Saving Africa's Soils:

Science and Technology for Improved Soil Management in Africa

NEPAD

World Agroforestry Centre
TRANSFORMING LIVES AND LANDSCAPES

CIAT
Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture

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Diverse smallholder farming landscape in Kisii District, Kenya
Credit: KD Shepherd

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Preface

Soil fertility degradation has been described as the single most important constraint to food security in sub-Saharan Africa (SSA).

African leaders recognize that science and technology are vital to transform the continent's agriculture and related socioeconomic systems. This recognition is embedded in the New Partnership for Africa's Development (NEPAD), in its Comprehensive Africa Agriculture Development Programme (CAADP) and in the decisions of the first meeting of the African Ministerial Council on Science and Technology (AMCOST). CAADP and AMCOST emphasize the role that scientific research and related technological innovations play in addressing constraints such as poor soil fertility, drought and land degradation.

The Secretariat of NEPAD, through the NEPAD Office of Science and Technology (NEPAD OST), commissioned the World Agroforestry Centre (ICRAF) to prepare a comprehensive background study to identify specific scientific and technological ways to improve soil fertility and soil management in Africa. The study was commissioned under the auspices of NEPAD's "Africa's Science and Technology Consolidated Plan of Action in Programme Cluster 2: Combating Drought and Desertification".

A critical first discussion among experts from African organizations and several centres of the Consultative Group on International Agricultural Research (CGIAR) led to the Bellagio Statement (TSBF-CIAT 2002), which described an integrated natural resource management approach to the diagnosis of soil problems and their management. Components of the Bellagio agenda have since been integrated into, and reaffirmed by, other important strategy documents. These include the proposal for the Sub-Saharan Africa Challenge Programme coordinated by the Forum for Agricultural Research in Africa (FARA), the Interacademy Council Report for Africa (2004), The Hunger Task Force Report of the UN Millennium Project (2005), the Millennium Ecosystem Assessment (2005), and NEPAD (2002).

The outcomes of the study are summarized in this report, compiled by ICRAF, TSBF/CIAT and regional partners. The report draws on a series of sub-regional reports by soil science experts based on targeted interviews with soil science professionals in East and Central Africa, Southern Africa, the West African humid tropics and the Sahel, together with a continent-wide summary of the emerging issues. The report was further considered by a Round Table of Experts from these regions, convened by ICRAF in Nairobi, 22–23 February 2006. The Round Table charted a 'way forward' for soil science research in Africa, laying out the main elements needed to support sustained agricultural production and environmental protection, and outlining the needs and strategies to build science and technology abilities on the continent for improved soil management.

Summary

Scientific research has contributed greatly to the improvement of agricultural practices in Africa; but despite the availability of high-yield and pest-resistant varieties of major crops, there is still a huge gap between the potential provided by this germplasm and the reality of farming yields (the yield gap), leaving Africa a long way from food sufficiency. The most important reasons for this are the continent's degraded soils and lack of investment in adequate soil management. Furthermore, the impact of soil degradation goes beyond food deficits, as soil is also relevant to other human needs as a regulator of water availability and quality, of greenhouse gases which affect the climate, and of the natural enemies of pests and diseases.

Research partners in Africa have a good record in developing the means to combat these threats. Improved understanding of cause and effect, leading to technological innovation, has provided successful soil management strategies in many locations. But these have been scattered and short-lived for a variety of scientific, economic, institutional and political reasons. This document examines the scientific and technological requirements for redressing these failures and for scaling up the widespread adoption of the use of soil management practices to conquer both the yield gap and environmental damage. It also addresses the necessary scientific and technical capacity required to achieve this, while recognizing that a supportive economic and political framework is essential for the investment in science and technology to succeed.

1. The state of Africa's soils

More than 70% of Africa's poor live in rural areas, a pattern that is expected to continue for many years. Since the rural poor derive most of their livelihood from agriculture, increasing agricultural productivity is essential for significant poverty reduction. Food insecurity, a fundamental measure of poverty, is one of the most pressing problems facing the continent. While per capita food availability in the rest of the world has increased significantly over the past 45 years, the situation in sub-Saharan Africa (SSA) has improved only slightly. For example, the average cereal yield is still below 1 tonne per hectare in SSA, and the continent-wide average yield has increased by a meagre 5.2 kg ha^{-1} y^{-1} over the past 33 years (FAOSTAT 2005). In contrast, crop yields on well-managed farms are several times larger and yields obtained on research stations are commonly ten times higher than farm average yields.

(a)

(b)

Africa's soils are rapidly degrading: (a) nutrient-depleted soils result in crop failures in a sub-humid area of Kenya; and (b) severe soil physical degradation from overuse of fragile soils in a semi-arid area of Mali.

Photo credits: KD Shepherd

About 55% of Africa's land area is unsuitable for agriculture. Only 11% of the continent, spread over many countries, has high-quality soil that can be effectively managed to sustain more than double its current population (Eswaran et al. 1997). Most of the remaining usable land is of medium or low potential, with at least one major constraint for agriculture. This land is at high risk of degradation under low input systems. By 1990 soil degradation was estimated to have affected 500 million hectares, or 17% of Africa's land (UNEP 1997). Susceptible drylands (arid, semi-arid, and sub-humid aridity zones), covering 43% of Africa, are the worst-affected areas, impacting 485 million people (Reich et al. 2001). Approximately 65% of agricultural land, 31% of permanent pastures and 19% of forest and woodland in Africa were estimated to be affected by some form of degradation in 1990 (Oldeman 1994). The current situation is undoubtedly worse. Soil moisture stress inherently constrains land productivity on 86% of soils in Africa (Eswaran et al. 1997), but soil fertility degradation now places an additional serious human-induced limitation on productivity.

Agricultural systems with insufficient nutrient input on land with poor to moderate potential are the root cause of human-induced soil degradation in Africa. Although many farmers have developed soil management strategies to cope with the poor quality of the limited resources they possess, low inputs of nutrient and organic matter contribute to poor crop growth and the mining of soil nutrients. Fertilizer use throughout the continent is by far the lowest in the world – less than 9 kg nitrogen ha^{-1} and 6 kg phosphorus ha^{-1}, compared with typical crop requirements of 60 kg nitrogen ha^{-1} and 30 kg phosphorus ha^{-1}. Mid-1990s estimates show that every country in Africa had a negative nutrient balance in its soils, in that the amount of nitrogen, phosphorus and potassium added as inputs was significantly less than the amount removed as harvest, or lost by erosion and leaching. This is in sharp contrast to the nutrient overload of soils in the northern hemisphere, but poses as great an environmental threat.

Soil fertility decline is associated with several simultaneous degradation processes feeding on each other to produce a downward spiral in productivity and environmental quality. For example, the combined effects of tillage and insufficient applications of nutrient and organic matter inevitably lead to a decline in soil organic matter. This reduces the retention of essential plant nutrients, breaking down soil physical structure and in turn diminishing water infiltration and the water storage capacity of the soil. Beyond this, African farmers face other degradation processes such as erosion, salinization and acidification.

2. Why soil is important

Soil fertility decline is not just a problem of nutrient deficiency. It is also a problem of physical and biological degradation of soils, of inappropriate crop varieties and cropping systems, and of pests and diseases. It relates to links between poverty and land degradation, often-perverse national and global incentive policies, and institutional failures.

The degradation of soil fertility is linked to other human and environmental problems. Malnutrition is a good example. It is a major factor in over 54% of deaths of children under 5 worldwide (Pelletier et al. 1995) and in SSA the percentage is higher than the global average.

(a)

(b)

Soil provides essential ecosystem services. (a) forest litter layer maintains good soil structure and water infiltration, and (b) measuring impaired water infiltration on a forest soil following many years of continuous cropping with low nutrient inputs.

Photo credits: KD Shepherd

Most of these deaths are not due to famine but to malnutrition, which, being linked to infectious diseases, is widely recognized as an underlying cause of mortality (Caulfield et al. 2004; Villamor et al. 2005). Projections suggest that malnutrition will worsen in SSA over the next decade, with the incidence of underweight children increasing by 9% (Caulfield et al. 2004). Thus, the failure of African agriculture to make use of newly available germplasm, which supports higher productivity and greater nutritional quality, is tragic. Soil degradation lies at the heart of this failure, as there is little incentive for farmers to invest in new germplasm once soils are degraded.

Box 1. Examples of soil-based ecosystem services

Ecosystem services are benefits people obtain from ecosystems. They include provisioning services such as the supply of food and water; regulating services that affect climate, disease and water quality; supporting services such as soil formation, photosynthesis and nutrient cycling; and cultural services. Soils play a key role in sustaining many ecosystem services.

Provisioning services

- maintenance and provision of genetic resources
- maintenance and regeneration of habitat
- maintenance of soil fertility
- maintenance of soil health

Supporting services

- biomass production
- carbon sequestration
- nutrient cycling
- water cycling
- soil formation
- habitat provision

Regulating services

- climate regulation
- pest and disease regulation
- water filtration
- erosion regulation
- regulation of river flows and groundwater levels
- waste absorption and breakdown

Cultural services

- aesthetic services
- recreational services
- fulfilment of cultural and spiritual needs

Source: Millennium Ecosystem Assessment 2005.

Apart from low food production, inadequate soil management has serious consequences for other natural resources essential to African livelihoods and development. Water for example. Increased sediment loads degrade the quality of surface water, which may harm fisheries as well as water supplies for people and animals, in turn leading to health problems. The Millennium Ecosystem Assessment has demonstrated how land degradation results in the dysfunction of terrestrial ecosystems and loss of biodiversity. The Global Land Assessment of Degradation, although based on expert opinion rather than field data, indicates that human-induced degradation of soils in Africa was already extensive by 1990, involving several processes. The areas affected were estimated at 46% by water erosion, 38% by wind erosion, 12% by chemical degradation, and 4% by physical degradation (Oldeman 1994). These effects are critical because people depend on soil to provide a wide range of essential 'ecosystem services' (see Box 1). These include support to food production and the water cycle, biological regulation of pests and diseases, regulation of major greenhouse gases such as carbon dioxide and methane, and serving as a rich source of medicines and other biochemicals present in soil organisms.

3. Success and failure in sustainable soil management

During the last 50 years, knowledge of Africa's soil resource base and of major soil constraints to agricultural production has grown. Nevertheless, this knowledge is still very limited, as noted in 1995 by distinguished soil scientist Paul Vlek. He commented that "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." The situation today in Africa is that achievements are scattered and impact is limited to small areas under careful supervision. Nevertheless, advances in methods, technology and concepts, as well as lessons learned, provide a platform for future success:

- **Diagnosis and targeting:** the availability of new remote sensing and geographic information tools has led to breakthroughs in objective assessment of spatial variation in soil quality and soil degradation across a range of scales, from plot to country. These techniques are instrumental in problem diagnosis and targeting interventions. However, they are still infrequently used.
- **Integrated nutrient management:** based on replicated experiments across Africa, a consensus has emerged that the highest and most sustainable productivity gains per unit nutrient added are from mixtures of inorganic inputs (fertilizers) and organic inputs. This moves away from the 'fertilizer package' approach, which has frequently failed in Africa. But it raises new challenges, namely to ensure fertilizer is available and to build farmers' capacity to produce organic matter.
- **Cropping system design:** significant adoption of various improved technologies that embrace ISFM has been documented across SSA (Barrett and Place 2002). These include soil and water conservation structures, cover crop and agroforestry-based organic nutrient management systems, and conservation tillage. Evidence shows that these significantly increase productivity and are attractive soil management options in addition to the application of fertilizer.
- **Emergence of integrated approaches:** the most meaningful lesson learned over the last two decades is that the causes of soil and land degradation (see section 2) are multifaceted, calling for a multidisciplinary response. It is now generally accepted that soil management recommendations need to be more than just technically sound. They should also be socially, environmentally and economically acceptable, making stakeholders participants in, rather than just beneficiaries of,

Large crop yields and healthy soils can be sustained using integrated soil fertility manage ment practices: a leguminous intercrop maintains soil cover in well-fertilized maize.

Photo credit: World Agroforestry Centre

research and development. The multiple services that soil gives to humanity have focused attention on the ecosystem, rather than the plot, as the unit of management. Carbon, nutrient and water cycles, rather than the mere status of these resources in the soil, have become the management target. Thus, to promote a more holistic approach to soil fertility management, substantial steps have been taken to integrate soil science with other disciplines including agronomy, ecology, economics and participatory social sciences. The principles of integrated soil fertility management (ISFM) emerging from this synthesis are influencing stakeholders in SSA to change the ways they address soil management at various levels. In particular, these tools are helping to improve understanding of how farmers adopt new technologies.

- **Working across scales:** with the realization that many factors are at work in land degradation comes appreciation of the importance of embracing different scales of interaction – across the landscape and within the soil. Substantial progress has been made in developing and integrating new tools to do this, such as participatory analysis, geographic information systems (GIS) and remote sensing, agro-ecological and farming systems analysis, monitoring and evaluation of ecosystem services, rapid spectroscopy techniques for soil analysis, and molecular tools to study soil biodiversity.
- **Networking:** great value has been added to African expertise through well-established research and development networks in the area of natural resource management, within and across borders and between national and international institutions. Two examples, regional and continental respectively, are the Soil and Water Research Management Network (SWMnet) of the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) and TSBF-CIAT's African Network for Soil Biology and Fertility (AfNet).

4. A science and technology platform to save Africa's soils

Given the insights and successes just listed, why are soils still such an obstacle to food sufficiency and environmental quality in Africa? Apart from economic and institutional issues surrounding soil management (which explain much of the failure), the major science and technology challenge is, as Vlek noted, that our knowledge is inadequate to tackle the immensity of the problems presented.

Drawing on the conclusions of various fora, the Round Table of Experts, which met in Nairobi in February 2006, identified four areas of research necessary to solve the development bottleneck on the degraded status of Africa' soils. These are:

- problem diagnosis and impact assessment;
- integrated soil management;
- management of soil ecosystem services;
- processes and policies for adoption of integrated soil management.

Taken together these constitute an essential science and technology platform for the development of practices aimed at restoring and sustaining the productivity and ecosystem service functions of Africa's soils.

4.1. Problem diagnosis and impact assessment

The status of Africa's soils makes depressing reading. There is little doubt that the problem is severe and widespread, but the data on which the diagnosis is based are dangerously deficient. The combination of laborious methods and a shortage of scientific and technical expertise means that diagnostic analysis has been limited geographically and has rarely been repeated.

A particular challenge is the high level of variation in the properties of African soils. This variation is often highest at the smallest scale, a farmer's field. Thus, a more systematic collection of data across a range of scales, from plot to continent, is essential to understand the constraints. Continuation of the intermittent, empirical diagnostic approach is too slow to secure sustainable soil management for the continent; fortunately, methods now exist for rapid and repetitive analysis on a continental scale.

A rigorous scientific framework for diagnosis of soil-related problems and assessment of intervention impacts is needed to accelerate reliable learning and precipitate policy action. The Round Table proposed an approach that aims to provide reliable data on the condition of the soil resource base and degradation trends; spatially explicit early warning of emerging soil-related problems and a scenario analysis; and reliable ex post information on impacts of large-area soil management interventions (Shepherd and Walsh 2007). This diagnostic approach (Box 2) will provide a vastly improved African soil database, form the basis for targeting intervention actions, and serve on a wider scale as the basis for policy action and dissemination. It calls for application of the latest scientific and technological

Box 2. Addressing soil-based constraints: a diagnostic surveillance approach

What does it do?

- Provides diagnostic information on agricultural and environmental problems to guide resource allocation and management decisions.
- Identifies cause-and-effect relationships needed for primary prevention, early detection and rehabilitation of affected areas or populations at different scales.
- Provides a scientifically rigorous platform for testing and monitoring management interventions in participation with stakeholders.

Where does it come from?

- Modelled from surveillance procedures developed in the public health sector.

How does it work?

- The components are made up of problem definitions, case definitions, and screening tests, which are applied in ground surveys.
- These ground surveys provide:
    - information on soil and vegetation conditions, land use management and socioeconomic conditions;
    - data on the prevalence of soil constraints and their associated management and risk factors;
    - scientifically sound baselines for monitoring changes and impacts.

What are its important features?

- Soil constraints at different scales (farm, watershed and region) can be estimated with known levels of confidence and causes of soil degradation identified.
- Research and demonstration trials are sited in landscapes and regions that systematically sample the full range of ecological and socioeconomic variability.
- Random sampling provides unbiased estimates on soil constraints and degradation.
- Control areas where interventions are not applied are identified enabling intervention impacts to be assessed.

advances, including remote sensing and GIS; infrared spectroscopy for rapid soil analysis; new multivariate statistical tools for handling hierarchical data; simulation and spatial modelling; and environmental accounting and economic valuation.

Science and technology can help save Africa's soils: analyzing soil samples using infrared spectroscopy, a rapid, reliable and low-cost method that uses only light.

Photo credit: W Opzeeland

Standardization of methods is central to this diagnostic approach; indeed it is a key requirement for producing useful research results efficiently. At the local level, links between indigenous knowledge and indicators and science-based assessments are critical. For example, farmers may observe poor crop growth on certain soils, but without scientific testing may not know that the cause is strong soil acidity and the solution is to lime the soil or grow tolerant crops. Involvement of policy makers is also essential for the production of policy-relevant information and for addressing key policy issues.

4.2. Integrated soil fertility management

Soil science faces major fertility challenges. It needs to produce soil management technologies that enable farmers to harness the yield potential of available crop germplasm, at the same time allowing them to arrest and correct the rampant degradation of African soils. Rehabilitation must focus on both productivity and securing other ecosystem services provided by soils. The good news is that, as described above, the principles for such management are well laid. For example, ISFM and reduced tillage serve this dual purpose. In particular they target the building of soil organic matter, the key to long-term production and improved ecosystem services from soils. The inevitable conclusion is that successful soil management requires a multidisciplinary, multiscale and system-level approach based on the principles of ISFM, which are now broadly accepted by the research community.

Integrated approaches to soil management recognize that the nutrient and water cycles in soil are inextricably linked and determine a soil's ability to sustain plant growth and provide essential environmental functions. ISFM integrates organic and inorganic nutrient sources, soil water management, and soil conservation. However, optimal ISFM practices tend to be highly site-specific due to high spatial variability, at both a local scale and across regions, in both biophysical and socioeconomic conditions. Science has a key role to play in dealing with this complexity: to discover and promote principles of IFSM – that is, principles that can be used everywhere to inform and guide local decision-making and experimentation at different scales. However, to refine these principles, an advanced

Box 3. Key questions for a science and technology agenda for ISFM

- How can organic and inorganic resources use be optimized (biophysically and economically) at farm level and through nutrient recycling at larger scales (e.g. rehabilitation of pasturelands or use of urban wastes)?
- What are the critical levels of soil organic matter required to maintain soil productivity and nutrient- and water-use efficiencies, thereby providing high returns to inorganic fertilizers?
- What are the most cost-effective techniques for increasing soil organic matter in plots that fall below these critical levels?
- What economic and resource-use efficiency gains can be made from biological nitrogen fixation, in terms of increased nitrogen-use efficiency and improved nitrogen cycling, through integration of legumes in cropping systems?
- What are the rules for combining organic and inorganic resources to manage multiple deficiencies of nutrients (e.g. potassium, micronutrients)?
- What are the interactions between tillage (reduced versus conventional) and nutrient and water cycles or pest (including weed) control?
- What gains, whether economic benefits or improvements in soil ecosystem services, can be made by enhancing the status of key groups of soil biota, indirectly through cropping system design, and/or directly through inoculation?
- How can soil and plant testing technologies appropriate for African smallholder farmers be modified to better target inorganic and organic nutrients in ISFM strategies?
- What are the impacts of more efficient fertilizer markets and increased commercialization of crop outputs on farmers' use of resources, and their effects on nutrient cycles and other resource-use efficiencies?

level of research design and coordination is required, ensuring the widest possible range of sampled conditions using consistent methodologies and with properly synthesized results.

Despite the advances to date, there are still many gaps in the principles for managing complex interactions among soil constraints, a major reason being that there are often difficult trade-offs to make between short-term productivity and long-term soil health. How to apply these principles locally through adaptive and farmer-centred research, and then transfer the resulting innovations to other communities, also requires scientific attention.

However, two less accessible factors, both driven by economic and political issues, will determine the success or failure of the science and technology programme. The first is the availability of affordable fertilizer in appropriate formulations. The second is the relationship between agriculture and the market, especially the balance between product homogenization and diversification. A major issue in ISFM is how to increase farmers' use of inorganic fertilizers and organic nutrients. Even with efforts to increase farmers' access to fertilizers in Africa, prices are likely to remain high relative to food crop value, particularly in areas far from markets. At the same time, there are competing demands for the limited supply of organic nutrients in forms such as animal manure and green matter. Because the availability to farmers of both sources of nutrients is limited, finding ways to manage trade-offs and increase nutrient-use efficiency is critical.

4.3. Soil ecosystem services

Soils provide an array of ecosystem services essential for the environment and human well-being (Box 1). Thus, improved understanding of the link between soil condition, soil management and the maintenance of ecosystem services is crucial to African development. These services depend on the efficient functioning of a wide variety of biochemical and physicochemical processes in the soil. Among the most important are those that contribute to the cycling of carbon, nutrients and water.

Understanding the factors determining the carbon cycle is of particular importance, specifically with regard to the dynamics of soil organic matter, which influences all ecosystem services. The balance between decomposition (releasing of energy and greenhouse gases) and soil organic matter synthesis (storing of energy and carbon sequestration) is central to these issues. Examples of key research questions related to soil-based ecosystem services are given in Box 4. An important feature of such a research agenda is that it emphasizes interactions with policy and decision making. A hypothesis can be advanced that 'optimization of all ecosystem services in agricultural landscapes is impossible', leading to the conclusion that the decision about protecting or enhancing ecosystem services must be based on concepts of trade-offs among the different services. An important output of research on such questions is general

Box 4. Key questions for research on soil-based ecosystem services

- What soil ecosystem services are impaired and where, and through which practices?
- What are critical soil condition limits, particularly with regard to soil organic matter content, for maintaining specific ecosystem services?
- What is the importance of below-ground biodiversity in maintaining soil ecosystem services?
- Which ecosystem services are critical for prevention of desertification and adaptation to drought and climate change?
- What are the trade-offs involved in using organic resources for agricultural production versus other ecosystem services?
- Can improved agricultural management practices restore ecosystem services?
- How do we reclaim lands where ecosystem services are degraded?
- What are the future needs of ecosystem services and who are the stakeholders of these services?
- What opportunities or incentives exist, or can be created, to compensate farming communities for providing ecosystem services even at the expense of production?
- How can impacts of ISFM interventions on soil-based ecosystem services be monitored to provide feedback for reliable learning?

principles for quantifying and managing the trade-offs among different ecosystem services (for example, provisioning versus regulating services).

4.4. Processes and policies for adoption of integrated soil fertility management

It is increasingly recognized that issues of how to scale up improved soil management practices, and reform institutions and policies to improve the environment for wider adoption of ISFM, require research. Significant adoption by farmers of improved technologies has been documented across Africa. The technologies include soil and water conservation structures, organic and inorganic nutrient management systems, and conservation farming methods. The need now is to find processes and policies for accelerating rates of adoption of improved practices over large areas of the continent. Key components of this research agenda are given in Box 5.

Box 5. Key components of research on the adoption of soil management technology

Adoption

- Systematic studies to better understand constraints to adoption in relation to future development scenarios (for example, soil type, access to market, and degree of commercialization);
- Systematic testing of technology performance and adoption across a wide range of biophysical and socioeconomic conditions;
- Well-designed studies to compare alternative dissemination methods (such as for marginalized groups) and ways of integrating them into extension services;
- The effect of scale of adoption on the costs and benefits of integrated soil management practices.

Partnerships

- Strengthening systems to deal with the demands of scaling up knowledge-intensive ISFM practices;
- Ways of fostering private–public partnerships in the fertilizer industry.

Identifying best practices

- Recommendations or targeting domains that work for integrated soil management, for example, precision agriculture versus large-area domains; approaches and principles versus practices;
- Incentive systems for rehabilitation of degraded lands including development of secure tenure.

Policy and institutional arrangements

- Incentives for efficient organization of soil science and research in national agricultural research systems and universities;
- Efficient mechanisms to link scientific advances with policy processes at local, country, regional and global levels;
- Mechanisms for integrating soil ecosystem services into development policy.

5. Building capacity for soil science and technology in Africa

The research agenda for saving Africa's soils outlined above implies a reorientation of conventional approaches to soil science, new skills and the re-tooling of soil laboratories. Integrated soil management needs interdisciplinary thinking, encompassing a range of spatial scales and interactions with many different stakeholders. Soil scientists today need to be able to design research projects that cover multiple scales (from farm plots to whole regions), consider an array of ecosystem services, and benefit from the participation of farmers and policy makers.

The new approaches to research do not mean that individual soil scientists have to be expert in each field. Rather, they need sufficient knowledge to design integrated studies and to interact with experts. In general, the 'new' soil science will increasingly demand strong skills in scientific method and quantification.

Soil science laboratories in Africa need to be updated – that is, they require new equipment and methods not previously used. For example, all laboratories should have access to facilities for remote sensing and other GIS technologies, and new infrared spectroscopic techniques that allow rapid, reliable, low-cost soil analysis. These laboratories should be inexpensive to equip and run, using mostly non-chemical approaches. They will need to be backed up by regional laboratories with more specialized equipment for advanced soil and plant analysis techniques and resources for advanced GIS and database management. Internet communication among laboratories will become increasingly important for integrated data systems.

Despite these needs, the Round Table experts, on the basis of analyses from each of the African regions, concluded that:

- across all countries surveyed, there is a general trend of declining capacity in conventional, let alone 'new', soil science;
- many national soil laboratories have closed and, of those still open, many are deteriorating;
- admissions to soil science and agricultural university courses have fallen dramatically, even at undergraduate level;
- many university soil science curricula are seriously out of date.

It is clear that an aggressive strategy is needed to reverse these trends and equip Africa's research and education systems with the human and physical resources required to support agricultural development and sustain the soil resource base.

Several of the ideas tabled by the Round Table of Experts are outlined briefly in Box 6. The establishment of regional centres of excellence with suitable expertise could be the key to upgrading both the physical and human capacity of African soil science. These could be clusters of international and national research institutes and universities that promote integrated approaches. They would have state-of-the-art facilities including laboratories, equipment, databases, virtual libraries, training materials and distance learning.

Box 6. Essential elements for building soil science capacity in Africa

Human resources

- Identify core curricula for MSc and MPhil courses, and coordinate places of learning. These curricula should include topics such as knowledge management systems, encompassing a common monitoring and evaluation framework to synthesize results.
- Design PhD fellowship programmes, sandwich programmes and research grant schemes.
- Build in multidisciplinary skills from BSc level upwards.
- Promote post-doctoral fellowships and visiting scientist positions at the regional centres of excellence.
- Identify and support key universities for training in soil and land issues in each sub-region.
- Attach post-doctoral and other young scientists to centres of excellence.
- Provide scholarships with an emphasis on encouraging women soil scientists.
- Provide short courses and attachments to address specific needs, through local opportunities or training at advanced research institutions.

Interaction and communication

- Create platforms that allow scientists to develop research proposals, compare research results, identify general lessons and improve joint implementation of programmes and projects across borders, by using and strengthening existing interactive and mutual-learning networks.
- Include in project proposals collaborative PhDs with students from the North.
- Promote south–south and south–north collaboration of scientists through both short- and long-term exchanges.
- Promote regular interactions with policy makers.

Physical resources

- Establish fully equipped regional laboratories with full soil and plant analytical capabilities.
- Upgrade sub-national laboratories for the new agenda (e.g. GIS, remote sensing, infrared spectroscopy).

Research and capacity building must involve all stakeholders: participatory planning of soil management interventions with farmers.
Photo credit: KD Shepherd

Linking education and technical training with the research programmes of the centres of excellence will take advantage of the latter's physical facilities and expertise. This problem-based approach to learning could build on existing clusters of national and international research institutes as well as on continent- and region-wide networks such as FARA, TSBF-AfNet, ASARECA's SWMnet and the African Capacity Building Foundation.

Finally, there is a need to build knowledge and skills in the area of linkages between soil science on the one hand, and policy formulation and development strategies on the other. Capacity building efforts need to be targeted at both soil scientists and non-scientists in the wider development community. For example, soil scientists need training on how to communicate findings to different audiences, and to develop joint learning processes with policy makers, development partners and the private sector.

The future livelihoods of the world's poorest people will depend on the development and widespread adoption of practices aimed at restoring and sustaining the productivity and ecosystem service functions of Africa's soils. However, resource-poor land users cannot bring about this transformation by themselves. Support from the international community and governments of affected nations should be directed at building a science and technology platform that accelerates progress and learning towards achieving sustainable soil management in Africa.

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List of acronyms

AfNet	African Network for Soil Biology and Fertility
AMCOST	African Ministerial Council on Science and Technology
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CAADP	Comprehensive Africa Agriculture Development Programme
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture)
FAO	Food and Agriculture Organization of the United Nations
FARA	Forum for Agricultural Research in Africa
GIS	geographic information system(s)
ICRAF	International Centre for Research in Agroforestry (World Agroforestry Centre)
ISFM	integrated soil fertility management
NEPAD	New Partnership for Africa's Development
SSA	sub-Saharan Africa
SWMnet	Soil and Water Management Research Network
TSBF	Tropical Soil Biology and Fertility Institute (CIAT, Kenya)
UNEP	United Nations Environment Programme

The **New Partnership for Africa's Development (NEPAD)** is a vision and strategic framework for Africa's renewal. The 37th Summit of the Organisation of African Unity (OAU) in July 2001 formally adopted the strategic framework document. NEPAD is designed to address the current challenges facing the African continent. Issues such as the escalating poverty levels, underdevelopment and the continued marginalisation of Africa needed a new radical intervention, spearheaded by African leaders, to develop a new vision that would guarantee Africa's Renewal.

The objectives of NEPAD are to:

- eradicate poverty;
- place African countries, both individually and collectively, on a path of sustainable growth and development;
- halt the marginalization of Africa in the globalization process and enhance its full and beneficial integration into the global economy;
- accelerate the empowerment of women.

For more information please see www.nepad.org

The **World Agroforestry Centre (ICRAF)** is part of The Alliance of 15 Centres supported by the Consultative Group on International Agricultural Research (CGIAR). We are an autonomous, not-for-profit research for development institution supported by over 50 different governments, private foundations, regional development banks, and the World Bank. The Centre was founded in 1978, initially as the International Council for Research in Agroforestry (ICRAF), to promote the exchange of information on agroforestry research in the tropics. The Council was created in response to a visionary study led by Canada's International Development Research Centre (IDRC), which coined the term 'agroforestry'.

In 1992, ICRAF joined the CGIAR and, in the years since then, has transformed itself into a world-class international agricultural research centre. In order to more fully reflect our global reach, as well as our more balanced research for development agenda, we adopted a new brand name in 2002 – 'World Agroforestry Centre'. Our legal name – International Centre for Research in Agroforestry – remains unchanged.

Our vision is an agroforestry transformation in the developing world – a massive increase in the use of working trees on working landscapes by smallholder rural households that helps ensure security in food, nutrition, health, fodder, shelter and energy, income and a regenerated environment.

Our mission is to use science to generate knowledge on the complex role of trees in livelihoods and the environment, and foster use of this knowledge to improve decisions and practices impacting on the poor.

For more information please see www.worldagroforestry.org

The **Centro Internacional de Agricultura Tropical (CIAT)** is a not-for-profit organization that conducts socially and environmentally progressive research aimed at reducing hunger and poverty and preserving natural resources in developing countries. CIAT is one of the 15 centers that make up the Consultative Group on International Agricultural Research.

For more information please see www.ciat.cgiar.org

The **Tropical Soil Biology and Fertility Programme (TSBF)** was founded in 1974 to develop capacity for soil biology as a research discipline in the tropical regions and to conduct research on the role of soil biology in maintaining or improving soil fertility and combatting environmental degradation.

For more information please see: www.ciat.cgiar.org/tsbf_institute