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Integrated Soil Fertility Management Research at TSBF: The Framework, the Principles, and their Application

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Abstract

Integrated Soil Fertility Management (ISFM) has been adopted by the Tropical Soil Biology and Fertility (TSBF) Institute, its African Network (AfNet), and various other organisations as the paradigm for tropical soil fertility management research and development. The development of ISFM is the result of a series of paradigm shifts generated through experience in the field and changes in the overall socio-economic and political environment the various stakeholders, including farmers and researchers, are facing. A first part of the paper illustrates these shifts and sketches how the science of organic matter management has developed in the framework of the various paradigms. The second part focuses on the technical backbone of ISFM strategies by illustrating the roles of organic resources, mineral fertilizer, and soil organic matter (SOM) in providing soil-related goods and services. Special attention is given to the potential occurrence of positive interactions between

these three factors, leading to added benefits in terms of more crop yield, improved soil fertility status, and/or reduced losses of C and nutrients to the environment. A third part aims at confronting the principles and mechanisms for soil fertility management, highlighted in the second section, with reality and focuses on the impact of other realms of capital on soil management opportunities and the potential of decision aids to translate all knowledge and information in a format accessible to the various stakeholders.

Paradigm shifts related to tropical soil fertility management: From a Nutrient Replenishment to an Integrated Soil Fertility Management agenda

During the past 3 decades, the paradigms underlying soil fertility management research and development efforts have undergone substantial change because of experiences gained with specific approaches and changes in the overall social, economic, and political environment the various stakeholders are facing. TSBF has traditionally put a lot of emphasis on the appropriate management of organic resources and the conceptualisation of the role of organic resources in tropical soil fertility management has obviously been adapted to the various underlying paradigms.

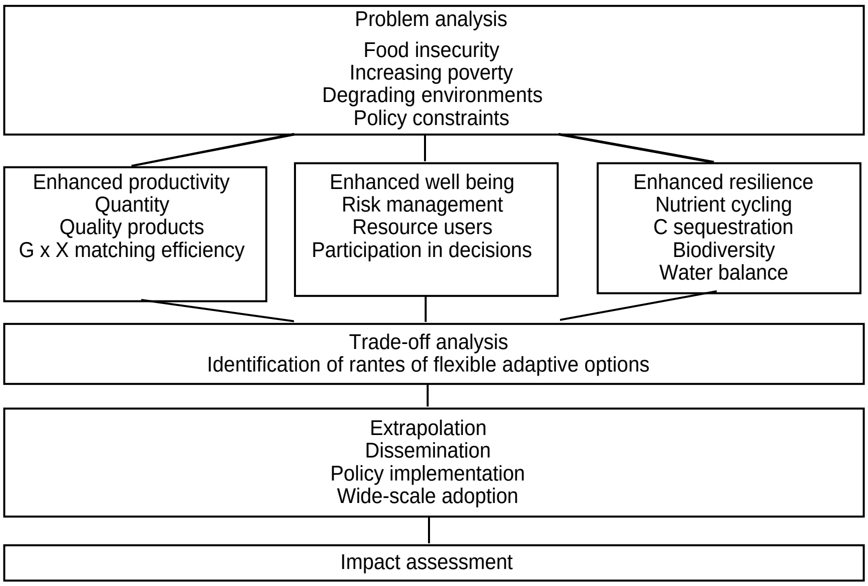
During the 1960s and 1970s, an external input paradigm was driving the research and development agenda. The appropriate use of external inputs, be it fertilizers, lime, or irrigation water, was believed to be able to alleviate any constraint to crop production. Following this paradigm together with the use of improved cereal germplasm, the 'Green Revolution' boosted agricultural production in Asia and Latin America in ways not seen before. Organic resources were considered less essential. Sanchez (1976) stated that when mechanization is feasible and fertilizers are available at reasonable cost, there is no reason to consider the maintenance of SOM as a major management goal. However, application of the 'Green Revolution' strategy in sub-Saharan Africa (SSA) resulted only in minor achievements because of a variety of reasons (IITA, 1992). This, together with environmental degradation resulting from massive applications of fertilizers and pesticides in Asia and Latin-America between the mid-1980's and early-1990's (Theng, 1991) and the abolition of the fertilizer subsidies in SSA (Smaling, 1993), imposed by structural adjustment programs led to a renewed interest in organic resources in the early 1980s. The balance shifted from mineral inputs only to low mineral input sustainable agriculture (LISA) where organic resources were believed to enable sustainable agricultural production.

After a number of years of investment in research activities evaluating the potential of LISA technologies, such as alley cropping or live-mulch systems, several constraints were identified both at the technical (e.g., lack of sufficient organic resources) and the socio-economic level (e.g., labour intensive technologies).

In this context, Sanchez (1994) revised his earlier statement by formulating the Second Paradigm for tropical soil fertility research: 'Rely more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use'. This paradigm did recognize the need for both mineral and organic inputs to sustain crop production, and emphasized the need for all inputs to be used efficiently. The need for both organic and mineral inputs was advocated because (i) both resources fulfil different functions to maintain plant growth, (ii) under most small-scale farming conditions, neither of them is available or affordable in sufficient quantities to be applied alone, and (iii) several hypotheses could be formulated leading to added benefits when applying both inputs in combination. The second paradigm also highlighted the need for improved germplasm, as in earlier days, more emphasis was put on the nutrient supply side without worrying too much about the demand for these nutrients. Obviously, optimal synchrony or use efficiency requires both supply and demand to function optimally.

From the mid-1980s to the mid-1990s the shift in paradigm towards the combined use of organic and mineral inputs was accompanied by a shift in approaches towards involvement of the various stakeholders in the research and development process, mainly driving by the 'participatory' movement. One of the important lessons learnt was that the farmers' decision making process was not merely driven by the soil and climate but by a whole set of factors cutting across the biophysical, socio-economic, and political domain. The Sustainable Livelihoods Approach (DFID, 2000) recognizes the existence of five realms of capital (natural, manufactured, financial, human, and social) that constitute the livelihoods of farmers. It was also recognized that natural capital, such as soil, water, atmosphere, or biota does not only create services which generate goods with a market value (e.g., crops and livestock) but also services which generate amenities essential for the maintenance of life (e.g., clean air and water). Due to the wide array of services provided by natural capital, different stakeholders may have conflicting interests in natural capital. The Integrated Natural Resource Management (INRM) research approach (Figure 2.1) aims at developing interventions that take all the above into account (Izac, 2000). The Integrated Soil Fertility Management (ISFM) paradigm, that forms and integral part of the INRM research approach with a focus on appropriate management of the soil resource, is currently adopted in the soil fertility research and development community. Although technically ISFM adopts the Second Paradigm, it recognizes the important role of social, cultural, and economic processes regulating soil fertility management strategies. ISFM is also broader than Integrated Nutrient Management (INM) as it recognizes the need of an appropriate physical and chemical environment for plant to grow optimally, besides a sufficient and timely supply of available nutrients.

Figure 2.1: The Integrated Natural Resource Management research approach



Source: Izac, 2000

The science of organic matter management as affected by shifts in soil fertility management paradigms

Although organic inputs had not been new to tropical agriculture, the first seminal synthesis on organic matter management and decomposition was written only in 1979 by Swift *et al.* (1979) (Table 2.1). Between 1984 and 1986, a set of hypotheses was formulated based on 2 broad themes, 'synchrony' and 'SOM' (Swift, 1984, 1985, and 1986), building on the concepts and principles formulated in 1979. Under the first theme, especially the O(rganisms)-P(hysical environment)-Q(uality) framework for OM decomposition and nutrient release (Swift *et al.*, 1979), formulated earlier, was worked out and translated into hypotheses driving management options to improve nutrient acquisition and crop growth. Under the second theme, the role of OM in the formation of functional SOM fractions was stressed. During the 1990s, the formulation of the research hypotheses related to residue quality and N release led to a vast amount of projects aiming at validation of these hypotheses, both within AfNet and other research groups dealing with tropical soil fertility. This information has been very instrumental for proper evaluation of the sustainability of LISA systems. As such systems did not emphasize the need for mineral inputs, organic resources were merely considered as short-terms sources of nutrients and especially N.

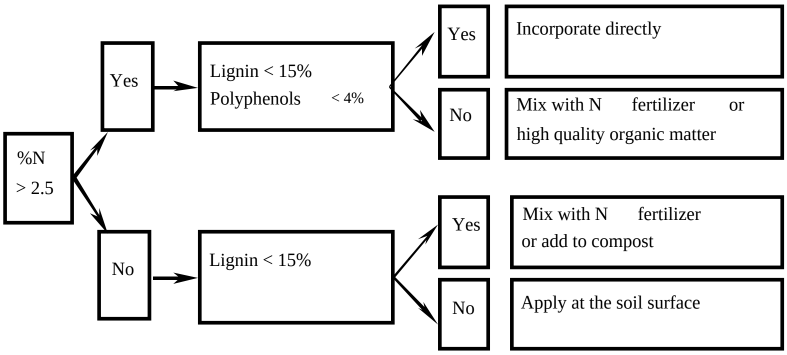
Table 2.1: A brief summary of the science of tropical organic resource management

Period	Observation	Reference
< 1970s	Organic matter as a 'blob'	Palm, personal communication
1979	Organisms - Physical environment – Quality framework for organic matter decomposition	Swift *et al*., 1979
1984-1986	Development of the 'synchrony' research theme within the Tropical Soil Biology and Fertility programme	Swift, 1984; Swift, 1985; Swift, 1986
1990s	Various experiments addressing the 'synchrony' hypothesis	Various
1995	International Symposium on 'Plant Litter Quality and Decomposition'	Cadisch and Giller, 1997
2000	Development of the 'Organic Resource Database' and the Decision Support System for organic N management	Palm *et al*., 2001
> 2001	Quantification of the Decision Support System for organic N management	The current and future publications

Two major events further accentuated the relevance of the topic in tropical soil fertility management. Firstly, a workshop was held in 1995 with the theme 'Plant litter quality and decomposition' resulting in a book summarizing the state of the art of the topic (Cadisch and Giller, 1997). Secondly, TSBF in collaboration with its national partners and Wye College developed the Organic Resource Database (ORD) and related Decision Support System (DSS) for OM management (Figure 2.2) (Palm *et al*., 2001). The Organic Resource Database contains information on organic resource quality parameters including macronutrient, lignin and polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agroecosystems. Careful analysis of the information contained in the ORD led to the development of the

DSS which makes practical recommendations for appropriate use of organic materials, based on their N, polyphenol, and lignin contents resulting in four categories of materials (Figure 2.2). Recently, a farmer-friendly version of the DSS has been proposed by Giller (2000).

Figure 2.2: The Decision Support System for organic matter management



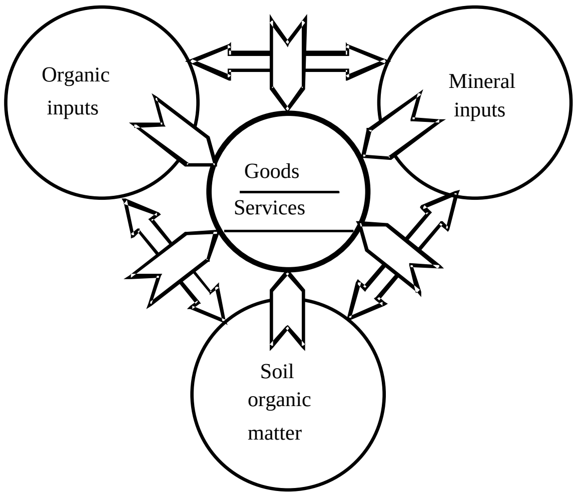
Source: Palm *et al*., 2001

The DSS recognizes the need for certain organic resource to be applied together with mineral inputs, consistent with the Second Paradigm. Organic resources are seen as complimentary inputs to mineral fertilizers and their potential role has consequently been broadened from a short term source of N to a wide array of benefits both in the short and long term (Vanlauwe *et al.*, 2002a). The ISFM paradigm has also led to increased emphasis on the social, economic, and policy dimensions of organic and mineral input management (TSBF, 2002). In this context, it is important to note the full-time involvement of a social scientist in TSBF and the recognition for more social input need in AfNet.

The technical backbone of ISFM: optimal management of organic resources, mineral inputs, and the soil organic matter pool

Optimum management of the soil resource for provision of goods and services requires the optimum management of organic resources, mineral inputs, and the SOM pool (Figure 2.3). Each of these resources contributes to the provision of goods and services individually, but more interestingly, these various resources can be hypothesized to interact with each other and generate added benefits in terms of extra crop yield, an improved soil fertility status, and/or reduced losses of nutrients to the environment.

Figure 2.3: The goods and environmental services generated by the soil are the result of the management of organic resources, mineral inputs, and the SOM pool and the interactions between these various factors

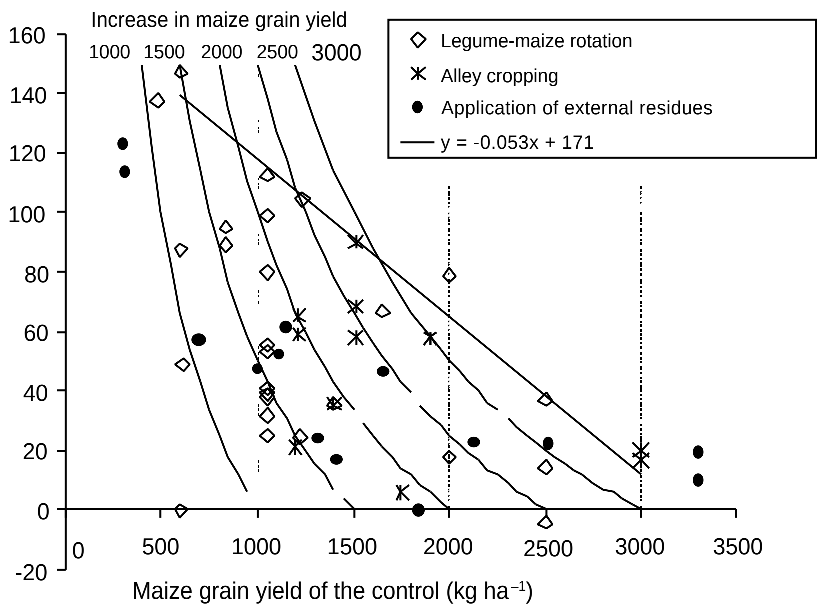


Impact of individual factors on the provision of goods and services

Numerous studies have looked at crop responses to applied fertilizer in sub-Saharan Africa and reported substantial increases in crop yield. Results from the FAO Fertilizer Program have shown an average response of 750 kg maize grain ha^{-1} to medium NPK applications (FAO, 1989). Value–to–Cost ratios (VCR) varied between 1.1 and 8.9, and were usually above the required minimum ratio of 2. National fertilizer recommendations exist for most countries, but actual application rates are nearly always much lower to nil due to constraints of a socio-economic rather than a technical nature. For a variety of reasons, fertilizers are relatively expensive in SSA, certainly if compared to - often subsidized - prices in, for example, Western Europe ($7.5 per 50 kg bag of urea in Germany, 1999, vs $13-17 per 50 kg bag of urea in Nigeria in, 1999, — S Schulz, personal communication, 2000). This is further aggravated by the lack of credit schemes to purchase these inputs as there is often a large time-gap between revenue collection from selling harvested products and fertilizer purchase. In terms of environmental services, mineral inputs have relatively little potential to enhance the SOM status (Vanlauwe *et al.*, 2001a) and may, in the case of N fertilizer, contaminate (ground)water resources when not used efficiently. The production of N fertilizer itself requires a substantial amount of energy, usually derived from fossil fuels, and contributes to the CO_2 load of the atmosphere.

In cropping systems with sole inputs of organic resources, short-term data reveal a wide range of increases in maize grain yield compared to the control systems without inputs (Figure 2.4). With higher soil fertility status, the maximum increases were observed to decrease to virtually nil at control grain yields of about 3000 kg ha^{-1}. Although yields on fields with a low soil fertility status, e.g., with control yields below 1000 kg ha^{-1}, can easily be increased up to 140% after incorporation of a source of OM in the cropping system, this would lead to absolute yields hardly exceeding 1500 kg ha^{-1} (Figure 2.4). In most cropping systems, absolute yield increases in the OM-based treatments are far below 1000 kg ha^{-1}, while significant investments in labour and land are needed to produce and manage the OM. This is partly related to the low N use efficiency of OM to be low (Vanlauwe and Sanginga, 1995; Cadisch and Giller, 1997). Other problems related to the sole use of organic inputs are low and/or imbalanced nutrient content, unfavorable quality, or high labor demand for transporting bulky materials (Palm *et al.*, 1997).

Figure 2.4: Increase in maize grain yield relative to the control in cropping systems based on organic matter management (legume-maize rotation, alley cropping, systems with application of external organic matter) without inputs of fertilizer N as influenced by the initial soil fertility status, expressed as yield in the control plots. The linear regression line shows the estimated maximal increases in grain yield. The curved lines show the absolute yields in the treatments receiving organic matter (in kg ha^{-1})



Source: Vanlauwe *et al.*, 2001a

Although most of the organic resources show limited increases in crop growth, they do increase the soil organic C status (Vanlauwe *et al*., 2001a) and have a positive impact on the environmental service functions of the soil resource. This is evidenced by the existence of steep gradients in soil organic C status between fields at the farm scale caused by long-term site-specific soil management by the farmer (Table 2.2). Soil organic matter is not only a major regulator of various processes underlying the supply of nutrients and the creation of a favourable environment for plant growth but also regulates various processes governing the creation of soil-based environmental services (Figure 2.5). Consequently, the high SOM status in the homestead fields is often observed to be related positively with crop yield (Figure 2.6).

Table 2.2: Soil fertility status of various fields within a farm in Burkina Faso. Home gardens are near the homstead, bush fields furthest away from the homestead and village fields at intermediate distances

Field	Organic C (g kg^{-1})	Total N (g kg^{-1})	Available P (mg kg^{-1})	Exchangeable K (mmol kg^{-1})
Home garden	11 – 22	0.9 – 1.8	20 – 220	4.0 – 24
Village field	5 – 10	0.5 – 0.9	13 – 16	4.1 – 11
Bush field	2 – 5	0.2 – 0.5	5 – 16	0.6 – 1

Source: Prudencio *et al*., 1993

Figure 2.5: Regulating nutrient supply and soil-based environmental services

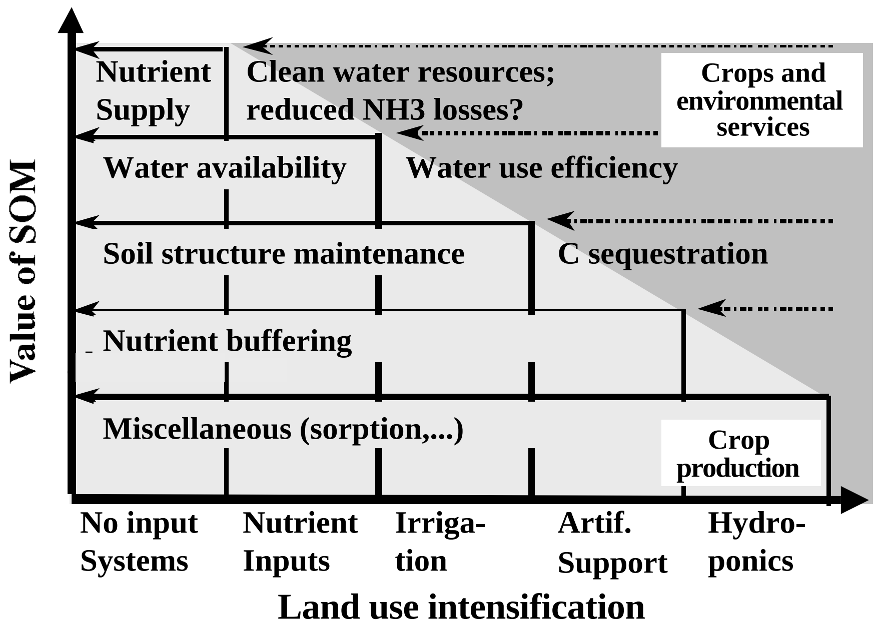
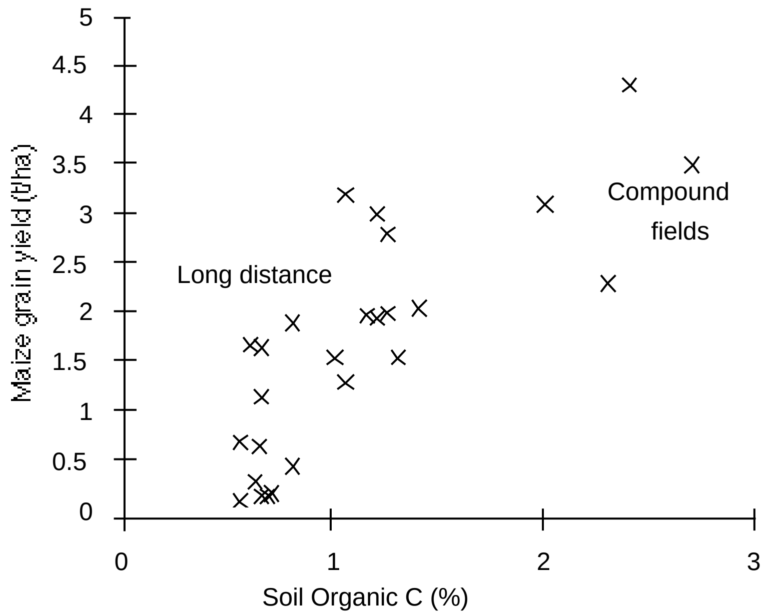


Figure 2.6: Relationship between the soil organic C content and maize grain yield for a set of fields varying in distance to the homestead in Northern Nigeria



Source: Carsky *et al*., 1998

From the crop production point of view, the relevance of SOM in regulating soil fertility decreases (plain horizontal arrows on figure 2.5) as natural capital is being replaced by manufactured or financial capital with increasing land use intensification. From an ISFM point of view, that also considers environmental service functions besides crop production functions, one could argue that the relevance of SOM does not decrease (dashed horizontal arrows on Figure 2.5).

Potential interactions between the various factors on the provision of goods and services

The Second Paradigm initiated a substantial effort on evaluating the impact of combined applications of organic resources and mineral inputs as positive interactions between both inputs could potentially result in added benefits. A *Direct* and *Indirect Hypothesis* which could form the basis for the occurrence of such benefits has been formulated by Vanlauwe *et al*. (2001a). The *Direct Hypothesis* was formulated as: *Temporary immobilization of applied fertilizer N may improve the synchrony between the supply of and demand for N and reduce losses to the environment.* The *Indirect Hypothesis* was formulated for N supplied as fertilizer as: *Any organic matter-related improvement in soil conditions affecting plant growth (except N) may lead to better plant growth and consequently enhanced efficiency of the applied N.* The *Indirect Hypothesis* recognizes that organic resources can have multiple benefits besides the short-term supply of available N. Such benefits could be an improved soil P status by reducing the soil P sorption capacity, improved soil moisture conditions, less pest and disease pressure in legume-cereal rotations, or other mechanisms. Both hypotheses, when proven, lead to an enhancement in N use efficiency, processes following the *Direct Hypothesis* through improvement of the N supply and processes following the *Indirect Hypothesis* through an increase in the demand for N. Obviously, mechanisms supporting both hypotheses may occur simultaneously.

Testing the *Direct Hypothesis* with ^{15}N labelled fertilizer, Vanlauwe *et al*. (2002b) concluded that direct interactions between OM and fertilizer-N not only exist in the laboratory but also under field conditions. The importance of residue quality and way of incorporation in the overall size of these interactions was also demonstrated. In a multilocational trial with external inputs of organic matter, Vanlauwe *et al*. (2001b) observed added benefits from the combined treatments in 2 of the 4 sites, which experienced serious moisture stress during the early phases of grain filling. The positive interaction in these 2 sites was attributed to the reduced moisture stress in the 'mixed' treatments compared to the sole urea treatments because of the presence of organic materials (surface and sub-surface placed) and constitutes evidence for the occurrence of mechanisms supporting the *Indirect Hypothesis*. Although more examples can be found in literature supporting the *Indirect Hypothesis*, it is clear that a wide range of mechanisms could lead to an improved use efficiency of applied external inputs. These mechanisms may also be site-specific, e.g., an improvement in soil moisture conditions is of little relevance in the humid forest zone. Unravelling these, where feasible, as a function of easily quantifiable soil characteristics is a major challenge and needs to be done in order to optimize the efficiency of external inputs. On the other hand, when applying organic resources and mineral fertilizer simultaneously, one hardly ever observes negative interactions, indicating that even without clearly understanding the mechanisms underlying positive interactions, applying organic resources in combination with mineral inputs stands as an appropriate fertility management principle.

Because SOM affects a series of factors supporting plant growth and because of the observed within-farm variability in soil fertility and SOM status, interest has been recently developed in relating the use efficiency of mineral N inputs to the SOM status. A set of hypotheses follows the general principles behind the *Indirect Hypothesis* outlined above and result in positive relationships between SOM content and fertilizer use efficiency. On the other hand, SOM also release available N that may be better synchronized with the demand for N by the plant than fertilizer N and consequently a larger SOM pool may result in lower use efficiencies of the applied fertilizer N. A preliminary investigation, carried out in a long-term alley cropping trial showed a negative correlation between the proportion of maize N derived from the applied fertilizer and the topsoil organic C content and supports the latter hypothesis (Vanlauwe *et al.*, Unpublished data). Other reports show higher use efficiency of N fertilizer (Breman, personal communication) and P fertilizer (Bationo, personal communication) for homestead fields with a higher SOM content.

Finally, application of organic resources is the easiest way to enhance the SOM pool. Although it is only possible in the medium to long term to induce substantial changes in soil organic C content in experimental trials using realistic organic matter application rates, the above-mentioned often drastic differences in SOM between fields within one farm prove that farmers are already managing the SOM status. While residue quality has been shown to significantly affect the short-term decomposition/ mineralization dynamics (Palm *et al.*, 2001), it is unclear whether quality is still an important modifier of the long-term decomposition dynamics. Several hypotheses have been formulated, most of them postulating that slowly decomposing, low quality organic inputs with relatively high lignin and polyphenol content will have a more pronounced effect on the SOM pool than rapidly decomposing, high quality organic inputs (Figure 2.2). The *C stabilization potential* could be an equivalent index to the N fertilizer equivalency index used to describe the short term N release dynamics. The few trials that have shown significant increases in SOM have used farmyard manure as organic input, which may be related to the presence of resistant C in the manure as the available C is digested while passing through the digestive track of the animal.

Production of organic matter in existing cropping systems: the bottleneck in implementing ISFM practices

Although there is a wide range of potential niches to produce organic resources within existing cropping systems (Table 2.3), introducing an organic matter production phase in a cropping system creates problems with adaptability and adoptability of such technologies, especially if this fallow production phase does not yield any commercial product, such as grain or fodder. Although a significant amount of organic matter can potentially be produced in cropping systems with in-situ organic matter production, adoption of such cropping systems by the farmer community is low and often driven by other than soil-fertility regeneration arguments. Dual-purpose grain legumes, on the other hand, have a large proportion of their N derived from biological N fixation, a low N harvest index, and produce a substantial amount of both grain and biomass, have a great potential to become part of such cropping systems (Sanginga *et al.*, 2001). Further advantages besides a substantial amount of N fixation from the atmosphere associated with growing high biomass producing legumes in rotation with cereal are, among others, potential improvement of the soil available P status through rhizosphere processes operating near the root-zone of the legume crop (Lyasse *et al.*, 2002), reduction in pest and disease pressure by e.g., *Striga* spp, (iii) improved soil physical properties. These processes yield benefits to a cereal crop beyond available N but are often translated into N fertilizer equivalency values. Obviously, values greater than 100% should be sometimes expected.

Table 2.3: Place and time of production of organic matter (fallow species) relative to crop growth and the respective advantages/disadvantages of the mentioned organic matter production systems with respect to soil fertility management and crop growth. 'Same place' and 'same time' mean 'in the same place as the crop' and 'during crop growth'

Place and time of organic matter production - example of farming system	Advantages	Disadvantages
Same place, same time - alley cropping	- 'Safety-net' hypothesis (complementary rooting depths) - Possible direct transfer from N_2 fixed by legume species	- Potential competition between crop and fallow species - Reduction of available crop land
Same place, different time - crop residues - legume-cereal rotation - improved tree fallows - manure, derived from livestock fed from residues collected from same field	- 'Rotation' effects (N transfer, improvement of soil P status,...); - Potential inclusion of 'dual purpose' legumes - In-situ recycling of less mobile nutrients - No competition between fallow species and crops	- Land out of crop production for a certain period - Decomposition of organic matter may start before crop growth (potential losses of mobile nutrients, e.g., N, K,...) - Extra labour needed to move organic matter (manure)
Different place - cut-and-carry systems - household waste - animal manure, not originating from same field	- Utilization of land/nutrients otherwise not used - No competition between fallow	- Extra labour needed to move organic matter - No recycling of nutrients on crop land - Need for access to extra land - Manure and household waste often have low quality

Source: Adapted from Vanlauwe *et al*., 2001a

In cut-and carry systems, which involve the transfer of nutrients from one area to another, it is necessary to determine how long soils can sustain vegetation removal before collapsing, especially soils which are relatively poor and where vegetative production can be rapid. Cut-and-carry systems without use of external inputs may be a 'stay of execution' rather than a sustainable form of soil fertility management. Of further importance is the vegetation succession that will occur after vegetative removal. It is possible that undesirable species could take over the cut-and-carry field once it is no longer able to sustain removal of the vegetation of the selected species. Where an intentionally planted species is used, the natural fallow species needs to be compared to determine what advantage, if any, is being derived from the extra effort to establish and maintain the planted species.

From theory to practice: Implementation of ISFM practices at the farm level

Having focussed on the principles and technical issues underlying the ISFM research agenda, these need to be put into the wider context this paper started off with. This section aims at looking at ISFM options from the farmer perspective and considers ways to disseminate these options to the various stakeholders.

Beyond the soil: Links with other realms of capital

So far, the paper mainly focussed on the management of natural capital with some inclusion of manufactured capital in the form of mineral inputs. However, as stated above, farmers' livelihoods consist of various realms of capital which all contribute to their decision-making process regarding soil fertility management. One obvious factor affecting the way farmers manage their soils is related to their wealth in terms of access to other realms of capital, such as cash, labour, or knowledge. Rommelse (2001) reported that in a set of villages in Western Kenya, wealthy farmers spend 102 USD on farm inputs per year compared to 5 USD for poor farmers. Besides having an overall impact on the means to invest in soil fertility replenishment, farmers' wealth also affects the strategies preferred to address soil fertility decline. In two districts in Western Kenya, Place *et al.* (2002) observed that wealthy farmers do not only use more frequently mineral fertilizers compared to poor farmers, but also a wider range of soil management practices. Farmer production objectives, which depend on a whole set of biophysical, but also social, cultural, and economic factors, also take into account the fertility gradients existing within their farm boundaries. Most soil fertility research has been targeted at the plot level, but decisions are made at the farm level, taking into account the production potential of all plots.

In Western Kenya, e.g., farmers will preferably grow sweet potato on the most degraded fields, while banana's and cocoyam occupy the most fertile fields (Tittonell, personal communication).

Finally, farmers are not the only stakeholders benefiting from proper land management. As stated earlier soils provide and regulate a series of important ecosystem services that affect every living organism and society as a whole and maintaining those ecosystem service functions may be equally or more vital than maintaining the crop production functions. Unfortunately, little information is available on the potential trade-offs between the use of land for either of both functions, on the most appropriate way to create a dialogue between the various stakeholders benefiting from a healthy soil fertility status, and on the role policy needs to assume to resolve above questions. The INRM research approach is aiming at creating a basis for such trade-off analysis and stakeholder dialogue.

Putting it all together: User-friendly decision aids for ISFM

After having obtained relevant information as described above, two extra steps may be required to complete the development of a user-friendly decision aid: (i) all above information needs to be synthesized in a quantitative framework and (ii) that framework needs to be translated in a format accessible to the end-users. The level of accuracy of such quantitative framework is an important point to consider. The generation of a set of rules of thumb is likely to be more feasible than software-based aids that generate predictive information for a large set of environments. The level of complexity is another essential point to take into consideration. For instance, if variation between fields within one farm is large and affects ISFM practices, then this may justify having this factor included in decision aids. Other aspects that will influence the way information and knowledge is condensed into a workable package are: (i) the targeted end-user community, (ii) the level of specificity required by the decisions to be supported, and (iii) level of understanding generated related to the technologies targeted. Van Noordwijk *et al.* (2001) prefer the term 'negotiation support systems' because the term 'decision support systems' suggests that a single authority makes decisions that will then be imposed on the various stakeholders. In an INRM context, it is recognized that different stakeholders may have conflicting interests related to certain specific soil management strategies and that a certain level of negotiation may be required.

The final format of the decision aid should take into account the realities on the field. Some of these realities, among others, are: (i) large scale soil analyses are not feasible, so local soil quality indicators need to be included in decision aids as farmers use those to appreciate existing soil fertility gradients within a farm; (ii) conditions within farms vary as does the availability of organic resources and fertilizer, therefore rules of thumb rather than detailed quantitative recommendations would be more useful to convey the message to farmers; (iii) farmers decision making processes involve more than just soil and crop management; and (iv) access to computers, software and even electricity is limited at the farm level, necessitating hard copy-based products.

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