degradation and restoration of soil fertility for the first time in 1995, in response to concerns over land degradation. A review by Coote et al. (1998) in Malawi also reveals more positive responses by policy makers to ISFM issues in the 90s than before. Given this background, the current state of knowledge on ISFM, which is only beginning to yield policy changes, should be viewed as a major breakthrough in transforming these farming communities.

The prevailing anticipation for high technology adoption rates and livelihood impacts is probably farfetched. For instance, NGOs and private sector stakeholders are only slowly coming into the fold, for instance through networks such as SOFECSA. Maybe this should be viewed as the beginning of a comprehensive and coordinated action plan that warrants sustained support, at a scale greater than before, in order to trigger the required leap.

There is no justification for donor fatigue, and the desire for impact should systematically build on current achievements rather than reflect an element of desperation. Studies are required not only to analyse the consequences of current policies with a view to integrate ISFM issues, but also to identify a regionally relevant framework for engaging policy makers at various levels down to the village. There is a need to explore effective ways of managing information on agricultural policy making in general.

A common weakness in policies on ISFM in the different countries is that the policy documents generally do not commit to action, most likely due to lack of empirical evidence/data suggestive of specific points of action. Capacity for implementation of the existing policies is therefore questionable. The plethora of information made available through soil fertility research and development initiatives over recent years should be appropriately used to review and strengthen these policies. Data mining initiatives aimed at analysing trade offs between adoption of ISFM technologies and other livelihood options at different scales should be supported. For example, the AfricaNUANCES initiative of Giller et al. ([www.africanuances.nl/about.htm](http://www.africanuances.nl/about.htm)) could be strategic in advising policy.

## **Existing capacity for ISFM delivery**

Institutions in the region are highly constrained by lack of qualified staff and the capacity to retain them. In recent years, institutions have simply failed to secure a critical mass of research scientists to articulate their soils research agenda, mostly due to lack of capacity locally (e.g. Mozambique) or lack of resources to attract and/or replace staff (e.g. Malawi, Zambia and Zimbabwe). Apart from high staff turnover, authorities have identified advancement of the few experienced staff into administrative senior positions as well as the HIV/AIDS pandemic as major contributing factors.

Because of insufficient capacity to train people at the national or regional levels, there are critically small pools of qualified ISFM personnel from which to draw replacements. For instance, there is very limited capacity for ISFM in Mozambique, with only one PhD-level local soil fertility scientist for the entire national research system (Table 1). The Department of Rural Engineering (Faculty of Agronomy) which teaches soil fertility in the Eduardo Mondlane University (UEM) has a student-lecturer ratio of over 40:1, compared to a target of 8 set ten years ago, meaning the situation is worsening as student numbers increase. The Department of Agricultural Research and Technical Services (DARTS) in Malawi has is reported to have a vacancy rate of about 30% for professional staff (over 40% for soils). In Zimbabwe and Zambia, a significant number of ISFM specialists in the public research and



extension systems have been lost to NGOs where they are often assigned jobs that have nothing to do with soil fertility. On the other hand, a high number of the personnel running ISFM initiatives for several institutions in the region have not received formal training in soil fertility.

A limited number of local and international NGOs and private companies are now engaged in ISFM-related work including provision of agricultural inputs such as seed and fertilizer. There is currently little information about their human resources capacity to implement ISFM initiatives, although undocumented evidence indicates major constraints due to lack of expertise. This means that there is limited capacity for extension and scaling up of ISFM technologies among smallholder farming communities. For effective delivery of ISFM, capacity building is required at all levels from professional scientists to farmers. The major challenge is therefore to put in place sustainable ISFM training programmes.

Table 1 Existing capacity for integrated soil fertility management and related disciplines in the Agricultural Research Institute of Mozambique (IIAM) as of June 2005

Discipline	Post required			In place		
	BSc	MSc	PhD	BSc	MSc	PhD
Plant Breeding		1			2	
Microbiology		2				
Statistics		3		1		
Informatics		3				
Soil Fertility	2	4	2	2	2	1
Pedology		2			1	1
Soil & water Management	3	3			1	
Land Evaluation		3			1	

### Strategic areas for ISFM capacity building

The following are identified as major areas for capacity building, with due recognition given to the need for both institutional and individual capacity building needs:

1. Development and integration of relevant ISFM curricula into universities and other tertiary agricultural/environmental colleges. Current understanding of biophysical process issues provides an opportunity to develop comprehensive curricula. Human resources training at MSc and PhD levels for both biophysical and socio-economic scientists at the regional level is now feasible and should be a priority. Selected universities should be strategically supported to run such programmes, either by simply strengthening existing courses or establishing new programmes. This may involve strategic support of regional and international expertise for the curriculum reform process up to the inception of the degree programmes. The established university centres should then also be responsible for running regional short courses on topical issues for professionals and general practitioners.

2. Strengthening capacity for visionary prioritization of agricultural research and development based on current scientific understanding of ISFM. Greater support to regional networks is required for development of common and efficient methods for technology development, testing, monitoring, evaluation and impact assessment. Such networks should provide platforms for improving the skills and excellence in ISFM research, development, dissemination and utilization among scientists, entrepreneurs and farmers.
3. Developing coordination mechanisms for ISFM delivery activities that involve NGOs, the private and public sectors through support for establishment and strengthening of networking at national and regional levels. Extension agencies should be consistent in the information they give farmers. For instance, consistency could be achieved by developing similar technology fact sheets for farmers in an area, with clear indications of where improvements have been made over time. Creating awareness on the need for coordinated activities could provide a good start. Such networks should provide training for technical and field-level staff (public, NGO and private sector extension personnel) and this can be done through sequential short courses led by the existing national staff complements with input from external expertise (from regional institutes, International Agricultural Research Centres [IARCs] and ARI). For example, training of a large number of technical staff is an urgent priority for Mozambique, given the long gestation period for degree programmes.
4. Development of basic infrastructure, including equipment, and instrumentation to facilitate wide-scale soil testing and systems characterization for ISFM delivery. This should take advantage of recent advances in use of infrared diffuse reflectance spectroscopy to create a comprehensive baseline database for monitoring the relative impact of old and new technologies.
5. Regional assessment of productivity constraints and soil degradation. Through complementary use of geographic information systems, this will provide a basis for targeting of technologies during evaluation and scaling up. As part of the wide-scale characterisation, crop response curves for different crops to both mineral and organic fertilizers under different environments should be determined. In areas where mineral fertilizer use is not widely adopted, as in Mozambique, this information could create awareness among farmers. Laboratories established to support this initiative could provide support for established degree training programmes. For example, there is no equipped and functional soil microbiology lab in IIAM and UEM in Mozambique, and this has implications for any efforts to promote ISFM in that country.
6. Development and maintenance of an ISFM database at national and regional levels to facilitate evaluation and impact assessment as well as promote information dissemination. Information centres (libraries) need to be established in specific centres at the district level or lower. The centres can act as nuclei for information dissemination for scaling up of ISFM technologies and other development initiatives. These should help to developing the capacity of local institutions to support soil fertility management initiatives and to provide training to target farmer groups on the relevant basic principles of soil fertility management.
7. Development and/or strengthening of capacity for mineral fertilizer manufacturing and marketing. This should involve organisational and infrastructure development support for the public and private sectors. High import and delivery costs are a major constraint for access of mineral fertilizer by farmers.

## Strategies for capacity retention

Loss of institutional memory through departure of experienced staff has not only undermined gains on ISFM, but also resulted in poor priority setting for research and development. The following are perceived as potential avenues for retention of ISFM capacity in the region:

1. Development and/or strengthening of joint (inter-country) research projects providing for staff exchanges deliberately targeted at building specific skills/capacity. These may also involve university students.
2. Setting up of fellowships to promote attachment of junior and middle-career scientists to other institutions — such as IARCS and universities — to strengthen their skills and expose them to the diversity of ISFM approaches.
3. Sponsored professorships, where renowned technical experts are financially supported to work with specific groups at national or regional level over a given timeframe, with the specific aim of developing capacity and imparting skills. A good example is the role Prof Ken Giller played at the University of Zimbabwe over a three-year period with support from the Rockefeller Foundation.
4. Sponsored visits by experts over short periods to deliver modular courses at universities and other institutions as part of a strategy to reinforce MSc and PhD training in the region, an option several times cheaper than sending a whole group of students for training abroad. For particular skills, the students can then be sent to the advanced institutions for limited periods, with the objective of ultimately enabling selected national or regional institutions to offer advanced and high-quality MSc and PhD training. Experts can be drawn from within the region (e.g. from local universities and international agricultural research centres) or abroad, from universities of international standing and other advanced research institutions.
5. Development of postdoctoral opportunities for regional scientists. Many scientists in the region go directly from PhD training into professional positions without additional mentoring that would allow them to consolidate the knowledge that they have gained from their formal training. Additional support to scientists through postdoctoral mentoring programmes will be essential for building their technical capacity and allowing these scientists to become independent researchers.
6. Targeted research support to newly established and mid-career scientists in strategic local institutions, coupled with comprehensive involvement of experienced personnel. This will provide resources to enhance their capacity as well as offer incentives to retain them in the institutions.

## Conclusion

The major force driving ISFM research and development should hinge on whether science and technology can give rise to innovations that can hasten the evolution of productive and sustainable farming systems in Southern African. Capacity building and retention at institutional and individual levels holds the future for sustainable ISFM as a fulcrum for development and improved livelihoods.

# Report on East and Central Africa

## Summary

There has been a significant concentration of efforts to improve soil fertility and land degradation management in Africa. Despite these efforts, challenges have kept evolving faster than the gains made from technology innovations. The result is a net loss in the inherent and actual capacity of the soil resource for sustainable livelihoods. This is an issue of great concern, considering that agriculture is the backbone of most economies of Sub-Saharan Africa. This report emanates from a study set to investigate the level of science and technology in soil fertility improvement and land degradation management pathways taken in handling challenges in the sector and an exploration of capacity building needs in Africa.

Four countries, namely Kenya, Uganda, Tanzania, Ethiopia and Rwanda, were selected for the investigation that informed this report. Data were collected from heads of learning and research institutions using semi-structured interviews. The results show evidence of a good understanding of biophysical aspects of soil fertility improvement and land degradation management. The existence of trained manpower was also significant.

Challenges of soil fertility improvement and land degradation management have been growing in the region. Poor links between technology development and dissemination are largely to blame for this. This is aggravated by poor collaboration between institutions dealing with soil fertility improvement and land degradation management. The human capacity suffers two major drawbacks: a low level of multidisciplinary manpower and poorly equipped human resource to handle the evolving challenges.

Retooling of the existing manpower and widening the scope of training were recommended to address the key challenges. Institutions lacking in capacity identified strengthening of collaboration between institutions as a strategic approach to efficient utilization of surplus capacity in some institutions.

Integration of soil fertility and land degradation management technologies/innovations with socio-economic attributes for wider uptake is poor. Continuous soil mapping and land use characterization is lacking due to lack of capital resources and poor incentives.

Policy support to soil fertility and land degradation management is generally weak and there is need to address these challenges if soil fertility improvement and land degradation management are to be attained.

## Introduction

Most of the economies in Sub-Saharan Africa largely depend on agriculture for food and income provision. In this region, more than 50% of the population rely on agriculture for their livelihood and the sector contributes more than 30% of the Gross Domestic Product (Van Straaten, 2002). Soil fertility decline and land degradation are critical constraints to agricultural development in the region. The focus of efforts to solve these problems has been on increased food production through a series of interventions. A recent innovation was the application of the Green Revolution, which, however, eluded most African land managers due to its capital-intensive nature and lack of political will.

Poverty remains a hindrance to accelerated development in Africa, where more than half of the population live on less than 1 US dollar a day. This situation has had a profound effect on both the criteria households use to make decisions and the level of investment in agriculture.

Plant nutrient deficiency, poor soil management, poor soil conservation management, poor land tenure systems and inadequate extension infrastructure are among the major causes of poor land productivity in SSA (Gachenge & Kimaru 2003). Land degradation is widespread in the region and has been on the increase despite the awareness of its effects. This calls for a concerted effort to address the challenge at the regional level and in a holistic way.

Land degradation refers to the reduction in the capability of land to produce benefits from a particular land use under a specific form of land management (Blaike and Brookfield, 1987). Soil erosion, soil fertility degradation, deforestation and degradation of water resources are the main causes of land degradation in SSA. Degradation of soil fertility is one of the key constraints to food security in SSA (Bationo *et al.* 2004). The annual soil depletion rate in SSA is estimated at 22 kg nitrogen, 2.5 kg phosphorus and 15 kg potassium per hectare per year. This is equivalent to US \$ 4 billion in fertilizer (Sanchez, 2002).

The two most widespread limiting nutrients to food production are N and P, in that order (Bekunda *et al.* 1997). Replenishing these nutrients has been the concern of many African governments for years. However, despite the efforts in nutrient study and management, soil fertility decline in countries like Ethiopia has subjected four million people to severe famine and reliance on relief food for survival (Walsh, 2003).

NEPAD's recognition of the need to intervene in soil fertility enhancement and land degradation management is timely and could boost progress towards achieving food security and sustainable development in Africa. There is, however, need to carefully diagnose the problem in retrospect in order to design approaches that are achievable, reproducible and with high positive impact. To do this, we conducted a survey that focused on capacity needs and capacity building.

Capacity building here is seen as the structured process by which individuals, groups, organizations, institutions and society increase their abilities to perform core functions, solve problems and define and achieve objectives, in order to understand and deal with their development needs in a broad context and in a sustainable manner.

The report is organized under four thematic areas:

1. An overview of international advances to soil science and related technological innovations.
2. The identification of specific scientific and technological trajectories relevant in the improvement and management of new opportunities.
3. An assessment of East and Central Africa's capacity (with emphasis on the role and participation of universities and related research institutions) in science and technology development for improved soil fertility and land degradation management.
4. The identification of specific areas where capacity building can be better attained through regional and international cooperation.

Finally, the report recommends a framework for building capacity in scientific research and technology development to improve soil fertility and management.

## **Approaches and methods**

### **Study sites**

The study covered Kenya, Uganda, Tanzania, Ethiopia and Rwanda. Economies of these countries are largely agrarian, making soil fertility improvement and land degradation management essential for accelerated economic growth. Within these countries, learning and research institutions dealing with soil fertility and land degradation management studies in these countries were identified and selected for the survey.

### **Data collection instruments**

An interview guide was used to obtain pertinent data and information from the heads of institution and key scientists that were visited. Secondary data from publications and on-going experiments was also used to draw on past experiences and milestones in shaping the study for better interventions in future.

### **Results and discussion**

From the survey, the four thematic areas outlined in the Terms of Reference were summarised and presented for each country. The results are based on the four themes and presented by country in order to compare the status of the themes across the countries.

## **Kenya**

### **International advances in soil fertility and land degradation management**

The subject of soil fertility and land degradation has received considerable attention in the country. Substantial work has been done, generating positive impacts at the household, national and regional levels. These initiatives have been undertaken by the research organizations and learning institutions. The approach taken by learning institutions has largely centred on teaching, research and extension. In Moi University, for instance, soil fertility and land degradation are handled at the undergraduate and postgraduate levels. The undergraduate syllabus has a total of 8 courses on biophysical aspects of soil fertility and land degradation, including soil classification, characterization, microbiology, and soil management. The syllabus covers the biophysical aspects of soil management and particular applications of the knowledge in fertility improvement.

### **Scientific and technological pathways for improvement and management of new opportunities**

Soil fertility and land degradation have been addressed in the past through a number of pathways adopted by both learning and research institutions. Learning institutions are classified into four main categories: certificate colleges, diploma colleges, undergraduate and postgraduate. The undergraduate and postgraduate training falls under the Ministry of Education, whereas the certificate and diploma colleges are under the Ministry of Agriculture

and the Ministry of Environment respectively. The placement of colleges handling the same subject in different ministries matter restricts the smooth flow of knowledge, information, physical and human resources for the subject. This leads to duplication of efforts.

Within the learning institutions, three main pathways have been used to address soil fertility improvement and land degradation management. These are teaching, research and dissemination. As noted earlier, teaching takes pre-eminence. The paths adopted by learning institutions are syllabus/curriculum-oriented and do not respond adequately to the emerging challenges. The procedures for curriculum review in line with emerging challenges are long and require massive capital outlay. This has led to institutional curricula that do not proactively consider emerging challenges.

For the research institutions, the 'diagnostic and design' methodology has conventionally been applied as a pathway to research and dissemination. Technological approaches to soil fertility and land degradation challenges are designed preceded by an accurate diagnosis. The funds available and the donor requirements dictate the scope and line of intervention. Under this set-up, output-oriented and long-term studies and research on soils are seldom realized.

Emerging opportunities and challenges cannot be adequately addressed under the current organization. There is therefore a need to harmonize soil research experiments and findings within the various research institutions and understand reasons for divergence in findings. This would allow for knowledge sharing and technology monitoring/evaluations in a coordinated way.

Furthermore, the link between learning and research institutions requires strengthening to allow for knowledge generation that is responsive to the emerging challenges. Once this is achieved, both research and learning institutions need to develop and extension and dissemination framework, together with the National Agricultural Research System (NARS) and other stakeholders such as NGOs, community-based organizations (CBOs) and the private sector. This proposed pathway will lead to a smooth feed-forward and feedback process between the institutions, researchers and farmers.

## **Capacity in science and technology**

Capacity building in soil fertility improvement and land degradation management takes place by way of teaching, research and dissemination. The institutions acknowledged the fact that human capacity has been developed considerably over the years, considering the number of graduates the institutions produce every year. Looking at the status quo, it would appear that learning institutions in Kenya, Uganda and Tanzania have an adequate number of full-time professional staff to adequately teach soil fertility and land degradation management. This position requires careful re-evaluation as it hides the real challenges facing soil fertility management and land degradation. The capacity in the universities is tailored to address largely the teaching need, although in principal, research and dissemination form part of the universities' mandate.

Lack of employment opportunities is also to blame for stagnated capacity building in some countries. At Moi University, for instance, most of the staff in soil science was trained between 1989 and 1993, as a result of large capacity building projects built upon collaboration between Oxford and Toronto Universities. Scientists who were trained then are still young and on the job. However, many graduates passing through their hands have no opportunities for employment.

The staffing Kenyatta University was a little different. The Department of Environment Foundation/Science under which agroforestry falls was established in 1999. It has six full-time staff and the postgraduate student population has been fairly stable over the past five years as indicated in Table 1 below.

Table 1: Postgraduate student enrolment in Kenyatta University (2000 - 2004)

Year	Number of students
2000	10
2001	11
2002	12
2003	13
2004	12

Source: Department of Environmental Foundation/Science, Kenyatta University

Kenyatta University has maintained this number of researchers because of a fairly good level of research funds tenable through collaborative initiatives with ANAFE, the Africa Centre for Technology Studies (ACTS), ICRAF and the Ministry of Agriculture. The staffing level was classified as adequate, but there was need to equip the staff with proposal writing and project management skills. There is also a need to train extension practitioners, who understand the challenges facing farmers.

The University has already developed a training manual for extension workers and is managing five demonstration farms in central Kenya. A critical challenge is how to maintain frontline extension staff. Farmers cannot pay them and the Ministry of Agriculture is unable to absorb most of them, despite the significant role they can play in improving soil fertility and land degradation management.

Moi University has established a farmer's soil testing centre, the country's second after the one at Kabete, near the Kenyan capital, Nairobi, that has served the country for a long time. The new centre will serve farmers in the western, Rift Valley and Nyanza provinces, eliminating the need for costly travel more than 300 kilometres to have their soils tested at Kabete.

However, in Moi University's case, there is still a major need to build capacity by training a multidisciplinary team that understands both biophysical and socio-economic aspects of soil fertility management. Extension services also need strengthening to support farmers to use soil test results. This is cognizant of the fact that socio-economic constraints often make farmers to deviate from the prescriptions given to them for their soils.

The Ministry of Education, Science and Technology has initiated the National Council of Science and Technology to diagnose emerging challenges and recommend possible intervention pathways. The council facilitates information flow through a feed-forward and feedback process from education planners and technology designers to the wider operational environment. The council is able to assume a bird's eye view of the entire educational programme and can thus link training to industrial and technological demands. Giving the



council a wider mandate to complement efforts by the Regional Council of Education would allow for better knowledge sharing in the region.

## **Uganda**

### **International advances in soil fertility and land degradation management**

Like Kenya, Uganda's economy is highly dependent on agriculture, making soil fertility improvement and land degradation management equally significant. Again as in Kenya, Uganda's research in this field has generated considerable benefits at the household, national and regional levels.

Research has mainly been undertaken by the research organizations and learning institutions. Learning institutions have focused on teaching, research and extension.

Makerere University, one of the oldest in the region, has soil science courses in the faculties of Agriculture and Forestry. As in Kenya, more emphasis is put on equipping students with knowledge on biophysical aspects of soil management and particular applications of the knowledge in fertility improvement. Elemental nutrient requirements, budgets and impacts are well documented. The link between this knowledge and development as defined in the context of the ability to address emerging challenges is very poor.

### **Scientific and technological pathways for improvement and management of new opportunities**

Many similarities are evident between the Kenyan and Ugandan systems with regard to the pathways taken by research and learning institutions to address the challenges of soil fertility improvement and land degradation management. The four categories of learning institutions are also found in Uganda, where, like in Kenya, they are under different ministries.

The active incorporation of emerging challenges in knowledge and technology generation is an issue that requires attention by development agencies. The close similarities of pathways used by Kenya and Uganda to address soil fertility and land degradation challenges provides a suitable entry point for regional programmes to address common problems.

Regional collaboration has so far been limited, with exchange programmes for students and staff concentrated on the North-South collaboration. Yet higher positive impact can be attained in the regional exchange programmes due to similarities of socio-economic environments in the region.

There is a need to enrich the pathways taken in handling soil fertility improvement and land degradation management. The current and emerging challenges can be turned into opportunities for improved soil fertility and land degradation management in a research-for-development continuum. This proposed pathway would lead to a smooth feed-forward and feedback process between the institutions, researchers and farmers.

### **Capacity in science and technology**

Learning institutions in Uganda, as those in Kenya, focus on teaching, research and dissemination. For instance, Makerere University's soil science syllabus is similar to that of Moi University in scope and course content. This setting allows for easy management of

exchange programmes, but has not been optimally utilized. At the undergraduate level, however, there are disparities in entry requirements. Secondary level education takes four years in Kenya and six in Uganda.

Over the past five years, the number of postgraduate students studying soil science courses in Ugandan universities has significantly declined due to lack of employment for graduates as can be seen from the case of Makerere University as indicated in Table 2 below.

Table 2: Postgraduate Soil Science Students in Makerere University for the last 5 years

Year	Number of students
2000	12
2001	9
2002	5
2003	4
2004	4

Source: Department of Soil Science, Makerere University

The decline in student enrolment has largely been attributed to the lack of interest in the discipline due to narrow employment opportunities for the soil science graduates. The University has 14 full time staff, against the low number of students. This is a policy issue requiring attention to give soil science a wider niche in terms of manpower in the agricultural sector. Currently, agricultural engineering, marketing and extension take the bulk of the labour force in the Ministry of Agriculture. Certificate and diploma holders in these areas access jobs more easily than do students trained in soil science. To effectively widen the soil science job market niche within the agricultural docket, curriculum review would be requisite to train a multidisciplinary capacity to include other disciplines of agriculture, but without diluting the soil science course content. Retooling of the current capacity in the light of emerging challenges would also be a matter of importance.

## Tanzania

### International advances in soil fertility and land degradation management

Like in the rest of East Africa, agriculture is the backbone of the Tanzanian economy and her, too, soil fertility improvement and land degradation management is of paramount importance. Research and training in this field is similar to that in Kenya and Uganda, with learning institutions have focused on equipping students with knowledge on biophysical aspects of soil management and particular applications of the knowledge in fertility improvement. Soil fertility and land degradation challenges keep eluding research planners and education practitioners.

## **Scientific and technological pathways for improvement and management of new opportunities**

Teaching, research and dissemination are the pathways to addressing soil fertility and land degradation management in Tanzania. Challenges in these pathways are similar to those of Kenya and Uganda; hence the remedies prescribed for these countries apply to Tanzania as well.

However, research institutions have adopted a proactive approach to the subject by launching research for development. Many challenges have been addressed through this approach, although the scale of its application is curtailed by resource constraints. Nevertheless, the framework for the pathways has been laid and only needs to be strengthened and better equipped to address emerging challenges.

## **Capacity in science and technology**

Tanzania has devoted resources to establishing capacity in soil fertility improvement and land degradation management. As was the case of the other countries, much of the capacity is polished in biophysical aspects of the problem only. Redefining capacity building in the context of emerging land use challenges is necessary. The socio-economic and academic programmes in the East African countries allow for a lot of resource and knowledge brokering and sharing, an aspect that has not been fully exploited for development. Kenya and Uganda have fairly mature NARS, while Ethiopia and Rwanda have young programmes. Exchange between the incipient and mature NARS could facilitate accelerated gains in the younger institutions.

## **Ethiopia**

The Ethiopian situation was different from other countries in the East Africa region. The country lacks adequate staff and a representative curriculum that is responsive to the soil fertility and land degradation challenges at postgraduate level. This calls for initiatives to promote capacity exchange among learning institutions, IARCs and NARS so that more developed NARS and IARCs can help the country's nascent NARS and learning institutions. Such initiatives require commitment by both governments and the academia in the region. However, the challenge is mainly to scholars in the region as they are better placed to foster cross-boundary programmes, given that governments would require political goodwill.

The scientific inclusion of Ethiopia in the East African region was a good initiative, which has been supported politically by the formation of the Inter-Governmental Authority on Development (IGAD). A thematic approach rather than one based on geographical demarcations presents an opportunity for concerted efforts by different governments towards sustainable development. This would also enhance peace and stability, as most collaborative ventures are clouded in suspicion due to weak bonding factors.

There have been widespread studies of N and P for soils in the region. ICRAF, for instance, has initiated a series of on-station and on-farm trials to investigate the status of various nutrients and uptake dynamics. At household level, the focus has largely been on soil fertility replenishment, particularly for N and P deficiency.

A study on integrated soil fertility management using inorganic and organic inputs indicated prospects for improved yields, though these prospects have not been explicitly researched on (Place *et al.* 2003). There has also been a keen focus on erosion control from the planners and

researchers, an aspect that has received rather limited attention from land users due to lack of evidence of immediate returns.

Despite these tremendous efforts, soil nutrient and land degradation management are still major challenges due to technology and management gaps outlined in the synthesis section of this report.

## **Rwanda**

Rwanda reported a shortage of professional staff as a constraint to soil fertility improvement and land degradation management. The National University of Rwanda trains an average of 15 - 20 students every year in soil science. The Ministry of Agriculture, ISAR and NGOs absorb soil science most of the graduates.

At postgraduate level, the Government of The Netherlands has supported the initiation of a four-year master's degree programme in agroforestry and soil management. The target was to train 20 masters-level students annually for two years, translating to a capacity of 40 soil science graduates by the end of the fourth year. The second phase of the programme will focus on further training to PhD level in order to have a capacity for training master's students within the University. The implementation of this noble venture requires a focused execution to avoid repeating the mistake of mass outlay of capacity without a structured framework for horizontal and vertical integration within the subject and institutional domains.

It is worth noting that much of the current staff in Rwanda needs retraining in soil fertility and land degradation management. Many of the scholars studied outside the country due to political instability that prevailed in Rwanda a decade ago. Their experience with soil science research was based on external environments that may not have internal validity in Rwanda.

The biophysical aspects of soil science alone cannot on their own enable the current capacity to combat rapidly increasing soil fertility challenges. For instance, expertise is needed to address accelerated soil erosion occasioned by an upsurge in the human population resulting from high birth rates and return of citizens displaced abroad.

## **Synthesis of East and Central Africa survey results**

### **Capacity building needs**

From the survey, the following is a summary of the position of East and Central Africa's capacity in soil fertility and land degradation management.

1. Multidisciplinary/interdisciplinary and participatory approaches in handling soil fertility challenges are weak.
2. Geo-chemical, biogeochemical and biological nutrient cycles are poorly integrated with other denudation processes in the design of soil fertility improvement.
3. Changing socio-economic and biophysical environments are not considered in the design of approaches and in the training of staff.
4. Most of the staff members are trained in the biophysical aspects, with socio-economic domains and indigenous knowledge application largely ignored.

5. Most of the capacity builders (staff) have little knowledge in writing winning proposals. This is delegated to consultants who write very good proposals, but who are often disconnected from the real challenges. Some of these projects win funding, but, unfortunately, fail to solve the real challenges in soil fertility management.
6. Skills in documenting knowledge advances through the writing and presentation of scientific papers and demand-driven proposals at a regional level are weak.
7. Linkages between knowledge generation and technology implementation are poor.
8. Improvement of equipment and facilities for soil fertility testing and land degradation management is required.
9. There is a need to strengthen the link between technology generation and utilization by providing support to mutually interlinked national universities, farmers and research institutions.
10. Strengthening different competencies within institutions aimed at establishing a virtual centre of excellence in a networked framework for the mutual benefit of all the institutions. This will enhance resource sharing and the development of a holistic approach to soil fertility and land degradation challenges.

## **Case study of an integrated institutional approach to capacity building in Africa**

In the preceding sections, we have analyzed the position of East and Central Africa with regard to capacity building in soil fertility improvement and land degradation management. The following case study presents efforts by African Network for Agriculture, Agroforestry and Natural Resources Education (ANAFE), a lead agency in the ICRAF's theme of strengthening institutions, in addressing the capacity gaps across the region.

### ***ANAFEs' approach to capacity building***

ANAFE has been one of the key proponents of capacity building in soil fertility improvement and land degradation management. Past approaches have been based on the development of research priorities with universities and provision of research support to selected students. To step up gains and increase the accuracy of capacity building in line with the emerging challenges, ANAFE is designing a programme on Building Africa's Scientific and Institutional Capacity (BASIC) for agriculture and natural resources.

The BASIC programme was established following the realization that the hopes for universities to provide solutions to Africa's problems have diminished, leading to general disenchantment with the role of research and education. This resulted in an enormous loss of skills through immigration of talented scientists abroad and to other occupations, and reluctance of able students to consider careers in agricultural research.

The serious consequence of this has been set out in many reports that highlight the importance of universities in Africa as vibrant centres of excellence, capable of propelling their nations into the knowledge economy. Despite the importance of agriculture in Africa, tertiary agricultural education has not been spared the erosion of capacity caused by decades of under investment, loss of staff incentives and failure to recruit replacements for an ageing cadre of professors.

ANAFE came up with the BASIC proposal after extensive consultations among African universities and other stakeholders and with Northern universities, international agricultural research centres (IARCs) and national agricultural research institutes (NARIs). The main thrust of the programme is to invigorate tertiary agricultural education so that Africa can be capable of sustained endogenously driven innovation in agriculture and natural resources management.

If agriculture is to be the engine of development in Africa as envisioned by NEPAD, then graduates must be the drivers of development in whatever fields they join. Agricultural graduates will have to be adept at participatory practices that respect the intellectual contribution of all stakeholders, especially farmers. They also need to understand the consequences of rapid technological change in the context of globalization and the risks and uncertainties associated with changing demographic structures and climate.

To restore the capacity of universities to deliver high-quality teaching in agriculture and natural resource management, it will be necessary to re-invigorate and update the curricula in terms of content and coverage of disciplines and to redress the attrition of faculty due to retirement, brain drain and disease, especially HIV/AIDS.

Other areas of improvement are in motivating expertise, re-tooling them in participatory skills, improving incentives, opening more opportunities for career advancement and revitalizing the interaction among peers in African and non-African universities, and their counterparts in agricultural research and industry. There is need to improve the deployment of existing capacity, especially human in order to improve the attractiveness of academic careers. Improved organizational structures and inter-institutional collaboration mechanisms will be needed, especially to link universities with research, industry and development entities. This calls for formulation of supportive policies.

## **Policy and Institutional Environment**

Many commendable educational projects are on-going, but they are too restricted in disciplinary and institutional scope to achieve the scale of impact that will turn around Africa's regression into poverty. A solution that comprehensively addresses the educational programmes of whole cohorts of graduates is required to achieve the Millennium Development Goals. This will also harness the contribution of the private sector and aid in the success of continental scale projects developed for the implementation of NEPAD's Comprehensive Africa's Agriculture Development Programme (CAADP).

### ***Challenges in capacity building***

Education programmes in agriculture, forestry and environment are delivered from dated, narrowly defined and specialized perspectives. As a result, such programmes cannot keep pace with the scope and analytical skills and techniques needed to solve real development problems.

Furthermore, teaching is conducted in the framework of the old linear process of education-research-extension-adaptation and adoption. The current content and delivery of agricultural courses does not equip students with knowledge and skills for a fulfilling career.

Universities pay little attention to developing soft sciences, skills in human resource management, project and institutional management, negotiating skills, conflict resolution, monitoring and evaluation, as well as organizing and sharing knowledge.

Teaching weaknesses have been identified as bottlenecks in developing the capacity of students to cope with complexities of smallholder systems. Graduates are weak in fostering entrepreneurship and promoting agricultural businesses through value adding processing and formation of marketing institutions essential to rural innovation. The content and material used for teaching is often adapted from other parts of the world without adequate contextualization and adaptation to local environments.

University staffs also face constraints. Their time for teaching and research is shared among a myriad of other distracting activities, including consultancies, administration and often irrelevant projects for which funds are available. This calls for actions to strengthen capacity for managing intellectual resources and for accompanying improvements in policies, institutional structures, management systems and styles.

### **Proposed remedies**

In September 2004, FARA and ANAFE co-sponsored and convened a workshop hosted by the African Union to develop the BASIC initiative. Sixty participants, including senior educators, policy makers, researchers, investors and development stakeholders, developed BASIC as a concept for a wholly new approach to strengthening African capacity to build its own indigenous human capacity for agricultural research and development.

### **The BASIC initiative**

By 2015, with strengthened and better mobilized scientific and institutional capacity, Sub-Saharan Africa will have wide-scale application of endogenously produced sustainable agricultural innovations that improve livelihoods, advance economic development and conserve the environment. Agricultural universities in sub-Saharan Africa will catalyse, guide and lead scientific and institutional capacity building nationally and regionally.

To strengthen the capacity of African universities to build the capacity Africa requires for endogenously driven innovation systems that will make African agriculture increasingly knowledge-based and rooted in sustainable natural resource management.

BASIC endeavours to foster tripartite partnerships between African universities, Northern universities and Agricultural Research Institutes and Centres. This is aimed at achieving three interlinked outcomes. First is development of a new cadre of better trained graduates entering African agricultural research, training, industry and policy making institutions, as a key to agricultural and national development in Africa. Second, is improved research and training in collaborating non-African universities as a result of feedback from working together in BASIC. These outcomes will lead to improved policy making in Northern countries, especially on their development assistance programmes. In addition, research institutions will have a much greater impact through the awareness, internalisation and application of their findings and products by succeeding generations of African graduates.

### **ANAFE's sponsorship of soil science research**

ANAFE has sponsored students in public universities dealing with various aspects of agroforestry, which inevitably include soil studies. The number of students supported was, however, dependent largely on the resource base. Table 3 gives a summary of sponsored research programmes sponsored by ANAFE in the East and Central Africa region between 1987 and 2002. An in-depth analysis of the capacity in learning institutions revealed a

shortfall of adequately trained personnel who are dynamic enough to handle the ever-evolving soil fertility challenges.

Newly trained scientists need re-tooling and multidisciplinary training to effectively use the knowledge acquired as a vehicle for development. To ensure this, there is need to develop a new model of capacity building that integrates training, practical field experiments, changing land use practices as well as feedforward and feedback tailored dissemination.

Table 3: Annual recruitment of trainees for degree and non-degree related studies

Year	Non-degree	Masters	PhD
1987	0	0	1
1988	0	1	0
1989	0	0	1
1990	0	0	1
1991	2	2	3
1992	1	6	4
1993	2	10	7
1994	1	7	2
1995	15	11	3
1996	0	3	4
1997	1	9	8
1998	3	10	6
1999	1	15	5
2000	0	37	9
2001	4	31	4
2002	4	21	6
Total	34	163	64

Source: Awimbo *et al.* 2004

Adequate capacity building requires an approach that integrates technical, socio-economic and policy issues at multiple technological and geographical scales. A sufficient condition would be attained when such capacity building is linked to development of viable markets for sustainable outputs. Looking at the current scenario in retrospect, a number of options would guide capacity building initiatives. First, capacity building needs to be looked at in a holistic way. Training personnel without looking at their horizontal and vertical integration in the soil management challenges is inconsequential. In the case of Moi University, for instance, training would have been structured to allow for the production of capacity at all levels of learning. An ideal situation would develop capacities at the certificate, diploma, degree and postgraduate levels, each occupying a unique niche in soil fertility and land management for development continuum.

These levels are currently defined, but linkages within them are poor or non-existent. This is largely a policy issue as was seen in the country reports for Kenya, Ethiopia and Uganda. Higher learning institutions dealing with soils fall under the Ministry of Education, while middle level colleges dealing with soils are under the Ministry of Agriculture or that of



Environment. These institutions operate independently although they are dealing with the same subject matter. This was evident in a comparison of the soil fertility studies at Moi University and Bukura Institute of Agriculture, a middle level college.

Secondly, the current capacity needs re-equipping to make it more responsive to evolving soil fertility challenges. This is particularly important considering the fact that the earlier efforts at capacity building were largely done from outside the continent. People who trained outside Africa may be very smart in biophysical aspects of soil fertility and land degradation, but quite uninformed when it comes to the practical aspects, especially if their research was not indigenous. Even in cases where research was done in Africa, it worth noting that soil fertility challenges keep evolving, a state that is exacerbated by changing lifestyles. Most peasant farmers migrated from their native lands with agrarian practices that they still embrace in a different ecological setting.

In western Kenya, for instance, maize-focused farming has led to a vicious cycle of poverty as the soil resource base can hardly support viable maize production. In Uasin Gishu District of Kenya, continued application of inorganic fertilizers in a continuous cropping regime has led to the lowering of soil pH. Important elements like phosphorus are thus fixed and not made available to plants despite continued fertilizer application. Such changes in the state of soil and its management require constant re-tooling of manpower to make it dynamic and responsive to new approaches. This continuing education dimension of capacity building is lacking.

Thirdly, the capacity to conduct resource assessment and soil problem mapping and to monitor changes is lacking. The Regional Centre for Mapping and Resource Development has access to remote sensing technologies suitable for soil mapping. These include advanced applications such as Quickbird, which has a high resolution of 61 cm. The Shuttle Radar Topographic Mission (SRTM) undertaken from 11 to 22 February 2000 collected data on the earth's surface between 60 degrees north and 56 degrees south of the equator. Such data can be superimposed on specific soil maps and appropriately corrected to provide location-specific information. Personnel with the technical knowledge required for these advanced approaches to soil mapping are few, but the major limitation is the high cost. The information obtained using these approaches needs to be updated regularly to ascertain changes and trends in the resource, but this is not tenable due to its capital-intensive nature.

Finally, the present human resource capacity in soil fertility and land degradation is too pedagogically focused and does not have the capacity link with other disciplines to use other indicators of inherent soil fertility. For instance, indigenous vegetation is often a good indicator of soil quality and the Cajandah index of site classification would characterise a site on the basis of vegetation.

The recent focus on yield has led to a concentration on elemental improvement, making the use of indigenous knowledge using vegetation classification inapplicable. Yet such this would have been given farmers a good substitute, given that the modern soil characterization methods are quite costly. In simple terms, characterization of soils has been taken from the farmers completely, repackaged into an advanced but costly exercise, and then taken back to the farmers as a requirement for successful soil management.

Commercialisation of agriculture has also had a negative impact on indigenous soil management. In the past, diversification of crop production and fallowing led to a balanced uptake and release of nutrients through biogeochemical nutrient cycles. Continuous monocropping of cereals is proving to be an unsustainable venture, making scientists to revert to the diverse cropping systems and new approaches to enhance the regeneration of soils

through fallowing. The inclusion of indigenous knowledge is nascent and needs to be given more attention by scientists not only for development of improved cropping systems, but for enhancing communication with farming communities.

The physical capacity has been established in terms of laboratories for soil analyses. The required infrastructure for capacity building in soil fertility improvement and land degradation management is also established. But there are three fundamental limitations:

1. Physical support to the human capacity is lacking. Much of the capacity was initiated as collaborative ventures funded by donor agencies. Through such ventures, human and physical capacity was improved in institutions. However, once the active phase of these collaborations ended, it became extremely difficult to maintain the ventures. Sustainability was not carefully factored in the planning phase of the collaborations.
2. In an attempt to make the projects or facilities continue to be of use, institutions have been forced to embrace piece-meal support from various development agencies. The development partners' requirements, however, are quite different from the perceived approaches to the problem of soil fertility improvement and land degradation management. It is imperative that development partners study the problem of soil fertility improvement and land degradation management so that their funding can directly address the regional problem.
3. Incentives on investment in agriculture have reduced. Poor markets for agricultural produce have eroded the benefits at a farmers' level. This makes them reluctant to concentrate on soil fertility improvement and land degradation management despite their awareness of the resultant merits.

At an institutional level, there are five main opportunities for development in soil fertility and land degradation management:

1. There is need to conceptualise soil fertility management as an integral part of the entire land use for development continuum. This will tie soil management to marketing of produce and income, rather than leaving it in isolation. The benefits from other sectors can then be traceable to good soil management.
2. Interaction with policy makers needs to be enhanced to mainstream soil management in the entire agricultural development continuum.
3. Strengthened interaction between learning, research and extension is required. Through a collegial research approach, smooth feed-forward and feedback mechanisms can be established between research/learning institutions and technology users.
4. The physical infrastructure needs to be expanded to cope with the projected improved scale of soil resource management.
5. The curriculum needs revision in line with the emerging land/soil management challenges. The current curriculum trains managers, but it needs to train practitioners who can input the knowledge acquired into viable use.

With this understanding, knowledge and technology gaps in soil fertility and land degradation management are summarized below.

## Knowledge and technology gaps in soil fertility and land degradation

From the survey, we have established that there have been commendable efforts to generate knowledge and technology innovations by both learning and research institutions. However, the uptake of technologies and innovations is poor due to the following gaps:

1. **Poor linkage between knowledge generation and application.** Learning institutions have three main mandates: to teach, conduct research and disseminate findings to target users. The survey revealed that more attention is given to teaching, largely due to resource constraints and partly due to the fact that research and dissemination are handled by other entities. It is also assumed that students are equipped to undertake dissemination upon completion of their course when they receive 'the power to read and do all that appertains' to their degrees. This has resulted in a backlog in dissemination and knowledge evolution that is commensurate to the level of the evolving challenges.
2. **Linear/narrow approaches to soil fertility and land degradation management.** Commendable studies and research activities have been initiated on soil fertility improvement. The study of soils has, however, been undertaken largely in isolation of the overall land management practice. It is worth noting that most of the soils in Africa are already highly degraded. Management has thus focused on an improvement of the soils for certain specific benefits, mostly improved crop yields. Fertility improvement is thus focused on the crops in question without regard to the overall land management. In the Nyando Basin of Lake Victoria, for instance, households are still grazing their animals and cultivating in areas where continuous soil erosion has led to the development of deep gullies. The result is a decrease in productivity and accelerated degradation of the land. Consequently, residents are subjected to a complex maize-focused poverty circle. An integrated approach to soil management is required to address both the immediate and long-term soil fertility and land management needs so as to make a lasting impact.
3. **Fragmented experimental units.** There are numerous small experiments in soil fertility and land degradation management. Much as the challenges facing land users are zone-specific, a coordinated approach to soil fertility improvement and land degradation management is missing. There is evidence of duplication of efforts in soil fertility studies in Ethiopia, due to the absence of a soil research database. Information sharing among the various institutions is poor, making many challenges to keep growing. Despite the various efforts to better manage put in measures to manage soils, soil loss through erosion is still as high as  $130\text{-t ha}^{-1}\text{ yr}^{-1}$ . Nutrients are also leached, thereby undermining efforts towards increased crop yields. Most of the fragmented experimental units are as a result of limited funding. A regional approach is needed to diagnose the problems of soil fertility and land degradation management and pool all the research initiatives into a mutually coordinated and supportive framework. This will keep stock of the gains made, while, at the same time, enhancing knowledge/technology brokering and sharing within the region. Resource leveraging can also be achieved, as all the initiatives will be directed towards a common goal.
4. **Lack of perceived benefits in investing on soils.** Despite the high level of awareness on the benefits of investing in soils, the perceived benefits are either low or not feasible. Studies on soils have not been linked to markets and thus significant gains made are not seen as an incentive to continued efforts to improve soil fertility and manage land degradation. It is in isolated cases, such as on horticultural farms, where the benefits of soil improvement are realized in direct economic gains. In most

other cases, benefits of improved soil management are not easily quantified. Where these benefits are quantified, they are indirectly linked to the immediate needs of households. Although households are the main direct users of the soils, much of the knowledge and expertise remains with the researchers and learning institutions. In other cases, an increase in yields is seen upon initiation of good soil management. This was seen in western Uganda where massive plantations of cabbage were grown as cover crops, effectively controlling erosion. The benefits of this successful venture were, however, short-lived, as there was no market for cabbages. Farmers abandoned the practice, not because it was not viable, but it was not responding to their immediate needs.

5. **Lack of clear government policy and support.** It is interesting to note that despite agriculture being the mainstay of many African economies, there is lack of government support to soil fertility improvement and land degradation management. In Kenya, for instance, education planners are phasing out the study of agriculture in the primary school curriculum. Yet much of the effective extension has been through schools. The implication of the phase-out is ignorance or antipathy to soil management by students, who will not regard its importance as a vital resource for development.

At the soil knowledge application level, clear policies are lacking on placement of soil science experts. Most soil science graduates fail to get good jobs, unlike their counterparts in other fields. This has further eroded interest in the subject, leading to lack of commitment to conserve and improve soils. It was noted in the African Capacity Building Facility Conference held in Nairobi from 30<sup>th</sup> June to 1<sup>st</sup> July 2005 that there is a significant brain drain in Africa. The soil fertility and land degradation sector has clearly been one of the worst hit sectors, due to lack of clear policies. The soil management continuum is not given a holistic focus. Much emphasis is given to the marketing end, which incidentally is not linked to the soil base. All the countries visited in the region exhibited poor synergies between the Ministry of Agriculture, research institutions and learning institutions as far as soil fertility and land degradation are concerned. Even networks such as the Trees on Farm Network (TOFNET) are experiencing difficulty in dealing with NARS/NAROs due to poor policies.

6. **Lack of demand-driven agricultural innovations.** Most of the soil interventions improvement initiatives are centred on increasing yields, rather than on overall development. Some of the yield improvement innovations such as the elemental application of fertilizers (notably N and P) have resulted in soil fragmentation as is evident in the Rift Valley wheat growing area. Specific innovations that enhance plant nutrient levels as a long-term capital for production are thus needed. The focus is currently on integrated options for soil fertility management in Africa. Continued use of inorganic fertilizers has largely been the cause of nutrient imbalance, deficiency of some nutrients, deterioration of the soil structure and acidification of soils. Integration of inorganic and organic nutrient input is an appropriate way of building soil capital (Mutuo *et al.* 1998; Nziguheba *et al.* 2004). It has also been established that organic and inorganic nutrient inputs cannot be entirely substituted one for the other, but rather work best when managed in complement to one another (Vanlauwe *et al.* 2002a; Sanchez and Jama 2002; Place *et al.* 2003).
7. **Poor dissemination methods.** Much of the knowledge generated through research does not go beyond researchers. Horizontal and vertical dissemination approaches are

lacking, retarding the development of soil fertility and land degradation management. Postgraduate students supported by the ANAFE programme have performed poorly in publishing their work in peer-reviewed journals. Out of the 227 graduate trainees registered in 16 years, only 43 managed to publish one or two articles (Awimbo *et al.* 2003). Knowledge in soil science thus remains largely in grey literature, making its advancement rather difficult.

## **Approaches by other institutions**

Apart from the country-specific research and learning institutions, other institutions dealing with soil fertility improvement and land degradation management were also visited. These included TSBF-CIAT, SWMNET, TOFNET, ACTS, CAB International, ICRAF and the African Virtual University. These organizations had unique approaches in dealing with the subject of soil fertility and land degradation management, but similar a purpose and goals.

TSBF-CIAT has been supporting research in soil fertility and land degradation management in collaboration with universities and development partners, notably the Rockefeller Foundation. In terms of capacity building, TSBF endeavours to revive the curriculum support programme in soil biology and fertility with a strong focus on encouraging “T-shaped” skills, i.e. scientists with multidisciplinary skills and vision as well as disciplinary expertise. Member research organizations are also to be assisted to develop their communication skills with respect to a wide range of partners and stakeholders.

By utilizing the African Network for Soil Fertility (AfNet) as a self-learning network structured as a series of communities of interest, TSBF-CIAT seeks to promote and encourage the development of management and leadership skills. Progress has also been made in development of South-South linkages for the transfer of knowledge, experience, technology and capacity building with MIS (Latin America), South Asia Regional Network – SARnet (India) and others.

To reduce domination of AfNet by biophysical scientists, special efforts are being made to organize training in social science to encourage T-shaped skills. Opportunities for market-led ISFM are also embraced by linking TSBF’s capacity for generating ISFM results with complementary development-oriented expertise of other networks, institutions and NGOs. A hypothesis-driven conceptual framework has been recommended for development to foster the adaptive and market-led end of TSBF’s work.

Partnerships, the conceptual framework and success stories of ISFM are to be used to start pilot studies on market-led ISFM. To date TSBF-CIAT has about 80 sites of network trials in different agroecological zones distributed in East, South, Central and West Africa. Through the trials, a new paradigm of ISFM embracing a holistic approach to soil fertility research has been adopted. In addition, other proposals addressing markets have been developed.

Trees on Farm network (TOFNET) and Soil and Water Management Research Network (SWMNET) are networks of the Association for the Advancement of Agricultural Research in Eastern and Southern Africa (ASARECA). They are designed to foster research for development approaches by working with National Agricultural research Systems (NARS) and NGOs in 10 ASARECA member countries. The networks operates at a strategic level and emphasizes influencing the tactical (NARS and NGOs) and operational levels (technology implementers, mostly farmers) to achieve the goals of ASARECA as defined in six interlinked themes.

Capacity building is undertaken largely at the technology implementation phase to improve research for development approaches. Higher level capacity building focuses on developing multidisciplinary research managers capable of offering strategic guidance to research activities in various levels. Dissemination of technologies has also been an area of concern, considering the low uptake of candidate agroforestry technologies across the ASARECA member countries.

CABI Publishing is a dynamic and expanding division of CAB International, a not-for-profit organization dedicated to the dissemination, application of scientific knowledge in support of sustainable development. CABI Publishing produces over 60 new books each year. These consist of research monographs, student textbooks and major reference works, including dictionaries and encyclopaedias. These publications are developed on behalf of, or in association with a number of learned societies, research institutes, commercial companies and donor organizations. These include the World Bank, The Nutrition Society, The International Union of Forest Research Organizations (IUFRO) and many international research centres affiliated to the CGIAR.

ICRAF is playing a major role in soil fertility improvement and land degradation management. It houses many organizations, institutes and networks, to which it offers technical and scientific backstopping for research for development initiatives. The Maseno Regional Research Station in Kenya concentrates on soil fertility improvement through the promotion of viable and cost-effective agronomic practices such as improved fallows and domestication of tree crops. Land degradation issues are addressed through wide-scale and long-term experiments in the Nyando Basin and the river basins draining into Winam Gulf of Lake Victoria. ICRAF's work is organized around four themes that address the subject directly or indirectly. The approach is regional, with proven candidate technologies developed in a collegial research approach supported by on-station and on-farm trials.

Within ICRAF, is a training unit that aims to improve capacity by focusing on five interlinked training domains. The first domain is group training for in-service staff on topical areas conducted for each region. Subjects covered are often demand-driven as determined by the Regional Scientific Committee (RSC). Through these training courses, high level scientists and researchers are equipped with knowledge and skills to impart to practitioners and researchers under them. The focus is thus regional and not grassroots-focused.

The second domain is the individual training, mostly in the form of student attachments for MSc, PhD and post-doc scientists. The young scientists are assigned to an established scientist to have their skills sharpened for better output. This section is under reconstruction to enable it manage the high demand for the facility while maintaining efficacy in imparting knowledge and skills.

The third domain focuses on the development of learning resources. Training manuals have been developed covering topical areas. This programme is tailored to developing learning resources for use at tactical and implementation levels of research for development activities. A training toolkit has been developed as a milestone to sustainable effective training in a simplified framework.

The fourth is the training focusing on farmers of the future. Strategic incorporation of agroforestry at primary and secondary school level is expected to translate into improved domestication of viable trees in a sustainable farming system framework.

The fifth domain is the virtual learning, a new concept that is expected to be fully operational by the end of this year. It entails distance learning using the Internet. From a site in Belgium, computer software has been developed to allow for on-line training, deposit of meta-data for

learning materials on the Internet, including PowerPoint presentations and video downloads. This step could greatly reduce the cost of conference training in the long run, while ensuring trainees always get the latest state of knowledge and actively take part in knowledge dissemination by posting their findings to the Internet.

Demonstrations for practical teaching have been conventionally done by PowerPoint presentations, although the use of video downloads is becoming common. One limitation to the video downloads is the requirement for larger bandwidth. There is also limited interaction between the trainer and the trainees, a limitation that could be addressed if telephone conferences are included in the approach. The other limitation is on the intellectual property rights of the material sent to the web. ICRAF has designed a paralegal system of copyright inclusion to the material, which would abide in the scientific spheres, though not necessarily applicable in the legal framework.

Through the online initiative, scholarly work can easily reach a wider audience at minimum cost and can also be acknowledged as published, albeit in the form of grey literature. An improvement in the system to white publication through resource support to the system to include peer reviewers and designers would boost technology dissemination.

The African Virtual University is also offering undergraduate courses in Information Technology in a similar pattern. Limitations to the system are the same, but their audience is basic scientists looking for degrees, unlike the ICRAF system that empowers the trainers of trainers. Virtual learning is a concept that needs to be developed as it is an essential vehicle to accelerated development.

## **Conclusion**

The study reveals challenge-oriented capacity building needs in Africa. In terms of human capacity, two critical issues need to be addressed: scientific training of manpower, and re-tooling of the existing manpower to handle emerging challenges. For the first need, strengthening of collaboration between institutions would lead to efficient utilization of surplus capacity in some institutions by those lacking in capacity. Both North-South and South-South linkages are encouraged. The second need is quite critical and need to be urgently addressed.

The knowledge and technology status of soil fertility and land degradation management in Africa is good in biophysical aspects. Integration of these technologies with socio-economic attributes for wider uptake is evidently poor. Continuous soil mapping and land use characterization is lacking due to lack of capital resources and poor incentives. Policy support to soil fertility and land degradation management is quite weak in Africa. The technological and infrastructure base for wide-scale knowledge transfer through approaches such as virtual learning needs to be improved to help Africa catch up with advances in the developed world. There is need therefore to address these challenges if stable, viable and sustainable agriculture is to be realized in Africa as a backbone to economic development.

# Report on the Sahel

## Introduction

The Sahel, or semi arid lowlands of West Africa, is characterized by low and highly unpredictable rainfall patterns (200 to 600 mm year<sup>-1</sup>), with a 9-month dry season. The region experiences frequent periods of drought coupled with high temperatures, often reaching 40° to 50°C. This, combined with a high population growth (3%), which exceeds growth of food production (2%), has led to continuous decline in per capita food production and incomes since 1980. As the ratio of population-to-land has increased, soil fertility has gradually been depleted by successive crop harvests, leaching and erosion.

The predominant soils of the region are Entisols, Alfisols and Vertisols, which are naturally poor (Wilding and Hossner, 1989) due to inherited properties from parent materials. The parent sandy and fluvial sediments from which most of these soils developed were apparently locally derived from polycycled and pre-weathered continental terminal sandstone bedrocks (Sombroek and Zonneveld, 1971). These soils have low activity clays (LAC) and thus poor fertility properties (Juo and Adams, 1986). LAC soils normally contain predominantly kaolinite, Fe and Al oxides and hydrous oxides in the clay fraction. In terms of chemical properties, they have values of ECEC less than 12 Cmol<sub>c</sub> per 100 g of clay (Juo and Adams, 1986). These soils are poorly buffered, mostly acidic, and deficient in N and P (Takow *et al.* 1991; Doumbia *et al.* 2003). In particular, Alfisols are frequently deficient in N and P and tend to acidify under continuous cultivation (Deckers, 1993 and Bekunda *et al.* 1997).

Low and declining soil fertility is considered as one of the most important constraints to agricultural productivity in the Sahel. Recent research has shown that productivity could be multiplied five times with the same amount of rainfall if an adequate fertilizer regime was used. Because of low vegetation cover at certain crucial periods of the year, soil erosion is another degrading factor estimated to remove soil at 10 times of the rate of natural soil formation, and affect 72% of the arable land. Soil lost through erosion has been to be estimated 2.5 times richer in nutrients than the remaining ones.

It is established that the production of 84% of these soils is limited by water problems (Spencer *et al.* 1995). In addition to losses of soil, rainwater runoff removes about 40% of nutrients applied to soils (van der Pol, 1992). By increasing rainfall infiltration rates from 40 to 60%, farmers can greatly increase yields and double or even quadruple their disposable income, depending on rainfall. Income can be increased by another 50% if infiltration rates are raised to 80% (Day and Aillery, 1989). However, without fertilizer application, only 15% of rainwater is used by plants. With adequate fertilizer application, plants would use about 50% of rainwater (Breman *et al.* 1998). Furthermore, if plant nutrients were not limiting, plant production would be five times greater with the actual rainfall properties (Groot *et al.* 1998).

Additional constraints limiting soil fertility management in the Sahel are:

1. socio-economic conditions disfavoured the use of chemical fertilizers (Kelly *et al.* 1998),
2. application of fertilizer rates less than recommended (Van der Pol and Giraudy 1993),



3. specific constraints limiting the use of Tilemsi phosphate rock (Kamara *et al.* 1994),
4. abandoned or reduced fallow period (Hoefsloot *et al.* 1993),
5. removal of crop residues (Van der Pol 1992),
6. putting marginal lands under cropping (Van der Pol and Giraudy 1993),
7. continuous cutting of trees for firewood (Kieft *et al.* 1994), and
8. overgrazing of pasture land (Van der Pol 1992).

Because of declines in crop yields, agricultural activities are spreading to marginal lands and areas traditionally used by livestock, leading to numerous conflicts between agriculturists and pastoralists, people with different land-use rights. The combined effects of soil-fertility depletion, active soil erosion and land-use conflicts have accelerated the degradation of the natural resources base by a poverty-stricken population forced to overexploit soils, rangelands, and forests in order to subsist.

Soil fertility decline in the region is due to ecological and socio-economic constraints that have resulted in the breakdown of traditional farming systems. Therefore, the problem of soil fertility depletion is complex and it is unrealistic to consider it in isolation from the many social and economic constraints that people face daily in this region. In spite of the many efforts and resources invested, soil fertility replenishment and management in the Sahel is still an acute problem. It continues to jeopardize development programmes aimed at reducing hunger and malnutrition in the region.

This synthesis will highlight major new research initiatives underway in the region and the knowledge gaps, but it mainly focuses on a critical assessment of biophysical, socio-economic and institutional constraints hindering adoption of the available soil fertility management technologies and farming practices. In addition, suggestions are made for the regional capacity building at institutional and individual levels.

## **Soil fertility research activities, achievements and gaps**

Research for soil fertility management in the Sahel has made important progress, especially in biophysical aspects. Agricultural research has been in a number of phases.

Before and some years after independence (early 1960s), research activities were specifically focused on crop responses to different types and combinations of fertilizers. Special attention was given to cash crops such as groundnuts (in the Senegalese Groundnut Basin and Mali), cotton (in the Southern Mali Region and Burkina Faso) and irrigated rice. These activities were not integrated and scientists worked mostly in isolation in laboratories and field stations on a single crop/commodity basis.

Emergent new national scientists with more understanding of the traditional farming systems and practices characterized the second phase, which came about from the mid-1960s. Research activities became more widespread and covered staple food crops such as millet, sorghum, and maize in addition to the cash crops mentioned earlier. Symptoms of soil fertility decline were observed locally but not generalized and some field and laboratory activities were anticipated to improve understanding of the problem and how to tackle it. However, efforts were mostly geared toward the use of mineral fertilizers in combination with improved farming practices to increase crop yields.

Because research was mostly conducted in research stations and laboratories, both phases were characterized by: (i) lack of integration of different scientific disciplines, and (ii) little or no application of traditional knowledge and know-how in the technology development chain.

The third phase came about in the late 1970s when low adoption of new technologies became obvious and agricultural research started being criticized, even by government officials, as being too expensive and non-productive. Lack of or insufficient understanding of farmers' constraints and traditional farming systems/practices was found to be among the causes of low adoption. The Farming Systems Research approach was then initiated to improve dialogue and collaboration between rural populations, scientists and extension specialists. In the case of Mali, this programme was supported and funded from 1979 by the Royal Tropical Institute (KIT) of the Netherlands, Canada's International Development Research Centre and the United States Agency for International Development (USAID).

This approach was key to linking research and development, with scientists carrying out their research activities directly on-farm in close collaboration with farmers on commonly defined constraints. This era gave a lot of insight into the understanding of the non-specialized, complex agro-silvo-pastoral farming systems of the region, where households undertake a wide array of farming and non-farming activities to sustain their livelihoods. As a result of this 'revolution', soil fertility research has evolved to become more complex, multidisciplinary and thematic, with almost all aspects of soil physical and chemical properties being examined from biophysical, social and economic viewpoints.

As different phases succeeded each other, so did research administration and its funding in the Sahel. In Mali, for instance, research institutions are now considered as decentralized public scientific institutions called *Etablissements Publics à Caractère Scientifique et Technologique* (EPCSTs). The research institutions receive some financial support from the government, but they also have to compete for funds to support their activities. Agricultural research (IER) administration is regionalized and organized into commodity-based programmes on millet, sorghum, maize, small ruminants, forestry, irrigated rice, valley-bottom rice, cattle, fruits and vegetables, peanuts, beans, cotton and poultry. These programmes are supported by laboratories, farming systems research teams and economic studies (ECOFIL). However, with limited capacity, the institutions cannot seize most opportunities, making it difficult for them (e.g. IER) to secure funding and keep top scientists.

Because of inadequate production of locally available soil improving materials — such as manure, compost, household waste, tree biomass, and rock phosphate — and distortions between the ratios of chemical fertilizers and the price of food crops, it is now being recognized that only an integrated approach, combining organic and mineral sources of nutrients, would be the most appropriate and effective way to tackle the soil fertility decline problem in the region (Bekunda *et al.* 1997; Sanchez *et al.* 1997). Thus, current soil fertility research in the Sahel mainly focuses on:

- Crop-livestock integration to ensure proper fodder production to improve animal production, which, will help increase the production of large quantities of high-quality manure to be applied for soil fertility replenishment and to increase crop yields.
- Farming practices that integrate legumes in intercropping or in rotation with cereals to benefit from their atmospheric N fixing capabilities
- Appropriate and efficient combinations of organic and mineral sources of nutrients capable of supporting high grain yields with reasonable and affordable financial investments.

- Selection of drought resistant/tolerant and early maturing crop varieties to better cope with rainfall shortages.
- Water harvesting techniques have been used in Mali (Gigou *et al.* 1999), Burkina Faso and Niger to reduce runoff and soil erosion and to increase infiltration. Examples include digging of 'zai' pits known as 'tassa' in Niger, 'demi-lune' catchments, construction of stone lines along contours, 'diguettes filtrantes', ridges and the relatively new initiative of capturing water through ridge-tillage along contour lines, also known as 'aménagement en courbes de niveau' (ACN) in Mali.
- Broad or unique fertilizer recommendations only correcting the deficiencies of major nutrients are extended in many Sahelian countries (Poulain 1976; Piéri 1989). Research is being conducted to make specific fertilizer recommendations on the basis of site-specific soil physical and chemical properties, soil series or types, and crop yield goals (Doumbia 2003).
- The fertilizer micro-dosing technology based on the application of small quantities of fertilizers in the hills of plants thereby enhancing fertilizer use efficiency, and through the built-in 'warrantage system' establishes a link between the credit schemes and cereal grain markets (Tabo *et al.* 2005)
- To a lesser extent C sequestration potentials of Sahelian soils.

More recently, through ICRAF leadership, agroforestry has gained more research attention in the Sahelian agricultural research agenda. After more than 10 years of fruitful collaboration with the national agricultural research institutions (IER, INERA, INRAN and ISRA), many tree-based technologies were developed and adapted to the region's conditions. Of particular interest for soil fertility management are: (i) the fodder banks, which, if well adopted would contribute to better crop-livestock integration to support both animal performance and manure production for soil fertility replenishment, and (ii) improved fallows with species such as *Tephrosia candida*, *Sesbania sesban* and *Gliricidia sepium* capable of tripling crop yields after the fallow phase.

It is worth mentioning that the current state of generalized crop yield decline due to poor soil fertility management cannot be explained by a dearth of information and appropriate technologies. There are a number of well-documented farming practices aimed at improving soil fertility management (RCS-Sahel 1991) such as: Techniques of optimum soil occupation such as crop rotations and intercropping; soil preparation techniques including deep-ploughing and mulching; and protection of soil organic reserves through manuring, fallowing, green manuring, etc.

In addition, past and present research has generated a wealth of information and technologies related to crop responses to different fertilizers, high-yielding (and pest-tolerant) improved crop varieties, better crop and livestock integration strategies, etc., well tailored to the different main farming systems. Hilhorst *et al.* (2000) grouped the various soil fertility-enhancing methods according to the role they play in the flow of nutrients into, out of, or within the farm. They mostly aim to add nutrients to the farm, reduce losses of nutrients from the farm, maximize the recycling of nutrient already within the farm, and increase the efficiency of nutrient uptake.

Most of these soil fertility management methods and technologies are the result of intensive collaboration between research/extension and farmers within farm conditions and have their efficiency proven and ascertained nationwide. However, the reality is no, or at best, a very low adoption rate, leading to continued soil nutrient mining, poor crop performance, hunger and malnutrition in the region.

There are well-documented cases where farmers apply more than or at least the recommended rates of fertilizers to support major cash crops such as rice (Office du Niger, Mali), cotton (CMDT Mali, Burkina) and groundnut (Senegal and Mali) (Hilhorst *et al.* 2000; MDR 2002). However, none or little inputs are applied to staple cereal food crops such as millet and sorghum (MDR 2002). The benefit of applying organic sources of nutrients (manure, household waste and compost) is well known to farmers and they apply them continuously on farms close to the homestead, though at insufficient quantities. However the application to bush fields, located far away from the homestead is constrained by the lack of adequate quantities and means of transportation (animal-pulled carts). This is a clear indication that farmers are rational in making decisions and whenever they have been able to make a profit from farming and have access to appropriate support services, they continue to invest in soil fertility management.

Unfortunately, the Sahelian farmers operate in non-enabling macro-economic policy and environmental conditions. As pointed out by Hilhorst *et al.* (2000), changes in macro-economic policies have had an impact on soil fertility management. In the 1990s, these practices were particularly affected by structural adjustment programmes and associated policies such as currency devaluation, then liberalization of crop and input prices, the abolition of subsidies, changes in input delivery and agricultural credit systems, and the downsizing of government services.

Thanks to the FAO and the World Bank-led soil fertility initiative (SFI) for Africa initiated in 1996, some Sahelian countries such as Mali and Burkina Faso have elaborated national action plans for soil fertility management. But the Government of Mali, for example, does not have any well-elaborated and articulated national policy on supply of inputs in general and fertilizers in particular (MDR 2002). Thus, the current situation is more due to a lack of political will and inappropriate market conditions than a dearth of appropriate technologies and information related to better and integrated soil fertility management.

However, the following aspects, which hold lot of promise, have not been adequately tackled so far:

- Phosphorous deficiency is seriously hampering improved crop yields in the Sahel, mostly because of the acidic soils and P sorption by hydrous oxides of Fe and Al (Juo 1981; Le Mare 1981). Though the positive role of vesicular arbuscular mycorrhiza (VAM) fungi in solubilising soil P has been well established, Sahelian soil scientists have not paid due attention to its potential.
- Although water and nutrient interaction research is essential for increasing and stabilizing crop production, and for maximizing the return to inputs of fertilizer, far fewer studies on this interaction have been carried in the dry lands of Africa, compared to the studies on nutrient or to those on water separately.
- Research in the Sahel has not yet provided any tangible answer on the technically and economically appropriate combination of organic and mineral sources of nutrients efficient to support soil fertility and crop yields. In other words, the 'fertilizer equivalent' of the organic sources of nutrients (manure, compost, household waste, etc.) is still not known sufficiently enough to build on and rationalize the use mineral fertilizers. However, it is known that farmers reduce the amounts of mineral fertilizers to be applied whenever they apply a certain amount of organics.

## Capacity strengths and needs

Through years of experience, Sahelian research institutions have established some assets on which to capitalize and build for the future. Some important examples include, but are not restricted to the following:

- Elaboration and adoption of National Soil Fertility Strategic Plans (Burkina Faso and Mali) are proof that soil fertility decline (and its consequences) is of national concern in many Sahelian countries, though these plans have yet to be fully implemented. As the Malian Ministry of Agriculture pointed out, to further the implementation of the soil fertility plan there is need to: (i) assist national institutions involved in soil fertility management in terms of human resources, materials/equipments, and funding, (ii) assist farmers' organizations to promote sustainable soil fertility management through a fully integrated soil fertility management, including land tenure security, (i) moving towards commercial and maximum value added agriculture, and (iv) making the private sector (both agricultural inputs and outputs dealers) and farmers and farmers' organizations more professional (MDR 2002).
- Some countries, such as Burkina Faso, have initiated national soil mapping on scales of 1/50 000 or 1/100 000 for better understanding of the repartition of the different soil types, their characteristics and specific needs to better target the interventions. To date, the task is accomplished at more than 70% in Burkina Faso.
- All countries have appropriate soil and GIS laboratories and access to major facilities through the CGIAR and other advanced research institutions such as IRD, INSAH, AGRHYMET and CERAAS to carry out important high-tech research. The national research and extension institutions have a good number of highly qualified scientists and technicians.
- The Sahelian governments make a great deal of effort to support salaries and other research-related expenditures, although these are never sufficient and vary from one country to another.

Sahelian agricultural research institutions are evolving in a theoretically appropriate administrative environment in the sense that most of them have relative autonomy to manage their financial and human resources. This situation is appropriate to remove unnecessary administrative and political pressure on scientists and the research agenda. However, this comes with deep budgetary cuts from governments at a time when scientists are neither well prepared nor sufficiently equipped to compete for scarcer and highly competitive research funds.

Thus, while it is worth securing this administrative environment, it is crucial to make adequate investments to build and strengthen capacities of the research institutions in writing winning proposals, building alliances, and lobbying to enable them attract donor funds for research in line with national priorities.

The current brain drain, if not halted, will compromise the future of the Sahelian agricultural research institutions. The Sahelian NARS cannot afford to lose their only most important resource – scientists. It is therefore crucial that salaries are raised and incentives and work conditions improved. While NARS may be successful in attracting donor funds to conduct research, they are unlikely to halt the brain drain. Governments must have political will and invest resources to keep their scientists if research is at all a national priority.

Also, there is a lack of well-trained, highly qualified scientists in some important research disciplines such as biotechnology, microbiology, natural resource management as well as

extension and scaling up. Indeed, agricultural research has evolved and so should the specialists. There is a need to train new types of researchers that have a comprehensive view of how different disciplines are interconnected and who can approach a specific problem from different points of view and work in synergy within teams of specialists.

The farming systems research approach has had a great impact on the way scientists deal with extension and farmers in the technology development chain. However, there still are serious gaps in the scaling up process. New breeds of scientists are needed to gain decision makers' and politicians' support and to accompany technology deliverance to end-users.

## **Capacity building for strategic action**

The very nature of the Sahelian soils (poor structure, low pH, low CEC) and the severe climatic conditions make them deficient in all major soil nutrients. In particular, soil available P is recognized as one of the most limiting nutrient hindering high crop yields in the region. The region is blessed for having many sedimentary phosphate rock deposits of medium to high solubility — two sites each for Burkina and Mali, three in Niger and four in Senegal. Phosphorous being one of the most stable soil nutrients, a reasonable and realistic strategy would be to invest in building soil P capital in the region.

The different gaps indicated in this review paper require specific areas of capacity building for strategic actions. These include:

- Helping to establish fertilizer dealers at the village level, a key constraint to the use of fertilizers is their unavailability at this level. This is a critical issue on which SASAKAWA GLOBAL 2000 has been working on in Mali. The programme supplies fertilizers to dealers in the village. The dealer sells the fertilizers, pays back SG 2000 and gets new stock. This process goes through several cycles before the dealer become self-sufficient. Initiatives such as this are needed throughout the Sahel to move average fertilizer application beyond the rate of 8 kg/ha.
- Assisting set up decentralized savings and credit institutions at the village level. Decentralised credit can help tackle lack of access to fertilizers by resource-poor farmers. Although several initiatives have been initiated, there is room for more action, specifically in areas not covered by the well-structured production systems such as Office du Niger in Mali.
- Helping to develop cereal banks/warrantage at the village level. These will assist farmers to better access inputs and get a higher value from their products. The lessons learnt from the USAID's TARGET micro-dosing project need to be extended or replicated in several other areas/countries.

## **Conclusion**

In spite of the many efforts and resources invested, soil fertility replenishment and management in the Sahel is still an acute problem that continues to jeopardize development programmes aimed at reducing hunger and malnutrition in the region. This short review highlights the existence of numerous and well adapted soil fertility replenishment and management technologies and information in the Sahel and argues that the current situation is more due to a lack of political will and inappropriate market conditions. The conducive administrative environment under which most Sahelian NARS operate is worth maintaining.

However, the current scientific brain drain has to be halted and a new generation of scientists is needed to make research institutions more efficient in both technology generation and delivery chains.

The review adopts the view of Hilhost *et al.* (2000), who state that: “Investment in soil fertility management will not increase if farming is neither profitable nor essential for maintaining livelihoods. Comprehensive and focused national policies could help to improve access to markets and support services for acquiring inputs and selling produce, finance and information, and help create conditions that make agriculture a more attractive option, giving farmers a reasonable returns to their investments.”

# Report on the African Humid Tropics

## Introduction and methodological approach

The decline of soil fertility is recognized as a serious hindrance to future food production in Africa. It is widely accepted that the supply of plant nutrients dictates land productivity. Although decision makers in many African countries actually accept that improved plant nutrition and soil management contribute to growth in yields, more investment in agricultural production is devoted to genetic improvement, improved control of pests and diseases and better agronomy and crop management.

Many soil fertility research projects and laboratories, particularly under the national research system and universities are closing down for lack of funds and/or mismanagement. Indeed, agricultural research in many African countries has been neglected since the late eighties because of economic hardships in many countries. The new trend over the past five years is that of many countries putting emphasis on “vital sectors” such as health, education and strategic equipment.

At global level, greenhouse gas emissions, air pollution, deforestation and biodiversity loss are highlighted in many country agendas to mobilize research and development funds, while little or no attention is given to soil fertility management. Available funds are often managed by international NGOs, with no sizable impacts on the development of African countries where projects are executed.

The New Partnership for Africa’s Development (NEPAD), recognizing that agriculture–led development is fundamental to fighting hunger, reducing poverty and generating economic growth, has embraced soil fertility as a key issue requiring more attention on the continent. To actualize this desire, a strategic action plan for Africa is necessary, but there is also a need review the state of the art knowledge on soil fertility management. The present investigation was initiated to serve this purpose for the Africa humid tropics.

This report intends to initiate baseline data collection for the African humid tropics (AHT). The study covered the state of knowledge, advances and capacity needs assessment of institutions in order to propose a framework for action to implement existing techniques and address unresolved issues.

This survey focused on six (6) research institutions and universities in Cameroon.

1. The Institute of Research for Development (IRD)
2. The International Institute of Tropical Agriculture (IITA)
3. The Institute of Agricultural Research for Development (IRAD)
4. The World Agroforestry Centre (ICRAF-AHT)
5. The University of Yaoundé I (UY1)
6. The University of Dschang (UDS)

Senior soil scientists and lecturers of the various institutions were interviewed either using a questionnaire (sample questionnaire appended) or in informal discussions, which followed



similar guidelines. These institutions are located in different ecological zones which are all representative of the mosaic landscape of the Africa humid tropics:

1. The humid forest zone (IRAD, IITA, UY1, IRD, ICRAF)
2. The humid highlands (IRAD, UDS, ICRAF)
3. Mono-modal humid forest (IRAD, UDS)

In each of the three zones, a workshop was organized with soil scientists to discuss the content of the questionnaire, analyze the output of the survey and scale up the study to similar ecological zones of the Africa humid tropics. Senior soil fertility scientists were then brought together in a workshop to sort, synthesize and validate information from the three zones. They also analyzed the general trends for the whole region. Their discussions were built on four major questions:

1. What are the tendencies, challenges and strengths of soil fertility research in Africa humid tropics?
2. How do the scientific publications from the region measure up in terms of quality, quantity, impact, and pertinence in developing strategies for improvement of soil fertility management?
3. What are the specific needs for soil fertility research in the region and what are the specific roles of partners (research institutions, universities, NGOs and farmers)?
4. What elements are needed to develop a strategic action plan for soil fertility research in Africa humid tropics?

This report summarizes the major findings of the survey and underlines the key issues at regional level arising from the discussion of the experts. It is expected that the most critical shortcomings of soil fertility research and development at regional scale have been identified and that the synthesis section indicates the strategic action plan for closing the loop.

## **The state of soil fertility research in the AHT region**

### **Accomplishments**

#### 1. Land evaluation and mapping

- a) Many characterization activities have been conducted and soil maps are available for the region. But these maps cover only 4% of the area (a in the case of Cameroon).
- b) Modelling of soil and land use dynamics within shifting agricultural landscape mosaic system.
- c) GIS biophysical characterization of the forest zone of Cameroon.
- d) Land evaluation for major cash and food crops and land uses of the region.
- e) Land degradation indicators and erosion risk.

#### 2. Soil microbiology and biology

- a. Selection of rhizobia and mycorrhizae strains adapted to acid soils.

- b. Evaluation of soil fauna (termites, earthworms, ants) activities and their effects on soil properties.
  - c. Studies on decomposition processes of soil litter and nutrient cycling.
  - d. Production of bio-fertilizers and field testing.
2. Soil Chemistry
- a. Determination of nutrient (N, P, K) availability in acid soils, and changes along the cropping intensity gradient.
  - b. Determination of nutrient requirements for major cash crops (cocoa, oil palm, coffee, banana, rubber). These studies were generally funded by agro industrial estates.
3. Agroforestry
- a. Screening of leguminous trees and shrubs for improved fallows.
  - b. Development of management principles of various agroforestry technologies (alley cropping, planted fallows, rotational fallows).
  - c. Determination of the effects of rotational fallow on major food and cash crop yields.
  - d. Evaluation of the potentials for adoption of agroforestry technologies.
  - e. Evaluation of land and tree tenure constraints affecting adoptability of planted fallows.
4. Integrated nutrient management
- a. Nutrient budgets along slash and burn chronosequences.
  - b. Nutrient stocks and fluxes in various land uses.

The above achievements show that significant soil fertility research has been conducted in the region, but these studies are generally fragmented as they were handled at country level by national research institutions and universities. International research institutions (IITA, IRD ICRAF) have a regional mandate. They also have qualified staff and more research funds that enable them to conduct intensive work, much of which is published in renowned journals. Unfortunately, collaboration between international and national institutions is not as close as it could be. Institutional conflicts have often arisen over ownership of funded projects, sharing of data and results when national and international scientists are involved in the same or similar projects.

### **On-going soil fertility research**

On-going activities have generally been initiated by individual scientists with meagre resources. No large-scale or multi-institutional project is actually underway. At IRD, there is no current activity in soil fertility research. At IITA, major field activities focus on soil

biology, soil nutrient management for targeted crops (plantain, groundnut, cocoa). In the UDS, the physical and chemical characterization of many land units in the south of Cameroon for crop production is being conducted, but only on limited scopes and generally as an activity for student internships and practical exercises.

At UY1, many topics were cited as current activities by various lecturers: soil microbial ecology in humid forest zone, selection of rhizobia and mycorrhizae for acid soils and specific crops, work with P-solubilizing micro organisms, work to understand effects of slashing and burning on soil properties and major crop yield.

At IRAD, there was no financial support for field research on soil fertility, but individual scientists still kept their research agenda. These included modelling and monitoring of soil property dynamics under shifting cultivation, specificity of mycorrhizae on acid soils, nutrient dynamics in forest soil ecosystems, crop response to chemical, biological and organic fertilizers, limiting factors in groundnut production.

## **Major gaps in soil fertility research**

Participatory research in soil fertility is largely lacking in the region. Farmers are not involved in many soil fertility research activities, although they are the end users of the results. This leads to a gap between farmer expectations and management capabilities and the recommendations of the study. Many studies have been conducted but very few results are put into practice by farmers, leading to little or no change in the gloomy trend of a deteriorating natural resource base. Therefore, a sound participatory learning and action research in soil fertility management should be developed.

Much is still to be done to improve farmers' capacity to analyze soil fertility and to find alternative ways of managing it. Specific tools to assess farmer knowledge in soil fertility and to integrate farmers in the research process need to be developed and implemented. Increased stakeholder awareness of new initiatives in soil fertility management is required as a component of natural resource management.

The role of agroforestry in soil fertility improvement is another major gap. As improved agroforestry technologies are developed, there is a need to focus on socio-economic determinants for adoption of major recommendations in soil fertility management and on impact assessment.

Sound methodologies need to be developed to scale up the results of soil fertility research from the field and farm to watershed/village and landscape, and even to regional levels. Soil degradation is a widespread problem, yet much of the research focuses on field scale solutions. Results and recommendations in soil fertility research should be considered at different spatial and temporal scales and the outputs need to be geared towards up-to-date concepts such as poverty alleviation, resilience, and economic growth. To achieve this goal, soil fertility researchers need to team up with scientists from other disciplines such as socio-economic, policy, culture, gender issues, indigenous knowledge, in order to generate viable development tools.

Another challenging gap will likely be the political environment in countries of the region. Countries "coming out of war" (DRC, Liberia, Togo), and those experiencing a crude oil boom (Equatorial Guinea, Gabon) may not have the same interest in soil fertility research as more stable ones (Cameroon, Nigeria, Ghana). Furthermore, it is likely that most of the results from past activities are no longer available. However, the Cameroon database which covers the different ecological zones of the region can be used to bridge the gap.

## **Closing the loop**

### **Soil fertility research in Africa humid tropics: Trends and challenges**

In the African humid tropics, there are many institutions with a good number of qualified scientists who can initiate and manage research and training programmes in soil fertility. These include national research institutions, universities, and international research institutions. Also, many scientific and research activities have been concluded on land characterization and mapping in the region, but unfortunately, few if any are at the farmers' scale. Therefore available maps and recommendations for soil fertility management are generalized principles with no direct utility as a development tool. Few localized and systematic soil fertility trials have also been conducted in many countries. These trials have largely been confined to single research stations or individual farmer's fields. Up-scaling or extrapolating these results for the whole region will likely generate many errors and uncertainties.

It is also observed that in many French speaking countries in the region soil fertility research is neglected. Laboratories in research institutions and universities, although fairly well equipped, are closed due to lack of technical staff to undertake analyses or maintain the facilities. The case of Cameroon is alarming. The former Centre National des Sols (National Centre for Soils) in charge of soil research at national level has been reduced to a mere unit under the forestry department.

Finally, institutions and even scientists work in isolation. No networking strategy has been developed for the region yet, so there are no formal channels for communication. This leads to duplication of research in spite of meagre resources, institutional conflicts and very often frustrations for scientists in national institutions with no major research funds (NARS), compared to international institutions, which are much better funded.

### **Scientific publications: Impact and challenges**

During the interviews, it was observed that soil scientists in the region have published extensively, but very few papers have been published in international journals. Most of the work is published as conference papers, technical reports and student theses, or in local journals. Most of the few publications in renowned scientific journals are generally written by scientists from international institutions, in spite of the high number of soil scientists involved in soil fertility research in the region. This is an indication of the low quality of the end products, which is usually attributed to the lack of funds to initiate high quality and competitive research work that would be of interest at the international level.

It was also noted that very few papers are published by multi-institutional teams of scientists and not even multidisciplinary teams within the same institution. Scientists operated in isolation or in fragmented groups, which usually limits them to publishing in local fora. Very few scientists, if any, have published books in soil fertility for the region and there is a need for handbooks that can be used as research guidelines, training and education materials in soil fertility, or as development and extension tools. Most of the papers published have no direct link with the livelihoods or aspirations of farmers.

Isolation of scientists is reinforced through the lack of access to scientific journals and access to information about new developments in the field. Publications are often not available for other soil scientists because NARS have neither subscriptions to scientific journals nor access to the Internet.

There is, therefore, a need to initiate farmer-oriented soil fertility research to train soil scientists in scientific reporting, and transforming scientific outputs of their research into development tools that can be easily used by extension agents and rural development agents, or as education tools. National research institutions should be facilitated to access to the Internet and documentation on good scientific quality. In addition, international institutions need to collaborate more closely with national research institutions and universities for capacity building, research partnership, and fundraising for research and development.

### **Specific needs for soil fertility research in the region**

Soil fertility research in the humid tropics of Africa needs to be orientated towards research and development (R&D) that is directly applicable to the situation of the smallholder farmer. Thus, research topics should be oriented toward problem-solving and developed from problems identified at the farmers' level. Also, soil fertility laboratories should be made accessible to farmers, NGOs, students, and scientists by subsidizing the cost of laboratory analyses.

Research should be linked to education at various levels, and to reinforce this aspect, scientists should be encouraged to develop multidisciplinary proposals, teaming up with scientists in other disciplines and from various institutions (universities, research institutions, NGO, farmers).

Funding strategies should be initiated at regional level for soil fertility research, from laboratory equipment and supplies, to field equipment for on-farm research. Capacity building should be initiated in new scientific techniques such as clay mineralogy, use of radio and stable isotopes, molecular tools, and geographical information systems (GIS).

For all the above changes to be possible, the priority should be on creating regional focal points to coordinate soil fertility research activities and facilitate information flow within and between regions.

### **Strategic action plan for soil fertility research in Africa humid tropics**

There is a need to create a synergy between the various institutions involved in soil fertility research, and even between scientists, through networking. The approach should be to identify soil fertility scientists in the different fields and for each institution, then develop a network of scientists throughout the region. This network can be strengthened by the following: supported access to the Internet for the institution, editing and publication of a peer reviewed scientific journal in soil fertility for the region, workshops and seminars for soil scientists at national and regional levels on new developments in soil fertility and, finally, mobilization of funds for multi-institutional and multi-disciplinary research proposals.

For soil laboratories the strategy should consider linking soil laboratories in the region with others on the continent and in the North, for control of norms (e.g. International Plant-analytical Exchange IPE, The Netherlands).

Collaboration among universities should be reinforced by improving agricultural, and especially soil fertility, curricula as well as development of up-to-date learning methods and materials. Networking between universities through existing agroforestry education networks such as ANAFE will be a key step in building soil fertility management capacities in the region.

## **Capacity building**

Scientists in national research systems are ageing. Therefore, the priority in capacity building will be to build the skills of junior scientists, including by training them at M.Sc. and at PhD levels.

More experienced scientists need to update their knowledge on modern research skills and approaches in fields such as clay mineralogy, land management and conservation, soil fertility and fertilizers, soil physics, soil chemistry, soil organic matter and soil biology. Short-term training courses, seminars at institutional level, workshops and conferences at regional level, and symposia need to be organized for scientists and field technicians in specific areas such as applied soil ecology, integrated nutrient management, nutrient budgeting. Also, short-term training courses are needed for technical staff on new laboratory methods and on how to use and maintain modern laboratory equipment. Such training can be organized in existing laboratories that are well equipped and have highly qualified staff, for instance those at IITA.

## **Lobbying to fund soil fertility research**

Existing soil fertility scientific results and achievements in the region should be valued and published for a wide audience. This will require a strategic synergy between various research institutions and universities of the region, through a regional network.

Results can be synthesized and published in international journals as well as in books and extension materials. Specifically, a handbook on soil fertility for the whole region could be developed. Networking will help to identify the weaknesses of the work already done and generate more winning proposals.

International research institutions should play the leading role in the network and assist local scientists to secure funds for soil fertility research, thus overcoming the antagonistic atmosphere that now prevails. At the African level, and even global level, this approach of lobbying will contribute to mobilizing funds for further research activities.

Multi-location trials should also be initiated to cover a good range of soils with similar conditions, thus fostering the scaling up of the results. The network could coordinate the execution of such trials and then initiate the impact assessment and the evaluation of the different activities.

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## Who we are

The World Agroforestry Centre is the international leader in the science and practice of integrating 'working trees' on small farms and in rural landscapes. We have invigorated the ancient practice of growing trees on farms, using innovative science for development to transform lives and landscapes.

## Our vision

Our Vision is an 'Agroforestry Transformation' in the developing world resulting in a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, income, health, shelter and energy and a regenerated environment.

## Our mission

Our mission is to advance the science and practice of agroforestry to help realize an 'Agroforestry Transformation' throughout the developing world.

