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Integrated Soil Fertility Management in Africa: From Knowledge to Implementation

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CONTENTS

Sustainable management of soil, water, and other natural resources is the most critical challenge confronting agricultural research and development in sub-Saharan Africa (SSA). Soil fertility decline is a multi-faceted problem and, in ecological parlance, a “slow variable,” one that interacts pervasively over time with a wide range of other factors, biological, and socio-economic. Sustainable agroecosystem management is not just a matter of remedying deficiencies in soil nutrients. Impediments include mismatched germplasm and faulty cropping system design, the multiple interactions of crops with pests and diseases, reinforcing feedback effects between poverty and land degradation, institutional failures, and often perverse incentives that stem from national policies and global dynamics. Dealing with soil fertility issues in cost-effective and sustainable ways thus requires a long-term perspective and a holistic approach such as embodied in the concept of integrated soil fertility management (ISFM).

The concepts of ISFM grew out of a series of paradigm shifts generated through experience in the field and from changes in the overall socio-economic and political environments faced by the various stakeholders, in particular, by farmers and researchers. In retrospect, the need for and elements of this integrated strategy should have been obvious much sooner than they were, but this is true for many advances in thinking and practice. We now understand better how the judicious use of mineral fertilizers together with organic sources of nutrients for plants and soil organisms supported by appropriate soil and water conservation and land and crop management measures can counteract the agricultural resource degradation that results from nutrient mining, the exploitation of fragile lands, and associated losses in biodiversity. Appropriate soil fertility management will produce benefits that reach beyond the farm, serving whole societies through the various ecosystem services associated with the soil resource base, e.g., provision of clean water, erosion control, and support for biodiversity.

Part III of this book presents a series of cases and analyses where new as well as often old knowledge is being drawn on to inform and formulate improved practices that can achieve more productive and more sustainable soil systems. In this chapter, after highlighting some of the problems underlying declining soil fertility in SSA, the region where we have been working, we briefly review some shifts in paradigms related to tropical soil fertility management. Several examples are then considered of how science has been translated into practice, with some discussion in conclusion of the challenges that persist and how we envisage addressing them.

18.1 Problems Driving Research and Development for Sustainable Soil Systems in Africa

The fertility status of most soils in SSA is generally poor due to low inherent quality and inappropriate management practices, the latter being the result of various other secondary and tertiary causes. This dynamic is seen from a number of observations that have specified the nature of soil systems' deficiencies and vulnerabilities in the region:

- Sharply negative soil nutrient balances at the regional and national scale for the major plant nutrients, with annual losses of NPK estimated at 8 million tons (Stoorvogel and Smaling, 1990). These negative balances reflect the very low use of mineral inputs across SSA, although they also show the effects of climatic and other conditions discussed in Chapter 2. How nutrient limitations can be mitigated through changes in soil system management is a principal focus of this and following chapters.
- Average crop yields on smallholder farms in many countries are generally around 30% of the yields obtained on research farms (Tian et al., 1995). Closing this yield gap is a major challenge to researchers and farmers.
- Moisture stress affects over two-thirds of all soils. While this often reflects adverse rainfall patterns, much is attributable to the soils' poor water husbandry. Their low levels of organic matter (living and dead) and their unfavorable topsoil structure exacerbate water shortages.

- It is estimated that nearly 500 million ha of land are degraded, approximately 40% of the total arable area, due principally to the forces of water and wind erosion (Oldeman, 1994), which have more adverse effects on soils that have diminished biological integrity.

All these processes have led to declining per capita food production in SSA, which has resulted in over 3 million tons of food aid yearly (Conway and Toenniessen, 2003). Inadequate and inappropriate soil systems management has exacerbated these problems to an alarming extent.

18.2 From an External-Input Paradigm to an Integrated Soil Fertility Management Paradigm

During the past three decades, the ideas that have shaped soil fertility management research and development efforts in SSA have undergone substantial change. During the 1960s and 1970s, an external-input paradigm was framing the research and development agenda. Appropriate use of certain external inputs, whether fertilizers, lime, or irrigation water, was believed to be able to alleviate any constraints to crop production. Organic resources were seen as only playing a minor role (Table 18.1). By working within this paradigm, and benefiting from the development and use of improved cereal germplasm, bolstered by extensive fertilizer demonstrations and subsidization, what became known as the Green Revolution boosted agricultural production in Asia and Latin America in ways not seen before. Seeking similar yield enhancement, subsidies together with government distribution schemes were introduced in many African countries to promote fertilizer use by farmers. However, while some of these met with success, overall they did not come close to overcoming the estimated nutrient depletion rates in SSA or in matching the use rates of farmers in Asia and Latin America. By the early 1980s, these programs became mostly financially unsustainable as costs rose and productivity gains were not achieved (Kherallah et al., 2002).

TABLE 18.1

The Changing Role of Organic Resources in Tropical Soil Fertility Management

Period	Soil Fertility Management Paradigm	Role of Organic Resources
1960s / 1970s	External-input paradigm	Organic matter plays a minor role
1980s	Biological management of soil fertility as part of low-external-input sustainable agriculture	Organic matter is mainly a source of nutrients and especially N
1994	Second paradigm — combined application of organic resources and mineral fertilizer	Organic matter fulfils other important roles besides supplying nutrients
Today	Integrated soil fertility management (ISFM) as a part of integrated natural resource management (INRM)	Organic matter management has social, economic, and political dimensions, with multiple stakeholders' interests

18.2.1 The Search for Less Input-Dependent Agricultural Systems

During the 1980s, exclusive reliance on chemical fertilizers for soil fertility enhancement was challenged by proponents of low-external-input sustainable agriculture (LEISA) who correctly argued that organic inputs were viewed as essential to sustainable agriculture (Okigbo, 1990). Further, it was argued that LEISA was preferable because it was more accessible to low-income rural households, who could afford little fertilizer and few agrochemicals. Organic resources were considered to be the major sources of nutrients (Table 18.1) and substitutes for mineral inputs. Additionally, the logistical problems of acquiring and transporting fertilizer, the uncertainty and unevenness of its supply in rural areas, and frequent issues of quality and efficacy reinforced the concern. However, LEISA approaches had little widespread acceptance, in large part because of technical and socio-economic constraints, e.g., insufficient training, lack of sufficient organic resources to apply in the field, and the labor-intensity of these technologies (Vanlauwe et al., 2001a, 2001b).

In this context, Sanchez (1994) proposed an alternative paradigm for tropical soil fertility research and remediation: “Rely more on biological processes by adapting germplasm to adverse soil conditions, by enhancing soil biological activity and by optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use.” This paradigm, discussed more in Chapter 49, recognized the need for judiciously combining both mineral and organic inputs to sustain crop production and soil system fertility. The need for both organic and mineral inputs was advocated because (i) both resources fulfill different functions related to crop growth, (ii) under most small-scale farming conditions, neither is available and/or affordable in sufficient quantities to be applied alone, and (iii) for reasons still not fully researched, there were often added benefits when applying both inputs in combination, reflecting a degree of synergy. The alternative paradigm also highlighted the need for improved germplasm well-adapted to local conditions and able to give the most output from the available land, labor, water and nutrient inputs

As in the first paradigm, the LEISA approach put more emphasis on the quantity and quality of nutrient supply than on managing the demand for these nutrients. Obviously, optimal synchrony or use-efficiency requires that both supply and demand be coordinated. While organic resources were initially seen as complementary inputs to mineral fertilizers, over time, as seen in Table 18.1, their role has been seen as more than a short-term source of N, evolving to emphasize a wide array of benefits that can be derived from organic inputs to soil systems, both in the short and long term.

18.2.2 The Search for Optimizing Strategies

From the mid-1980s to the mid-1990s, the shift in thinking toward a more combined use of organic and mineral inputs was accompanied by a movement toward more participatory involvement of various stakeholders in the research and development process. One of the important lessons learned was that farmers’ decision-making processes are not driven primarily by variations in soil and climate but by a whole set of factors encompassing the biophysical, socio-economic, and political domains (DFID, 2000).

18.2.2.1 Integrated Soil Fertility Management

The ISFM paradigm shown in Figure 18.1 goes beyond the third paradigm to recognize the important roles that social, cultural, and economic processes play in soil fertility management strategies and also the many interactions that soil fertility has with other ecosystem services. ISFM presents a holistic approach to soil fertility research and practice

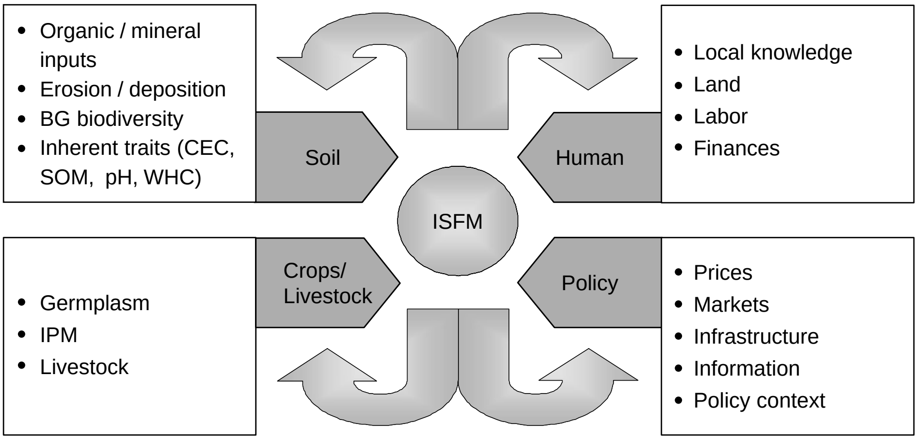

FIGURE 18.1
The processes and components of integrated soil fertility management (ISFM). BG, belowground; CEC, cation exchange capacity; SOM, soil organic matter; WHC, water-holding capacity; IPM, integrated pest management.

that embraces the full range of driving factors and consequences related to soil degradation — biological, physical, chemical, social, economic and political. Organic resource use has many social, economic, and policy dimensions besides biological and technical aspects reflected in belowground relationships.

The emergence of the ISFM paradigm parallels the development and spread on a wider scale of concepts of integrated natural resource management (INRM). It is increasingly recognized that natural capital (soil, water, atmosphere and biota) not only creates services that generate goods having market value, e.g., crops and livestock, but also services that are essential for the maintenance of life, e.g., clean air and water. Organic resource management is viewed as the link between soil fertility and broader environmental benefits, particularly ecosystems services such as carbon sequestration and biodiversity protection (Swift, 1997). Due to the wide array of services accruing from natural capital, different stakeholders may have conflicting interests in natural capital, and thus thinking has to extend into social and even political domains. INRM aims to develop policies and interventions that take both individual well-being and broader social needs into account (Izac, 2000). Soil system management is one component, but a basic component, of larger INRM strategies.

18.2.2.2 Tropical Soil Biology and Fertility Research

The Tropical Soil Biology and Fertility (TSBF) Institute, initially a program of UNESCO, was founded in 1986 to promote and develop capacities for soil biology as a research discipline benefiting the tropical regions. For over a decade, the program worked closely with the International Center for Agroforestry Research in Nairobi. However, since 2001 it has operated as an institute within the International Center for Tropical Agriculture (CIAT) based in Colombia, while remaining based in Kenya.

The biological management of soil fertility is held to be an essential component of sustainable agricultural development. The program's mission is directed toward four goals:

1. Improve understanding of the role of biological and organic resources in tropical soil fertility and their management by farmers to improve the sustainability of land-use systems.

2. Enhance the research and training capacity of national institutions in the tropics in the fields of soil biology and management of tropical ecosystems.
3. Provide land users in the tropics with methods for soil management that improve agricultural productivity while conserving soil resources.
4. Increase the carbon storage equilibrium and maintain the biodiversity of tropical soils in the face of global changes in land-use and climate.

The implementation strategy for achieving these goals has evolved along with the changes in soil fertility management paradigms described above. In the following section, this will be seen from two case studies examining the contributions that scientific investigations have made to better soil system management.

18.3 Translating Science into Practice

Despite the inherent complexity of the problems underlying the widespread decline in soil fertility in SSA, the good news is that progress is being made. At a 2002 meeting organized by the Rockefeller Foundation to take stock of progress with soil fertility research for development, advances were identified in three areas: (i) number and range of stakeholders influenced, (ii) soil management principles identified or clarified, and (iii) methodological innovations (TSBF, 2002a). National and international research and development organizations, networks, NGOs, and extension agencies working in SSA are increasingly using ISFM approaches (e.g., World Vision, 1999). There has been a rapid increase of membership and activities of the African Network for Tropical Soil Biology and Fertility (AfNet) coordinated by TSBF, with growing agreement on how soil systems can be better managed (Bationo, 2004).

International agricultural research has contributed significantly to the development of sound soil management principles that can help achieve sustainable crop production without compromising the ecosystem service functions of soil systems. Examples of such principles are:

- Application of organic resources in optimizing combinations with mineral inputs so as to maximize input-use efficiencies and farmers’ return to their investment.
- Integration of multiple-purpose woody and herbaceous legumes into existing cropping systems to increase the supply of organic resources, crop yields, and farm profits (e.g., Sanginga et al., 2003).
- Enhancement of the soil organic carbon pool as an integrator of various soil-based functions that are related to production and ecosystem services (Swift, 1997).
- Improved sustainability of nutrient cycles through the integration of livestock with arable production activities.
- Soil conservation methods to control soil loss and improve water capture and use-efficiency.

Due to the complex and interactive nature of the major factors that promote poverty and act at different scales, it has been necessary to develop approaches that deal with such a complex environment:

- Pro-poor participatory research approaches that increase the appreciation and use of local knowledge systems in the development of improved soil management interventions and principles have been developed (e.g., Defoer and Budelman, 2000).

- Tools for scaling-up improved soil management practices, including GIS spatial analysis to better characterize problems and target interventions and to obtain a better understanding of information flow pathways, are emerging.
- Rapid assessment techniques using diagnostic indicators of land quality, e.g., spectrometry techniques such as in Shepherd et al. (2005), are now available.
- Molecular tools are being used to study soil biodiversity and pest population dynamics.

The following two sections describe areas where scientific principles have been translated into practice. They also illustrate how the dominant soil fertility management paradigm has shifted.

18.3.1 The Organic Resource Quality Concept and Organic Matter Management

Although use of organic inputs is hardly new to tropical agriculture, the first seminal analysis and synthesis on the decomposition and management of organic matter (OM) was contributed by Swift et al. (1979). Between 1984 and 1986, a set of hypotheses was formulated in terms of two broad themes for soil system management: synchrony, and soil organic matter (SOM) (see Swift, 1984, 1985, and 1986). These two focuses built upon the concepts and principles presented in 1979.

Under the first theme, the organisms-physical environment-quality (OPQ) framework for understanding OM decomposition and nutrient release, formulated by Swift et al. (1979), was elaborated and translated into specific hypotheses. These could explain the efficacy of management options that improved nutrient acquisition and crop growth with an explicit focus on organic resource quality. Under the second theme, the role of OM in the formation of functionally-different SOM fractions was stressed. It should be noted, however, that during this period, organic resources were still mainly regarded as sources of nutrients, and specifically of N (Table 18.1). Their multiple functions within soil systems were not much considered.

During the 1990s, the formulation of research hypotheses related to residue quality and N release led to many research efforts to validate these hypotheses, both within TSBF and other research groups that dealt with tropical soil fertility. Results from these activities were entered in the Organic Resource Database (ORD) (ftp://iserver.ciat.cgiar.org/webciat/ORD/) (Palm et al., 2000). This database contains extensive information on organic-resource quality parameters, including macronutrient, lignin, and polyphenol contents of fresh leaves, litter, stems, and/or roots from almost 300 species utilized in tropical agroecosystems. Data on the soil and climate from where the material was collected are also included, as are decomposition and nutrient-release rates for many of the organic inputs.

Analysis of N-release dynamics revealed four classes of organic resources having different rates and patterns of N release associated with varying organic resource quality assessed in terms of their N, lignin, and polyphenol content (Palm et al., 2000). Based on this analysis and information, a decision support system (DSS) for management of organic N was formulated (Figure 18.2a). This system distinguishes four types of organic resources, suggesting how each can be managed optimally for short-term N release to immediately enhance crop production. Materials with lower N and higher lignin and/or polyphenol contents are expected to release less N and thus they require supplementary N in the form of fertilizer or higher-quality organic resources to maintain nutrient supply at comparable levels.

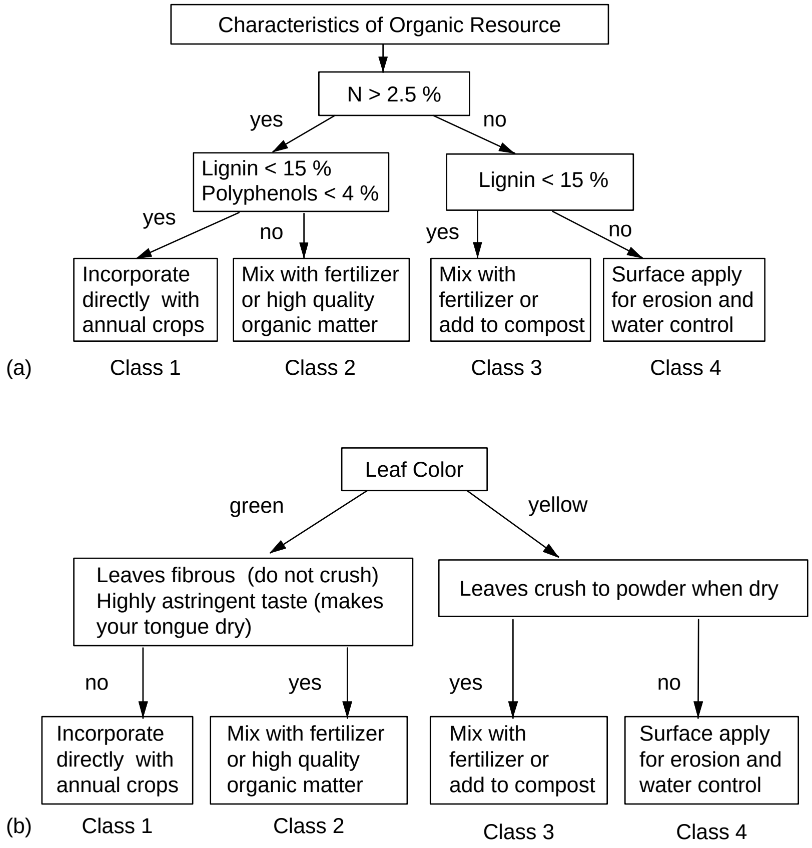

FIGURE 18.2
A decision tree to assist management of organic resources in agriculture. (a) is based on Palm et al. (2000); (b) is a "farmer-friendly" version of the same from Giller (2000).

Being based on laboratory incubations, the DSS needed to be tested under field conditions and was assessed in western, eastern, and southern Africa, using biomass transfer systems with maize as a test crop. The results clearly indicated that (i) the N content of the organic resources is an important factor affecting maize production, (ii) organic resources with a relatively high polyphenol content result in relatively lower maize yields for the same level of N applied, (iii) manure samples do not observe the general relationships followed by the fresh organic resources, and (iv) N fertilizer equivalency values of organic inputs often approach or even exceed 100% of what would be supplied from inorganic sources.

These results gave strong support for the DSS constructed by Palm et al. (2000), except for manure samples. Manure behaves differently from plant materials since it has already gone through a decomposition phase when passing through the digestive system of cattle, rendering the C less available and thus resulting in relatively less N immobilization, as discussed in the preceding chapter. The observation that certain organic resources have fertilizer equivalency exceeding 100% indicates that these organic materials can alleviate other constraints to maize production besides low soil-available N. In the short-term, organic resources not only release nutrients; they can enhance soil moisture conditions or improve the available P in the soil (Nziguheba et al., 2000). In the long term, continuous inputs of OM influence the levels of incorporated SOM and the quality of some or all of its nutrient pools (Vanlauwe et al., 1998; Cadisch and Giller, 2000).

Following field-level testing of the DSS, it has been applied and adapted in a variety of farmer learning activities. These give farmers the knowledge they need to identify and evaluate the potential use of organic resources in their environment. Because there is so much diversity of such resources in any given context, the elements of the DSS provide a generic, easy-to-use tool for farmers to use when confronted with resources that scientists have not themselves evaluated.

Farm-level adaptation of the DSS began with exercises where researchers and farmers in selected communities identified all the organic resources available locally as potential soil inputs. The quality analysis of these materials in one setting (Table 18.2) shows that among

TABLE 18.2

Organic Resources (leaf residues) and Their Chemical Composition, Identified in Farms Around Emuhaya Division, Vihiga District, Western Kenya

Genus and Species Name	Common Name or Local Name	N	P	K	Lignin	PP[a]	Class[b]
		% Dry Matter					
Markhamia lutea		3.20	0.24	1.77	21.21	3.99	1
Psidium guajava		2.32	0.19	1.50	11.20	14.35	3
Persea americana	Avocado	2.07	0.12	0.82	20.25	10.90	4
Not identified	Not known	4.98	0.44	6.66	14.93	3.27	1
Bridelia macrantha		2.37	0.17	1.13	18.53	8.31	4
Vernonia spp		4.88	0.42	4.72	11.31	2.44	1
Croton macrostachyus		4.33	0.38	1.75	10.25	8.42	2
Not identified	*Esikokhakokhe*	3.84	0.39	6.59	9.07	1.32	1
Solanum aculeastrium	Sodim apple	2.87	0.21	1.25	13.70	2.39	1
Erythrina exselsa		4.99	0.33	2.42	6.63	2.26	1
Buddleja davidi		3.30	0.27	1.46	7.94	6.20	2
Senna didymobotra		5.23	0.39	2.13	4.62	4.08	2
Vernonia auriculifera		3.65	0.35	5.25	14.86	4.93	2
Hurungania madagascariensis		3.21	0.18	1.04	13.31	12.70	2
Spathodea campanulata	Nandi flame	3.09	0.21	1.76	17.34	8.58	2
Erythrina abyssinica		2.66	0.20	1.70	11.21	3.36	1
Morus alba	Mulberry	2.86	0.43	2.16	4.28	4.62	2
Acanthus pubescens		3.30	0.30	2.11	5.17	7.56	2
Ricinus commus	Castor plant	4.21	0.30	2.34	3.39	5.27	2
Maesa lanceolata		2.78	0.22	2.06	10.37	12.04	2
Mangifera indica	Mango plant	1.52	0.12	1.00	11.15	12.43	3
Teclea nobilis		3.15	0.22	1.57	9.05	4.83	2
Not identified	*Libinzu*	3.91	0.29	3.28	12.27	5.67	2
Sapium elliptian		3.11	0.18	0.77	6.34	11.73	2
Vangneria apiculata		3.67	0.23	1.76	4.91	4.27	2
Ficus spp		2.55	0.20	2.62	9.55	5.76	2
Ipomoea potatus	Sweet potato	5.07	0.34	2.56	4.34	8.81	2
Not identified	*Omuterema*	3.85	0.34	5.27	2.85	1.20	1
Plectranthus barbatus		3.87	0.28	4.01	16.11	4.98	2
Maesa lanceolata		3.80	0.28	3.92	10.70	6.65	2
Vernonia spp		4.26	0.37	3.67	9.80	5.09	2

Source: Authors' data.

[a] PP, polyphenols.

[b] Class refers to classes 1 to 4 indicated in Figure 18.2.

the plant resources that farmers would consider incorporating into their soils, the large majority were class 2 resources. Of the 38 organic resources assessed, only eight belonged to class 1 and could be classified as equivalent to N fertilizer. *Tithionia diversifolia* had already been identified as a high-quality organic resource during a previous hedgerow survey in the same area, also belonging in class 1 (Gachengo et al., 1999).

When these results were presented and discussed with farmers in a second step, the decision-tree criteria proposed by Palm et al. (2000) were translated into a more farmer-friendly version, using locally-acceptable criteria that do not require scientific equipment (Figure 18.2b). This locally-adapted decision tree was then used by local farmer field schools to design their own experimental trials that tested the validity of the claims that scientists were making regarding the use and management of organic resources (TSBF, 2002b).

These trials, conducted at a variety of sites and through several seasons, provided many opportunities for farmers to compare the effects of these organic inputs under different conditions. During evaluation activities, farmers ranked the classes of organic resources in terms of effect on maize yield as: Tithonia (Class 1) > manure > Calliandra (class 2) > maize stover (Class 3). They confirmed the hypothesis that the differing quality of organic materials would have a demonstrable impact on crop yields.

Scientists also drew many valuable lessons from this exercise. They found, for example, that farmers considered the biomass transfer technology being tested to be less practical and cost-effective than using compost, a common local practice. Their interest in adding their organic resources to compost heaps before application to the soil has stimulated new joint research activities between farmers and scientists on how to improve compost quality (TSBF, 2002b). (Benefits of composting are discussed in Chapter 31.) A second line of experimentation used the resource-quality concept to assess the use of organic materials, especially comparatively-scarce, high-quality Tithonia residues, on high-value crops such as kale rather than on maize (TSBF, 2002b).

18.3.2 Exploring Positive Interactions between Mineral and Organic Inputs

The paucity of class 1 resources at the farm level, and the consequent advice to mix class 2 or 3 resources with minimal amounts of fertilizer N, has led to a diversification of the research agenda toward the combined application of organic and mineral inputs. As mentioned above, such a strategy is consistent with the ISFM paradigm and can potentially lead to added benefits in terms of extra crop yield and / or extra soil fertility enrichment where there are positive interactions between both inputs, as illustrated in Figure 18.3.

Although the concept of interaction between two plant growth factors was already implied in Liebig's Law of the Minimum, it has recently received new attention in work dealing with the combined application of fertilizer and organic inputs. Besides adding nutrients, organic resources also provide C as a substrate for soil organisms and may interfere with pests and diseases when the plants are grown *in situ*.

Two sets of hypotheses can be formulated, based on whether the interactions between fertilizer and organic matter are direct or indirect. Since fertilizer N is susceptible to substantial losses if not used quickly and efficiently by a crop, direct interactions result from microbially-mediated changes in the availability of the fertilizer N when there is an increase in available C. Further, the addition of fertilizer N may also affect the availability of soil-derived N, although this will be less important whenever the bulk soil is C-limited. Indirect interactions are the result of a general improvement in plant growth and demand for nutrients by alleviation, through the addition of organic matter, of another growth-limiting factor.

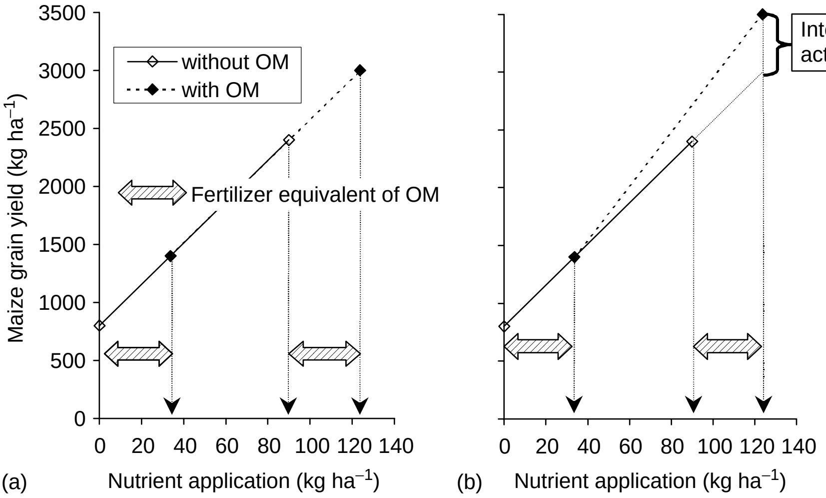

FIGURE 18.3
Theoretical response of maize grain yield to the application of certain level of nutrient as fertilizer in the presence or absence of organic matter (a) without interaction, and (b) with positive interaction between the fertilizer nutrient and organic matter. *Source*: Vanlauwe et al. (2001a, 2001b).

The direct hypothesis regarding N fertilizer can be stated as: temporary immobilization of applied fertilizer N may improve the synchrony between the supply of and demand for N and also reduce losses to the environment. Observations made under controlled conditions justify this hypothesis, showing interactions in decomposition or N mineralization between different organic materials (Vanlauwe et al., 1994) or between organic matter and fertilizer N (Sakala et al., 2000).

The indirect hypothesis may be formulated for a certain plant nutrient X supplied by fertilizer amendments as: any organic matter-related improvement in soil conditions affecting plant growth (except that attributable to nutrient X) may lead to better plant growth and consequently to enhanced efficiency of the applied nutrient X. The growth-limiting factor can be located in the domain of plant nutrition, soil physics or chemistry, or soil (micro)biology.

Most of the mulch effects or benefits of crop rotation could be classified under the indirect hypothesis. Positive interactions based on the indirect hypothesis may be immediate through direct alleviation of growth-limiting conditions after applying organic matter, e.g., improvement of the soil moisture status after surface application of organic matter as a mulch, or delayed through the improvement of the SOM status after continuous application of organic matter and an associated better crop growth, e.g., improvement of the soil's buffering capacity.

Under on-station conditions, positive interactions can often be observed and measured. However, explaining the mechanisms underlying these interactions is often more problematic:

- In a field study in West Africa, Vanlauwe et al. (2002) observed positive interactions, likely caused by higher soil moisture retention in treatments where organic resources were applied (Figure 18.4).
- Bationo et al. (1995) observed a doubling of the fertilizer N-use efficiency after application of crop residues in Sahelian conditions, attributable to much less wind erosion on treatments when crop residues were applied.

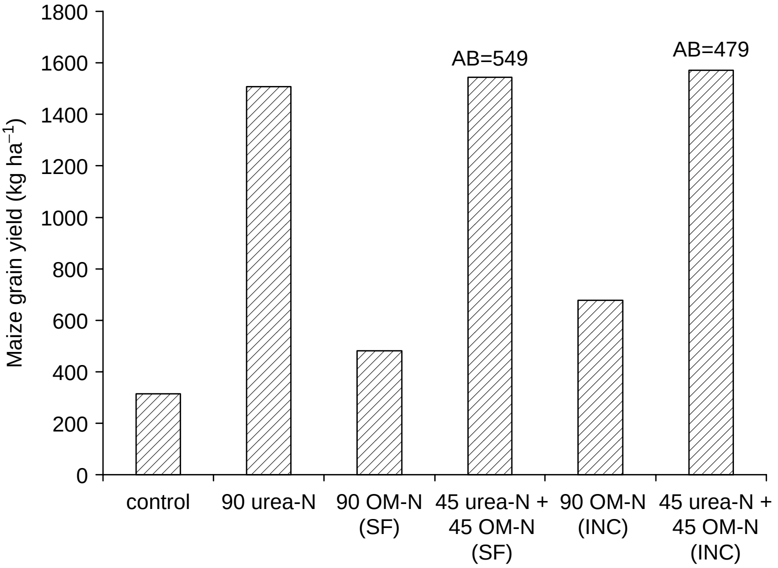

FIGURE 18.4
Maize grain yields in Sekou, southern Benin Republic, as affected by the application of urea, organic materials, or the combination of both. SF, surface-applied; INC, incorporated; OM, organic matter; AB, added benefits. Numerical values for treatments are expressed as kg N ha^{-1}. Adapted from Vanlauwe et al. (2001a, 2001b).

- In Zimbabwe, added benefits ranging between 663 and 1188 kg maize grains ha^{-1} were observed by Nhamo (2001), possibly because the supply of cations contained in the manure alleviated constraints to crop growth caused by the low cation content of the very sandy sites where clay content ranged between 2 and 10% and CEC varied between 1.2 and 2.5 cmol kg^{-1}.

Translating these principles into cropping systems that are adaptable by farming communities has resulted in a series of development innovations, e.g., rotations of maize with promiscuously-nodulating soybean that combine high N-fixation and the ability to kill large numbers of *Striga hermonthica* seeds in the soil; and rotations of millet and dual-purpose cowpea that greatly enhance the productivity and sustainability of integrated livestock systems (Sanginga et al., 2003).

These two systems are effectively used for the replenishment of soil nutrients and organic matter. They contribute positive residual soil N for the following crops while at the same time providing farmers with seeds for food and fodder for feed, as well as income from marketing these farm products. Another option offered to any farmers who have manure available is the opportunity to derive benefits from the combined application of manure and fertilizer to maize. This practice allows farmers to complement the modest fertilizer quantities that they can afford with high-quality organic nutrients, thereby benefiting from the synergism that occurs when combining the two sources of nutrients. Currently, Sasakawa Global 2000 is testing the above options in Northern Nigeria with promising results.

18.4 Challenges and the Way Forward

Although soil fertility replenishment has had a prominent position on the research and development agenda in SSA for decades with tangible progress as seen above, widespread adoption of ISFM strategies is lacking. A full discussion of the reasons for this is beyond the scope of this chapter, but certain issues that have hampered large-scale adoption of ISFM options can be singled out.

18.4.1 Adjusting to Variability at the Farm and Community Level

Farmers' production objectives are conditioned by a complex set of biophysical as well as social, cultural, and economic factors. One must also take account of the fertility gradients existing within farm boundaries. Most soil fertility research has been targeted at the plot level, but decisions are made at the farm level, considering the production potential of all plots. In Western Kenya, farmers will preferentially grow sweet potato on their most degraded fields, while bananas and cocoyam occupy the most fertile fields (Tittonell et al., 2005). Current recommendations for use of organic resources and mineral inputs do not take into account these gradients in soil fertility status. On the contrary, recommendations are often formulated at the national level and disregard the much greater variations that exist between regions in terms of inherent soil properties and access to input and output markets (Carsky and Iwuafor, 1999).

18.4.2 Use of Adapted Germplasm to Overcome Abiotic and Biotic Constraints and Create More Resilient Cropping Systems

Breeding and biotechnology can help small farmers to sustainably increase their productivity through improved drought-tolerance, soil acidity-tolerance, pest-resistance, and increased efficiency of N-fixation. ISFM acknowledges the importance of the interaction between new crop germplasm and more efficient natural resource management for intensifying food and forage crop systems. Such a combination would utilize the best variety for a given environment when grown in an improved soil using appropriate crop management technologies. Interactions between adapted germplasm and key inputs such as organic residues, mineral fertilizers, and water can lead to improved use-efficiency of nutrients and water at a system level. ISFM bridges a commodity focus and an eco-regional approach, working alongside germplasm development and integrated pest and disease management.

18.4.3 Market-Led Integrated Soil Fertility Management

ISFM practices require some additional inputs of resources, whether minimal amounts of mineral fertilizer, more organic matter, improved germplasm, or greater labor. As most of these inputs require access to financial resources, implementing ISFM strategies will often require farmers to have access to local or national markets so that they can acquire more resources to reinvest in improved soil fertility management. It has been hypothesized that improved profitability and access to markets will motivate farmers to invest in new technology, particularly to integrate use of new varieties with improved soil management options (John Lynam, 2004, personal communication).

Some current evidence does not show conclusive support for this hypothesis, however. For instance, the increased movement of bananas to urban markets in Uganda without replenishment of the soil resource base could lead to a faster degradation of banana-based systems within the production areas. It is also important to consider nutritional consequences. Farmers who sell most of their produce could use the money received for other uses rather than ensuring sufficient and nutritious food for the household. This could lead to poorer health status with unfavorable consequences for household labor availability and quality.

18.4.4 Scaling Up

The knowledge-intensive nature of ISFM means that the kind of simplistic extension methods such as “training and visit” promoted by the World Bank in the 1980s and 1990s are not suitable for disseminating soil management technologies. This lack of suitability accounted in part for the collapse of training-and-visit extension in the mid-to-late 1990s (e.g., Gautam, 2000, on Kenya experience). Since then, the move in many countries toward the decentralization of government services, the improved capacity of NGOs in service delivery, and the beginnings of farmer groups and collective action have created the preconditions for greater innovation and for the redesign of extension and dissemination systems.

Recognizing the wide diversity in agroecological and socio-economic conditions under which most farmers work has led to a general realization that research and extension agencies do not have the capacity to fine-tune their technological recommendations to the level required by farmers. As extension services have become increasingly marginalized and nonfunctional, the gaps in knowledge-dissemination and technological improvement have been largely filled by a variety of NGOs and, in some cases, community-based organizations. Scaling up information dissemination requires the reinforcement of communication networks and strengthening of information centers (agricultural input suppliers, community centers, field schools), as well as supporting farmers in various ways to transfer knowledge farmer-to-farmer across communities.

18.4.5 Policy Changes

Since the 1980s, most countries in SSA have initiated extensive agricultural market reforms (Kherallah et al., 2002). The expectation of agricultural market reform is that increasing crop prices and improving markets will generate a positive supply response, increasing both agricultural output and income levels. However, the average growth of agricultural production per capita has been negative in SSA since the 1970s. In many countries, reform has meant the elimination of government input and credit subsidies. This has kept yields stagnant or reduced them, or has made input supplies irregular or completely absent, undermining the stability of local prices. What production growth has occurred has often been due either to expansion of crop area rather than increases in productivity per unit area, or to the output of cash-crop farmers still operating within systems who have good access to credit and inputs.

For ISFM to operate on a broader scale, there is a need for (i) regional policy harmonization and policy reform frameworks for improved management within subregional areas, (ii) development of appropriate partnerships to facilitate efficient input-output markets and strengthen their links to ISFM, (iii) identification of marketing opportunities through participatory research within a comprehensive, resource-to-consumption framework, and (iv) development of appropriate seed supply systems and resilient germplasm. Since not all farmers have the capacity to buy themselves out of poverty, there is a major need for a series of “stepping stones” that enable poor farmers to have access to inputs, services, and markets so that they can “climb out of poverty” as their agricultural productivity increases.

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