CHAPTER

6

Integrated Soil Fertility Management in Central Africa: Experiences of the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA)

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Abstract

Agricultural intensification is a necessity in the densely populated areas of sub-Saharan Africa and certainly so in the Great Lakes region of Central Africa, the operational domain of the Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA). The integrated soil fertility management (ISFM) paradigm has been accepted by the research and development community, including the Alliance for a Green Revolution in Africa, as a viable set of principles to foster agricultural intensification. In this paper we first describe the production environment of CIALCA's mandate areas and its impact on livelihood characteristics and constraints on enhanced productivity. We then develop the definition of ISFM and evaluate its relation with eco-efficiency principles. ISFM components are illustrated with data from various cropping systems in the mandate areas and specific reference is made to issues of dissemination and the creation of an enabling environment for the uptake of ISFM technologies. We found that ISFM principles are relevant for increasing system productivity within the Great Lakes region but that unfavorable conditions for their uptake are a major impediment to their potential impact. CIALCA and future initiatives should simultaneously invest in the development and evaluation of ISFM practices and the creation of an environment that favors their uptake.

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Introduction

The Consortium for Improving Agriculture-based Livelihoods in Central Africa

The Consortium for Improving Agriculture-based Livelihoods in Central Africa (CIALCA; www.cialca.org) is a research for development consortium led by the Tropical Soil Biology and Fertility Research Area of the International Center for Tropical Agriculture (TSBF-CIAT), the International Institute of Tropical Agriculture (IITA), and Bioversity International. It involves a diverse range of partners across the research-to-development continuum. Its major goal is to improve the livelihoods of rural households in Central Africa through the identification, evaluation, and promotion of technological options to enhance the productivity of banana-, maize-, cassava-, and legume-based systems and creation of an enabling environment for their adoption. CIALCA has been operating since late 2005 in 10 mandate areas in Burundi, the Democratic Republic of the Congo (DR Congo), and Rwanda. This paper focuses on the seven areas located in the highlands of Burundi, Rwanda, and South Kivu Province in eastern DR Congo (Figure 1A). These areas lie at altitudes varying between about 850 meters above sea level (masl) in the Rusizi Plains near Lake Tanganyika to over 2000 masl in some of the higher parts of Gitega (Burundi) and South Kivu (DR Congo). These areas have some of the highest population densities in Africa, with the average ranging between 238 people/km^2 in Kigali-Kibungo (Rwanda) and 514 people/km^2 in Gitarama (Rwanda) (Figure 1B).

Environmental and farming system characteristics of the mandate areas

All mandate areas contain highland perennial systems following the farming systems classification of the Food and Agriculture Organization of the United Nations (FAO) (Dixon et al., 2001). More than half of the farmers in the mandate areas grow banana, maize, cassava, and bush or climbing beans (Ouma and Birachi, 2011). The length of growing period varies

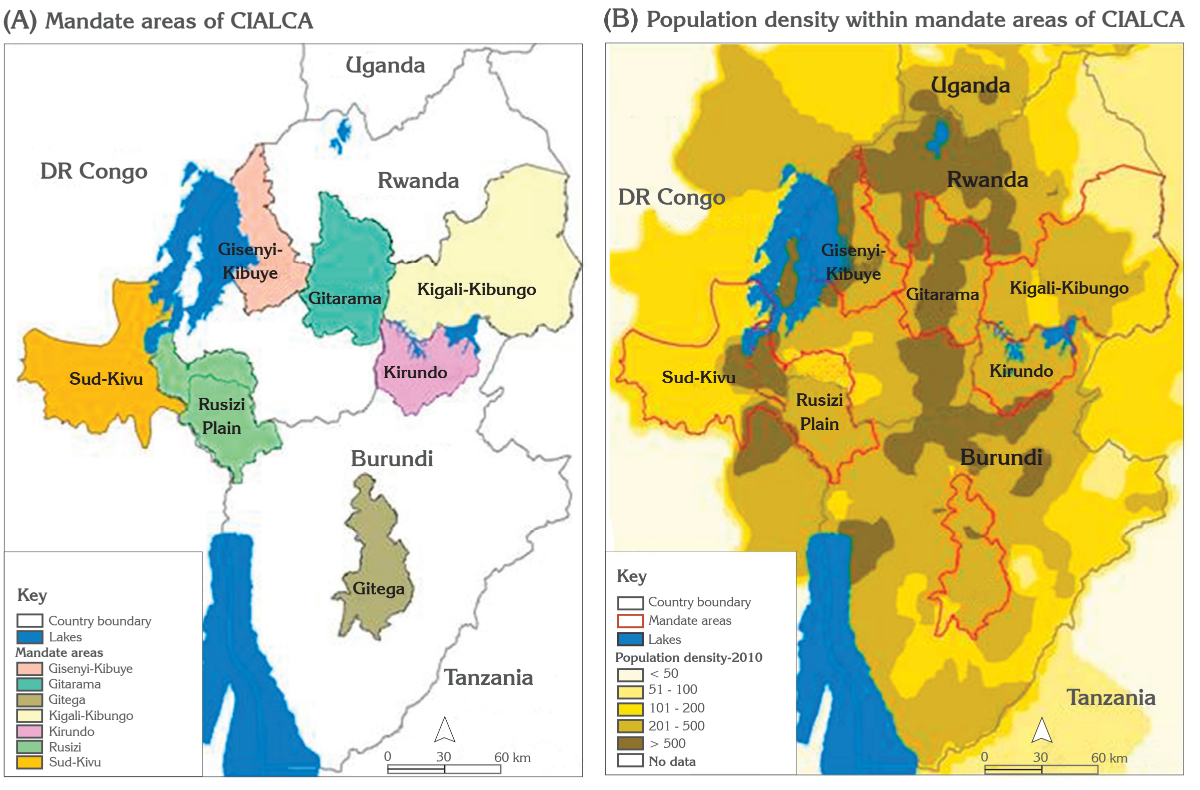


Figure 1. Maps showing **(A)** the seven CIALCA mandate areas in Burundi, eastern Democratic Republic of the Congo, and Rwanda and **(B)** population densities in these areas.

between 240 and 365 days (Figure 2A), with a clear gradient from east to west. Most areas have two growing seasons: February–August and September–January. The reliability of these seasons varies between the mandate areas. Greater climate variability has been observed in recent years, especially in terms of variability in the onset of the rainy season and increasing frequency of mid-season drought events. The main soil types are Ferralsols and Acrisols according to the World Reference Base for Soil Resources classification (IUSS Working Group WRB, 2006) (Figure 2B). These have inherently good physical properties but poor chemical properties and low nutrient stocks due to long-term leaching. Average slopes are steep and vary between 11% (Kigali-Kibungo) and 24% (Rusizi Plain) (Figure 2C). This and the lack of a dense network of primary and rural feeder roads results in an average travel time to major markets varying from 2 hours (Gitega) to nearly 7 hours (Rusizi Plain) (Figure 2D).

As a result of these biophysical features, farms in the mandate areas are relatively small, contain a diverse range of crops, are labor-limited, have varying but low numbers of livestock, and use very few external inputs such as improved varieties, fertilizer, or pesticides (Table 1). Only in Gitega does a considerable proportion of households use fertilizer (Table 1). Utilization of improved crop varieties is limited, with improved banana varieties used by 0–19% of households, improved groundnut and soybean varieties by 0–6% of households, improved cassava varieties by 0–16% of households, and improved maize varieties by 0–24% of households (Ouma and Birachi, 2011). The only exception is improved bean varieties, which are used by 5–91% of households in the mandate areas. Most households (50–85%) sell their agricultural produce at the farm gate or in local markets (Ouma and Birachi, 2011). Only in South Kivu do 20% of the households visit a regional market. Between 60% and 90% of the households sell fresh food products, while 10–25% of households sell processed products (Ouma and Birachi, 2011).

In many densely populated areas of sub-Saharan Africa (SSA), fallow periods are no longer an option and organic resources are scarce. This has commonly resulted in large variability in soil fertility between fields within a single farm. These "soil fertility gradients" are created by the position of specific fields within a soil-scape (Deckers, 2002), by the selective allocation of available nutrient inputs to specific crops and fields, and by improved management (e.g., time of planting, weeding, etc.) of plots with higher fertility (Tittonell et al., 2005b). In the CIALCA mandate areas, large differences in crop productivity over relatively short distances can be observed. For instance, in East Province of Rwanda, bean yields without inputs varied between less than 50 kg/ha and more than 2000 kg/ha (Figure 3A).

Livelihood characteristics of the mandate areas

An important consequence of the production environment and its many constraints, as described above, is substantial food insecurity. Between 38% and 72% of all households often have too little to eat and more than 80% of the households consume a maximum of two meals per day (Table 2). Over 70% of the households consume vegetable protein on a daily basis, over 80% of households consume animal protein only once a week or less often (Ouma and Birachi, 2011). Since agricultural outputs are limited, 29% to 73% of the adult population is involved part-time or full-time in off-farm activities, resulting in substantial off-farm income for most households. Literacy levels are relatively high, with between 52% and 84% of the household heads having completed at least primary education (Table 2).

In terms of gender relationships, women contribute significantly to agricultural activities (Table 2). Both men and women are involved in crop management, though dominance of one gender is evident in certain enterprises in some mandate areas. In most cases, women dominate management of staple crops such as beans and cassava that are largely targeted for home consumption. Gender dominance in banana management is not evident, except in South Kivu where it is male dominated. In some of the mandate areas banana cultivation is largely male dominated while harvest activities are dominated by women.

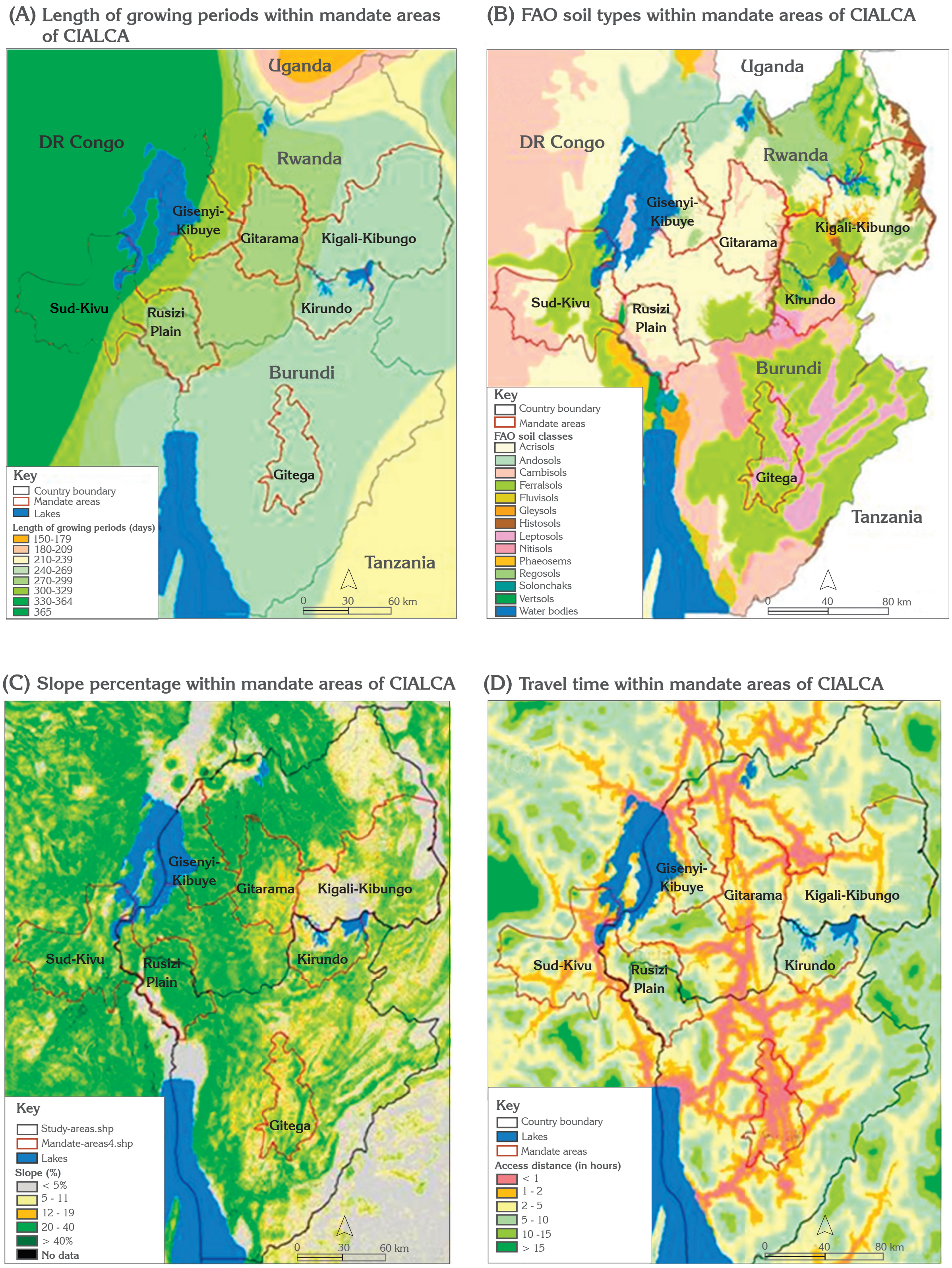


Figure 2. Maps showing **(A)** length of growing period, **(B)** main soil types, **(C)** slopes, and **(D)** distance to markets for the CIALCA mandate areas in Burundi, eastern Democratic Republic of the Congo, and Rwanda.

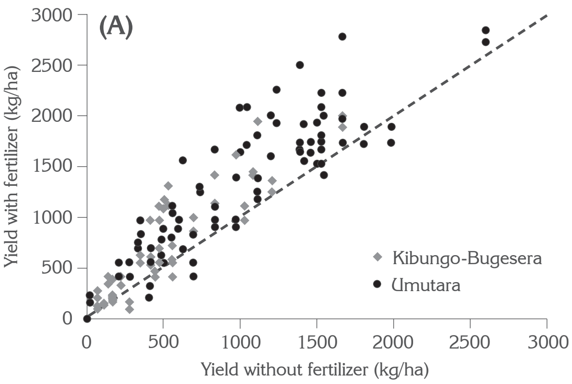
SOURCE: World Agroforestry Centre Geographical Information Systems Group.

Table 1. Characteristics of farming systems in seven CIALCA mandate areas in the African Great Lakes region.

Mandate area	Average farm size (ha)	Household size (no. of members)	Household members engaged full-time in farm activities (no./ household)	Ruminant livestock ownership (TLU[a]/farm)	Proportion of households using fertilizer (%)	Proportion of households using organic inputs (%)
Gitega	1.0	6.0	2.1	0.3	49	66
Kirundo	1.1	6.2	2.4	0.5	3	44
Rusizi Plain	2.0	5.9	2.2	0.4	13	29
South Kivu	0.7	7.0	2.1	0.4	0	19
Kigali-Kibungo	1.8	5.7	2.7	0.8	6	43
Gisenyi-Kibuye	1.8	6.4	2.6	0.9	4	39
Gitarama	2.4	6.6	2.9	1.5	20	36

a. TLU: tropical livestock unit = 250 kg body weight.

SOURCE: Adapted from Ouma and Birachi (2010).



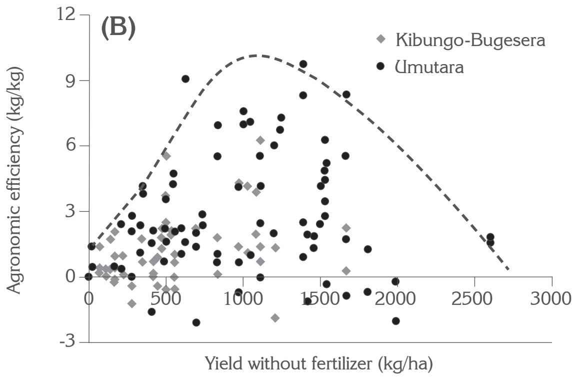


Figure 3. Grain yield of common beans with diammonium phosphate fertilizer and agronomic efficiency as a function of grain yield without fertilizer as observed in farmers fields in two mandate areas in the Eastern Province of Rwanda. Bugesera and Kibungo belong to the Kigali-Kibungo mandate area while Umutara is in the North-East of Rwanda.

SOURCE: Adapted from Pypers et al. (in preparation).

The poor security environment and inefficient government structures during the past few decades have forced farmers to support one another, and this is reflected in substantial levels of social capital as illustrated by household membership of a farmer group (14–45%) or a credit and savings group (3–46%) (Table 2).

In most communities in SSA, access to resources is not homogeneous, with some households having greater access to, for instance, land, labor, livestock, and capital, than others (Tittonell et al., 2005a). This is also the case for the farming households within the CIALCA mandate areas (Ouma and Birachi, 2011). Households with greater resource endowment commonly have a wider range of options to improve productivity and are less risk-averse (Shepherd and Soule, 1998). This needs to be considered when identifying best soil management practices.

Table 2. Livelihood indicators of farming households in the CIALCA mandate areas.

Mandate area	Proportion of households experiencing food insecurity often or sometimes[a] (%)	Proportion of households consuming two or fewer meals per day (%)	Proportion of household heads that have completed primary education (%)	Proportion of household members involved part time or full time in off-farm activities (%)	Involvement of women in agricultural activities (%)[b]	Proportion of households belonging to a farmer group (%)	Proportion of households belonging to a credit and savings group (%)
Gitega	63	96	54	44	67	31	3
Kirundo	72	100	52	57	59	45	7
Rusizi Plain	40	97	64	29	60	14	18
South Kivu	61	80	62	73	71	40	40
Kigali-Kibungo	38	96	70	39	75	30	26
Gisenyi-Kibuye	39	90	84	39	77	24	24
Gitarama	44	90	81	39	83	35	46

a. "Often" means that the households do not have enough food to eat for most of the year; "sometimes" means that households do not have enough food to eat occasionally.

b. Refers to decision-making on management of banana, cassava, bean, groundnut, and cowpea enterprises based on gender and includes all cases where the woman or both the man and the woman were involved.

SOURCE: Adapted from Ouma and Birachi (2010).

Major constraints to increased and eco-efficient productivity

Major constraints to eco-efficient intensification can be identified for various system goals:

- *Enhanced production:* Low use of external nutrient inputs, or agriculture that is mainly based on nutrient mining, combined with the low inherent soil nutrient stocks results in low crop productivity. Few crop residues are incorporated into the soil, and this is compounded by a lack of farmyard manure. This results in declining soil organic matter stocks and impairs various functions that enhance the efficiency with which water and nutrients are used by crops. The widely used unimproved germplasm has low demand for nutrients and the efficiency of conversion of nutrients and water to yield is also low. The relatively steep slopes and minimal use of erosion-control measures result in substantial soil losses.
- *Enhanced profit and competition:* Low overall production, limited processing of produce, and the lack of market infrastructure results in local produce being unable to compete with imported food. As a consequence farm incomes and profits are low. Moreover, due to the recent civil strife in the area, food and emergency aid systems have only been recently phased out, leaving behind a rural population that has become accustomed to free inputs.
- *Enhanced sustainability:* The low use of external inputs and the lack of investment capacity of the farmers results in declining crop productivity and worsening environmental, economic, and social sustainability. This has been exacerbated over the recent decades with the drastic decline in livestock numbers in all mandate areas. Livestock was very likely one of the most important factors sustaining agricultural production in the past.
- *Enhanced resilience:* Climate change is resulting in greater climate variability, particularly more variable onset of rains to begin the growing seasons and more frequently mid-season droughts. This is causing yield losses. Farmers have little say in setting the price for agricultural products, reducing their ability to raise their income and profits.

- *Enhanced equity:* Women manage most of the household food-security crops while men most often manage cash crops. Men take most decisions on investments in agriculture and control income from sales while women implement most labor-intensive field activities.

These constraints are exacerbated by the lack of effective extension systems, the lack of a conducive policy environment, and the lack of conditions that enable farmers to move from subsistence to commercial agriculture. The main exception is Rwanda where, over the past 15 years, institutional and policy-related changes have created a production environment that is well-placed to tackle constraints through investments in input value chains for improved seeds and fertilizer, provision of access to credit, initiatives to increase cattle ownership and to empower women, and the creation of an effective extension system.

Integrated Soil Fertility Management: Definition and Relationship with Eco-Efficiency

Context for system intensification

The Green Revolution in South Asia and Latin America boosted crop productivity through the deployment of improved varieties, water, and fertilizer. However, efforts to achieve similar results in SSA largely failed (Okigbo, 1987). The need for sustainable intensification of agriculture in SSA has gained support in recent years, especially in densely populated areas where natural fallows are no longer an option, as is the case in the African Great Lakes region. There is a growing recognition that farm productivity is a major entry point to overcoming rural poverty. A recent landmark event was the launching of the Alliance for a Green Revolution in Africa (AGRA) (Annan, 2008). Since fertilizer is an expensive commodity, AGRA has adopted integrated soil fertility management (ISFM) as a framework for boosting crop productivity through reliance on soil fertility management technologies, with emphasis on increased availability and use of mineral fertilizer.

Operational definition of ISFM

We define ISFM as "A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles" (Vanlauwe et al., 2011). The goal of ISFM is optimized crop productivity through maximizing interactions that occur when fertilizers, organic inputs, and improved germplasm and the required associated knowledge are integrated by farmers (Figure 4).

Focus on agronomic use efficiency

The definition focuses on maximizing the efficiency with which fertilizer and organic inputs are used since these are both scarce resources in the areas where agricultural intensification is needed. Agronomic efficiency (AE) is defined as incremental return to applied inputs:

$$AE \text{ (kg/kg)} = (Y_F - Y_C) / (F_{appl})$$

where Y_F and Y_C refer to yields (kg/ha) in the treatment where nutrients have been applied and in the control plot, respectively, and F_{appl} is the amount of fertilizer and/or organic nutrients applied (kg/ha).

Note that maximal AE also leads to maximal value:cost ratios since both indicators are linearly related for specific input and output prices.

Fertilizer and improved germplasm

In terms of response to management, two general classes of soils are distinguished: (1) soils that show acceptable responses to fertilizer, or "responsive soils" (Path A, Figure 4) and (2) soils that show little or no response to fertilizer due to other constraints besides the nutrients contained in the fertilizer, or "less-responsive soils" (Path B, Figure 4). In some cases, where land is newly cleared or where fields are close to homesteads and receive large amounts of organic inputs each year, a third class of soil exists where crops respond little to fertilizer as the soils are fertile.

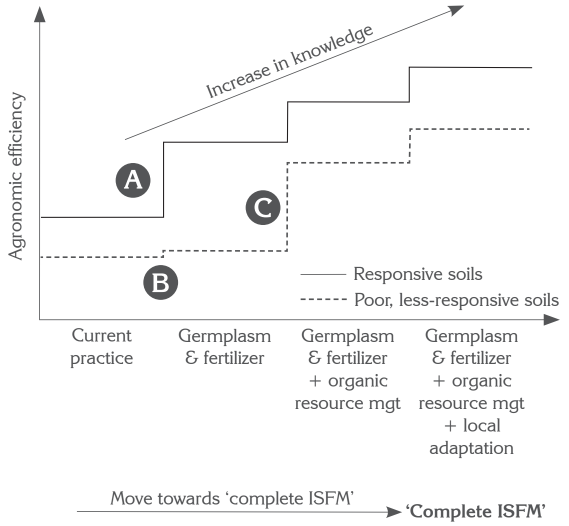


Figure 4. Conceptual relationship between the agronomic efficiency of fertilizers and organic resources and the implementation of various components of integrated soil fertility management (ISFM). "Current practice" assumes the use of the current average fertilizer application rate in sub-Saharan Africa of 8 kg of fertilizer nutrients per hectare.

SOURCE: Adapted from Vanlauwe et al. (2011).

The ISFM definition proposes that application of fertilizer to improved germplasm on responsive soils will boost crop yield and improve AE relative to current farmer practice, which is characterized by traditional varieties receiving too little and poorly managed nutrient inputs (Path A, Figure 4). Major requirements for achieving production gains on responsive fields within Path A (Figure 4) include the use of disease-resistant and improved germplasm; crop and water management practices; and application of the "4R" Nutrient Stewardship Framework—a science-based framework that focuses on applying the right fertilizer source, at the right rate, at the right time during the growing season, and in the right place (IFA, 2009).

Combined application of organic and mineral inputs

Organic inputs contain nutrients that are released at a rate determined in part by their chemical characteristics or organic resource quality. However, organic inputs applied at realistic levels seldom release sufficient nutrients for acceptable crop yield. Combining organic and mineral inputs has been advocated for smallholder farming in the tropics because neither input is usually available in sufficient quantities to maximize yields and because both are needed in the long-term to sustain soil fertility and crop production. An important question arises within the context of ISFM: Can organic resources be used to rehabilitate less-responsive soils and make these responsive to fertilizer (Path C in Figure 4)? In Zimbabwe, applying farmyard manure to sandy soils at relatively high rates for 3 years resulted in a clear response to fertilizer where there was no such response before rehabilitation (Zingore et al., 2007). In southwestern Nigeria, integration of residues from Siamese senna (*Senna siamea*), a leguminous tree, reduced topsoil acidification resulting from repeated application of urea fertilizer (Vanlauwe et al., 2005).

Adaptation to local conditions

As previously stated, soil fertility status can vary considerably within short distances with substantial impacts on fertilizer-use efficiency. Three broad classes of fields can be distinguished that occur across a range of agroecologies: (1) fertile, less-responsive fields, (2) responsive fields in which a strong response to fertilizers is found, and (3) poor, less-responsive fields. Figure 4 illustrates examples 2 and 3, above. In addition to fertilizer and organic input management, other measures for adaptation to local conditions include application of lime on acid soils, water harvesting techniques on soils susceptible to crusting under semi-arid conditions, or soil erosion control on hillsides. Lastly, adaptation also includes considering the farming resources available to a specific farming household, often referred to as farmer resource endowment. The status is related to a specific set of farm typologies. In other words, ISFM options available to a specific household will depend on the resource endowment of that household.

A move towards complete ISFM

Complete ISFM comprises the use of improved germplasm, fertilizer, appropriate organic resource management, and local adaptation. Several intermediary phases have been identified that assist the practitioner's move towards complete ISFM, starting from the current average practice of applying 8 kg/ha fertilizer nutrients (NPK) to local varieties. Each step is expected to provide the management skills that result in yield and improvements in AE (Figure 4). Figure 4 is not intended to prioritize interventions but rather suggests a stepwise adoption of the elements of complete ISFM. It does, however, depict key components that lead to better soil fertility management. In areas, for instance, where farmyard manure is targeted towards specific fields within a farm, local adaptation is already taking place, even if no fertilizer is used, as is the case in much of Central Africa.

Integrated soil fertility management and eco-efficiency

CIAT equates eco-efficient agriculture to more productive, profitable, competitive, sustainable, resilient, and equitable agriculture. Although this definition is primarily quantitative, it also allows qualitative assessment of the ISFM paradigm relative to current agricultural practices.

ISFM aims at eco-efficiency in various ways. The definition of ISFM itself embeds the concept of eco-efficiency through its focus on maximizing the agronomic efficiency of inputs, with enhanced productivity and profitability and minimized losses to the environment as direct consequences. Intensifying agricultural production can also reduce the pressure to open up new land that is often poorly suited to crop production but valuable in the context of other ecosystem functions. The concept of local adaptation embedded in the definition requires consideration of not only soil fertility gradients but also resource endowment of farming families, thus promoting increased equity among households.

The rehabilitation of less-responsive sites is a special case, as immediate returns to investment are not expected to be high. Implementing ISFM options restores productivity through a gradual increase in soil fertility resulting from more-effective use of improved germplasm, fertilizers, organic inputs (crop residues, farmyard manure), or even biofertilizers. Rehabilitating such soils enhances eco-efficiency at the farm level since more of the land area will be using agricultural inputs more efficiently.

A main issue related to sustainability is whether applying fertilizer can generate the required crop residues and other organic inputs that are needed to optimize the AE of fertilizer and sustain the soil-based ecosystem functions and services, governed by the soil organic-matter pool. There are indications that it can. Bationo et al. (1998) found that where fertilizer was applied to millet, sufficient residue was produced to meet both farm household demands for feed and food and the management needs of the soil in terms of organic-matter inputs and protection of the soil from wind erosion.

Integrated Soil Fertility Management: Application of Principles Applied in Systems Relevant to the African Great Lakes Region

Principles embedded within the definition of ISFM need to be applied within existing farming systems. Based on the main principles underlying ISFM and the specific production environment of the African Great Lakes region, specific entry points have been identified covering the various dimensions of ISFM (Table 3). Rehabilitation of non-responsive soils is not included in the table because it is unlikely to be a major short-term entry point towards ISFM. Some of these potential entry points are further developed in the following sections, based on results obtained within the CIALCA mandate areas and following the ISFM stepwise approach.

Step 1: Fertilizer and varieties

For a significant improvement in eco-efficient crop productivity, an enhanced supply of nutrients has to go hand in hand with a greater demand by the crop. Applying fertilizer to germplasm that is unresponsive, not adapted to the environment, or that is affected by pests and diseases will result in low AE values. In South Kivu, DR Congo, for example, improved, open-pollinated maize varieties yielded more than local varieties without

Table 3. Potential entry points toward ISFM[a] in the context of the CIALCA[b] mandate areas of the Great Lakes region of Africa.

ISFM step	Potential ISFM interventions	Comments
Fertilizer and varieties	Use of improved varieties of cassava, legumes, maize, and banana	Requires effective seed systems; the private seed sector is still at best nascent in the African Great Lakes countries
	Enhanced use of fertilizer adapted to specific crops	Requires input value chains, including agro-dealer networks for last mile delivery
	Appropriate fertilizer management practices (4 Rs: right source, right rate, right time, right place)	Requires specific training on the appropriate use of fertilizer
	Appropriate agronomic practices (e.g., planting in lines, appropriate planting densities, and intercropping arrangements)	Usually require additional labor; shortage of labor is a major constraint in the mandate areas
Organic matter x fertilizer interact	Appropriate utilization and management of available manure and compost	Little farmyard manure is available because farmers have few cattle
	Integration of dual-purpose legumes (food and feed) in cassava, maize, and banana-based	Enhanced production of grain legumes requires markets for these products, which is systems a major issue for soybean
	Targeted application of organic inputs on crops with relatively wide spacing, in combination with fertilizer	Spot placement of inputs requires substantially more labor (a major constraint in the mandate areas) and is usually only practicable on small areas
	Inclusion of organic mulches for moisture conservation in banana plantations	Mulch is a major constraint in newly-established banana plantations before self-mulching is initiated
Local adaptation	Target most responsive soils with microdoses of fertilizer	Capacity to diagnose soil fertility constraints to enable identification of appropriate fertilizer types and rates is very limited
	Application of lime in areas with high soil acidity and high exchangeable aluminum	Lime of adequate quality is in short supply in the mandate areas
	Erosion control measures on steep slopes	Investments in erosion control require substantial effort and finances and often collective action

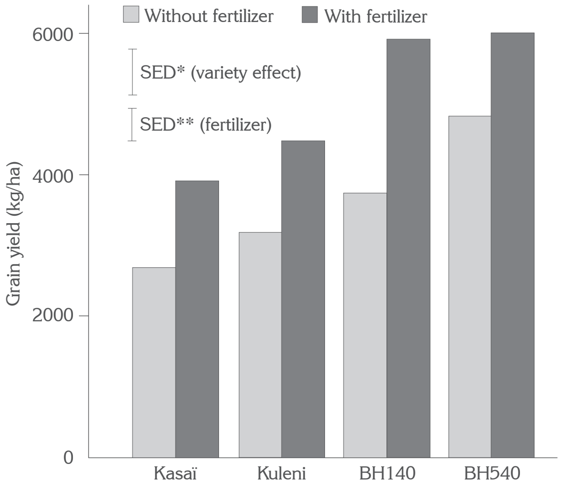
a. ISFM: integrated soil fertility management.

b. CIALCA: Consortium for Improving Agriculture-based Livelihoods in Central Africa.

fertilizer but some varieties also had a higher response to fertilizer application, resulting in higher AE values (Figure 5). Similarly, replacing mosaic-virus-susceptible cassava varieties with tolerant varieties resulted in a substantial increase in cassava response to fertilizer (unpublished data from authors).

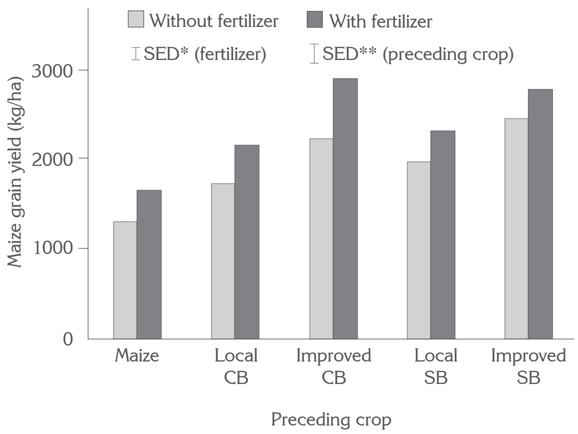
Step 2: Organic matter x fertilizer interactions

Pypers et al. (in preparation) observed a significant effect of previous cropping on maize yields both with and without fertilizer in field demonstrations in South Kivu, DR Congo (Figure 6). Yields of maize following soybean or climbing beans (*Phaseolus vulgaris)* were 27–57% higher than that of maize following maize. Rotational benefits were also greater when improved, dual-purpose legume varieties with a low harvest index were grown. These legumes gave similar grain yields to local varieties (not shown), but grain yields following maize crops were 20–34% higher than those of maize following local legume varieties. These yield improvements were related to greater biological nitrogen (N) fixation in the improved legumes, which derived a



SED: standard error of difference; *=significant at P<0.05; **=significant at P<0.01. There was no significant fertilizer × variety interaction.

Figure 5. Grain yield of two local maize varieties (Kasaï and Kuleni) and two improved, open-pollinating maize varieties (BH140 and BH540) as affected by application of 13 kg phosphorus, 60 kg nitrogen, and 25 kg potassium per hectare across four sites in South Kivu, Democratic Republic of the Congo.



SED: standard error of difference; *=significant at P<0.05; **=significant at P<0.01. There was no significant fertilizer × preceding crop interaction. CB: climbing bean (*Phaseolus vulgaris*); SB: soybean.

Figure 6. Maize grain yield as affected by application of compound fertilizer (NPK, 17:17:17) at 100 kg/ha and the crop grown in the preceding season (maize, climbing beans [CB] or soybean [SB]) in South Kivu, Democratic Republic of the Congo.

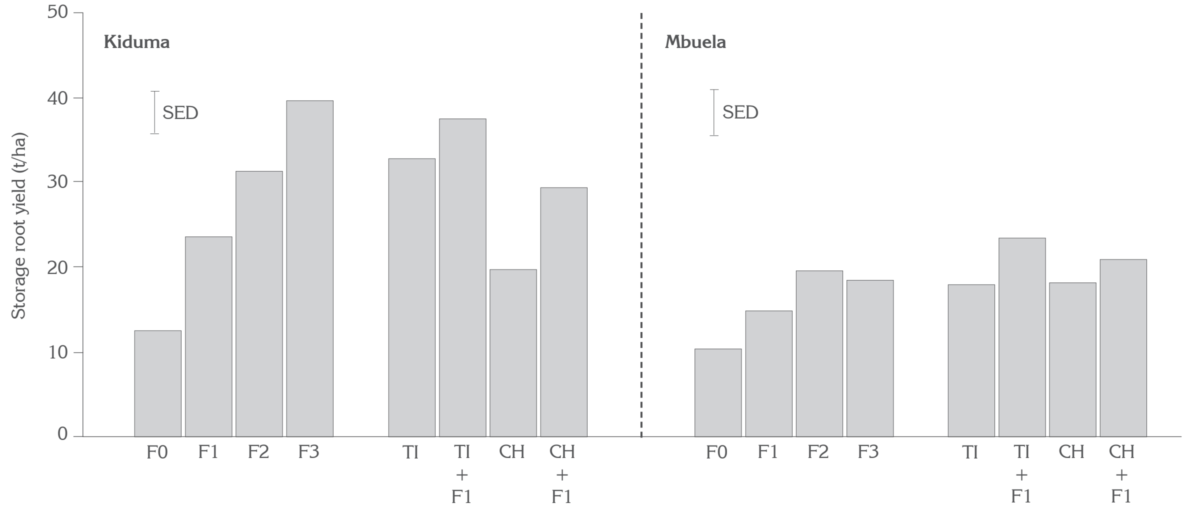
SOURCE: Adapted from Pypers et al. (in preparation).

greater proportion of N from the atmosphere (due to their longer growing period relative to local varieties) and gave a higher biomass yield. Independently, application of compound fertilizer (N : phosphorus [P] : potassium [K], 17:17:17) increased maize yields by 22–39%. Combining crop rotation and fertilizer application resulted in yield increases up to 120% relative to the unfertilized maize-maize rotation, and a mean fertilizer value:cost ratio of 2.7 (Pypers et al., in preparation).

Fertilizer response and the effect of combining inorganic and organic nutrient resources were also evaluated in cassava systems. The most common fertilizer, NPK 17:17:17, was applied with or without green manure made from *Tithonia* sp. or *Chromolaena* sp., and effects on storage root yield evaluated in two locations with differing soil fertility status (Figure 7) (Pypers et al., 2012). Control yields were similar at the two sites (12 t/ha fresh roots), but response to fertilizer differed between the sites: storage root yields reached 40 t/ha at Kiduma but only 20 t/ha at Mbuela. A much larger response to *Tithonia* sp. green manure was also observed at Kiduma, which was likely related to the higher quality and nutrient contents of the green manure grown at that site. Combining organic and inorganic nutrient resources did not result in positive interactions. No significant differences in yield were observed comparing sole application of fertilizer or green manure added to the control, relative to yields obtained with combined application of both nutrient sources (Figure 8) (Pypers et al., 2012). In maize-based systems, positive interactions between organic and inorganic fertilizers often arise from better synchrony in N release and N uptake by the crop. In cassava systems, where K is more often the most limiting nutrient, such a mechanism is likely to be less relevant. Potassium is mostly retained on the exchange complex, and has little affinity for organic matter.

Step 3: Local adaptation

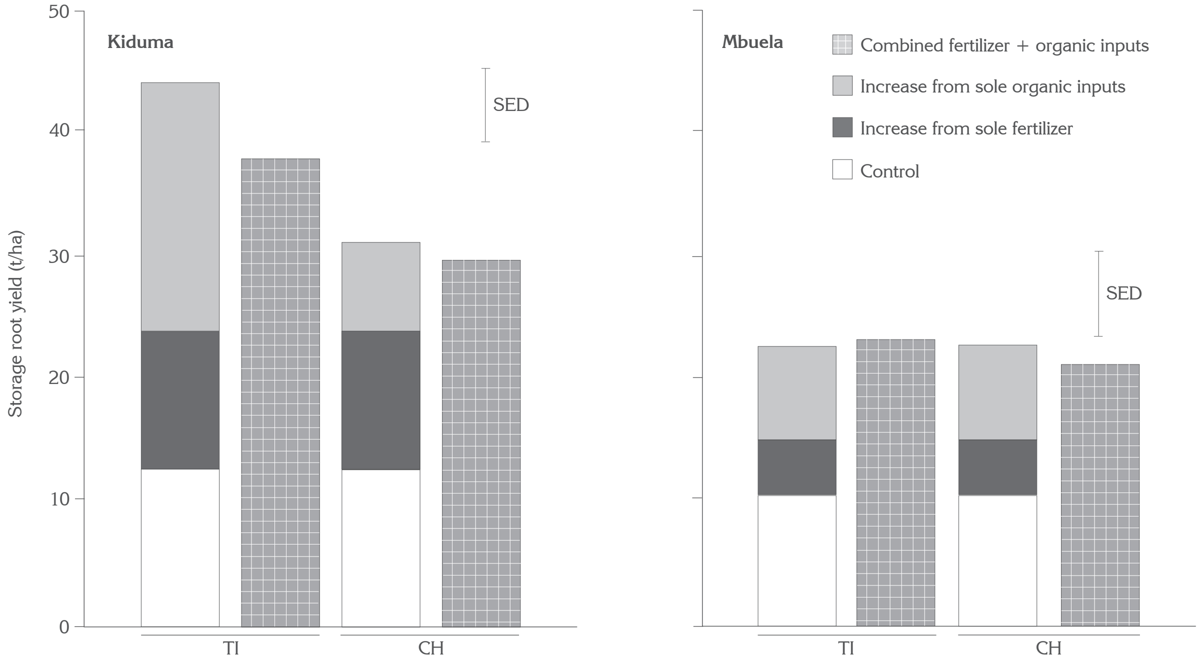
Response to fertilizer also varies according to specific local conditions. For example, bean yields increased between 0 and 1 t/ha (Figure 3A). AE averaged 2 kg of grain per kilogram of diammonium phosphate fertilizer applied, but



SED: standard error of difference at P<0.05.

Figure 7. Cassava storage root yields as affected by applying compound fertilizer (17 nitrogen:17 phosphorus: 17 potassium) at rates of 0 (F0), 283 (F1), 850 (F2), and 1417 (F3) kg/ha, and green manure (TI = *Tithonia* sp.; CH = *Chromolaena* sp.) at 2.5 t dry matter/ha alone or together with compound fertilizer at 283 kg/ha in two trial locations in Bas-Congo, Democratic Republic of the Congo.

SOURCE: Adapted from Pypers et al. (2012).



SED: standard error of difference at P<0.05.

Figure 8. Comparison of cassava storage root yields obtained by combining fertilizer inputs with organic inputs (TI = *Tithonia* sp.; CH = *Chromolaena* sp.) with incremental yield increases obtained from sole fertilizer or organic input application in two trial locations in Bas-Congo, Democratic Republic of the Congo.

SOURCE: Adapted from Pypers et al. (2012).

varied between -2 kg/kg and 10 kg/kg (Figure 3B). This variability is related to both management and soil factors. Late planting and poor crop management reduce crop yield and agronomic efficiency. Fields far from homesteads commonly have poor, degraded soils and respond poorly to fertilizer. Fertile homestead fields, where nutrients from household waste are accumulated, also often respond poorly to fertilizer because control yields are already high. Soils with intermediate soil fertility levels that are deficient in N and P but have a moderate soil organic-matter content and a good soil structure are often the most responsive to fertilizer. As a result, maximal values of AE follow a dome-shaped curve when plotted as a function of control yields (Figure 3B) (Pypers et al., in preparation). AE can be maximized by targeting fertilizer to the most-responsive soils.

On sloping land, anti-erosion measures are necessary to conserve the fertile topsoil and sustain long-term crop productivity. Without such measures, soils will degrade and become unproductive. One technique often promoted is progressive terracing using *Calliandra calothyrsus* hedgerows combined with earth embankments whereby the soil is deposited above a furrow dug along the contour (*fanya juu* in Kiswahili). However, these measures often have few short-term benefits and reduce the area available for cropping. In addition, hedgerows may compete with the crops, and earth embankments may bring up less fertile subsoil. A trial was conducted in South Kivu to evaluate the trade-offs between crop production and soil conservation in these systems. Yields were highest on plots without any anti-erosion measures (Figure 9) (Pypers et al., in preparation). Plots with both *fanya juu* and calliandra hedgerows yielded only half as much as the control plots in the first year. In the fourth year, yields in the systems with anti-erosion measures were only 17–33% lower than from the control plots. After 4 years, more than 30 kg of soil had been lost per square meter of the control plots, which implies that about 3 cm of topsoil had eroded away. *Fanya juu* embankments were more effective in protecting the soil than were calliandra hedgerows, and the two measures combined resulted in a five-fold reduction in soil loss. While anti-erosion measures are obviously necessary to maintain soil fertility, there are few short- or medium-term benefits for farmers. Application of fertilizer and large quantities of organic matter to the terraces may accelerate soil fertility restoration, but an external incentive and communal action may be required if these measures are to be implemented (Pypers et al., in preparation).

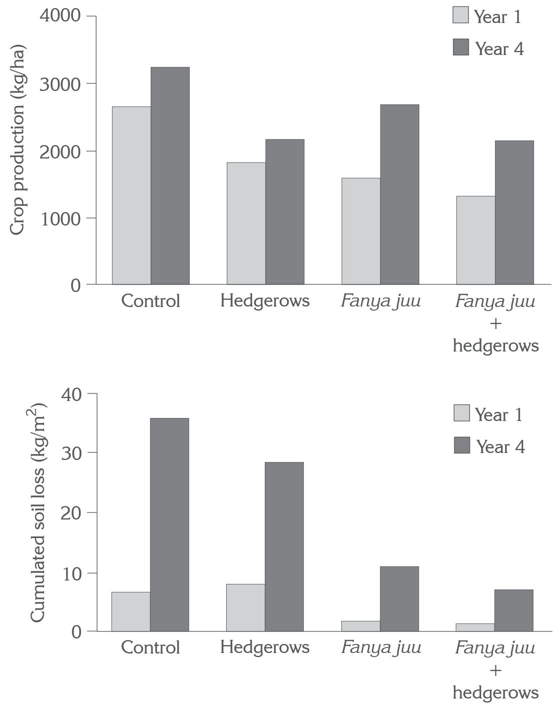


Figure 9. Average crop production for a soybean–maize rotation system and cumulated soil loss during the first and fourth year after establishment of anti-erosion measures: *Calliandra calothyrsus* hedgerows, terraces established using *fanya juu* embankments, or both in South Kivu Province, Democratic Republic of the Congo.

SOURCE: Adapted from Pypers et al. (in preparation).

Dissemination of ISFM within the CIALCA Mandate Areas

Complexity and dissemination

The gradual increase in complexity of knowledge as one moves towards complete ISFM (Figure 4) has implications on the strategies used to promote widespread dissemination. The operations of each farm are strongly influenced by the wider rural community, policies, supporting institutions, and markets. Not only are farms linked to the off-farm economy through commodity and labor markets, but the rural and urban economies are also strongly interdependent. Farming households are also linked to rural communities and social and information networks, which provide feedback that influences farmer decision-making. Because ISFM is a set of principles and practices to intensify land use, uptake of ISFM is facilitated in areas with greater pressure on land resources.

The first step towards ISFM requires fertilizer and improved varieties. An essential condition for their adoption is access to farm inputs, produce markets, and financial resources. To a large extent, adoption is market-driven as commodity sales provide incentives and cash to invest in soil fertility management technologies, providing opportunities for community-based savings and credit schemes. Dissemination strategies should include ways to facilitate access to the required inputs, simple information fliers, spread through extension networks, and knowledge on how to avoid less-responsive soils. Such knowledge can be based on farmers' experiences since most local indicators of soil fertility status are linked to the production history of particular fields (Mairura et al., 2008). A good example of where the seeds and fertilizer strategy has made substantial impact is the Malawi fertilizer subsidy program. Malawi became a net food exporter through the widespread deployment of seeds and fertilizer, although the aggregated AE was only 14 kg of grain per kilogram of N applied (Chinsinga, 2007). Such AE is low and application of ISFM could at least double this, with all consequent economic benefits to farmers.

As efforts to promote the seed and fertilizer strategy are under way, activities such as farmer field schools or development of site-specific decision guides that enable more-complex issues to be tackled can be initiated to guide farming communities towards complete ISFM. This may require improved management of organic matter and local adaptation of technologies. The latter will obviously require more intense interactions between farmers and extension services and will take a longer time to achieve its goals. Farmer adoption of ISFM may be further accelerated by implementing campaigns that address all of these aspects by offering farmers information, technology demonstrations, product exhibits, financial incentives, and opportunities to develop their skills within their own farms.

CIALCA's experience shows that the need for intensive farmer facilitation and training increases rapidly with increasing complexity of knowledge. This demands considerable investment in farmer training and knowledge-support resources. The CIALCA Knowledge Resource Centre was established in the African Great Lakes region to identify and leverage new impact pathways for ISFM technologies. By working closely with extension agents and outreach partners, targeted information tools can be developed to support adoption of practices by farmers in specific settings. A particular challenge is to develop innovative knowledge products that take into account the low rates of adult literacy and formal education prevalent in the region. Rural radio is one tool that offers a wide reach, and is very useful for raising awareness around a particular issue. However, it is less suitable as a training tool, particularly as knowledge complexity increases. It is therefore important to stress the need for integrated, multipronged communications approaches using a mix of tools when attempting to achieve impact of ISFM at a large scale.

Policies towards sustainable land-use intensification, and the necessary institutions and mechanisms to implement and evaluate these, also facilitate the uptake of ISFM. Policies favoring the importation of fertilizer, its blending and packaging, or smart subsidies are needed to stimulate the supply of fertilizer. Specific policies addressing the rehabilitation of degraded, non-responsive soils may also be required since investments to achieve this may be too large to be supported by farm families alone. In recent years, several initiatives have been set up in the CIALCA area to facilitate access to fertilizer. In

Rwanda, for example, the Crop Intensification Program has invested in training agro-dealers (small-scale agricultural supplies traders), the development of specific fertilizer recommendations for the major crops, and smart subsidy schemes. In DR Congo, the CATALIST (Catalyze Accelerated Agricultural Intensification for Social and Environmental Stability) project successfully lobbied for the removal of import duties on fertilizer and persuaded private-sector partners to invest in fertilizer supply, resulting in 60 t of fertilizer being imported during the February 2011 planting season, a first for eastern DR Congo.

An enabling environment

A set of enabling conditions can favor the uptake of ISFM. One factor that is expected to catalyze uptake of productivity-enhancing technologies in CIALCA is linkage to defined markets.

CIALCA's market intervention seeks to achieve three objectives: (1) improve the economic livelihoods of men and women in rural areas; (2) create sustainable market linkages and relations for actors; and (3) enhance adoption and raise scale of production. CIALCA has intervened in markets by working with farmers' organizations to achieve a marketable production scale. Capacity building on collaborative action, marketing and business planning skills, and management of credit and finances has ensured that farmers are now able to bulk their produce, wait for better prices, and earn higher incomes from their produce. Besides the farmers, training also targets the institutions and organizations that support the farmers' organizations, such as non-governmental organizations (NGOs) and national research staff, to ensure post-project sustainability. For instance, farmers in South Kivu were able to raise their sales revenues by 50% through strategic storage facilitated by inventory credit schemes (*warrantage* in French): farmers did not have to sell immediately after harvest but were able to store their produce collectively, awaiting better prices for their products. Through group efforts, farmers were also able to acquire credit for their ISFM-based farming activities and, because they had targeted production to key markets, were able for the first time to borrow funds without collateral. In addition, farmers working in groups have been able to initiate mutual savings schemes that supplement other sources of finance, particularly for investment in new technologies. Farmers' production projections (captured in business plans) are based on the expected application of specific ISFM technologies to achieve projected yields. This creates a direct link between the ISFM technologies and the intended livelihood improvement through incomes expected to be generated.

Another factor that may facilitate the dissemination of ISFM involves the promotion of improved nutrition. CIALCA's baseline studies indicate that the primary underlying cause of malnutrition in the mandate areas is poor-quality diets, characterized by high intakes of food staples but low consumption of animal and fish products, fruits, and vegetables. Staple foods (overwhelmingly cassava, maize, and banana in this example) account for 80% of total per capita energy intake. As such, most of the malnourished are those who cannot afford to purchase highly nutritious foods and also lack access to agricultural technologies and knowledge to grow these foods. By incorporating legume-based products into local diets and demonstrating impact of improved dietary intake on nutrition, CIALCA is encouraging communities to adopt ISFM technologies. While dissemination and adoption of complete ISFM is the ultimate goal, substantial improvements in production can be made by promoting the greater use of farm inputs and improved germplasm within market-oriented farm enterprises. To minimize conflict between food security and income generation, an interdisciplinary approach is used to integrate expertise in farming systems analysis and agronomy, human nutrition, and development economics. Strategic partnerships are forged with a wide range of development partners including health-based NGOs, farmers' groups and community-based organizations to facilitate technology dissemination and uptake.

Conclusions: Key Lessons for Research, Development, and Policy

The main principles underlying ISFM have been shown to be applicable to maize- and cassava-based cropping systems in the African Great Lakes region. Combinations of different ISFM components have resulted in substantial added benefits through higher resource-use efficiencies. Nonetheless, responses to ISFM interventions were variable, highlighting the need for local adaptation and identification of interventions best suited for a particular production environment and household resource endowment.

The seed and fertilizer approach is providing substantial increases in productivity in Central Africa, and initial efforts should be directed towards increasing farmers' access to these inputs and associated information on how best to utilize them (e.g., avoidance of non-responsive soils). As productivity increases, approaches can gradually shift towards more complex interventions, but this will certainly require more intensive interaction with farming communities. Investment in input supply chains and engagement of farming households in output value chains are crucial to large-scale impact. Such investments are best underpinned by activities aimed at strengthening the ability of farmers' associations to work collectively in purchasing inputs and marketing their produce, increasing access to credit, and strengthening the abilities of farmers to manage financial and other resources.

Policy has a crucial role to play in delivering ISFM practices by facilitating access to agricultural inputs and credit, establishing an effective extension system, upgrading rural infrastructure (including feeder roads and local storage facilities), empowering women farmers or female-led households, and investing in national agricultural research capacity. Governments also have a role to play in ensuring that development organizations do not spread contradictory messages within farming communities; a number of such organizations are still advocating against the use of fertilizer and strongly promoting organic agriculture, which, based on ISFM research, is less likely to raise productivity following eco-efficient principles.

Lastly, monitoring and evaluating the performance of specific interventions under farmer-managed conditions is crucial to better understanding the relevance of these interventions and eventual adaptation of the processes of technology identification and dissemination. This can only be achieved in a meaningful way through investments in capacity building and community participation.

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