IFDC

Development and Dissemination of Sustainable Integrated Soil Fertility Management Practices for Smallholder Farmers in Sub-Saharan Africa

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Preface

The productivity of most agricultural systems of sub-Saharan Africa (SSA) is naturally low because of inherent soil fertility. Low-input agriculture, where nutrient outputs consistently exceed nutrient inputs, often further aggravates the situation. As a result, widespread and severe household food insecurity and acute poverty occur in the region. Technological, economical, and socio-political measures are needed to curtail further soil degradation and to achieve sustainable agricultural growth.

This technical report summarizes results obtained by IFDC and Tropical Soil Biology and Fertility Institute—International Center for Tropical Agriculture (TSBF-CIAT) using the International Fund for Agricultural Development (IFAD) research grant R-535 on "Development and Dissemination of Sustainable Integrated Soil Fertility Management (ISFM) Practices for Smallholder Farms in Sub-Saharan Africa" in West Africa and southern and eastern Africa. The objective of the project was to contribute to sustainable increases in farm productivity and farmers' incomes through participatory development, validation, and dissemination of improved ISFM strategies. This was expected in the long run to reduce environmental degradation and to trigger rural development and economic growth. The project intended to provide a source of knowledge and advice for investment projects in the region (especially IFAD-funded) and should result in increased and more sustainable impact of these projects. The project started in May 2001. Many activities were carried out in close collaboration with various stakeholders in both regions until December 2004. This technical report presents the main results and conclusions. Details are provided on the accompanying CD-ROM.

The report was prepared by Abdoulaye Mando, Herbert Murwira and Marco Wopereis and was edited by Lynda Young, Marie Thompson, and Lisa Thigpen. André Bationo, Rob Groot and Amit Roy made useful comments on the various versions of the manuscript.

The steering committee has been composed of Henk Breman and Robert Groot (Directors, IFDC-Africa), Sanginga Nteranya (Director, TSBF-CIAT) and Douglas Wholey (IFAD, Rome). Amit Roy (President and Chief Executive Officer, IFDC, Muscle Shoals) contributed at a crucial moment of the project.

Integrated Intensification and Input Accessibility Programs of IFDC, TSBF-CIAT office in Zimbabwe, various members of AfNet and all members of the AISSA network implemented the project.

Amit H. Roy
IFDC President and
Chief Executive Officer

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Summary

The Development and Dissemination of Sustainable and Integrated Soil Fertility Management (ISFM) Practices for Smallholder Farms in Sub-Saharan Africa—in short the "ISFM Framework Project"—was implemented by IFDC and TSBF of the International Center for Tropical Agriculture (CIAT), and partners at key sites in seven West African countries. The key sites in West Africa were Benin, Burkina Faso, Mali, Niger, Nigeria, Togo, and Ghana, and Malawi, Zambia, and Zimbabwe were key sites in southern Africa. The ISFM Framework Project started in May 2001 and ended in December 2004. At all sites, activities were based on annual action plans that were developed with partners during annual workshops. Action plans typically included training, research, public awareness, and up/out scaling activities. Partners included seven IFAD investments programs, thirteen national research institutes and universities, fifteen non-governmental organizations (NGOs), five financial institutions, and ten national extension agencies. Two networks were active in coordinating the research and extension efforts—the Agricultural Intensification in Sub-Saharan Africa (AISSA) network established with financial backing from this project and convened by IFDC and the African Network for Soil Biology and Fertility (AfNet) convened by TSBF-CIAT.

The project's logical framework encompassed the entire research to development continuum from process research to adaptive research and dissemination although with a bias toward the latter. At the process level, the project generated improved understanding of interactions between organic inputs and mineral fertilizers and their impact on soil organic matter buildup and nutrient supply. More insight was also gained into farmers' priorities in terms of soil fertility management and social and gender differences among farmers in terms of access and management of soil resources. At the action research level, the key challenge was to combine local knowledge of socio-economic and biophysical determinants of yield and soil quality with scientific knowledge of agro-ecological principles to develop practical and feasible technologies with a potential to boost farm production and at least maintain or improve soil fertility. A large number of technological options (two to three options per site) were evaluated in three main farming systems, i.e., the agro-pastoral millet/sorghum system, the maize-mixed system, and the irrigated rice-based system.

In low-input systems, most technologies that were evaluated were based on combined use of organic inputs and judicious use of mineral fertilizers. Organic inputs included household waste, cattle manure, and straw. Other technological options tested with farmers focused on the introduction of N-fixing legumes in farming systems, such as mucuna, soybean, and cowpea. Fertilizer-N recovery rates were doubled in most cases (from a low 0.10–0.15 kg kg^{1} to 0.4 kg kg^{1} for sorghum). Yields were increased from 0.4 to 0.7 t ha^{1} to 2 to 2.7 for sorghum and from 0.8 t ha^{1} to 3 to 4 t ha^{1} for maize.

In the Sahel and sudano-savanna zone, water conservation technologies were combined with improved soil fertility management (including precision placement of micro doses of mineral fertilizer) to achieve higher and more sustainable yield. In high-input rice-based systems, the focus was on site-specific nutrient management and improved crop management in general. Compared with existing recommendations, yield gains of 0.15 to 0.55 t ha^{1} were obtained with site-specific approaches at equal costs leading to increased gross returns above fertilizer costs by an average of US $140 per season compared with both farmers' practice and existing recommendations.

The research results were used to develop and/or fine tune several decision support tools that can be used to conduct ex-ante impact analyses of promising technologies.

The National Agricultural Research and Extension Systems (NARES) and NGO staff involved in the project were trained in participatory learning and action-research approaches with emphasis on agro-ecological principles rather than technology prescriptions. Attention was also paid to the development of institutional arrangements to facilitate the adoption of the technological options, such as improved access to mineral fertilizer and credit, through collaboration with two other IFDC projects funded by the United States Agency for International Development (USAID) and the International Fertilizer Industry Association (IFA). These efforts culminated in the development of the Competitive Agricultural Systems and Enterprises (CASE) approach. CASE combines participatory development of improved natural resource management technologies with coordinated efforts to experiment and extend alternative institutional arrangements that link farmers with input dealers, micro-finance, and traders. CASE also strengthens the innovative capacities of the various stakeholders involved. The CASE approach was evaluated with partners within the AISSA network.

As a result of the project, 40 scientific papers were published or submitted to journals; four Ph.D. theses and numerous M.S. theses were also written. Seven technical advisory notes (TANs) were derived from the research data. The project summarized agro-ecological principles of ISFM in a manual; it also contributed to a facilitators' manual, a technical manual for inland valley rice systems, and an ISFM manual published with an NGO (VeCO).

The project actively worked with partners within the following IFAD-funded investment programs:

- The former rural development project in southern Togo (PODV).
- The South-West Development Project.
- The special program for soil and water conservation and agro-forestry in Burkina Faso.
- The Smallholder Floodplains Development Program, Malawi.
- The Southern Province Household Food Security Program in Zambia.
- The South-East Dry Areas Project.
- The Smallholder Dry Areas Resource Management Project in Zimbabwe.
- The Umutara Community Resources and Infrastructure Development Project (UCRIDP) in Rwanda.

The project provided technical backstopping and training and stimulated participatory research on technological options and institutional arrangement to accelerate agricultural intensification using the CASE approach. Project staff also participated in formulation missions for the Programme d'Investissement Communautaire en Fertilité Agricole (PICOFA) and Projet de Développement Rural Durable du Burkina Faso (PDRDB) investment programs in Burkina Faso. Contacts were also established with IFAD investment programs in Ghana, Nigeria, Benin, and Mozambique.

Two international training courses (one in English, one in French) were organized on the technological and institutional aspects of ISFM for partners from NARES, NGOs, Food and Agriculture Organization of the United Nations (FAO), and investment program staff. The English training material is currently used for a distance learning course via the Internet by the Sustainable Development of Learning Network in Bangkok. Several training courses tailored to specific needs and demands of partners at key sites were also provided. Many exchange visits and workshops were organized to enhance knowledge dissemination between countries and regions.

The main lessons from the project are that translating research results into farm practice is not just about technologies but more especially about people and reinforcing their decision-making and their capacity to analyze trade-offs and options and to access information, services, and markets. This calls for a new approach to doing business in agricultural research and development. This new paradigm places emphasis on interdisciplinary teamwork, inter-institutional partnerships, stakeholder involvement, participatory approaches, and systems thinking.

Chapter 1
Introduction

Context

Agriculture is generally promoted as the engine of economic growth for sub-Saharan Africa (henceforth called Africa). This is not without reason because about 70% of the population in this continent live in rural areas and depend on agriculture for their livelihood (NEPAD, 2003). Soil fertility is critical to agriculture and therefore to food security and livelihoods in Africa.

In its broadest sense, soil fertility can be seen as a mixture of soil chemical, physical, and biological factors that affect land potential. This definition will be used in this report because farmers' nutrient management practices will often result in changes in soil properties other than chemical status (e.g., application of compost will have a beneficial effect on the capacity of the soil to supply nutrients to the crop but also on its structure). Integrated soil fertility management (ISFM) refers to making the best use of inherent soil nutrient stocks, locally available soil amendments, and mineral fertilizers to increase land productivity while maintaining or enhancing soil fertility (in its broadest sense–see above).

In Africa, soil fertility management is usually the entry point to interventions aiming at improving agricultural productivity. ISFM should be embedded in a framework that includes aspects such as weather; the presence of weeds, pests, and diseases; crop management; and, beyond that, socioeconomic aspects such as input and output prices, labor availability, and the farmer's production objectives.

Soil fertility varies in the African landscape due to natural processes, such as wind erosion and dust deposition, erosion and sedimentation of soil particles with moving water, and due to human interventions such as fertilization, burning vegetation, and grazing livestock. Soil fertility is strongly related to parent rock and topography. Human settlements may also have a strong influence on soil fertility. Prudencio (1983) described the concentric rings of varying soil fertility status that are often said to be typical of West Africa. Such ring patterns often disappear if population density exceeds a certain threshold level (Defoer et al., 2000). In such situations unfertilized fields may be found next to fertilized fields. Instead of rings one would then observe a patchwork of areas of diverse soil fertility status. There may be considerable within-field variability due to termite hills, sandy patches, and abandoned kraal sites (Carter and Murwira, 1995). Another factor that may influence soil fertility and its management is the degree of access to resources (e.g., access to land, carts, cattle, labor, and cash). Land tenure is a very important issue. Farmers who do not own the land they cultivate may be hesitant to invest in soil fertility because the pay-off is not always directly visible. Access to resources often differs among household members; for example, women may have only limited access to certain resources.

Over the past decade there has been growing concern about the fertility of soils and, consequently, the sustainability of land use in Africa. Many studies suggest that soils are rapidly degrading. Sanchez et al. (1997) stated, for instance, that "soil fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa." Soil degradation seems to be more important in the Sudano-Sahelian regions of West Africa and in some countries in East Africa, such as Sudan, Ethiopia, Somalia, and Kenya. Stoorvogel and Smaling (1990) have analyzed the nutrient balances for different cropping systems in Africa. They concluded that soil nutrient depletion is quite severe in Africa. Estimates of net losses were 10 to 25 kg N, 4 kg

P_2O_5 and 19 kg K_2O ha^1 year^1. Extrapolating these results over space and time (see e.g., Sanchez et al., 1997), one can calculate that an average of 660 kg N ha^1, 75 kg P ha^1, and 450 kg K ha^1 has been lost during the past 30 years from about 200 million ha of cultivated land in 37 African countries.

A rather desperate picture of the situation of agriculture in Africa emerges from the above. Soil nutrient depletion is the result of increasing pressure on agricultural land, resulting in much higher nutrient outflows that are not compensated for because of the breakdown of traditional practices, such as fallowing, intercropping legume crops, mixed crop-livestock farming, and opening of new lands. In addition, poor road and market infrastructure, lack of timely access to credit and inputs at reasonable costs, lack of timely information and ineffective extension systems impede agricultural intensification based on “external inputs.” However, despite the “gloom and doom” of national-level studies and analyses, there are also important signs at the grassroots level that seem to nuance both the results and their interpretations (e.g., Scoones and Toulmin, 1999). The diversity of, on the one hand, socio-economic and demographic conditions in Africa and, on the other hand, the farming systems themselves, is enormous. There are indeed several successful stories of adaptation and technological progress, just as there are also examples of clearly non-sustainable “coping” strategies and severe signs of land degradation.

The diversity of farmer reality implies that solutions need to be site-specific, which requires much emphasis on farmer experimentation and participatory learning, and building of partnerships between soil fertility management stakeholders (farmers, credit providers, input dealers, research and extension agencies, government) at village, regional, and national levels. Moreover, the need for external inputs to boost yields and fight soil degradation requires innovative ways to enhance farmers’ access to input and output markets.

The dynamic environment in which the farmer operates also implies that effective solutions of the past may not work in the present situation. Under such conditions the traditional prescriptive approach does not work and needs to be replaced by an ability to analyze and understand the situation and to offer alternative options to solve problems or exploit opportunities in a sustainable manner. This calls for tools that can support decision-making in smallholder agriculture in sub-Saharan Africa. Such decision support tools (DSTs) can assist with the diagnosis and analysis of problems and opportunities related to soil fertility and identify options for improved ISFM.

To face the diversity and complexity of farmer reality, the project, therefore, used a combination of market-driven participatory approaches and systems thinking. The project has worked over a period of 3 years in West Africa and east and southern Africa to develop options for improved and sustainable agricultural productivity with smallholder farmers and other stakeholders. Project activities were designed to deliver the five primary outputs that are defined in the Technical Assistance Grant Agreement (TAGA):

1. Prototype, and/or demonstrated and/or validated, sustainable ISFM practices for dissemination directly to farmers and via technical reports and technical advisory notes/knowledge management notes.
2. Proven methodologies to facilitate further refinement, dissemination, and adoption of such practices.
3. Trained personnel in collaborating with national and other partner organizations, capable of successfully applying the above methodologies.
4. Improved awareness among key stakeholders of actions needed to remove socio-economic constraints to adoption of ISFM practices.
5. Economic data on the public goods benefits of selected ISFM practices.

Pilot Sites

A recent FAO report (Dixon et al., 2001) defined and described the most important farming systems occurring in SSA, in terms of their constraints and opportunities in alleviating poverty and/or promoting agricultural development. This project worked in three farming systems that have great potential for poverty alleviation (Appendix 1 and Figure 1):

- Agro-pastoral millet/sorghum systems (millet, sorghum, livestock, remittances), classified as having a high potential for poverty reduction and a low/moderate potential for agricultural growth. These systems are often affected by drought and the soils have inherent low fertility. This system occupies nearly 200 million ha and accounts for an agricultural population of 33 million people in sub-Saharan Africa (Dixon et al., 2001). In West Africa it stretches from the Sahelian zone to the Northern Sudan zones. In southern Africa the systems are found in the drier low-medium altitude areas ranging from 400 to 700 m above sea level. Rainfed sorghum and pearl millet are the main sources of food but are rarely marketed. The main causes of vulnerability are drought, sometimes leading to complete crop failure, and low inherent soil fertility further aggravated by low input use. The poverty incidence and the absolute number of poor living from this particular farming system are relatively high. With partners, the project focused on developing green water-based ISFM options (integrated water and nutrient management), target application of inputs, and integrated fertilization and organic input management. Pilot countries were Burkina Faso, Mali, Niger, northern Ghana, Togo, Zimbabwe, and Zambia.

Figure 1. Location of Countries With Pilot Sites

- Maize-mixed systems (maize, cassava, cattle remittances) are classified as having a high potential for poverty reduction and a moderate/high potential for agricultural growth. This system occupies nearly 246 million ha and accounts for an agricultural population of 60 million people in sub-Saharan Africa (Dixon et al., 2001). The maize-mixed system is the most important production system in the regions of east and southern Africa and has therefore received most of the project research effort in those regions. It stretches across plateau and highland areas from Kenya to Tanzania to Zambia, Malawi, Zimbabwe, and South Africa. In West Africa the system is found in the highland parts of western Cameroon, Nigeria, and the coastal savanna zones in Benin and Togo. The main staple food is maize, and the main sources of vulnerability are drought and market volatility. The system is currently under crisis—farm input use has sharply fallen because high prices make fertilizer use uneconomic and product prices have become more volatile than ever following liberalization. As a result, yields have declined and soil fertility is declining because smallholder farmers revert to extensive forms of soil management. Chronic poverty is linked to small farm size and the absence of draught oxen. Average farm size may continue to decline as population pressure increases. There are signs of soil fertility decline, with a drop in soil organic matter combined with increased soil acidity levels in some soils. The farm gate input/output price ratio for maize has steadily deteriorated. To address the above issues, this project initiated a number of activities to improve fertilizer use efficiency. This included the exploration of other sources of nutrients and carbon for the soil such as legumes and agro-forestry. With partners, the project developed legume-based ISFM technology in the coastal savanna zone of Benin and Togo, northern Nigeria and central Togo, Zambia, Malawi, and Zimbabwe. Furthermore, agroforestry based options and P recapitalization based options were explored in the coastal savanna of West Africa and in the Nigerian grain belt (sub-humid zone).

- Irrigated systems (rice, vegetables, livestock) have fairly good potential for poverty reduction and a high potential for agricultural growth. They cover about 35 million ha and include large irrigation schemes as well as riverine and flood recession-based systems that are found in pockets along major rivers, and Sahelian oasis agriculture. In nearly all cases, irrigated farming is combined with rainfed cropping and/or animal husbandry. Poverty indices are lower than elsewhere although poverty is also striking there. Crop failure is generally not a problem, but livelihood is vulnerable to water shortages, scheme breakdowns, and often deterioration of input/output price ratios. The IFSM project focused on improving nutrient use efficiency (mainly nitrogen) through the use of sound DSTs for site-specific option identification and the promotion of urea granules and collar chart technology. Pilot sites were located in Burkina Faso (Bagré Irrigation Schemes), Mali (schemes within the "Office du Niger"), Niger (Gaya scheme along the River Niger), Togo (Zio scheme), and Malawi (Flood Plain Development Project supported schemes).

Outline of the Publication

Chapter 2 of this publication will present key sites and partners involved in the project, and the general approach used to build partnerships at the key sites. Chapter 3 presents the methodological research and development approach that was developed during the timeframe of the project. This CASE approach combines the participatory development of agricultural technologies, based on ISFM, with coordinated efforts to experiment and extend alternative institutional arrangements that link farmers with rural bankers, input dealers, and traders and strengthens the innovative capacities of the various stakeholders—including the service providers (e.g., research, extension organizations, and NGOs)—involved. These activities respond to TAGA output (2) as defined in the introduction in Chapter 1. The development of the CASE approach was made possible through collaboration with the Input Accessibility Program of IFDC, financial support from the Fertilizers and Sustainable Agricultural Development (F&SAD) project financed by IFA, and the "Farmers for the Future" project funded by USAID.

CASE was combined, where possible, with systems approaches to develop ISFM options. Chapter 4 presents decision support framework and other DSTs that were adopted in the project. These tools greatly facilitated further refinement of ISFM technologies, and Chapter 4, therefore, also responds to TAGA output (2). Chapter 5 gives an overview of the type of agricultural technologies and institutional arrangements developed around ISFM learning plots and learning systems using the CASE approach (see Chapter 2). In West Africa, this work benefited from matching funding from the F&SAD project financed by IFA and the "Farmers for the Future" project funded by USAID.

Chapter 6 gives highlights of more strategic research that was conducted at key sites with partners from NARES and universities. This strategic research was meant to improve our understanding of (long-term) benefits of combined use of organic inputs and mineral fertilizer on agricultural productivity and soil fertility. Chapters 5 and 6 respond to outputs (1) and (5) as defined in the TAGA. Chapters 7 and 8 present the results of capacity building and public awareness efforts conducted within the project and respond to output (3) and (4). Collaboration with IFAD-funded investment programs is discussed in Chapter 9. The publication ends with a set of conclusions in Chapter 10.

Chapter 2
Partners and Partnership Building

The project was conducted in 16 regions in West Africa and 8 regions in southern and East Africa (Appendix 1). In these regions, IFDC and TSBF-CIAT were already mostly active before the start of this research grant. Partnerships during the timeframe of the project were re-enforced. In general, inter-institutional platforms were established that included institutions that facilitate agricultural intensification (Figure 2). These platforms have the following functions:

1. Determine strategies for implementation.
2. Develop annual action plans and budget.
3. Coordinate implementation.
4. Monitor and evaluate actions.
5. Facilitate collaboration.

PCU Meeting for Action Plan Preparation in Southern Benin

At each key site, partners elaborated an action plan for each specific farming system. Such plans include participatory research and development on agricultural technologies, credit systems, and improving input and output market access. Follow-up meetings and backstopping missions to the pilot regions took place to provide technical support to the implementation of the action plans. Action plans focused on the maize-cassava systems in Benin and Togo, the maize-legume systems in north and central Togo and northern Nigeria, the maize-cotton systems in Mali and Togo, the sorghum/maize based systems in Burkina Faso, and the soil and water conservation dependent production systems in Niger. In southern Africa, action plans were developed for the maize-legume systems of Malawi, southern Zambia and Zimbabwe, the crop-livestock systems of Zimbabwe, and the rice-maize systems of the flood plain areas in Malawi.

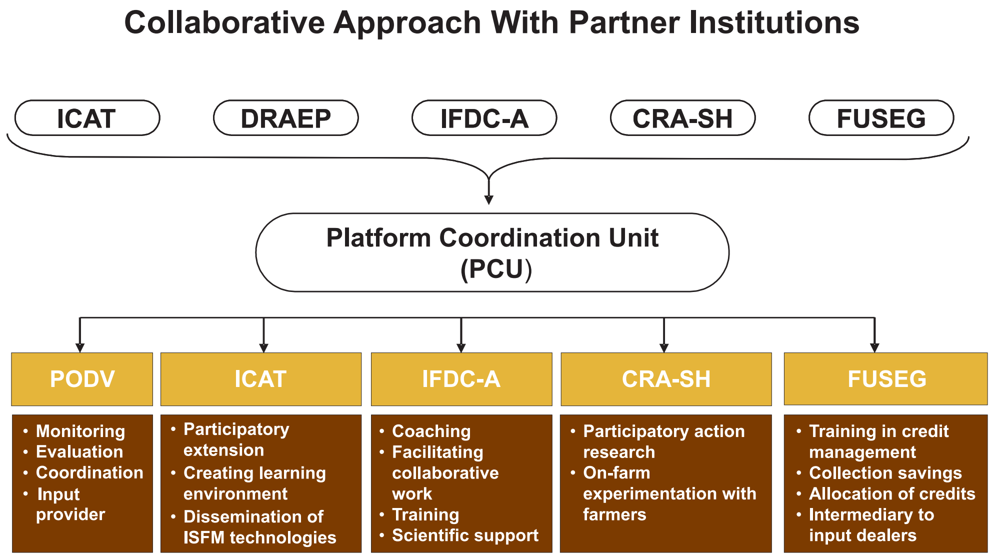

Figure 2. Institutional Platform for ISFM Promotion in Southern Togo. ICAT (Togolese National Extension Institute): Extension Organization, CRA-L (Agricultural Research Central—Littoral Region): Research Organization, FUCEC: Micro-Finance Organization, and PODV: IFAD Investment Project.

Chapter 3
Facilitating Innovation and Institutional Development: The CASE Approach

Over the timeframe of the project, an innovative and flexible methodology to sustainable agricultural intensification was developed in collaboration with partners and the Input Accessibility Program of IFDC: the CASE approach. The acronym CASE stands for "Competitive Agricultural Systems and Enterprises." It emphasizes the importance attached to competitiveness, both related to the agricultural production systems within the target region and to the rural and urban enterprises that are directly linked to the agricultural production systems, by providing inputs and market outlets. CASE is based on the agri-business system at the regional level (see Figure 3) and combines participatory methods to develop and extend ISFM strategies with support to institutional changes that facilitate effective linkages between farmers and the market.

The CASE approach is a "grassroots" approach and plays a pro-active role in linking farmers and villages with urban retailers, traders, and consumers.

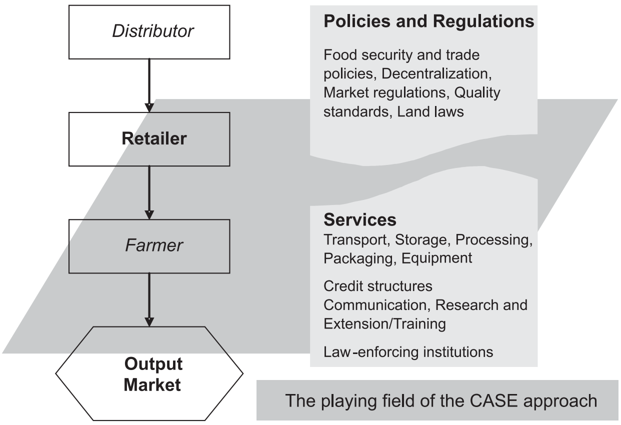

Figure 3. The Agribusiness System

CASE is implemented through two iterative and partly overlapping participatory learning cycles. Each cycle consists of a D(iagnosing), A(ction planning), T(rying things out), and E(valuating) phase: a research-DATE and an extension-DATE. Both learning cycles address the technological and institutional aspects. The research-DATE builds up new experiences and expertise, the extension-DATE focuses on scaling-up (and -out) of the results (see Figure 4).

DATE/R (Research)

Learning cycles for Action-Research are used to strengthen farmers' and other stakeholders' capacities in observing, analyzing, and dealing with constraints and also opportunities to improve the competitiveness of agricultural production systems and (rural) enterprises within the target region. Ways to improve access to information (technologies, prices), extension services, credits, inputs, and commodity markets can all become the focus of a "learning activity." ISFM farmer groups, for in-

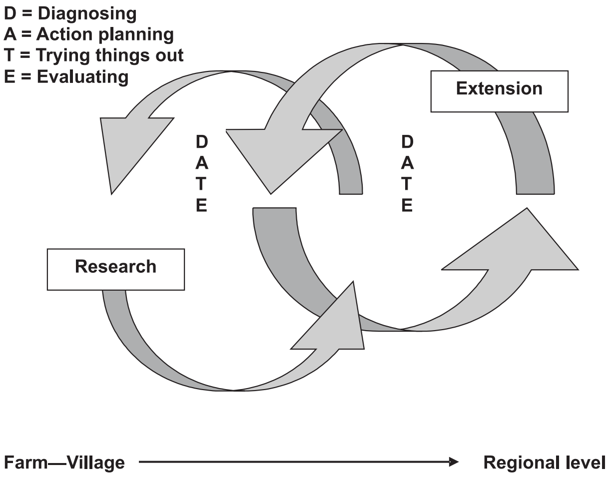

Figure 4. Research and Extension DATE-Cycles

stance, have been set up to observe and analyze soil fertility management practices, and to take decisions in view of trying to improve these. The focus is on developing answers to site-specific problems and to exploit opportunities, making the best use of locally available resources, knowledge and skills, in combination with research-based understanding and analysis of the underlying principles. Social learning is promoted through "learning plots," i.e., by working together on some common fields managed by the ISFM farmer groups. Key issues for facilitators of such learning plots are to promote efficient ways to memorize and capitalize learning through drawings, reports, photographs and videos (if possible), to maintain flexibility in "training modules" and to keep the focus on the processes instead of "static technical prescriptions." An important aspect of the learning plots is that objectives, activities, and training modules are to be decided upon by the farmer group and the facilitators together, with an accent on sharing experiences and development of tools. Villages or groups of stakeholders that are involved in DATE/R cycles gradually become very experienced "rural knowledge centers" or "rural knowledge groups," able to train other farmers or stakeholders.

DATE/E (Extension)

The extension-DATE deals with dissemination and adaptation of successful technologies and institutional arrangements from the research-DATE at a (sub-)regional scale, and the more general support for institutional change that reinforces linkages between farmers, credit providers, input dealers, and traders. The DATE/E cycle diffuses information from the rural knowledge centers/groups to other villages or stakeholder groups through exchange visits, farmer-to-farmer training, demonstration plots, etc. Facilitators have an important role to play vis-à-vis their own organizations, to promote (and institutionalize) the CASE approach. Dissemination of information within the region, between farmers and other stakeholders, but also beyond the region to national-level actors is important, to create awareness and to emphasize possibilities and favorable conditions for a sustainable intensification process, and the roles any actor can play. Effective knowledge of information networks, both formal and informal, is crucial to explore alternative communication strategies.

Further Reading

Maatman, A., and M.C.S. Wopereis. 2004. "Facilitating Innovation for Sustainable Agricultural Intensification in West Africa: The CASE Approach," presented at the SANREM Conference, Bamako, Mali, February 2004 (on enclosed CD).

Wopereis, M.C.S., and T. Defoer. 2005. "Moving Methodologies to Enhance Agricultural Productivity of Rice-Based Lowland Systems in Sub-Saharan Africa," submitted to *Nutr. Cycl. Agroecosyst.* (on enclosed CD).

Chapter 4
Decision Support Tools for Improved ISFM

Decision support tools can be distinguished according to their nature or the type of decision to be made (Struif Bontkes and Wopereis, 2003). Some decision tools are very simple to use and require very limited data, while others are more complex and can only be used by trained researchers. Table 1 provides an overview of the DSTs and their nature used in this project.

Decision-making in agriculture can be categorized in different ways—for instance, decision-making related to the time horizon of the decision: short term (when to apply fertilizer), medium term (choice of crop variety), or long term (decision to start agro-forestry).

Five stages can be distinguished in the decision-making process along the research and development continuum:

- Strategic Site Selection Phase—In this phase zones are identified that are suitable to deploy a particular activity; e.g., a zone that is suitable to promote the cultivation of cotton. Such zones should satisfy a number of criteria such as climate, soils, and accessibility.
- Diagnosis/Analysis Phase—In this phase problems are identified and analyzed. For example, actual production levels are far below what may be expected, given soil and weather conditions (observation), and this is caused by nutrient leakages in the system (analysis).

Table 1. DSTs Used in This Project and Their Level of Complexity. The Site and Farming System for Each DST is Indicated

Decision Support Tool	Type/Complexity	Site	Farming System
Soil maps	Data base/Simple	Togo	Maize-mixed
Cropping calendars	Simple	Togo, Bagré, Burkina Faso	Maize-mixed; irrigated rice
Dichotomy keys	Simple	Burkina Faso	Sorghum/millet agro-pastoral systems
Resource Flow Map (RFM)	Nutrient flow diagram/Simple	Benin, Togo, Mali, Zambia, Zimbabwe	Maize-mixed
Manure guide	Simple	Zimbabwe, Zambia	Maize-mixed
QUEFTS	Optimal fertilizer doses/ Medium	Bagré, Togo, Burkina Faso	Maize-mixed
NUTMON	Quantification of nutrient flows/Medium	Benin, Togo	Maize-mixed
RIDEV	Dynamic rice model/ Medium	Bagré, Burkina Faso	Irrigated rice

- Options Identification Phase—Here options are identified and compared for improvement, and ex-ante evaluations are conducted, including financial consequences and risk analysis. For example, “What is the maize yield response to alternative soil fertility management options?” or “What is the risk related to a particular choice of maize cultivar x fertilizer dose x sowing period combination?”
- Evaluation Phase—In this phase results obtained in the field are evaluated and interpreted. This phase can also be used to evaluate and improve the tool itself.
- Technology Diffusion Phase—Once a number of viable technologies have been developed for a particular set of conditions, it is necessary to explore the likelihood of success of a technology for a different set of conditions, by matching the technology profile with environmental characteristics of those conditions.

The project developed and used DSTs in a number of ways. Some highlights are given below.

Resource Flow Mapping

The ISFM project used resource flow mapping (RMF) to analyze nutrient flows at field to farm scale and improve nutrient resource allocation in some pilot sites in southern Benin, central and southern Togo, southern Mali, and Zimbabwe. RFM is a robust method to visualize how farmers manage their nutrient resources and a tool to explore alternative allocation strategies. In this project, farmers developed resource flow maps at the start and at the end of the growing season to facilitate exchange of information among farmers in order to raise awareness and to stimulate them to take particular actions. The objectives of RFM were to engage farmers to (1) document/discuss current farmers’ resource use trends, (2) discuss the driving forces behind the trends, and (3) identify opportunities for improving resource use efficiencies. From the third objective, the researchers and the farmers actively discussed soil fertility management options that could improve overall resource use efficiencies at the farm level. Subsequently, on-farm experiments were designed to compare the efficiencies and economics of alternative soil fertility management options.

Farmers thus appreciated the resource flow maps as a means of presenting a holistic view of their farming activities, keeping track of their management trends, and finding opportunities for improving the productivity of their farms through alternative resource use options. The farmers also appreciated the importance of taking and keeping records of their farming activities for future use. In southern Togo, the use of RFM has convinced farmers to start collecting and storing the household waste for soil management purposes. The manure quality improvement work reported in the next section was inspired from farmers’ realiza-

Farmer in Benin is Presenting the Resource Flow Map of His Farm

tion that there were large losses of nutrients from cattle kraals and during storage. The RFM exercises in Zimbabwe were carried out on farms to monitor the year-to-year trends in resource use on smallholder farms. The exercise was done at eight farms representative of four wealth categories in Murewa, northeastern Zimbabwe. Emphasis was placed on collecting quantitative data relating to labor profiles and assessing changes in cropping patterns from the previous year. Estimation of the resources available to farmers was done to improve how the farmers manage the resources available to them, particularly in relation to how they distribute the resources among the different components of their farms. Based on the resource flow maps and depending on the farmers' circumstances, practical interventions to improve resource use efficiency were explored.

In some regions (central Togo and southern Benin) the NUTMON (Nutrient Monitoring) DST was introduced to obtain more quantitative assessments of soil nutrient status and flows and of economic performance indicators. Farmers generally appreciated RFM because it allowed them to visualize their access to and allocation of generally scarce nutrient resources.

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Manure Decision Guides for Maize Cropping in Zimbabwe

Farmers in Zimbabwe traditionally rely on cattle manure to manage soil fertility, and more than 30% of the total N budget in communal areas is contributed from manure. Much work has been done on understanding the effects of manure on crop response, and on manure quality and how quality can be improved by better methods of composting and beneficiation with inorganic fertilizers, especially phosphate rock. Recommendations on rates of manure application for field crops are varied but difficult to compare across sites because nutrient content data are often not cited. However, it is difficult to come up with prescriptive guidelines on the use of manure because the quality varies considerably from farmer to farmer because of they way it is managed and stored prior to application in the fields (Murwira et al., 2002). Our challenge is to translate the scientific understanding we have into farm practice taking into consideration quality and quantity of manure available, short- and long-term effects, economic factors, environmental factors, farmer perceptions, and limiting nutrients. This requires sharing with farmers the scientific principles of using manure and the development of communication strategies that could bring about a positive change in the way farmers manage resources available to them. This has led to the development of a framework for decision-making on manure use. The FMDG was accompanied by a set of detailed notes that provide different soil fertility management information of importance to smallholder farmers (CD-ROM:CHAPTER4.2 \Manure.PDF).

The decision guide was tested widely in Murewa and Shurugwi, Zimbabwe and with 120 farmers directly involved with the project to ensure that it was sufficiently robust. Non-participant farmers were surveyed and data subjected to descriptive analysis to assess the compatibility of the use of the guide to farmers living under different environments. Performance comparisons were made between participant and non-participant farmers. Gross margin and linear programming analyses were also used to assess the potential implications in terms of resource utilization and crop choice from the use of the guide.

The use of the guide resulted in improved utilization of resources, but farmers were affected differently depending on the quality of manure they used, amount of labor available to them, and soil type. Farmers using the guide achieved higher maize yield responses.

The heterogeneity in farmers' socio-economic and biophysical environments means that the main emphasis should be focused on the use of the guide as an extension learning framework that could be used to inform farmers on different soil fertility management options available to them. The approach taken to validate the decision guide is that farmers must understand the agro-ecological principles from which scientists derived them, and this can only be done through a process of researcher farmer dialogue and mutual learning. The decision guide or framework was found to be a very useful learning tool for how farmers can improve soil fertility management through manure use. While a singular decision guide for a particular option forms the best way of exploring the way it is managed and how its management can be improved, farmers are most often managing combinations of different resources. The challenge therefore remains of how to integrate use of different decision guides for optimal management of multiple resources. Similarly, a range of platforms and learning spaces suitable for different categories of farmers should also be identified and tested.

A key lesson from these results is that farmers need to be engaged in a dialogue on how they can arrive at solutions that suit their requirements and circumstances. Developing a framework for such a learning process can be very fruitful but demanding. The framework for manure decision-making in Zimbabwe looks complex but has been widely tested on its usefulness. It has been demonstrated that it can stimulate discussions on various aspects of manure management and the decisions that farmers take before and after application of manure to soil. It is important to emphasize that the decision guide is more of a conceptual framework for social learning rather than a clear guide for decisions.

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Benefits of Site-Specific Nutrient Management for Irrigated Rice in Burkina Faso

The Bagré Irrigation Scheme (600 ha) is located in the eastern part of Burkina Faso on the central plateau. The scheme is situated in the Boulgou province, approximately 150 km southeast of the capital, Ouagadougou, and about 50 km north of the border with Togo. Irrigation for the Bagré Irrigation Scheme is gravity driven and is supplied from the Nakambe River (formerly White Volta). Cultivation of the first irrigation scheme started in 1997, in which the presented study was conducted (Nimatoulaye Scheme or V1 with a total area of 106 ha). The main crop is irrigated rice, which is cultivated in the wet season (main sowing time from July to August) and the hot dry season (main sowing time from January to February). Almost 100% of the irrigated area is cropped twice a year. Direct seeding and transplanting are both practiced. Existing fertilizer recommendations are 300 kg ha^{1} "cotton fertilizer" ($N/P_2O_5/K_2O$ 12/24/12) applied basally or shortly after transplanting and 100 kg ha^{1} urea (46/0/0) in the WS or 150 kg ha^{1} urea in the dry season. Recommended total NPK dose therefore is 82/31/30 kg ha^{1} and 105/31/30 kg ha^{1} in the wet season and dry season, respectively. Urea is recommended to be top-dressed in two equal splits at early tillering and panicle initiation. Dominating cultivars are FKR19 (TOX 7281) and FKR14 (4418). Apart from irrigated rice, most farmers grow rainfed maize, millet, or sorghum in the surroundings of the scheme during the wet season and some farmers grow vegetables during the dry season. Most farmers also have some livestock (cattle).

Based on an agro-economic characterization study, Segda et al. (2005) concluded that the most promising ways to achieve higher productivity and input use efficiency in the Bagré Irrigation Scheme in Burkina Faso were to (1) improve timing and quality of crop management practices and (2) improve existing fertilizer recommendations. Fertilizer recommendations in Burkina Faso have not changed since the introduction of irrigated rice and are presently uniform over large areas and cut across diverse climatic and edaphic environments. Especially the widespread use of compound fertilizers, not tailored to the needs of the rice crop, constitutes an obstacle for optimization of nutrient management. The farmers' timing of crop management practices was highly diverse and did not take into account the difficult climatic environment. Farmer's knowledge of existing recommendations was imperfect, partly explaining the non-adoption. Other factors included problems with collective and individual planning of the cropping calendar for double cropping of rice (two rice crops on the same field per year), and the need to also attend to rainfed crops outside the scheme.

A combination of two simulation models combined with field data was used to develop improved and site-specific nutrient management (SSNM) practices for irrigated rice in Bagré, Burkina Faso. Existing fertilizer recommendations are 82 kg N ha^{1} (wet season) or 105 kg N ha^{1} (dry season), 31 kg ha^{1} P and 30 kg K ha^{1}. The RIDEV model was used to improve timing of sowing date to avoid cold-induced sterility and timing of N fertilizer applications. The FERRIZ model was used to determine SSNM recommendations based on estimations of indigenous nutrient supply for N, P, and K; yield potential (Y_{pot}), internal N, P, and K efficiency of rice; fertilizer N, P, and K recovery fractions; and fertilizer and rice prices. Simulations suggested decreasing P and K doses to 21 kg P ha^{1} and 20 kg K ha^{1}, but to increase the N dose to 116 kg N ha^{1} in medium-yielding seasons (Y_{pot} = 8 t ha^{1}) and to 139 kg N ha^{1} in high-yielding seasons (Y_{pot} = 9 t ha^{1}). SSNM keeps the P balance neutral, but a negative K balance was tolerated based on the high soil K supply. Compared with existing recommendations, yield gains of 0.15 to 0.55 t ha^{1} were simulated at equal costs. These yield gains were confirmed in farmers' fields during three consecutive growing seasons (Figure 5). SSNM increased gross returns above fertilizer costs by an average of US $140 per season compared with both farmers' practice and existing recommendations.

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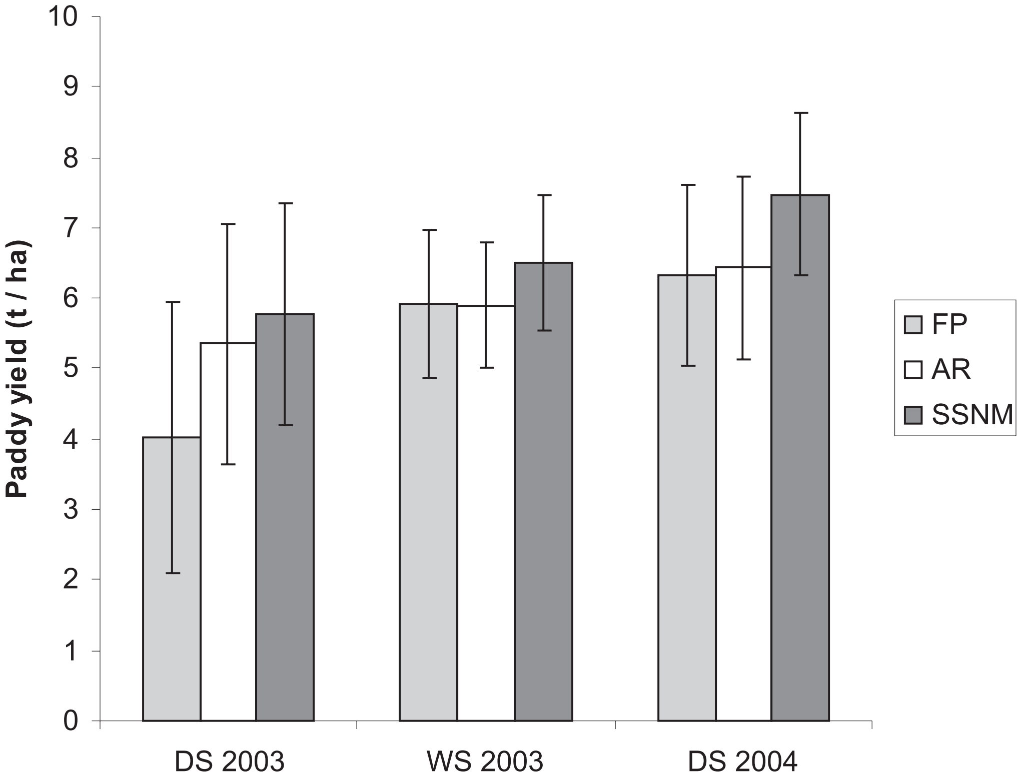

Figure 5. **Paddy Yield Response to Farmers' Practices (FP), Actual Fertilizer Recommendations (AR), and SSNM During the Dry Season (DS) of 2003, the Wet Season (WS) of 2003, and the Dry Season of 2004, Bagré, Burkina Faso**

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Mineral Fertilizer Recommendations as a Function of Farmer Purchasing Power in Southern Togo

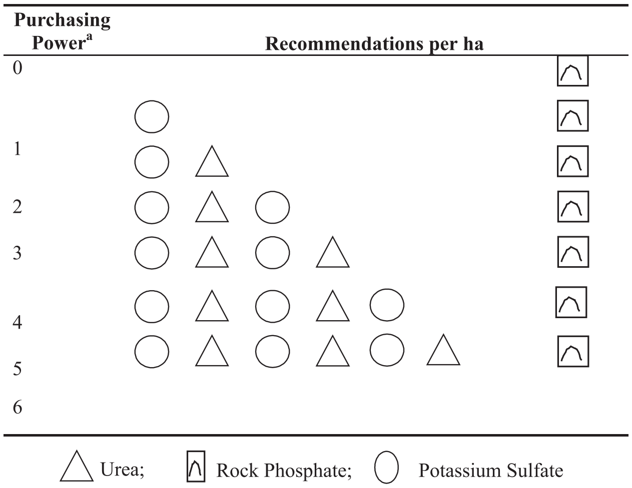
The coastal region of Togo is densely populated and characterized by degraded "terre de barre" or ferralsols, which have low agricultural production potential. To develop site-specific recommendations for mixed maize farming systems in the region, the project worked with 20 farmers in the village of Djaka Kopé. Farmers installed small "nutrient-omission plots" (omitting application of either N, P, or K, but applying the other two major nutrients) in part of their fields on "terre de barre" soil during the main rainy season in 2003. Some fields had profited from a mucuna short fallow during the preceding short rainy season in 2002; others had not. Results for maize yield are shown in the table below.

Table 2. **Maize Yield as Affected by Nutrient Omission on Plots With and Without Mucuna**

Treatments	With Mucuna	Without Mucuna
	(t ha^{-1})	(t ha^{-1})
–N	2,504	1,240
–P	2,378	1,264
–K	1,394	1,120

From the table, it is clear that K is the element most limiting maize yield in the area. There is also a strong beneficial effect from inclusion of mucuna in the production system in this region, especially on the capacity of the soil to supply N and P. Partners in this project used the QUEFTS model and frequent interactions with farmers to develop “à la carte” recommendations of ISFM options as a function of farmer purchasing power. One of such à la carte recommendations is shown below.

Table 3. Alternative Recommendation for Fertilizer Application in Maize-Cassava System Under Fallow Management



a. Expressed in number of bags of fertilizer.

The table gives six alternative soil management options depending on purchasing power of the farmer. The optimum nutrient management is to apply phosphate rock every 3 years, three bags of K_2SO_4, three bags of urea, and to add organic resources to the soil at least bi-annually. For the studied region, the use of mucuna short fallow was found to be the best option to add organic matter to the soil. The poorest farmer is advised to do his best to add organic resources and phosphate rock. If one can afford only one bag of fertilizer, then he/she is advised to buy a potassium source of fertilizer.

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Decision Support Tool for Combined Use of Organic Inputs x Fertilizer Use for Sorghum/Millet Systems in Semi-Arid Zones

Strategic research was conducted with partners in Burkina Faso, Niger, and Mali on integrated soil fertility and water management. More details are provided in Chapters 5 and 6. Based on the outcome of the research, a decision dichotomy key was developed to guide allocation of organic resources and fertilizer for sorghum/millet under semi-arid West African conditions. This key is valid for soils with low organic matter (<1%) and low total nitrogen (<0.5 g kg^1) and having a sandy to loamy-sandy texture.

1. Low variability in rainfall distribution?
    1.1. Yes (see 2).
    1.2. No (see 6).

2. Is organic resource available?
    2.1. Yes (see 3).
    2.1. No (see 11).

3. Are nitrogen fertilizers available?
    3.1. Yes (see 4).
    3.2. No (see 5).

4. Low variability in rainfall distribution, organic resources available, nitrogen fertilizer available: (1) Combining slowly decomposable resource (e.g., crop residues) with adequate nitrogen fertilizer or (2) easily decomposable organic material with a low dose of nitrogen fertilizer will give optimum crop production and will maintain soil carbon stock and biological activity. It allows the maintenance of soil moisture in case of short drought period. The material should be plowed in because rainfall intensity and high temperature may accelerate fertilizer loss if surface-placed. Enhanced yield will allow for fertilizer-N investment and in general will induce economic benefit. Fertilizer-N added should be appropriate because very low fertilizer addition may lead to temporal nitrogen immobilization, which may reduce crop performance.

5. Low variability in rainfall distribution, organic resources available, nitrogen fertilizers not available (3.2). The use of easily decomposable organic material (compost, manure, etc.) with tillage or other soil and water conservation (SWC) measure is recommended. High crop yield is achieved with interesting economic benefit and soil carbon buildup will depend on the quantity of organic resource applied. Policy measures should be taken to improve input accessibility.

6. High variability in rainfall distribution (1.2).

7. Is organic resource available?
7.1. Yes (see 8).
7.2. No (see 15).

8. Are nitrogen fertilizers accessible?
8.1. Yes (see 9).
8.2. No (see 10).

High variability in rainfall distribution, organic resources available, nitrogen fertilizers available (8.1): Combining high quality organic material (manure, compost, etc.) with a low dose (<40 kg N ha^{1}) of nitrogen fertilizer and soil and water conservation measures (e.g., stone rows, pitting, minimum tillage) are recommended. A low dose of urea will be enough because a high urea dose may exceed the capacity of available anion sites of organic material to fix nitrogen and therefore a huge quantity of nitrogen may be lost. Deep tillage is not recommended because tillage may accelerate the mineralization of the material (and sometime the native soil carbon) and the risk of unsynchronized nutrient release and crop needs may be high. Minimum tillage, however, is required for crust control. Combining slowly decomposable resources (e.g., crop residues) with an adequate dose of nitrogen fertilizer with minimum tillage may also give optimum crop production and will maintain soil carbon stock and biological activity. Enhanced yield due to fertilizer-N will allow for the fertilizer-N cost with economic benefit.

9. High variability in rainfall distribution, organic resources available, nitrogen fertilizer not available (8.2): Surface placement of crop residues or plowing easily decomposable organic resources is to be preferred. Surface-placed crop residues will improve soil moisture and will enhance the contribution of soil fauna in improving soil physical properties and the breakdown of the material resulting in increased nutrient use efficiency by crops. Addition of phosphate rock in combination with organic resource with low C:N ratio will reduce phosphorus limitation to crop. The maintenance of soil carbon with surface-placed crop residues will depend on their C:N ratio. Residues with C:N ratio >50 will induce a priming effect with subsequent decrease of soil carbon concentration and the reduction of crop performance. Enhanced yield due to fertilizer-N will allow for the fertilizer-N cost with economic benefit. Measure to facilitated fertilizer access is recommended.

10. Low variability in rainfall distribution, organic resources not available (2.2).

11. Are nitrogen fertilizers accessible?
11.1. Yes (see 13).
11.2. No (see 14).

12. Low variability in rainfall distribution, organic resources not available, nitrogen fertilizers available (12.1): The application of a low dose of urea (50–60 kg N ha^{1}) with tillage is recommended because the recovery of fertilizer is low in general (<30%), and due to the low soil organic matter and clay concentrations, the capacity of nutrient storage is very low. Surface-placed nitrogen loss is through runoff or volatilization. However, hardly any economic benefit of fertilizer-N is achieved with this option. The alternative is the production of organic resource at the same time in the farm (intercropping with legumes, improved fallow, parklands, etc.). This will improve fertilizer recovery and make fertilizer use profitable.

13. Low variability in rainfall distribution, organic resources, and nitrogen fertilizers not available (12.2): This option will lead to soil mining. Although water may not be limiting, the crop water use efficiency will be low because of nutrient scarcity, and yield will decline rapidly with an increase of soil carbon depletion. When space is still available, fallow is the way to reconstitute soil fertility. Soil degradation is imminent.

14. High variability in rainfall distribution, organic resources not available (7.2).

Are nitrogen fertilizers available?
14.1.1. Yes (see 16).
14.1.2. No (see 17).

15. High variability in rainfall distribution, organic resources not available, nitrogen fertilizers available (15.1.1). The use of nitrogen fertilizer in these conditions is not recommended because dry periods will result in low nitrogen use efficiency that further increases drought stress in the crop with subsequent negative effects on crop yield. No significant economic benefit can be expected in this situation. Loss in benefit increases when increasing the dose of fertilizer-N.

16. High variability in rainfall distribution, organic resources not available, nitrogen inputs not available (15.1.2). This option leads to soil carbon and nutrients depletion; soil crusting will rapidly take place leading to unproductive soil unless short periods of cropping are alternated with long periods of fallow.

Chapter 5
Participatory Evaluation and Learning of ISFM Options

ISFM options were defined and developed with farmers using learning plots in sub-Saharan Africa following DATE-R cycles (Chapter 2). The project worked in three primary farming systems, as distinguished by Dixon et al. (2001), that are of major significance in sub-Saharan Africa (Appendix 1). The options that were tested were identified by farmers and the testing was conducted by the farmers themselves to promote learning by doing and to allow farmers to adapt the technology to their particular circumstances. Where possible, attention was also paid to facilitating access to inputs, especially credit and mineral fertilizers. Technologies being tested often involved combinations of locally available organic resources and the judicious use of mineral fertilizers to enhance crop yields, build up soil fertility, and improve fertilizer use efficiency.

A large variety of ISFM options have been developed and validated in the different pilot regions. At each pilot site, farmer learning groups and local facilitators exchanged experiences around learning plots. Learning plots often allowed comparison by many farmers (most of the time above ten) of one or two alternative technological options compared with common farmer practice. Plot size depended very much on the site but ranged from 0.04 ha to 0.5 ha. In some cases, one common learning plot was used per village, but generally five to ten learning plots were used per village to allow larger exposure of farmers and to ensure that results were representative of village conditions. The frequency of farmer meetings around the learning plots was also site specific. At some sites, farmers met only a few times per year (i.e., for a planning meeting, experimental set-up, at plot management periods, and at farmer field days) while some met every 2 weeks (e.g., in southern Togo). ISFM options evaluated comprised more site- and season-specific mineral fertilization, soil and water conservation methods (zaï pockets, stone bunds, vegetation strips, no-tillage), and soil amendments (phosphate rock, limestone, and organic resources) as adapted to various soils and climatic conditions and for a range of cropping systems and varieties. The following section will present selected examples of technologies that were tested and promoted at the different pilot sites within the three farming systems. A full overview of ISFM options tested is given in Appendix 1.

Agro-Pastoral Millet/Sorghum Systems

Zaï Pocket and Micro-Dose Technology (Pitting): Central Burkina Faso, Northern Niger, and Zambia—Using the zaï technique, soil physical and chemical properties of degraded soils are restored by mixing small quantities of organic resources (e.g., manure or compost) and mineral fertilizer in small holes (20–40 cm diameter and 10–15 cm depth). Rates used vary, but on average about 300 g of organic resources and about 2.5 g of mineral fertilizer (e.g., urea, DAP, or 15N–15P–15K) is used per hole. The holes are dug in alternate rows, and when digging them, the soil material is placed down-slope to harvest the runoff that is generated in the space between two holes. The number of holes per hectare varies with the crop, e.g., about 0.6 m * 0. 4 m for sorghum, and 0.6 m * 0.6 m for millet. The application of mulch between the holes enhances the effect of zaï.

The major constraints identified by partners were the workload and the risk of inundation and leaching during exceptional rain events. The technology was found to be very efficient in reducing poverty because it allowed farming on marginal, heavily degraded soils while rehabilitating them. For example, in Niger on a sandy soil, average yield improved to about 1 t ha^{1} from a low 0.2 t ha^{1} with a benefit-to-cost ratio above 5. In Burkina Faso on loamy-sandy soils, sorghum yields without zaï were essentially nil but improved to 1.4 t ha^{1} with the zaï technology. The zaï technology was mainly tested in Niger and Burkina Faso, involving five learning groups of about 15 farmers each. The technology is now spreading rapidly beyond the pilot sites (Mando et al., 2005). The project worked in partnership with local NGOs, the national extension service in the Gaya and Maradi departments in southern Niger, the Niger national research institute, and an FAO project on fertilizer inputs to test and expand the technology. In Niger, the use of inventory credit was instrumental to improved fertilizer access. In Burkina Faso, partners were the national extension agency and an IFAD investment project.

Zaï Pits Under Millet in Gaya (Niger)

In southern Africa, mainly in Zambia, an alternative type of zaï was evaluated with farmers, involving rather large size pits. Maize is planted in pits that are 0.5–1 m depth and 1.5 m apart. The pits are often filled with grass scavenged from within or outside the fields. Yields are improved from 0.5 t ha^{1} to 2.5 t ha^{1} because of improved water capture and nutrient release. There is potential to increase yields further by applying fertilizers and using higher quality residues in the pits. Despite being labor intensive, the technology is being widely adopted.

Cultivation of Maize in Pits
at Choma, Southern Zambia

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Combining Mineral Fertilizer and Organic Inputs and Water Conservation Measures: Central and Southern Burkina Faso, Northern Ghana, Southern Mali, and Northern Togo—In the savanna zones, i.e., in Burkina Faso, northern Ghana, Togo, and Mali, the ISFM learning groups tested the application of compost or manure in combination with mineral fertilizer for sorghum or maize.

In Burkina Faso and Mali, the external input was often combined with water conservation measures through the introduction of stone rows. These stone rows reduce erosion and conserve moisture. The amount of input very much depended on the sites. In the Kadiogo province of Burkina Faso, six learning groups in six pilot villages tested the application of stone lining and 5 t ha^{1} of compost, 60 kg N t ha^{1} as NPK and urea fertilizer, and 20 kg P and K ha^{1} as NPK fertilizer. In some pilot sites, phosphate rock was used as a P source. In other sites, stone rows were replaced by soil bunds or vegetation rows. On average, sorghum yields jumped from about 0.8 t ha^{1} to 2.7 t ha^{1}. Financial gains of about 145,000 to 180,000 FCFA ha^{1} year^{1} were seen when adding N through compost to both stone rows. The learning process in Burkina Faso was facilitated by the national extension authority based in the Kadiogo province, an African Development Bank (AfDB) project and local NGOs.

In northern Ghana and southern Burkina Faso where rainfall is more reliable, no water conservation techniques were used. Emphasis was on the combined use of compost and mineral fertilizer for maize and pepper production. Average maize yield was 2.6 t ha^{1} in ISFM plots with a cost-benefit ratio of about 3.5 against 0.9 on farmers' plots. These options generally resulted in yield gains of 1.5 t ha^{1}. The Savannah Agriculture Research Institute (SARI) in partnership with staff of the Ministry of Agriculture and Food at Tamale and an NGO named OIC (Opportunity Industrialization Centers) facilitated the learning process with four learning groups.

In Mali, a local NGO, AMED, and the natural resource management program of the national research institute in Sikasso facilitated the action research in villages in Koutiala and Sikasso. In these regions cotton, maize, and legumes (fodder and multi-purpose grain legumes), are often rotated with cotton; organic input is applied bi-annually (cotton year) and the whole farming systems is based on the integration of livestock and crop production. Maize only benefits from the residual effect of the compost and from fertilizers. To avoid mud, the cotton residues are brought into the kraals where they are mixed with cattle dung and their leftovers (stover and the legumes). This makes a very good manure consisting of a mixture of organic material with contrasting C/N ratio.

Manure Pitting: Zimbabwe—The sources of manure and the management strategies that farmers use are very diverse, which makes prescription of best manure utilization practices difficult. The manure produced from curing heaps is often of poor quality; hence, options are needed to improve on the efficacy of this key resource. This is not only

Compost Heap and Improved Kraal for Quality Compost Production

true from the research perspective but also from numerous discussions with farmers on their perceptions of how effective communal area manures are. One simple approach taken in the study areas was to look at ways in which farmers could manipulate biological processes to enhance quality of the manures. Anaerobic composting of manure in pits, an innovation on the conventional practice of curing manures in heaps, was proved to be an efficient process that resulted in lower N losses from the manure. The pitted manure produced higher maize yields in the first year of application than heaped manure at the equivalent N application rate of 100 kg ha^1. Residual yields, however, were lower in the second and third years in the pitted manure, but overall yields after 3 years (including the first year) were higher.

Maize-Mixed Systems

***Grain Legumes Rotated/Intercropped With Maize and P Recapitalization*—**In the maize-mixed systems where maize prices are generally declining while input prices have gone up, the project introduced grain-legumes as an alternative cash, nitrogen, and carbon source, i.e., soybean, cowpea, groundnut, C*ajunus cajan.*

In northern Nigeria, the Agricultural Research Institute (in partnership with the extension offices at regional level and an IFAD investment project) facilitated learning processes around plots with nine learning groups in nine pilot villages. In each village, over 15 small trials (learning plots) made of two to four plots were run. In the plots, maize and soybean, or sorghum and soybean, were interplanted in two alternate rows and changed rows in subsequent years. On these plots P was applied as phosphate rock at the rate of 180 kg P_2O_5 ha^1. N was applied as urea at 150, 45, and 20 kg ha^1 for maize, sorghum, and soybean, respectively. Yield was doubled in some pilot sites compared with control (5 versus 2.5 t ha^1 of maize).

In central and northern Togo and southern Benin, multi-stakeholder platforms also facilitated the learning process around learning plots where legumes (groundnuts, soybean, and cowpea) were rotated or intercropped with maize. Fertilizer rates and types depended on the learning group and their local conditions. In the coastal zones, the legume is grown during the short rainy season and maize during the long rainy season. Legume residues were returned directly to the farm as nitrogen and carbon inputs, except in northern Nigeria and Togo where residues were often fed to animals and manure was taken to the farms. In the above sites, maize yield ranged from 0.8 to 1.2 ha^1 on farmers plots and 3 to 4 ha^1 on plots with improved technology.

Intercropped Plot: Maize and Soybean

Mucuna Short Fallow

In the coastal savanna zone of West Africa, rainfall has a bi-modal distribution. The main rainy season lasts from March to July and the minor season from September to November. A major cropping system involves the cultivation of maize during the first season and again maize or cowpea during the second season. However, rains during the second season are not very reliable. Project partners and farmers tested cultivation of a maize crop during the first season and a cover crop (mucuna) during the second season. Mucuna was sown 45 days after sowing maize at a density of 0.8 m by 0.8 m (one seed per hole) and left as a cover crop during the short rainy season. Mucuna sowing is done during the second weeding. In southern Togo two NGOs (CREMA, C2D), the national extension service (ICAT), the national agricultural research institute (ITRA), a local rural bank, and two farmer unions facilitated the development of the mucuna-based technological option. About five learning groups (including over 12 farmer-based organizations and hundreds of farmers) were involved. Action-research was aimed at developing site-specific fertilizer application rates on maize and cassava following mucuna fallow. In Benin, a multi-stakeholder platform that included the agricultural research institute, extension services in two departments, and a local NGO facilitated the action research with six learning groups. Mineral fertilizers and phosphate rock were used. The participatory assessment of the technology from over 40 farmers' fields indicated that the system is highly profitable (Table 4)

Table 4. Performance of Mucuna and Fertilizer-Based ISFM Options in Southern Togo (Averaged Over 40 Farmers)

Technological Option	Maize	Cassava	Maize + Cassava	
	Yields t ha^{-1}	Yields t ha^{-1}	Total Net Benefit of the System (Euro)	Total Revenue (Euro)
Farmers practice (no mucuna and no fertilizer)	0.9	13	–7	124
Farmers practice (no mucuna and with fertilizer)	1.8	17	130	370
Mucuna + fertilizer	4.2	33	1,450	2,075

Mucuna Dry and Green Biomass on Farm in Southern Togo

Chapter 6
Improved Understanding of ISFM Interactions

Strategic research trials conducted within this project focused on an improved understanding of ISFM interactions at field level. A field-level ISFM framework was used to guide experimental design and data analysis, which is briefly explained below. For more details see the ISFM manual.

To improve ISFM recommendations to farmers, it is important to have a "farm perspective" in mind. Nutrients that are benefiting one field are often a loss to others. Farmers need, however, also best-bet recommendations for nutrient allocations for a range of fields. Yields obtained in farmer fields depend, among others, on nutrient levels in the soil, i.e., indigenous soil fertility (the "yield floor") and on climate-determined potential yield (the "yield ceiling"). The project used the following field-level ISFM framework to determine best-bet ISFM options for farmers to reach target values for yield and soil fertility, given crop management technology (choice of crop and variety, sowing date, crop establishment method, etc.), site (soil and weather conditions), input and output prices, and financial means of the farmer. The framework is adapted from Dobermann and Cassman (2002) and Haefele et al., (2002) and accounts for:

1. **Regional and Seasonal Differences in Yield Potential—**In principle, crop simulation models could help determine yield potential. If no crop simulation models are available or data to run such models are lacking, yields of best farmers or from experimental stations can serve as a proxy for potential yield.

2. **Indigenous Soil Nutrient Supplying Capacity—**Knowledge of the soil nutrient supplying capacity is crucial to site-specific ISFM, especially if the use of external inputs is limited (Haefele et al., 2003). Soil tests exist that permit estimation of soil nutrient-supplying capacity. However, these are often rather unreliable and not within reach of the average farmer in sub-Saharan Africa. For example—for lowland rice—no good soil tests exist to determine indigenous nitrogen supply (Dobermann et al., 2002). An alternative is to determine soil nutrient-supplying capacity through small nutrient-omission plots, where the nutrient of interest is deliberately not applied. The soil nutrient-supplying capacity is then estimated from crop nutrient uptake in that particular plot. Wopereis et al. (1999) and Witt et al. (1999) provide successful examples of this approach. Soil nutrient-supplying capacity varies widely among fields and seasons and is often related to some extent to soil organic matter content, although no clear relationship has been established for irrigated lowland rice fields (Cassman et al., 1996). Farmers could rely on such small nutrient-omission plots (and move them every year to another location to avoid prolonged soil nutrient depletion) to guide fertilizer applications before crop emergence (especially P and K fertilizers).

3. **Uptake, Recovery, and Residual Effects of Fertilizer Nutrients—**Recovery of fertilizer nutrients is key to ISFM. For rice, extensive knowledge is available on average recovery of N, P, and K in West Africa (Wopereis et al., 1999; Haefele et al., 2003) and Asia (Witt et al., 1999). Not much knowledge seems to be available on the recovery and residual effect of nutrients applied through organic amendments (manure, compost) and phosphate rock. Interactions between organic and mineral fertilizers may result in synergic effects. In the context of fertilizer N, which is the nutrient most susceptible to losses, direct interactions may be the result of microbial-mediated changes in the availability of the fertilizer N, due to the addition of available C. This interaction may lead to

temporary immobilization of applied fertilizer N; this may in turn improve the synchrony between supply and demand for N and improve fertilizer-N recovery by the plant. Indirect interactions are the result of a general improvement in plant growth and demand for nutrient by alleviation of another growth-limiting factor.

4. **Relationship Between Nutrient Uptake and Yield Formation—**The relationship between nutrient uptake and rice yield is not linear. Janssen et al. (1990) used two linear envelope curves to describe maximum accumulation and maximum dilution for nutrients to reach a particular yield level and used these to derive linear-parabolic yield curves as a function of nutrient uptake (N, P, and K in the present version of QUEFTS). Envelope curves for rice were developed by Witt et al. (1999) for Southeast Asia and Haefele et al. (2003) for West Africa.

5. **Dynamics of Nutrient Demand During the Cropping Cycle (Especially N)—**For most crops, the dynamics of demand for nutrients during the cropping cycle is well known. For rice, N application is needed at mid-tillering to boost tillering (“horizontal growth”), panicle initiation (“vertical growth”) and near booting (grain filling). Simulation models exist that can predict phenology as a function of sowing date and weather data. Such models can, therefore, guide farmers with optimal application dates for N. In practice, farmers will rely on expert knowledge for information on best timing of nutrient applications.

6. **Synergies Derived From Simultaneous Use of Organic Amendments and Mineral Fertilizers—**Very little information is available on synergies that can be derived from the use of organic amendments and mineral fertilizers. There is a need to understand how combined use of organic amendments affects the indigenous soil nutrient-supplying capacity (including residual effects), recovery of nutrients from mineral sources and internal nutrient efficiency (by addressing other yield limiting factors, e.g., other nutrients, water stress, etc.). If the indigenous soil nutrient-supplying capacity is improved over time, recovery of nutrients from mineral sources may decline because of declining returns to nutrient uptake as yields approach the yield ceiling. However, the nutrient uptake to yield curve is linear up to 70%–80% of the climatic yield potential, and farmers’ yields are often far below this level.

7. **Local Financial and Risk Considerations** (prices of inputs, such as labor and fertilizer prices and prices of produce; farmer purchasing power)—Recommendations need to be based on the socio-economic context (input and output prices), and allow for differences in farmer purchasing power. For example, if farmers can afford to buy only one bag of fertilizer, advice should be available to guide them about what to buy. Examples of how this can be done have been given by Haefele and Wopereis (2004).

8. **Crop Management Practices** (land preparation methods, crop establishment methods, soil and water management, etc.) and production systems (crop rotations, associations)—Crop management practices other than soil fertility management can determine to a large extent how effective ISFM is in practice. Neglected weed management is just one typical example. ISFM recommendations need to take peculiarities of crop management and production systems (e.g., maize-cassava associations) into account. Ultimately, ISFM recommendations should be developed that are specific for given crop management and production systems.

A number of strategic research trials were conducted to obtain improved knowledge of certain parameters in this framework for the three farming system studies, such as dynamics and variability of nutrient supplying capacity, fertilizer recovery, and insight in internal nutrient use efficiency for various crops, etc. Highlights are given below.

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Burkina Faso: Benefits of Integrated Soil Fertility and Water Management

Unreliable rainfall, inherent low soil fertility, and crust-prone soils affect crop growth in the semi-arid zone in Burkina Faso, resulting in low crop yields and recurrent food shortage. Increasing population pressure requires enhanced soil, water, and nutrient productivity. More efficient use of rainwater and soil nutrients is essential in this region. The ISFM project worked on physical barriers of runoff (vegetation bunds, stone rows, etc.) and pitting (the zaï technique) in order to increase water infiltration and on the judicious use of external inputs (compost, mineral fertilizer) in northern Ghana, Niger, Mali, and northern Togo. The synergistic effect of soil and water conservation (SWC) measures and nutrient inputs emerged in all the pilot sites as the best way to reduce runoff and soil loss and to improve nutrient use efficiency and crop yield.

This can be best illustrated through work conducted in partnership with INERA-Burkina Faso on the combined use of runoff barriers (stone lining or grass strips) and organic or mineral nutrient sources. Compared with control plots, the average reduction in runoff was 59% in plots with barriers alone, but reached 67% in plots with barriers + mineral N and 84% in plots with barriers + organic N. Plots with no SWC measure lost huge amounts of soil (about 3 t ha^{1}) and therefore nutrients (Figure 6). The results of 2 years of measurement showed that annual losses from eroded sediments and runoff reached 84 kg ha^{1} for OC, 16.5 kg ha^{1} for N, 2 kg ha^{1} for P, and 1.5 kg ha^{1} for K in the control plots with no SWC measures. The total soil loss from plots with stone rows and grass strips were respectively as important as only 30% and 42% of the losses from control plots. The application of compost leads to the reduction of total soil loss by 52% in plots without barriers and by 79% when applied in plots with stone rows compared with the losses in control plots. The application of urea in plots with and without soil conservation barriers also resulted in significant decreases in soil loss (Figure 6). Stone rows or grass strips without N input did not induce a significant increase in sorghum yield. Supplying compost or manure in combination with stone rows or grass

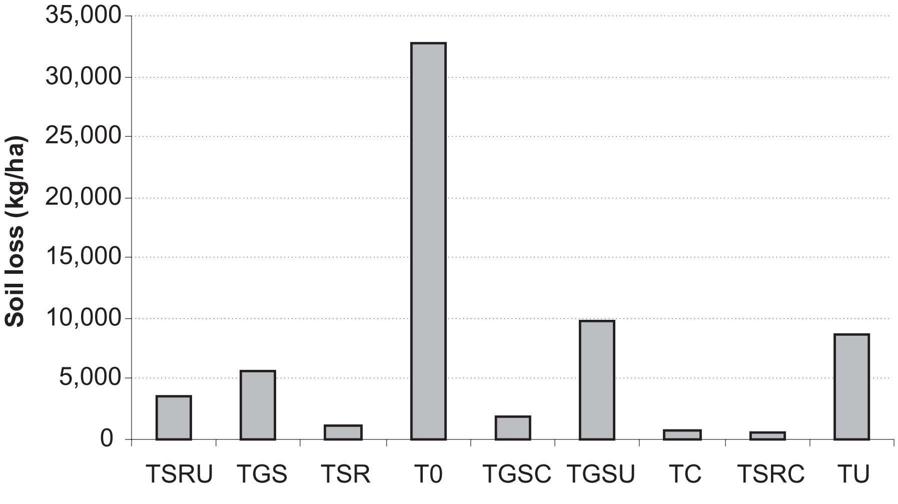

Figure 6. **Effect of Treatments on Total Soil Loss in 2002 at Saria, Burkina Faso; for T0: No SWC Measures, No Nitrogen Supply (Control Plot); Tsr: Stone Rows, No Nitrogen Supply; Tgs: Grass Strips, No Nitrogen Supply; Tsrc: Stone Rows + Compost; Tgsc: Grass Strips + Compost; Tsru: Stone Rows + Fertilizer N; Tgsu: Grass Strips + Urea**

strips increased sorghum grain yield by about 142% (0.8 t ha^1 versus 2.5 t ha^1), compared with a 65% increase due to mineral fertilizers (0.8 t ha^1 versus 1.7 t ha^1).

The integration of water and nutrient management through the combination of SWC measures and the application of organic or mineral N inputs improved water use efficiency and nutrient uptake by the sorghum crop.

The technology results in financial gains of about 145,000 to 180,000 FCFA ha^1 year^1 when adding N through compost to both stone rows and grass strips and about 70,000 FCFA ha^1 year^1 when adding urea during a year with good rainfall. In drought years very little additional benefit is obtained from urea. Under the particular conditions of the experiment with moisture as a constraint, compost was more efficient because it provided not only nutrients but also contributed a lot to moisture conservation through improved soil structure. Results show the importance of combining SWC and nutrient management. Without nutrient inputs, SWC measures hardly affected sorghum yields, and without SWC, fertilizer inputs also had little effect. However, combining SWC and nutrient management caused a jump in sorghum yield.

Crops Behind Vegetation Band in Burkina Faso. Zougmoré, 2003

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Combined Use of Mineral Fertilizer and Organic Inputs Under Semi-Arid Conditions

Many studies in the semi-arid zone suggest that soils are rapidly degrading and that soil fertility depletion in smallholder farms is the fundamental biophysical root cause for declining per capita food production in SSA. Enhanced agricultural productivity in SSA therefore requires measures to reverse nutrient depletion and to increase nutrient and water (both rainfall and irrigation) use efficiency in the farming system. The project worked on judicious use of mineral fertilizers, in combination with locally available soil amendments, such as organic inputs (straw, compost, and fallow legumes). Our results suggest that single fertilizer use is not beneficial for crop production under most prevailing conditions in semi-arid rainfed systems. The data highlighted low fertilizer use efficiency by crop (Figure 7). Combining mineral fertilizers with organic resources resulted in improved nutrient and water use efficiency. The combination of fertilizer and organic resources with a low C/N ratio gives a better return than combining fertilizers with organic resources with a high C/N ratio, especially when rainfall is well distributed. Soil and water conservation measures are a prerequisite to the productive use of organic inputs and mineral fertilizers under semi-arid conditions. These conclusions can be illustrated by a trial conducted in Burkina Faso on a ferric lixisol under Sudano-Sahelian conditions and during the wet and dry seasons (average rainfall about 700 mm). This trial investigated the effect of tillage method, fertilization and their interaction effects on soil carbon and crop performance. Maize straw (high C/N ratio ranging from 59 to 90), sheep dung (low C/N ratio ranging from 19 to 25) or urea, were applied separately or in combination under a till and a no-till system. The experiment was a split-plot design with three replications (blocks) with tillage and no-till as the main treatments. The sub-treatments consisted of C = control (0 N), U = urea (40 kg N ha^1), U 80 = urea (80 kg N ha^1), SD = sheep dung (40 kg N ha^1), SD+U = sheep dung (40 kg N ha^1) + urea (40 kg N ha^1), S = maize straw (40 kg N ha^1), CO = compost (40 kg N ha^1), S+U = maize straw (40 kg N ha^1) + urea (40 kg N ha^1). Sorghum yield response to single or combined N doses in the 2 years that this trial was conducted show a number of features that are consistent across the years and the treatments.

In 2000 (low and erratic rainfall; less than 500 mm), with organic inputs in tilled plots, the highest yield was observed in sheep dung plots (1.83 t ha^1), i.e., a significant increase of 78% compared with the control. No significant increase was observed in straw plots compared with the control. In no-till plots, yield increased significantly by 265% in the sheep dung treatment and 184% in maize straw treatment compared with the control as the improved moisture content of the soil. With urea, no significant differences with control plots in crop yield were observed in tilled plots. Although not significant, yield in U80 and tilled plots was lower than the control (–24%) as a result of moisture shortage at later stages. When organic inputs and urea were combined, sorghum grain yield was significantly higher than the single addition of organic input or fertilizer. In 2001 with better rainfall distribution, single urea application increased sorghum grain yield significantly compared with the control, but yields were still significantly lower compared with other treatments. When organic resources and urea were combined in tilled plots—yields were significantly higher than single application organic resource or fertilizer. Yields in sheep dung plots + urea were twice as high as in the control and were significantly different from other treatments including straw + urea plots.

This study showed that under deficient rainfall conditions, crop performance was increasing with a decreasing C/N ratio of added-organic resource and the addition of urea to organic resource led to an increased yield. Yields were far greater in sheep dung plots compared with straw plots. The increase in yield due to urea addition was also increasing with increasing C/N ratio of the organic resource. The use of single organic resource at an equivalent dose of 40 kg N ha^1 resulted in higher crop yield than application of an equivalent amount as urea-N in the semi-arid West African sandy soils. Combining organic resources and fertilizer was found to be a better strategy for increasing crop yield than applying the same N amount in the form of urea. This is a result of an improved fertilizer recovery rate due to nutrient uptake and use efficiencies. Improved nutrient uptake/use efficiency is linked to many factors such as reduced leaching due to temporary immobilization, improved water use efficiency, and increased decomposition of organic matter as a result of the fertilizer mediated boost of the activity of soil micro-organisms. However, economic benefits will depend on amount and pattern of rainfall (determining water and nutrient use efficiency) and sorghum and nutrient input (fertilizer, compost) prices. Hardly any economic benefit was achieved with single urea application especially at high dose. The use of soil and water management measures is a key to increase the economic benefit of mineral, organic or combined organic and mineral sources of nutrient application under semi-arid conditions. We conclude that farmers in semi-arid West Africa should not view mineral source of nutrients as a replacement solution for organic resources but as complementary inputs.

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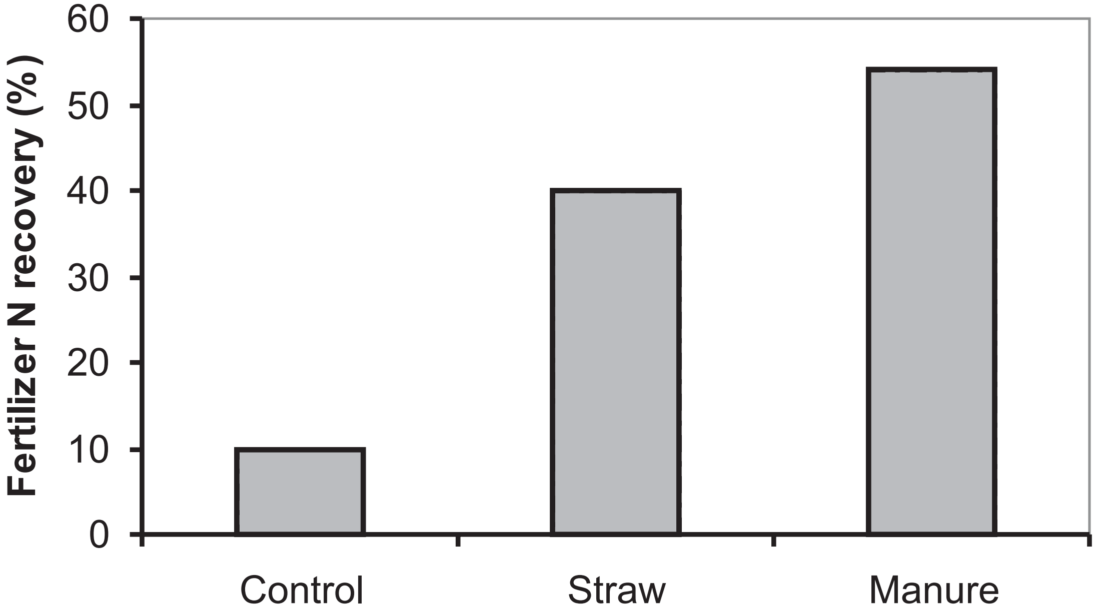

Figure 7. **Nitrogen Recoveries as Influenced by Organic Input Quality Under Sudano-Sahelian Conditions (Mando et al., 2005)**

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Ipomoea stenosiphon as a Soil Fertility Ameliorant in Zimbabwe

Ipomoea stenosiphon (Hall) A. Meeuse (local name-Gubvuwa), a plant species indigenous to Zimbabwe was studied to identify its potential to mineralize N in comparison with other agroforestry species and to determine its fertilizer equivalence (FE) value when used as a green manure in the semi-arid areas of Ngundu and Shurugwi, Zimbabwe. Prunings of the plant are reportedly in use for soil fertility by some farmers in Ngundu although the practice is not widespread. The organic amendments used in the study included *Acacia angustissima, Cajanus cajan, Leucaena leucocephala, Calliandra calothyrsus, Leucaena diversifolia, Leucaena esculenta, Leucaena pallida, Macroptilium atropurpureum, Lablab purpureus and I. stenosiphon. I. stenosiphon* significantly mineralized more nitrogen ($P<0.05$) compared with the other species except for *Leucaena leucocephala* and *Acacia angustissima* because of their higher N content of 3.23% and 3.03%, respectively, compared with 2.27% for *I. stenosiphon* (Figure 8).

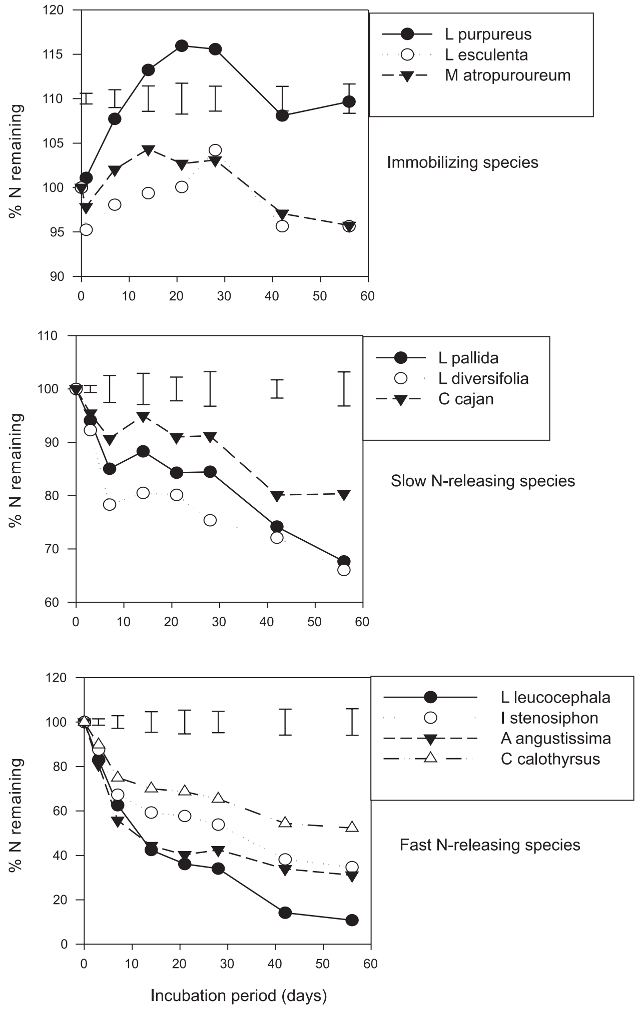

Figure 8. N Mineralization From *I. Stenosiphon* and Other Agro-Forestry Species

For most species, the highest amount of N was released within the first 2 weeks (Figure 8). The nitrogen FE (fertilizer equivalence) values for Ngundu and Shurugwi were 81 and 85, respectively, and 85 and 107 for phosphorus. Application of *I. stenosiphon* in Ngundu and Shurugwi as a source of N gave maize grain yield 128% and 161% more than the control treatment. *I. stenosiphon* was better as a source of P than N. High P and N fertilizer equivalence values were obtained in this study. Such high values have also been reported in other studies for different organic materials. Tithonia, *Senna spectabilis,* and calliandra had 119%, 72%, and 68% fertilizer equivalencies, respectively (Kimetu et al., 2003). *Senna spectabilis* has also been recorded to have an FE % of more than 139% in a study by Murwira et al. (2002). *I. stenosiphon,* as a high quality material with low (lignin + polyphenols) N ratio, can be applied directly to the soil as a source of both P and N. The P fertilizer equivalence was more than 100% in Shurugwi, an indication that it performed better than mineral fertilizer. This can also be attributed to its high P content of above 0.25%, the critical value for P mineralization. *I. stenosiphon* has additional effects of other nutrients like Ca, Mg, and K. These other nutrients are not present in mineral fertilizers. Fertilizer equivalence values below 100% for N indicate that an equivalent rate of N application in mineral form would do better than the inorganic form.

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Benefits of Legumes in Farming Systems

Fertilizer use in many subsistence agricultural systems remains insufficient to meet the N demand of crops. The project, therefore, explored a number of ways of incorporating N_2-fixing grain legumes into cropping systems and of improving fertilizer use efficiency through legumes. The broad objectives of the studies on integrating legumes into cropping systems were to establish the influence of soil biophysical conditions on the productivity of a range of annual N_2-fixing legumes in different agro-ecological zones, and to determine N uptake and N recovery by the following rotational maize crop. Studies were conducted in Zimbabwe, Malawi, and Zambia.

In Zambia, the study was conducted on 24 smallholder farms in two districts: Murehwa communal area and Shurugwi (18°S, 30°E) between November 2001 and May 2004. The mean annual rainfall is 750 mm for Murehwa and 650 mm for Shurugwi and occurs during a uni-modal rainy season extending from November to April. Murehwa’s experimental sites ranged from red and black clays to sands, whereas all sites in Shurugwi were of sandy texture. The soils in Shurugwi are largely derived from granite and are generally infertile. N and P deficiencies limit crop production. The experimental design enabled comparison of grain and green manure legumes for their ability to replenish soil N and support rotational maize. The treatments were: (1) *Mucuna pruriens*, (2) *Crotalaria juncea*, (3) *Crotalaria grahamiana*, (4) *Glycine max* (soybeans), (5) *Cajanus cajan* (pigeon pea), and (6) *Vigna unguiculata* (cowpea).

In Malawi, the experiment was carried out at three sites—Lisasadzi, Vangalala, and Bembeke. Lisasadzi has sandy soils and receives high and reliable rainfall of 700–1,000 mm annually. Vangalala is receiving generally less than 700 mm rainfall annually. Bembeke site has acid soils with high P fixation and receives an annual rainfall of 900–1,200 mm. At each of these sites, five types of legumes were planted (soybean, mucuna, cowpea, *Crotalaria juncea*, and *Crotalaria ochroleuca*). During the second season, all plots were cropped with maize to utilize residual N from the previous season. Unfertilized maize was included at each of these sites to set the lower boundary for maize yield potential and to be able to estimate legume N recovered by the maize crops.

In Zambia, four legumes (mucuna, *C. juncea*, soybeans, and cowpea) were planted at five farms in Kabwe, Misamfu, Muswishi, Mungwi, and Chimuka. Muswishi and Mungwi are in the medium rainfall areas with annual rainfall of 600–800 mm; Kabwe and Misamfu are in high rainfall zones (800–1,200 mm per year). All sites, except Kabwe, had low available P content of <7 mg kg^1.

Legume Productivity, Biological N_2-Fixation, and Maize Yields

In Zimbabwe, the across-site mean biomass production of mucuna and *C. juncea* of 2.3 t ha^1 was significantly higher than the other legumes at sites in Murehwa, whereas *C. grahamiana* produced significantly higher biomass in the Shurugwi sites. In the Shurugwi sites, *C. juncea* had the least mean biomass yield across the sites while cowpea produced the lowest biomass in the Murehwa sites. Following the biomass production trend, mucuna and *C. juncea* had the highest N inputs of 70 kg ha^1 while cowpea residues contributed only 25 kg ha^1 in Murehwa sites (Table 5). In Shurugwi, *C. grahamiana* accumulated as much as 100 kg N ha^1 while *C. juncea* performed poorly and only accumulated 20 kg N ha^1. At least two-thirds of the accumulated N was derived from biological N_2 fixation. Maize in plots that previously had *C. juncea* had the highest yields across most sites (that averaged 2.2 t ha^1), and this was closely linked to the large amounts of N added. Despite large differences in N input through the legumes, there were no significant treatment effects on grain yield on a number of sites. The plots that had no legume crop the previous season (the control) had the lowest maize yields of 0.5 t ha^1. Although cowpea had significantly low N input, the maize yields were not significantly different from the green manure treatments. *C. cajan,* which had poor biomass production the previous season, produced poor subsequent maize yields compared with other green manure treatments (Figure 8). Generally the early-incorporated legumes gave higher maize yields than the late-incorporated legumes because the late-incorporated legumes were woodier and lignified and had lost some of the N during seed formation. However, there were no overall treatment differences when residual effects were summed up over 3 years. This has important implications on labor use and choices that farmers can take. Early incorporation is likely to give more immediate benefits than late incorporation; for labor constrained households, the optimal choice would be the latter.

In Malawi, the soybeans gave the lowest biomass yields at the three sites while *C. juncea* and *C. ochroleuca* gave high biomass yields. Biomass

Table 5. Mean Biomass Production, Total Legume N Added (kg ha^1), and Biological N_2-Fixation by Legumes Grown on Several Smallholder Farms in Two Communal Areas in Zimbabwe. SEM = Standard Error of Mean of the Added N, Range = Largest–Lowest N Yield

Area	Legume Species	Number of Sites	Biomass (kg ha^{-1})	N Added (kg ha^{-1})	% N_2-Fixation	Range of Added N	SEM
Murehwa	Cowpea	14	836	25	70	43	3.3
	C. grahamiana	14	1,732	52	65	45	4.5
	Mucuna	14	2,330	70	76	91	7.2
	C. juncea	14	2,312	70	65	102	9.4
Shurugwi	Cowpea	11	831	25	70	58	6.9
	C. grahamiana	11	3,260	100	65	88	13
	Mucuna	11	1,562	47	76	139	11
	C. juncea	11	662	20	65	35	4.4
	Soybean	11	2,216	67	84	172	18.5

yields of the legumes, except for soybeans, were not significantly different at all sites. Surprisingly, cowpea, which is primarily a grain legume, produced large biomass that was equivalent to that of mucuna at the Vangalala and Lisasadzi sites. The Bembeke site had the lowest biomass yields with none of the legumes achieving 1 t ha^{1}, probably because of the acidic nature of the Bembeke soils, which could have hindered crop growth. Of the three sites, Lisasadzi had the highest biomass yields although the soil texture was sandy, and except for soybean, N addition was at least 350 kg ha^{1} (Table 6). At the Vangalala site, all legumes derived at least 90% of their accumulated N from fixation. Sharply contrasting to this was the Bembeke site where the legumes failed to establish well and thus fixed N poorly. Maize yields were significantly greater than for the unfertilized maize for all the legume treatments except soybean. At Lisasadzi, cowpea resulted in the highest maize grain yields of 1.8 t ha^{-1}, compared with 0.8 t ha^{1} for the control. At Vangalala all legumes significantly increased maize yields. Results from the Bembeke site were rather unexpected. Despite very poor legume growth and N added, maize yields were significantly higher than the control for all treatments except soybean.

Results for legume productivity in Zambia (Table 7) show that there was significant site effect on legume productivity ($p<0.01$). Crotalaria produced a minimum of 8.3 t ha^{-1} biomass and as much as 16 t ha^{-1} at the Muswishi site. Mucuna had biomass >10 t ha^{1} at two of the sites. Soybean performed poorly at the acidic Misamfu site, while cowpea failed to produce meaningful biomass at the two sites where it was grown (Table 7). Generally, mucuna and *Crotalaria* accumulated large amounts of N that could be adequate to support the rotational maize crop if other nutrient limitations for N uptake are removed.

The Challenge to Integrate and Increase Legume Production

Mucuna and *C. juncea* produced fairly large amounts of biomass and had high rates of N_2 fixa-

Table 6. Legume Productivity, Total Above-Ground Legume N Returned to Soils, and Estimated Percent Nitrogen Recovery by Maize Grown on Two Sites in Malawi

Site	Legume type	Legume Biomass (kg ha^{-1})	Legume N Added (kg ha^{-1})	Maize Yield (kg ha^{-1})	Total N Uptake	% N Recovery
Lisasadzi	C. juncea	15,600	468	1,481	34	4
	C. ochroleuca	13,467	404	1,552	29	3
	Cowpea	13,400	380	1,828	38	5
	Mucuna	12,800	360	1,237	29	3
	Soybean	1,267	26	1,125	25	19
	Control	-	0	814	20	-
	C. juncea	5,600	159	1,544	30	13
Vangalala	C. ochroleuca	13,733	410	1,604	32	6
	Cowpea	6,133	184	1,713	34	13
	Mucuna	5,600	168	1,333	28	11
	Soybean	3,600	108	1,119	23	12
	Control	-	0	474	10	-

tion while *Cajanus cajan* failed to produce useful amounts of biomass at sandy sites in Zimbabwe. The pooled data for legume productivity and N cycling for all sites show the wide variability in the performance of both green manure and grain legumes in the region. In Zimbabwe, mucuna has traditionally not been for human consumption. While our focus is on soil fertility buildup for subsequent maize crops, the farmers' production objectives are to meet immediate food security needs. Successful mucuna integration is dependent on many factors. During evaluation of mucuna, farmers in Benin realized that the immediate opportunity cost of the lost crop due to the mucuna cover crop was higher than the future benefits of mucuna green manure. Use of mucuna residue as fodder for livestock and enhancing the edibility of mucuna seeds for humans by removing the toxic L-Dopa could be a way of dealing with the constraint (Carsky et al., 2001).

Soybeans failed to accumulate meaningful biomass at most sites in Zimbabwe, but results from Zambian sites were encouraging. As a grain legume that has been bred to efficiently translocate N to the seed, soybeans will not be able to replenish N to high levels in already degraded soils. The poor biomass productivity in Zimbabwe by *Cajanus cajan* reported in this study only confirms earlier findings by Mapfumo et al. (1999), who reported N fixed on several farms on very sandy soils to be largely less than 20 kg ha^{1}. The growth and biomass production of these legumes might be improved if P fertilizer was applied. However, this option is not feasible under current farmer circumstances in most smallholder farms in southern Africa. Currently soil fertility management practices that require farmer's investment through use of mineral fertilizer to boost productivity of a non-food legume crop for soil fertility restoration do not seem to appeal to most farmers.

The results presented in this study have shown that N uptake and recovery after green manures are poor in most cases. The large N input through the large legume biomass is seldom translated into grain N of the subsequent maize crop. It is also clear from the data from the different sites that green manuring technology is a technically sound system under most biophysical conditions (except

Table 7. Legume Productivity, and Total Above-Ground Legume N Returned to Soils on Five On-Farm Sites in Zambia

Site	Legume Type	Legume Biomass (kg ha^{-1})	Legume N Added (kg ha^{-1})
Chimuka	Mucuna	3,783	113
	Crotalaria	8,314	250
	Soybean	1,959	59
Misamfu	Mucuna	10,000	300
	Crotalaria	10,167	305
	Soybean	792	23
Mushishi	Mucuna	4,302	129
	Crotalaria	16,216	486
	Soybean	2,308	69
	Cowpea	153	4
LSD (0.05)		1,445	24

very sandy and degraded soils), and the successful integration of the technology in farming systems has to be through identifying niches based on socio-economic considerations rather than biophysical ones.

Dual-Purpose Legumes

Grain legume species bred with large N harvest indices will lead to negative N soil balances because the N from biological N_2 fixation and returned to the soil through biomass will be lower than the amount of N sourced from the soil. Some grain legume varieties, however, export little soil N from the soils. Typically, long duration cowpea varieties used by many smallholder farmers have low harvest indices and residual benefits are expected to be large. In many experiments, grain legumes with high N harvest indices like some soybean varieties have increased subsequent maize yields in rotations, suggesting that factors other than N alone contributed to the yield increases in these cereal-legume rotations. Cowpea is grown to primarily provide household food needs, but some farmers produce surplus for sale. The challenge is to help smallholder farmers to move rapidly beyond subsistence needs to produce marketable cowpea and open opportunities for sustainable improvement in income. The challenges in the adoption of green manure legumes like mucuna will be met if there is another focus of using them as dual-purpose legumes—for soil fertility replenishment as well as for animal feed.

The range of legume options available for use on depleted sandy soils is narrow. Mucuna is remarkably adapted to harsh soil conditions and fixes the bulk of the N it accumulates without added P, but requires substantial labor and does not yield a directly usable product. Legume green manures and grain legume/cereal rotations are not enough in themselves to overcome major nutrient deficiencies in soils that are already very degraded in both N and P. This limits N use efficiency that is added through the legumes. Where both soil organic matter and P contents are very poor, legumes may not accumulate significant amounts of biomass, and when they do so, N use efficiency will invariably be poor due to other nutrients becoming more limiting. Thus, for the subsequent maize crop to effectively utilize the legume N, other deficient nutrients will have to be added through mineral fertilizers. The ISFM project has therefore promoted the application of fertilizer targeted at both the legume and the crop in all the pilot sites. The type of legume to be promoted on a specific site very much depends on the results of a thorough diagnosis. An example of such work is reported below.

Further Reading

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Nutrient Allocation Strategies for In- and Outfields in Northern Togo

Maize grain yield and response to N (0, 50, and 100 kg ha^{1}) and P fertilization (0, 15, and 30 kg ha^{1}) were determined for fields of four farmers differing in organic input history in the Sudan savanna zone of northern Togo over a period of 3 years. Each farmer selected a field that had benefited from long-term organic fertilizer inputs close to his family homestead (infield) and another field receiving considerably less or no organic fertilizer inputs (outfield). Soil organic C content was 13.4 g kg^{1} for infields and 6.3 g kg^{1} for outfields. Maize yields on infields were consistently 1.0 to 1.5 t ha^{1} higher than on outfields with and without fertilizer. Average recovery fractions of applied N fertilizer (RFN) were significantly ($p = 0.01$) higher on infields compared with outfields over 3 years (0.41 versus 0.33 kg kg^{1}). However, the agronomic efficiency of applied N (AEN) was similar over 3 years (19.0 kg grain kg^{1} N), comparing favorably to the relative cost of N fertilizer (4.0 kg grain kg^{1} N). The greatest differences between outfields and infields were observed in 2001 due to low and erratic rainfall. In that year, gains of infields over outfields were highly significant in terms of maize yield (from 0.8 to 2.0 t ha^{1}), RFN (from 0.21 to 0.33 kg kg^{1}), and AEN (from 9.4 to 14.4 kg grain kg^{1} N). Phosphorus had only a minor and, in most cases, non-significant effect. Highest N recovery rates were consistently obtained on infields using 50 kg N and 15 kg P ha^{1}. Results indicate that judicious use of mineral fertilizer (i.e., taking into account the indigenous soil nutrient supplying capacity and targeting yield levels below 80% of climate-determined yield) should be promoted on relatively fertile infields rather than on poorer outfields. This strategy would lead to reduced production risk in years with low rainfall, higher fertilizer recovery, and increased productivity.

In northern Togo, nutrient-omission trials identified N as the nutrient most limiting maize yield, both on compound fields (which had benefited from long-term organic fertilizer inputs close to the family homestead) and outlying fields (receiving considerably less or no organic fertilizer inputs). Soil organic C content was 13.4 g kg^{1} for compound fields and 6.3 g kg^{1} for outlying fields. This very large difference in soil fertility meant that maize yields on compound fields were consistently 1.0 to 1.5 t ha^{1} higher than on outlying fields. The current blanket recommendation for maize in northern Togo places great emphasis on P that is unnecessary and especially wasteful of resources on compound fields, which already contain large amounts of available P. This was observed through the nutrient-omission plots and through conventional laboratory analyses. Such observations are now being picked up by farmers.

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Maize-Mucuna-Cassava in Southern Togo

Maize and cassava are the main food crops grown by farmers in the coastal savanna region of Togo on degraded soil (rhodic ferralsols), low in soil K-supplying capacity, and non-degraded soil (plinthic acrisols). Agronomic trials were conducted from 1999 to 2002 on both soil types to investigate the impact of N and P fertilization and the introduction of a mucuna short fallow (MSF) on yield, soil N-supplying capacity (INS), N internal efficiencies (IEN), and N recovery rates (RFN) of maize. In all plots, a basal application of 100 kg K ha^{1} was applied to the maize crop. Maize and mucuna crop residues were incorporated into the soil during land preparation. Treatment yields were mostly below 80% of CERES-MAIZE simulated potential maize yields (limited by weather conditions only), indicating that nutrients were more limiting than weather conditions.

On degraded soil, maize yields jumped from a low 0.4 t ha^{1} to 2.8 t ha^{1} from 1999 to 2001 without N or P application nor MSF. This illustrates the importance of K application on these soils and incorporation of maize crop residues. In 2002, yields were stable or declined slightly because early drought affected seed establishment to some extent. Application of N and P mineral fertilizer resulted in yield gains of about 1 to 1.5 t ha^{1}. With MSF, additional yield gains of between 0.5 and 1.0 t ha^{1} were obtained at low N application rates and no decline in yield was observed in 2002, presumably because the mucuna mulch allowed better moisture conservation and seed establishment. INS increased from 10 to 42 kg ha^{1} from 1999 to 2001 and to 58 kg N ha^{1} with MSF. In the third year (2002), RFN averaged 0.32 kg kg^{1}. Application of P resulted in significant improvements in RFN and greatest gains were obtained with MSF (maximum observed RFN was 0.56 kg kg^{1} with MSF, 50 kg N ha^{1}, and 40 kg P ha^{1}). MSF did not significantly affect IEN, which averaged 45 kg grain (kg N uptake)^{1}.

On non-degraded soil and without N or P application, nor MSF, maize yields were about 3 t ha^{1} from 1999 to 2001, with INS ranging from 55 to 110 kg N ha^{1}. Application of 40 kg P ha^{1} resulted in significant maize yield gains of between 1.0 (1999) to 1.5 (2001) t ha^{1}. Average RFN was 0.22 kg kg^{1}. Inclusion of MSF did not significantly improve maize yields and even decreased RFN as determined in the third cropping year (2001). Average IEN was 43 kg grain (kg N uptake)^{1} and increased only slightly in the third year because of reduced N uptake at comparable yield levels.

Results illustrate the importance of site-specific integrated soil fertility management recommendations for the southern region of Togo that take into account the indigenous soil nutrient supplying capacity and yield potential. On degraded soil, the main nutrients limiting maize growth were K and N. On non-degraded soil, nutrients limiting growth were mainly N and P. Even on degraded soil rapid gains in productivity can be obtained, with MSF serving as a means to allow farmers with limited financial means to recuperate such soils, smother weeds, and give an initial N boost to the maize crop. With improved input market structures and a gradual introduction of mineral fertilizers and incorporation of crop residues, the MSF practice can be replaced by the more profitable mixed maize-cassava production system. MSF cannot be recommended on relatively fertile non-degraded soil.

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Agro-Forestry Southern Benin and Togo

Maize and cassava are the staple crops in southern Benin and Togo. Yields are usually only about 1 t ha^{1}, but potential yields—limited by temperature, solar radiation, and crop genotype—can amount to 6 to 8 t ha^{1} (IFDC, 2002). There is, therefore, a considerable gap between actual yields and yields that could be obtained if input use and management could be intensified. However, actual farmers’ yields are in reality stable or may even be declining as a result of decreasing soil fertility. Farmers often are entangled in a poverty cycle where low soil fertility leads to low yields and insufficient resources to purchase inputs to improve soil quality. Diagnostic conducted in the region indicated that the judicious use of mineral fertilizer combined with locally available organic resources and other soil amendments (integrated soil fertility management—ISFM) is a sound approach to improving soil productivity. However, in the coastal region, livestock is not an important component of farming systems and therefore manure is not available. Hence, the ISFM project has evaluated methods of organic material production at the time and the place as the staple crop. This included agro-forestry systems mainly on alley farming and woodlot of different species depending on the zone.

In Togo, the project evaluated the contribution of alley cropping and parkland of *Leucaena leucocephala* in maize-cassava mixed farming systems. A long-term trial on alley cropping and parkland of *Leucaena leucocephala* in combination with maize production has been established in Davié in the coastal region of Togo since 1998 and was evaluated in 2003. Gains with fertilizer application were highest on control plots without trees: 2.8 t ha^{1} (i.e., 1.4 t ha^{1} without fertilizer to 4.2 t ha^{1} with fertilizer). Yield gain in alley-cropped fields was 1.6 t ha^{1} (2.4 t ha^{1} without fertilizer and 4.0 t ha^{1} with fertilizer); yield gains in parkland fields were 1.6 t ha^1 (2.5 t ha^1 without fertilizer and 4.1 t ha^1 with fertilizer). Results indicate that the amount of mineral fertilizer applied (90 kg N, 55 kg P, and 60 kg K ha^1) should be adapted to the nutrient-supplying capacity of the soil that has improved over time in the agro-forestry treatments.

Farmers in southern Benin are associating *Acacia auriculiformis* A. Cunn and maize (two crops per year) during the first 1–2 years, after which Acacia is left to grow for another 2–3 years. Trees are generally cut in the fifth year after which maize is re-sown. The objective of this research was to determine the profitability of this system and to assess the response of maize to mineral fertilizer during the first and second year after cutting the woodlots. Maize yields during the main growing season increased by 73% on former woodlots without mineral fertilizer (from 1.3 t ha^1 to 2.2 t ha^1) and by 77% by 60 kg N and 10 kg P fertilizer ha^1 on control plots (without trees). However, in the second year after cutting the trees, maize yields increased by only 17% on former woodlots and by 61% by NP fertilizer on control plots in the main growing season. Benefits of Acacia on soil fertility were, therefore, relatively short-lived. Low maize yields (0.5 t ha^1) and negative returns to fertilizer use were obtained in the minor seasons because of erratic rainfall. With good access to maize and wood markets and over a 4year period, the Acacia woodlot system provided considerably higher net revenue (1212 € ha^1) compared with a continuous maize-production system (814 € ha^1), with a marginal rate of return of over 1000% (Table 8). Results indicated the need for P fertilization, both with and without Acacia. It is likely that N is also needed without Acacia and during the second and following years after cutting the woodlots. If fertilizer use is to become really profitable, it is important to look for a source of P that is cheaper than SSP, i.e., TSP or phosphate rock (which is mined in neighboring Togo).

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Table 8. Financial Analysis of the Maize-Acacia Woodlot System (4 Years) With Tree Harvest Paid by Wood Traders (Toose et al., 2005)

	With Trees	Without Trees
Total revenue trees (€ ha^{-1})	991	0
Total production costs trees (€ ha^{-1})	253	0
Net revenue trees (€ ha^{-1})	738	0
Total revenue maize first 4 years (€ ha^{-1})	684	1,239
Total production costs maize first 4 years (€ ha^{-1})	210	425
Net revenue maize first 4 years (€ ha^{-1})	474	814
Total net revenue per scenario (€ ha^{-1})	1,212	814
Total production costs per scenario (€ ha^{-1})	463	425
Superior?	Yes	
Marginal net revenue (€ ha^{-1})	398	
Marginal variable cost(€ ha^{-1})	39	
Marginal rate of return (%)	1,025	

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Long-Term Effect of ISFM Options

To investigate the long-term effect of ISFM options, the project entered into partnership with selected national research institutes that manage long-term trials. The project worked with Amadhu Bello University on the long-term trial in Zaria in northern Nigeria established since 1960, which studies the effect of fertilizer nitrogen, phosphorus, potassium, and cattle dung on maize productivity and soil fertility. The project also worked in partnership with the national research institute in Burkina Faso on two long-term fertility trials in Burkina Faso (established since 1980 and 1990) both looking at the effects of soil tillage and organic input quality and fertilizer on sorghum productivity and soil fertility. Some results of a long-term trial in northern Ghana initiated in 1995 on benefits of soil tillage were also analyzed. Highlights of this work are given below.

Effect of Long-Term Addition of Organic Input of Contrasting Quality on Soil Carbon and Crop Performance

A long-term trial sited in Saria, Burkina Faso, under Sudano-Sahelian conditions was used to assess the effect of organic and inorganic fertilization on soil organic matter (SOM) fractions and sorghum performance. Sorghum straw, kraal manure, and aerobic and anaerobic compost were applied yearly at 10 t ha^{1}, with and without 60 kg of urea N ha^{1}, since 1980. The other treatments included a control (no fertilization), sole inorganic fertilization (60 kg of urea N ha^{1}), and fallowing. All farmed plots were annually tilled with a tractor.

Long-term application of organic resources of varying C/N ratio and urea resulted into different SOM concentrations. Twenty years of continuous cultivation without external inputs (the control treatment) depleted SOM levels to below 50% of those under fallow (Figure 9). Sole urea application further depleted SOM status, presumably because of alleviation of nitrogen limitations to decomposition. Furthermore, organic inputs through the rhizosphere must have been lower in urea-only plots as a result of relatively low sorghum yields in these plots (Table 9).

Compared with the fallow treatment, SOM depletion seemed less pronounced in the case of application of organic material with a relatively low C/N ratio such as manure (Figure 9). Two processes may be responsible for the better SOM status in

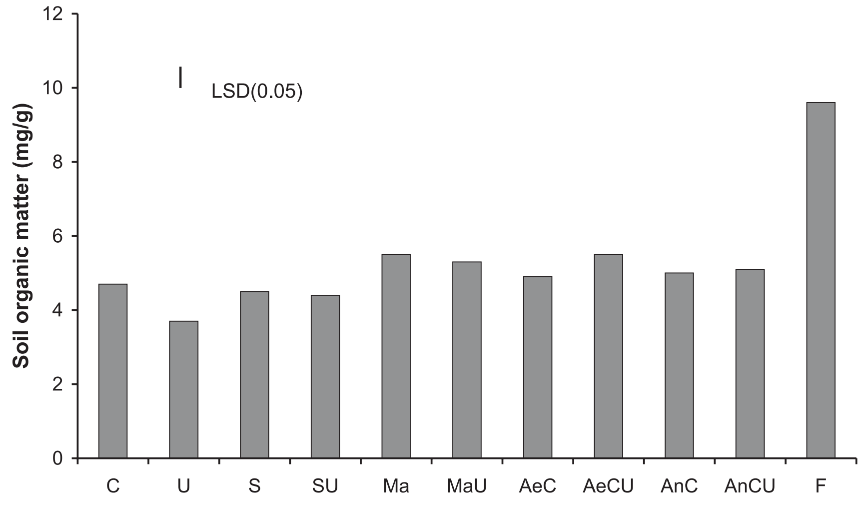

Figure 9. **Soil Organic Matter (SOM) Status in the 0- to 0.15-m Soil Layer as Affected by Inorganic and Organic Fertilization Determined in June 1999 in a Long-Term Experiment Established in 1980 in Saria, Burkina Faso. C = Control; U = Urea; S = Straw; SU = Straw + Urea; Ma = Manure; MaU = Manure + Urea; AeC = Aerobic Compost; AeCU = Aerobic Compost + Urea; AnC = Anaerobic Compost; AnCU = Anaerobic Compost + Urea; F = Fallow**

Table 9. Sorghum Straw and Grain Yields and N, P, and K Uptake as Affected by Long-Term Soil Management Options in 2000

Treatment	Yield (t ha^{-1})	
	Straw	Grain
Control plot	1.29 d	0.78 c
Urea	1.25 d	0.69 c
Straw	0.73 d	0.66 c
Straw + Urea	2.01 c	1.68 b
Kraal Manure	3.54 a	2.52 a
Kraal Manure + Urea	3.23 a	2.73 a

plots where low C/N organic resources were applied: (1) enhancement of biological activities leading to increased microbial biomass and faster incorporation of applied organic resources into SOM and (2) increased sorghum yields and, therefore, enhanced production of organic compounds in the rhizosphere in plots that received low C/N ratio material.

It should be noted that in the experiment reported here, crop residues were removed. There is, however, evidence that C transfer to the soil via the rhizosphere is just as important as through incorporation of the above-ground biomass (Martin and Merckx, 1993). Apparently, these two processes outweighed the increased SOM mineralization as a result of low C/N ratios. Heal et al. (1997) observed that the quality (nutrient concentration) of plant tissue in terms of C/N ratio is related to the C/N ratio of organic resources applied to these plants. This suggests that sorghum-derived organic inputs in the plots will be of better quality in manure plots than in straw plots and may also have contributed to C sequestration in the various plots.

Control, urea-only, and straw treatments resulted in the lowest grain yields (average 0.7 t ha^1) followed by the straw + urea, aerobic, and anaerobic compost treatments, with slightly higher yields (1.7 t ha^1) and a third and last group with the highest yields (2.7 t ha^1) comprised of the manure treatments (with and without urea) and the compost treatments with urea.

Sorghum yield increased with decreasing C/N ratio of organic resources used in this trial. Application of urea in combination with organic resources also led to an increase in sorghum yield in the straw and anaerobic compost treatments, but it had no significant effect in the manure and aerobic compost treatments. Yield gain as a result of urea application, therefore, increased with increasing C/N ratio of the organic resource used.

This indicates that in the manure and aerobic compost treatments, N was not required anymore and it signifies a need to account for the effect of long-term application of organic resources on soil nutrient-supplying capacity. This would help determine appropriate inorganic fertilizer application rates aimed at target yields.

Effect of Long-Term Tillage and Organic Matter Addition on Soil Carbon and Crop Yield

A randomized block design with four treatments (hand hoeing only, hand hoeing + manure, plowing only, oxen plowing + manure) in three replications was started in 1990 in Saria, Burkina Faso. Ten years later, total carbon, different fractions of SOM, microbial biomass, and CO_2 production were measured. Carbon concentration had dropped from 4.00 to 2.05 mg/g soil in plowed plots without manure and from 4.00 to 2.50 mg/g soil in hoed plots without manure. Manure addition mitigated the decrease of SOM in plowed plots and even built up SOM in hoed plots, where it increased to 5.80 mg/g soil. Crop yields were highest on plowed + manure plots and lowest on plowed plots with no manure (Table 10). It can be concluded that long-term continuous tillage without manure decreases soil organic carbon content, sorghum yield, and soil biological activity. The deeper the tillage is, the larger the decrease in carbon content will be. However, the practice of manure application in soil fertility management can mitigate this negative effect of tillage-based agricultural systems. Furthermore, plowing with manure has the most significant impact on yield and has little effect on soil carbon, and therefore should be promoted in the north Sudan zones.

Under the agro-pastoral cereal farming systems, tillage at shallow depth is of paramount importance to crop productivity. It breaks the soil sealing, which impedes water infiltration in the soil. A field experiment to assess the effect of tillage (zero tillage, hand hoeing, oxen-plow, and tractor-plow) on soil and crop production in maize/soybean rotation started in 1996, and evaluation in the 2000 and 2001 wet seasons on the Nyankpala farm of the SARI confirm the findings from Burkina Faso (Table 11). Indeed it was found that tillage is of paramount importance to crop production. Soil tillage significantly improves crop performance as a result of enhanced crop nutrient uptake and water use efficiency. However, tillage decreases soil carbon, and therefore tillage-induced disturbance should be kept to a minimum.

Table 10. Soil Total Organic Carbon (TOC, %) at 0–15 cm and Sorghum Grain Yield as Affected by Long-Term Tillage and Manure Management

Treatments	C	Sorghum Grain Yield
	(mg/g soil)	(t/ha)
H	2.5 a	0.62 a
H + M	5.8 c	2.35 b
P	2.1 a	0.46 a
P + M	3.6 b	2.62 b

Further Reading

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Table 11. Long-Term Impact of Tillage on Soil Carbon and Crop Yield Under Sudan Conditions

Tillage	Carbon at 0–30 cm 2001	Maize Yield 2000	Soybean Yield 2001
	(t/ha)	(kg/ha)	(kg/ha)
Manual	19.74	2,812	1,770
Bullock	19.19	2,983	1,793
Tractor	16.66	2,539	2,489
Zero	22.36	2,334	1,781

Chapter 7
Capacity Building

Buildings—Stakeholders (Facilitators) Capability

The ISFM project organized many training sessions tailored to the needs and demands of partners, i.e., NARS, extension agencies, and NGOs (Appendix 3). Training concerned participatory extension of ISFM options, agro-ecological ISFM principles, platform development, participatory planning, action research, credit management, participatory learning, etc.

The project also contributed to two international training courses on ISFM, one held in 2002 (in English) and one held in 2004 (in French) in Lomé, Togo. The 2002 training course was attended by a total of 22 senior staff members working as researchers or extension agents from five West African countries, three southern African countries, and two central African countries. The 2004 training course was attended by participants from five francophone countries. Participants were from IFAD investments projects, FAO, and Sasakawa 2000 projects and also included partners from NARES and NGOs.

During the first two days, participants were taken through various soil fertility-enhancing methods, such as improved crop management practices, measures to control erosion and leaching, and measures to improve soil organic matter maintenance. ISFM strategies (the key to raising productivity levels while maintaining the natural resource base) include the combined use of soil amendments, organic materials, and mineral fertilizers to replenish soil nutrient pools and improve the efficiency of external inputs. A field visit was organized the third day to a phosphate mine and to one of the villages. The objective of the visit was to share the experiences of stakeholders in this village in developing and using learning tools through action research, and in linking farmers to input dealers and credit institutes. The fourth day focused on the need for a holistic approach to promote ISFM-based agricultural intensification. It fosters alternative institutional arrangements, links farmers to input and output markets and to rural credit structures, strengthens farmers' organizations and traders' networks, and improves collaboration between research and extension institutions. The last

Group Photo of Trainees and Farmers in the Village Djaka Kopé, Togo, 2004 ISFM Training Course

day was spent developing a regional-scale action plan to promote ISFM-based intensification processes, taking into account the agro-ecological, socio-economic, and policy contexts of the region. At the end of each ISFM training session, all participants received the training material as hard copies (folders) and as electronic copies (CD-ROM).

The training (in English) is now used for a distance learning course at www.aglearn.net/isfmHome.html.

Strengthening and Empowering Farmer-Based Organizations (FBO) to Lead Research and Extension

The ISFM framework project has provided support to partners at the various pilot sites to help them facilitate the emergence of village-level farmer organizations. In some regions, such as southern Togo and Niger (Gaya region), these groups have grown and have found the need to form apex farmer-based organizations at the regional level. All activities at all sites were carried out in partnership with multi-stakeholder platforms and village-level farmer organizations to give them ownership of the results and to empower them to be trainers

Training efforts focused on making FBOs capable of analyzing their own needs, formulating their request in realistic and operational terms, and negotiating with other stakeholders. At every key site, partners have worked to strengthen the:

- Strategic Capacities of the FBOs—This was instrumental in allowing them to define how they intend to stand as an organization. In this respect some of them were trained in management skills (budgeting, formulation of farmer requests, designing, implementing, and evaluation work). They were also helped to develop effective communication strategies (access to information and its circulation among members).
- Financial Capability of the FBOs—In this field, the ISFM framework project has developed an approach to link FBOs to local micro-finance and analyzed the main constraints of credit accessibility. In some cases where the FBOs have no ideas or experience in dealing with financial institutes, the project introduced revolving funds not as financial tools per se but as learning tools on credit management to create opportunities to investigate the problem linked to credit management. Some FBOs have reinforced their revolving fund with their own savings as guaranty funds to local banks.
- Technical Capability—Facilitating organizations have provided guidance for the learning plot activities; they have also produced pamphlets in the local languages to document the lessons learned and spread information on best practices. Drawings and posters are often made together and used as training materials by the ISFM farmer groups. Some ISFM farmer groups gradually develop into rural knowledge centers, and diffusion of ISFM is occurring from these knowledge centers to neighboring villages.

While the first two objectives were achieved through punctual training sessions or through the management of their revolving funds, the third objective was achieved through participatory action research or learning throughout the crop production cycles. To address the huge diversity of farmer situations and the dynamic nature of ecological and mainly socio-economic farming conditions, the ISFM framework project has adopted an approach aiming at developing the farmers' analytical skills in order to allow them to explore possibilities and find out solutions on their own situations. In all pilot sites farmers were trained to:

- Carry out a diagnostic of their farm environment and identify the problems.
- Analyze the problems in their farms and the potential causes of and possible solutions to the identified problems.
- Be aware of major ISFM principles and be skilled to implement ISFM techniques.
- Investigate and test (if necessary) the performance of ISFM techniques.

Farmers are Evaluating Research During the Growing Season to Allow Them Basic Understanding of the Principle Behind ISFM Technology

Farmers are Evaluating Research at Harvest to See for Themselves the Performance of ISFM Technologies

Farmer learning groups are progressively evolving toward autonomous groups. These groups have various auto-financed activities including: sourcing of inputs; learning plots; small savings and credit schemes; collective storage, processing, transporting, and selling of agricultural produce; collection of information on market prices and actors; and contracting with regional-level traders, input dealers, and rural banks. Most ISFM farmer groups are linked to credit and savings banks. In some cases guaranty funds (e.g., making use of the revolving funds that had been managed in the past) have been established. Some farmer groups have begun adding their savings to the revolving funds. Contracts between farmer groups and (reliable) input traders have been established in southern Benin and Niger. In southern Benin the contract involves the importation and transportation of Togolese phosphate rock to the farmers. In Niger, the ISFM farmer organizations have established, on their own initiative, a union to improve negotiating power vis-à-vis public and private distributors of seeds, fertilizers, and crop protection products for lobbying purposes and to attract new donors who are willing to invest in ISFM or complementary activities. In southern Togo the union of farmer-based organizations has taken control of local community banks and now has two members on the board.

Finally, ISFM farmer organizations are progressively serving a wider community of farmers, beyond the initial group of ISFM farmers, particularly as knowledge centers.

Manuals

The project has contributed to the development of curriculum for low valley systems and a facilitator's manual in collaboration with another IFAD grant with WARDA. A curriculum for legume-based soil management under cassava and maize rotation systems was prepared and tested in southern Togo.

Further Reading

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Chapter 8
Public Awareness

The AISSA Network

IFDC and partner organizations active in the ISFM project launched the AISSA (Agricultural Intensification in Sub-Saharan Africa) Network in Lomé, Togo, on February 13, 2004, to formalize their partnership. The AISSA network provides a forum to exchange experiences and information on agricultural intensification, plan collaborative activities, produce and diffuse facilitation "tools" (manuals, guides, etc.), and lobby for more attention from both the public and the private sectors for agricultural intensification (including investments). More information on AISSA can be obtained from www.aissa.org. AISSA publishes a newsletter and a regular Faces of AISSA series.

The AfNet Network

The African Soil Biology Network (AfNet) of TSBF-CIAT (www.tsbf.org) is a voluntary network of mostly NARS (including universities) scientists in research and extension working on the strategic to adaptive research continuum throughout Africa. AfNet organized an international symposium held in Yaounde, Cameroon, during May 14–19, 2004, at which partners from both TSBF and IFDC presented some of their findings. AfNET publishes a regular newsletter called *The Comminutor*.

Publications

Over 36 scientific papers were published or submitted to journals; four of our partners were able to write their Ph.D. theses and numerous M.Sc. theses were written. Seven TANs were derived from the data and distributed. Furthermore, the project contributed to a facilitators' manual and a technical manual for inland valley rice (to be published with WARDA in mid-2005) and an ISFM manual published with an NGO (VeCO). Training materials were produced and interactive training via Internet was developed. ISFM success stories,

AISSA Publications

focusing on northern Togo, southern Togo, Zimbabwe, and Niger were written and published. These stories are published on the AISSA website and are distributed to donors, policymakers, rural development organizations, etc.

Farmer Field Days

Numerous farmer field days were organized to create awareness for ISFM at all key sites in Burkina Faso, Mali, Nigeria, Zimbabwe, Malawi, Togo, Ghana, Zambia, and Benin (Appendix 3). During these events, many farmers and other stakeholders (scientists, extension agents, input dealers, policymakers, and traders) gathered to visit and comment on ISFM learning and extension plots. A rural workshop on ISFM was held in early December in southern Togo. The workshop was attended by 200 participants, including scientists, farmers, leaders of farmer organizations, extensions, input dealers, and decision-makers from Togo and Benin. During the workshop, ISFM farmers learning groups presented the results of their action research, presented many performances in order to raise awareness, and discussed with various stakeholders about the policy and practical implications of their findings.

Study Tours

Numerous study tours were organized to allow stakeholders from different countries to visit others' countries to learn from their experiences (Appendix 3). These tours have brought enormous benefit to farmers. For example, partners from Ghana (FBO, SARI, and OIC) learned a lot from a local NGO—Research, Support, and Training for the Initiatives of Self Development (RAFIA)—in the north of Togo on how to strengthen farmer organizations and to set up a farmer-managed microcredit organization to support ISFM. Efficient methods of livestock and agricultural integration for enhancing soil fertility were introduced in northern Togo after a tour in Burkina Faso.

Participants Evaluate Action Research Plots During the Field Visits of the Rural Workshop in Southern Togo

Ghanaian Farmers Tour a Togolese ISFM Site

Other Initiatives

- Programs on various ISFM themes were recorded in partnership with local rural radios and aired in Ghana and Togo.
- Brochures and booklets were published to raise awareness. These documents highlight ISFM impact and present successful cases studies and outstanding experiences.
- Eight papers were presented during international workshops to inform scientists and policymakers about the project. Numerous presentations were made during project annual workshops and steering committee meetings (Appendix 2).

Chapter 9

Creation of Linkages With Rural Development Projects

Rural development projects are most often investment projects co-financed by governments and development agencies such as IFAD. These investment projects vary in nature, but are often aimed at infrastructure development, food security, irrigation, and market development. Soil fertility constraints are often ill-defined within these projects, even in those focusing on food security. The challenge to link soil fertility research results to these development projects therefore is great and entails recognizing that needs between projects vary, and that there is a complexity of problems to be addressed. Relevance of results depends on how research addresses the hierarchy of needs and the multiplicity of objectives of the target clients in the investment programs. This is the essence of research for development. The ISFM framework project used two approaches in working with IFAD investment projects: long-term commitments where the investment project itself was willing to bring in matching funds, and punctual support.

Long-Term Commitment

The project actively worked with farmer organizations developed through: (1) the former rural development project in southern Togo (PODV); (2) the South-West Development Project; (3) the special program for soil and water conservation and agro-forestry in Burkina Faso; (4) the Smallholder Floodplains Development Program, Malawi; (5) the Southern Province Household Food Security Project in Zambia; (6) the South-East Dry Areas Project (Zimbabwe); (7) the Smallholder Dry Areas Resources Management Project in Zimbabwe; and (8) the Umutara Community Resources and Infrastructure Development Project (UCRIDP) in Rwanda. It provided technical backstopping to these programs, training, and conducted action research to expand technological options available to farmers.

The objectives of the technical backstopping were in many cases to (1) facilitate sound ISFM technologies development and adoption through participatory action research and social learning approaches; (2) strengthen the capacities of local agriculture services providers (NGOs, NARS, public extension agencies) and farmer-based organizations; and (3) facilitate credit, input and market accessibility through institutional linkages.

All activities were carried out by local partner-organizations. IFDC and TSBF played a facilitating role and provided technical support when needed except in case of strategic research. On most occasions, the activities included participatory diagnosis of constraints and opportunities, negotiation of an institutional platform to promote ISFM, and initiating participatory research and learning cycles at the key sites.

Punctual Technical Backstopping

Project staff participated in project formulation missions for the PICOFA and PDRD projects in Burkina Faso and provided specific training to many IFAD projects in East and southern Africa and West Africa. Initial links were established with two IFAD investment projects in Benin, i.e., PDRT (Program for the Development of Root and Tuber Crops) and PROMIC, a micro-finance project. IFDC was requested to help PDRT fine-tune fertilizer recommendations for cassava, potato, and yam in northern Benin.

Visits were made to the IFAD investment project on flood plains in Malawi and to discuss soil fertility management options for optimum use of residual moisture for rice, bean (*Phaseolus* spp.), and maize production. Irrigation schemes were visited and the results of nutrient omission trials were discussed. Nutrient omission trials were used to fine-tune recommendations in the project areas.

Challenge

The major challenge observed to date in linking research grants with rural development projects has been in bringing together the critical mass of expertise required to effect a coherent participatory research and development program. There have been huge staff turnovers in most of the key national agricultural research systems (e.g., Zambia, Togo, Burkina Faso, and Zimbabwe) or the personnel are simply not there (e.g., Malawi). The political and economic challenges in the region (especially Zimbabwe and Togo) have also presented problems to successful linkage with development projects. Furthermore, investment projects were too often tied with their formulation documents leaving little room for innovation.

Chapter 10
Conclusions and Perspectives

The research work and the experience in developing and disseminating ISFM technology in SSA clearly indicate that there are potential benefits from the use of ISFM. These range from poverty reduction and economic development to environmental degradation mitigation. However, it came out clearly that translating research results into farm practice is not just about technologies, it is about people and reinforcing their decision-making abilities and their capacity to analyze trade-offs and options and to access information, services, and markets. All this calls for a new approach to doing business in rural development and research. There is a clear need to focus on other issues in addition to working on technology. This includes:

- **Market Focus—**Improved soil, water, and/or crop management will lead to increased production, but this will require good access to agricultural inputs (especially mineral fertilizers) and a reliable market to sell surplus production. By conducting farmer-led market research, the project will recommend efficient approaches to link smallholder farmers to markets (inputs, outputs, financial) and build their capacity to identify and exploit market opportunities.
- **Addressing the Diversity and Dynamics of Farmer Reality—**Soil fertility varies strongly in the African landscape due to natural processes and human intervention. Farmers who do not own the land they cultivate may well be hesitant to invest in soil fertility because the payoff is not always directly perceptible. Access to resources (land, inputs, financial) often differs among household members; for example, women may have only limited access to certain resources. The diversity and dynamics of farmer reality make farmer-led research an absolute necessity. By giving farmers the lead in research, they will become owners of the results and can become instrumental in training their colleagues.
- **Development of Institutional Platform and Networks—**In implementation of work in rural development, research, and innovation, institutions are more and more confronted with issues that are too complex to be resolved by a single organization on its own. At the present time, rural development has to meet many objectives such as improving the livelihoods of poor people, promoting sustainable use of natural resources and biodiversity, linking small-scale farmers to markets, and enhancing food security and safety simultaneously. A single institution can no longer make isolated contributions to rural development in their specialized field, but need to ensure that their products and services, jointly with those of other organizations, contribute to these broader objectives. For this to happen, organizations need to combine different kinds of expertise and to work in partnership with other rural development and research organizations. They also need to involve and collaborate with other groups that have a role to play in tackling the issues and achieving the broader development objectives such as the private sector (agro-dealers), policymakers, and other interest groups.

Chapter 11
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Appendix 1. Overview of Pilot Zones in the ISFM Project in West and Southern Africa

Appendix 1a Overview of Pilot Zones in the ISFM Project in West Africa

	Country and Pilot Zone	Ecological Zone[1]	Dominant Crops (Farming System)	ISFM Menu (i.e., Technical Options Promoted)[2]
	Benin			
1	Klouékanmé Department—southern Benin	Coastal Savannah	Maize, Cassava	HYV, PR, CF, ImprF (a.o. mucuna), CResR
2	Ifangni Department—southern Benin	Coastal Sav/Degr. Forest	Maize, Cassava, Oil Palm	
3	Ayapa Department—central Benin	Costal Savannah	Maize, Cassava	Agro-forestry
	Burkina Faso			
4	Southern BF	Southern Sudanian	Sorghum—Mixed farming	HYV, PR, CF, CResR, ImprF, Leg (cowpeas, groundnuts), OM, Fodder, IWNM,
5	Central and northern BF	Sahel-Sudan	Sorghum, Horticulture—Mixed farming	
6	Bagré Irrigation scheme		Irrigate rice	ICM, USG, Site-specific ISFM
	Ghana			
6	Tolon-Kumbungu District—northern Ghana	Southern Guinea	Maize, Groundnuts (Horticulture)	HYV, CF, Leg (groundnuts, pepper), CResR, OM, CT, IWNM
	Mali			
8	Sikasso Region—southern Mali		Cotton, Maize (Sorghum)	HYV, PR, CF, CResR, OM, Fodder
8	Koutiala Region—southern Mali	Northern Guinea	Cotton, Maize (Sorghum) (Mixed farming)	HYV, PR, CF, CResR, OM, Fodder
9	Office du Niger Irrigation Schemes	Northern Guinea Wetlands	Irrigate rice	ICM, USG, Site-specific ISFM
	Niger			
8	Gaya Region (Sokondji-Birni)—southern Niger	Northern Sudanian	Irrigated Rice (Horticulture)	HYV, CF, CResR
9	Gaya Region—southern Niger	Southern Sudanian	Sorghum, Millet (Horticulture)	HYV, CF, CResR, Leg (cowpeas, groundnuts), OM (zaï), Fodder
10	Konni Region—southern Niger	Sahelian	Millet (Sorghum)	
	Nigeria			
11	Zaria Region—northern Nigeria	Northern Guinea	Dry cereals based systems (Groundnuts)	HYV, CF (incl TSP), Leg (a.o. soybeans), CresR
	Togo			
12	Valley of Zio—southern Togo	Coastal Savannah	Irrigated rice (Maize, Manioc)	HYV, PR, CF, OM
13	Zio, Lac and Vo Departments—southern Togo	Coastal Savannah	Maize, Cassava (Horticulture)	
14	Yoto Department—southern Togo	Coastal Sav/Degr. Forest	Cotton/Maize relay cropping	HYV, PR, CF, CResR, ImprF, Leg (cowpeas, groundnuts, soybeans), OM, AgrF, Fodder
15	Dapaong Region—northern Togo	Southern Guinea	Sorghum, Maize—Mixed farming	
16	Sokodé Region—central Togo	Southern Guinea	Coton, Maize, Yams	

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1. Coastal Savannah: 210–270 growing days; Southern Guinea: 180–210; Northern Guinea: 150–180; Southern Sudanian: 120–150; Northern Sudanian: 90–120.

2. PR = phosphate rock, CF = chemical fertilization (urea, NPK, TSP), Leg = Leguminous crops (rotation, strips), ImprF = Improved fallows (cover crops), AgrF = agro-forestry, OM = organic matter production (litter and cattle pens, compost) and application, Fodder = fodder crop production, CResR = crop residue recycling, HYV = high-yielding (i.e., improved) varieties. Soil and water conservation methods are applied on all fields, ICM = integrated crop management, USG = urea supergranules, SWC = soil and water conservation, INWM= integrated nutrient and water management.

Appendix 1b Overview of Pilot Zones in the ISFM Project in Southern Africa

	Country and Pilot Zone	Ecological Zone	Dominant Crops (Farming System)	ISFM Menu (i.e., Technical Options Promoted)
	Malawi			
1	Salima—eastern Malawi	Lake shore	Maize, rice, beans	Mucuna, manure, compost
2	Dedza—southern central Malawi	Upland	Maize, beans	Mucuna, pigeon pea
	Zambia			
4	Choma—Southern Zambia	Savannah	Maize, groundnut	Dual purpose cowpea, mucuna, pit farming
	Zimbabwe			
5	Murewa District—north-eastern Zimbabwe	Savannah	Maize, groundnut	Pitted manure, soybean,
	Shurugwi—midlands	Savannah	Maize, groundnut, sorghum	Pitted manure, soil, and water conservation methods, *Ipomea stenosiphon*
	Ngundu—southern Zimbabwe	Savannah	Maize, groundnut, sorghum	

Notes: Rainfall
Shurugwi—600 mm, Ngundu—650 mm, Murewa—850 mm, Choma—900 mm, Salima—750 mm, Dedza—1,000 mm.
An ISFM approach was used in all cases.

Appendix 2. Publications List

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Newsletter 1: Launching of the AISSA Network

Newsletter 2: Gender and ISFM

Brochure Integrated Soil Fertility Management Project: Fertile Ground for Market Development

Appendix 3. List of Training and Public Awareness Activities in West Africa

Site	Partners	Number of Events	Nature of Activity	Participant Profiles	Number of Participants	Theme
Ghana	SARI, OIC	1	Farmers’ field day	Farmers	50	ISFM
Togo-North	RAFIA, ITRA, CRA/SS	17	Farmers' field day	Farmers, extensionists	880	ISFM
Togo-Central	DRAEP/ICAT-RC/CRA-SH	1	Farmers' field day	Farmers, extensionists, researchers	89	ISFM
Togo-Sud (maize/cassava system)	ITRA/CRA-L, ICAT-RM, PODV	29	Farmers' field day	Farmers, extensionists, NGO, researchers	666	ISFM, agro-forestry, strengthening FBO
Togo-Sud (maize/coton system)	ITRA/CRA-L, ICAT-RM, CREMA	12	Farmers' field day	Farmers, extensionists	450	ISFM
Burkina	DPAHRH-K-B/Z	17	Farmers' field day	Farmers, extensionists	700	ISFM
Nigeria	IAR/ABU	1	Farmers' field day	Farmers, extensionists, NGO, researchers, dealers	250	ISFM
Mali	IER, ESPGRN, AMEDD NGO	3	Farmers' field day	Farmers, extensionists	60	ISFM
Benin (agro-forestry)	GREPID	2	Farmers' field day	Farmers, extensionists	75	ISFM and agro-forestry
Burkina	PDES II	2	Farmers' field day	Farmers, extensionists	150	ISFM
Togo-Sud (agro-forestry, Davié)	ITRA/CRA-L, ICAT-RM	4	Farmers' field day	Farmers, extensionists	120	ISFM and agro-forestry
Niger	INRAN, APGR, DDA,	4	Farmers' field day	Farmers	620	
Niger	INRAN, APGR, DDA,	1	Study tour	Farmers, extension agents	20	Inventory credit and input supply
Ghana	SARI, OIC	1	Study tour	Farmers, extension agents, researchers	16	Farmers organization and rural credit
Ghana	SARI, OIC	1	Training course	Farmers, extension agents, researchers	30	ISFM principles
Togo-Sud (maize/cassava system)	ITRA/CRA-L, ICAT-RM	7	Training course	Farmers, extensionists	192	ISFM/PLAR, credit management, strengthening FBO
Togo-Sud (rice)	ITRA/CRA-L, ICAT-RM	10	Trainings courses	Farmers, extensionists, NGO, researchers, input dealers	185	ISFM, gender, marketing
Mali	PRAIA+9 partners	1	Training course	Policymakers, donors, researchers, development workers	20	

Appendix 4. List of Training and Public Awareness Activities in South Africa

Site	Partners	Number of Events	Nature of Activity	Participant Profiles	Number of Participants	Theme
Malawi	DARTS, Bunda College	3	Farmer field days	Farmers, extensionists	132	ISFM
		1	Field tour	Researchers, extensionists,	13	ISFM
		1	Planning workshop	Researchers, extensionists, NGOs	15	ISFM
Zambia	DR&SS, NGOs	4	Farmer field days	Farmers, extension, NGOs,	265	ISFM
		2	Field tours	Research, extension, NGOs	43	ISFM
		1	Planning Workshop	Research, extension, NGOs	25	ISFM
		1	Results-planning workshop	Research, extension, NGOs	17	ISFM
Zimbabwe	AREX, University of Zimbabwe, NGOs	4	Field days	Farmers, extension, research, NGOs	436	ISFM
		3	Feedback workshops	Farmers, research, extension	132	ISFM
		1	Planning workshop	Research, extension, NGOs, investment projects	43	ISFM
		2	Results workshops	Research, extension, NGOs, investment projects	44	ISFM

Appendix 5. List of Partner Institutes in South and West Africa

NGOs

- CREMA (Centre de Recherche et d'Essai des Modèles d'Autopromotion)/Togo
- RAFIA (Recherche, Appui et Formation aux Initiatives d'Auto développement)/Togo
- C2D (PODV) (Croisade pour le Développement Durable)/Togo
- AMEDD (Association Malienne d'Eveil au Développement Durable)/Mali
- IFAD ONG (Institut de Formation et Action pour le Développement des Initiatives Communautaires Durables)/Benin
- APGR (Action pour la Promotion des Groupements Ruraux)/
- AGIR+ (Association pour l'appui aux Groupes d'Initiatives en milieu Rural)/Burkina Faso
- OIC Tamale/Ghana
- Africare
- World Vision
- Kaluli Development Foundation
- Gwembe Valley Development project
- Concern Universal

GOs Research

- IER (Institut d'Economie Rurale)/Mali
- INRAN (Institut National de Recherche Agronomique du Niger)/Niger
- ITRA (Institut Togolais de Recherche Agricole)
- LSSEE (Laboratoire des Sciences du Soil, Eaux et Environnement)/Benin
- SARI (Savannah Agricultural Research Institute)/Ghana
- ARI (Animal Research Institute)/Ghana
- ABU/IAR (Amadou Bello University/Institute for Agriculture Research) /Nigeria
- Department of Research and Specialist Services, Zambia
- Department of Agricultural Research and Technical Services (DARTS), Malawi
- Department of Agricultural Research and Extension (AREX), Zimbabwe
- Bunda College, Malawi
- University of Zimbabwe and Zambia

GOs Extension

- ICAT-RC (Institut de Conseil et d'Appui Technique- Région Central)/Togo-central
- ICAT-RM (Institut de Conseil et d'Appui Technique- Région Maritime)/Togo-maritime
- DDDA (Direction Départementale de Développement Agricol)/Niger
- PI (Projet Intrants)/Niger (AMADOU Bassirou)
- DPAHRH/Z (Direction Provinciale de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques/ Zoundweogo)/Burkina Faso
- DPAHRH/K (Direction Provinciale de l'Agriculture, de l'Hydraulique et des Ressources Halieutiques /Kadiogo Burkina Faso
- DRAEP/RC (Direction Régionale de l'agriculture, de l'Elevage et de la Pêche/Région Centrale) Togo
- Department of Agricultural Research and Extension (AREX), Zimbabwe

Farmer-Based Organizations

- ACVR/GAIP (Association des Communautés Villageoises Responsables/Groupe d’Action pour l’Intensification de la Production et la commercialisation des produits agricoles)/Togo
- UGV-Afangnah (Union des Greniers Villageois)/Togo
- Groupements GIFS Banigbé/Togo
- Groupements GIFS Ifangni/Benin
- FEPAB (Fédération des Producteurs Agricoles de Burkina)/Burkina Faso
- Zimbabwe Farmers Union

Rural Finance Institutions

- CMEC (Caisse de la Mutuelle d’Epargne et Crédit)/Togo
- FUSEC and Adé Ga/Togo
- CREP Feminine-Ifangni/Benin
- UCEC/Z (Union des Caisses d’Epargne et Crédit de Zoundweogo)/Burkina

Acronyms and Abbreviations

ACIAR	Australian Centre for International Agricultural Research
AfDB	African Development Bank
AfNet	African Network for Soil Biology and Fertility
AISSA	Agricultural Intensification in Sub-Saharan Africa
CASE	Competitive Agricultural Systems and Enterprises
CREMA	Centre de Recherche et d'Essai des Modèles d'Auto promotion
DATE	Diagnostics, Action planning, Trying things out, and Evaluation
DSTs	Decision Support Tools
F&SAD	Fertilizers and Sustainable Agricultural Development
FAO	Food and Agriculture Organization of the United Nations
FBO	Farmer-Based Organization
FERRIZ	Fertilisation du Riz Irrigué (Operational Framework for Soil Fertility Management)
ICAT	Institut de Conseil et d'Appui Technique
IFA	International Fertilizer Industry Association
IFDC	An International Center for Soil Fertility and Agricultural Development
INERA	Institut National d'Etudes et de Recherches Agricoles
ISFM	Integrated Soil Fertility Management
ITRA	Institut Togolais de Recherche Agronomique (Togolese Agricultural Research Institute)
NARES	National Agricultural Research and Extension Systems
NEPAD	New Partnership for Africa's Development
NGO	Non-governmental organization
NUTMON	Nutrient Monitoring
OIC	Opportunity Industrialization Centers
PDRT	Program for the Development of Roots and Tubers
PICOFA	Programme d'Investissement Communautaire en Fertilité Agricole
QUEFTS	Quantitative Evaluation of the Fertility of Tropical Soils
RAFIA	Research, Support and Training for the Initiatives of Self Development
RFM	Resource Flow Mapping
RIDEV	Rice development
SARI	Savannah Agriculture Research Institute
SSA	Sub-Saharan Africa
SSNM	Site-Specific Nutrient Management
SSP	Single Superphosphate
SWC	Soil and Water Conservation
TAGA	Technical Assistance Grant Agreement
TAN	Technical Advisory Note
TSBF-CIAT	Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture
TSP	Triple Superphosphate
UCRIDP	Umutara Community Resources and Infrastructure Development Project
USAID	United States Agency for International Development
VeCO	Vredeseilanden Coopibo (Uganda)

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