Integrated soil fertility management: operational definition and consequences for implementation and dissemination

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Abstract
Traditional farming systems in sub-Saharan Africa depend primarily on mining soil nutrients. The African Green Revolution aims at intensifying agriculture through dissemination of Integrated Soil Fertility Management (ISFM). In this paper we develop a robust and operational definition of ISFM, based on detailed knowledge of African farming systems and their inherent variability and of optimal use of nutrients. We define ISFM as '*A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.*' The integration of ISFM practices into farming systems is illustrated with the dual purpose grain legume-maize rotations in the savannas and fertilizer micro-dosing in the Sahel. Finally, the dissemination of ISFM practices is discussed.

Key Words
Agronomic use efficiency, fertilizer, micro-dose, organic inputs, soil organic matter, soybean-maize rotation.

Introduction
The need for sustainable intensification of agriculture in SSA has gained support, because in part of the growing recognition that farm productivity is a major entry point to break the vicious cycle underlying rural poverty. Since fertilizer is an expensive commodity, the Alliance for a Green Revolution in Africa (AGRA) has adapted Integrated Soil Fertility Management (ISFM) as a framework for boosting crop productivity through reliance upon soil fertility management technologies, with emphasis on increased availability and use of mineral fertilizer. Various definitions for ISFM have been proposed but most definitions are incomplete in the sense that they fall short of defining principles that are unique to ISFM. The objectives of this paper are: (i) to develop a robust definition of ISFM that can be used as a practical means for objectively evaluating its implementation; (ii) to apply the definition to relevant technologies with great potential for dissemination to smallholder farmers; and (iii) to highlight factors that will facilitate the adoption of ISFM practices. Before proposing a definition for ISFM, it is important to sketch the context under which the smallholder farmer in SSA operates. At the regional scale, overall agro-ecological and soil conditions have led to diverse population and livestock densities across SSA and to a wide range of farming systems. Each of these systems has different crops, cropping patterns, soil management considerations, and access to inputs and commodity markets. At the national level, smallholder agriculture is strongly influenced by governance, policy, infrastructure, and security levels. Within farming communities, a wide diversity of farmer wealth classes, inequality, and production activities may be distinguished. At the individual farm level, it is important to consider the variability between the soil fertility status of individual fields, which may be as large as differences between different agro-ecological zones. The above section sketches a summary of the farming conditions in SSA and the variability that exists at different scales. Any definition of ISFM must consider these attributes.

Operational definition of ISFM

We define ISFM as '*A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity. All inputs need to be managed following sound agronomic principles.*' A conceptual presentation of the definition is shown in Figure 1. The definition includes a number of concepts that are described below.

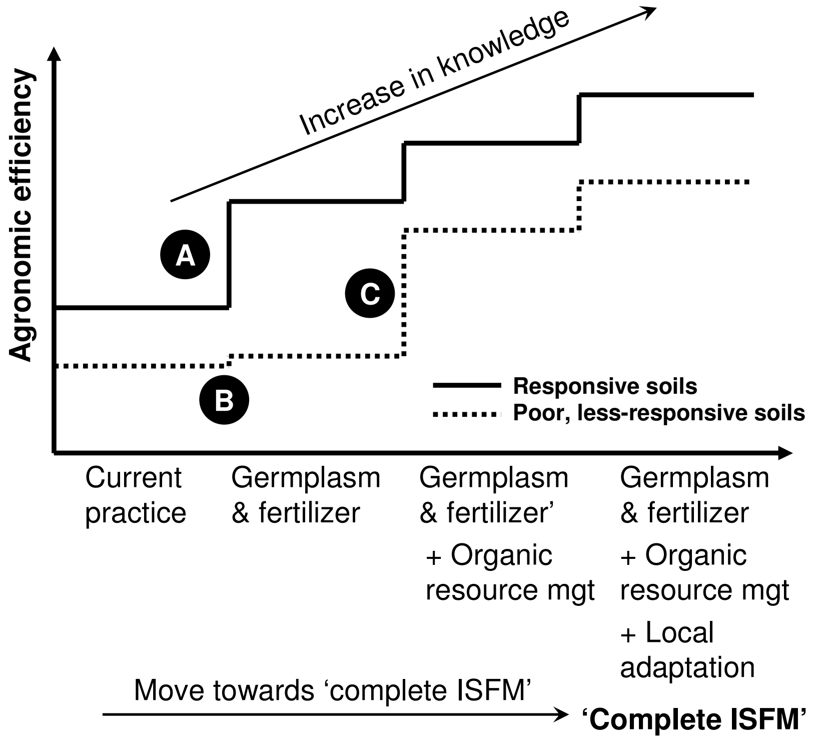

Figure 1. Conceptual relationship between the agronomic efficiency (*AE*) of fertilizers and organic resource and the implementation of various components of ISFM, culminating in complete ISFM towards the right side of the graph. Soils that are responsive to NPK-based fertilizer and those that are poor and less-responsive are distinguished. The 'current practice' step assumes the use of the current average fertilizer application rate in SSA of 8 kg fertilizer nutrients/ha. The meaning of the various steps is explained in detail in the text. At constant fertilizer application rates, yield is linearly related to *AE*.

Focus on agronomic use efficiency

The definition focuses on maximizing the use efficiency of fertilizer and organic inputs since these are both scarce resources in the areas where agricultural intensification is needed. Agronomic efficiency (*AE*) is defined as incremental return to applied inputs or: AE (kg/kg) = $(Y_F - Y_C) / (F_{appl})$ [1] where Y_F and Y_C refer to yields (kg/ha) in the treatment where nutrients have been applied and in the control plot, respectively, and F_{appl} is the amount of fertilizer and/or organic nutrients applied (kg/ha).

Fertilizer and improved germplasm

In terms of response to management, two general classes of soils are distinguished: (i) soils that show acceptable responses to fertilizer (Path A, Figure 1) and (ii) soils that show minimal or no response to fertilizer due to other constraints besides the nutrients contained in the fertilizer (Path B, Figure 1). We have classified above soils as 'responsive soils' and 'poor, less-responsive soils', respectively. In some cases, where land is newly opened, or where fields are close to homesteads and receive large amounts of organic inputs each year a third class of soil exists where crops respond little to fertilizer as the soils are fertile. These soils need only maintenance fertilization and are termed 'fertile, less responsive soils'. The ISFM definition proposes that application of fertilizer to improved germplasm on responsive soils will boost crop yield and improve the *AE* relative to current farmer practice, characterized by traditional varieties receiving too little and insufficiently managed nutrient inputs (Path A, Figure 2). Major requirements for achieving production gains on 'responsive fields' within Path A (Figure 1) include (i) the use of disease-resistant and improved germplasm, (ii) the use of the correct fertilizer formulation and rates, and (iii) appropriate fertilizer, crop and water management practices.

Combined application of organic and mineral inputs

Organic inputs contain nutrients that are released at a rate determined in part by their chemical characteristics or organic resource quality. However, organic inputs applied at realistic levels seldom release sufficient nutrients for optimum crop yield. Combining organic and mineral inputs has been advocated as a sound management principle for smallholder farming in the tropics because neither of the two inputs is usually available in sufficient quantities and because both inputs are needed in the long-term to sustain soil fertility and crop production. Two other issues arise within the context of ISFM: (i) does fertilizer application generate the required crop residues that are needed to optimize the *AE* of fertilizer for a specific situation and (ii) can organic resources be used to rehabilitate 'less-responsive soils' and make these responsive to fertilizer (Path C in Figure 2)? The first issue is supported by data obtained in Niger by Bationo et al (1998). Where fertilizer was applied to millet, sufficient residue was produced to meet both farm household demands for feed and food as well as the management needs of the soil in terms of organic inputs and surface protection of the soil from wind erosion. Evidence also supports the second rehabilitation issue. In Zimbabwe, applying farmyard manure for 3 years to sandy soils at relatively high rates enabled a clear response to fertilizer where such response was not visible before rehabilitation (Zingore *et al.* 2007). Applying above principles to maximize *AE* will require adaptation to the prevailing soil fertility status (SFGs) and other site-specific modifiers of crop growth.

Adaptation to local conditions

As previously stated, farming systems are highly variable at different scales and a challenge before the African Green Revolution is adjusting for site-specific soil conditions. Firstly, soil fertility status can vary considerably within short distances. A good proxy for soil fertility status is often the soil organic matter (SOM) content, provided that this parameter is not over-extrapolated across dissimilar soils. Soil organic matter contributes positively to specific soil properties or processes fostering crop growth, such as cation exchange capacity, soil moisture and aeration, or nutrient stocks. On land where these constraints limit crop growth, a higher SOM content may enhance the demand by the crop for N and consequently increase the fertilizer N use efficiency. On the other hand, SOM also releases available N that may be better synchronized with the demand for N by the plant than fertilizer N. Consequently a larger SOM pool may result in lower N fertilizer *AE*s. Evidence from Western Kenya shows that for fertile soils, *AE* for plant nutrients is less than that for less intensively managed outfields (Vanlauwe *et al.* 2006).

A move towards 'complete ISFM'

Several intermediary phases are identified that assist the practitioner's move towards complete ISFM from the current 8 kg/ha fertilizer nutrient application with local varieties. Each step is expected to provide the management skills that result in yield and improvements in *AE* (Figure 1). Complete ISFM comprises the use of improved germplasm, fertilizer, appropriate organic resource management and local adaptation. Figure 1 is not necessarily intended to prioritize interventions but rather suggests a need for sequencing towards complete ISFM. It does however depict key components that lead to better soil fertility management. For less-responsive soils, investment in soil fertility rehabilitation will be required before fertilizer *AE* will be enhanced.

Integration of ISFM principles in farming systems

Principles embedded within the definition of ISFM need to be applied within existing farming systems. Two examples clearly illustrated the integration of ISFM principles in existing cropping systems: (i) dual purpose grain legume – maize rotations with P fertilizer targeted at the legume phase and N fertilizer at rates below recommended rates targeted at the cereal phase in the moist savanna agro-ecozone (Sanginga *et al.* 2003) and (ii) micro-dose fertilizer applications in legume-sorghum or legume-millet rotations with retention of crop residues and combined with water harvesting techniques in the semi-arid agro-ecozone (Bationo *et al.* 1997; Tabo *et al.* 2007). As for the grain legume-maize rotations, application of appropriate amounts of mainly P to the legume phase ensures good grain and biomass production, the latter in turn benefiting a subsequent maize crop and thus reducing the need for external N fertilizer (Sanginga *et al.* 2003). As for the micro-dose technology, spot application of appropriate amounts of fertilizer to widely spaced crops as sorghum or millet substantially enhances its use efficiency with further enhancements obtained when combined with physical soil management practices aiming at water harvesting. Recycling crop residues can reduce wind and water erosion (Bationo *et al.* 1998) and thus further benefit growth and nutrient demand of a following cereal. Certain conditions enable the dissemination and retention of ISFM practices.

Dissemination of ISFM

The gradual increase in complexity of knowledge as one move towards complete ISFM (Figure 1) has implications on the strategies to adapt for widespread dissemination of ISFM. Furthermore, a set of enabling conditions can favor the uptake of ISFM. The operations of every farm are strongly influenced by the larger rural community, policies, and supporting institutions, and markets. Not only are farms closely linked to the off-farm economy through commodity and labor markets, but the rural and urban economies are also strongly interdependent. Farming households are also linked to rural communities and social and information networks, and these factors provide feedback that influences farmer decision-making. Because ISFM is a set of principles and practices to intensify land use in a sustainable way, uptake of ISFM is facilitated in areas with greater pressure on land resources. The first step towards ISFM acknowledges the need for fertilizer and improved varieties. An essential condition for its early adoption is access to farm inputs, produce markets, and financial resources. To a large extent, adoption is market-driven as commodity sales provide incentives and cash to invest in soil fertility management technologies, providing opportunities for community-based savings and credit schemes. Policies towards sustainable land use intensification and the necessary institutions and mechanisms to implement and evaluate these are also that facilitates the uptake of ISFM. Policies favoring the importation of fertilizer, its blending and packaging, or smart subsidies are needed to stimulate the supply of fertilizer as well. Specific policies addressing the rehabilitation of degraded, non-responsive soils may also be required since investments to achieve this may be too large to be supported by farm families alone. While dissemination and adoption of complete ISFM is the ultimate goal, substantial improvements in production can be made by promoting the greater use of farm inputs and germplasm within market-oriented farm enterprises. Such dissemination strategies should include ways to facilitate access to the required inputs, simple information fliers, spread through extension networks, and knowledge on how to avoid less-responsive soils. A good example where the ‘seeds and fertilizer’ strategy has made substantial impact is the Malawi fertilizer subsidy program. Malawi became a net food exporter through the widespread deployment of seeds and fertilizer, although the aggregated *AE* was only 14 kg grain per kg nutrient applied (Chinsinga 2008). Such *AE* is low and ISFM could increase this to at least double its value with all consequent economic benefits to farmers. As efforts to promote the ‘seed and fertilizer’ strategy are under way, activities such as farmer field schools or development of site-specific decision guides that enable tackling more complex issues can be initiated to guide farming communities towards complete ISFM, including aspects of appropriate organic matter management of local adaptation of technologies. The latter will obviously require more intense interactions between farmers and extension services and will take a longer time to achieve its goals.

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