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The Multiple Roles of Organic Resources in Implementing Integrated Soil Fertility Management Strategies

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Abstract

The Tropical Soil Biology and Fertility (TSBF) Institute, its African Network (AfNet), and various other organisations, have adopted ‘integrated soil fertility management’ (ISFM) 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 socioeconomic and political environment faced by the various stakeholders, including farmers and researchers. The first part of the paper illustrates these shifts and outlines 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 fertiliser and soil organic matter 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 greater crop yield, improved soil fertility status, and/or reduced losses of C and nutrients to the environment. The third section 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.

During the past four decades, the paradigms underlying soil fertility management research and development efforts have undergone substantial evolution to respond to changes in the overall social, economic, and political environment the various stakeholders are facing and the experiences gained by researchers.

During the 1960s and 1970s, an ‘external input’ paradigm was driving the research and development agenda. The appropriate use of external inputs, e.g. fertilisers, lime, or irrigation water, was believed to be sufficient to alleviate any constraint to crop production. Following this paradigm together with the use of improved cereal germplasm, the green revolu-

tion boosted agricultural production in Asia and Latin America in ways not seen before. However, for a variety of reasons, application of the green revolution strategy in sub-Saharan Africa (SSA) resulted in only minor achievements (IITA 1992). This, together with environmental degradation resulting from massive applications of fertilisers and pesticides in Asia and Latin-America between the mid-1980s and early-1990s (Theng 1991), and the abolition of the fertiliser subsidies in SSA (Smaling 1993), imposed by structural adjustment programs, led to a renewed interest in organic resources in the early 1980s following an ‘organic input’ paradigm. The balance shifted from mineral inputs only to low mineral input sustainable agriculture (LEISA) in which organic resources were believed to enable sustainable agricultural production. After a number of years of

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investment in research activities evaluating the potential of LEISA technologies, such as alley cropping or live-mulch systems, several constraints were identified both at the technical (e.g. lack of sufficient organic resources; lack of sufficient short-term yield increases) and the socioeconomic level (e.g. labour-intensive technologies).

In this context, Sanchez (1994) formulated 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 optimising nutrient cycling to minimise external inputs and maximise the efficiency of their use'. This paradigm did recognise the need for both mineral and organic inputs to sustain crop production, and emphasised the need for all inputs to be used efficiently. This advice was driven by (i) the lack of a sufficient amount of either mineral or organic inputs, (ii) the recognition that both inputs fulfil a set of different functions, and (iii) the potential for creating added benefits when applying organic resources in combination with fertilisers. The second paradigm also highlighted the need for improved germplasm; in earlier studies more emphasis was put on the nutrient supply side without worrying too much about the demand for these nutrients. 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 driven by the 'participatory' movement (Swift et al. 1994). 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, socioeconomic, and political domain. The 'sustainable livelihoods approach' (DFID 2000) recognises the existence of five realms of capital (natural, manufactured, financial, human and social) that constitute the livelihoods of farmers. It was also recognised 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 aims at developing interventions that take all the above into account (Izac 2000). The 'integrated soil fertility management' (ISFM) paradigm, which forms an 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 follows the second paradigm (Sanchez 1994), it goes further in explicitly recognising the important role of the social, cultural, and economic processes regulating soil fertility management strategies. ISFM is also broader than 'integrated nutrient management' (INM) as it recognises the need for an appropriate physical and chemical environment for plants to grow optimally, besides a sufficient and timely supply of available nutrients.

The Science of Organic Matter Management Following Shifts in Soil Fertility Management Paradigms

The conceptualisation of the role of organic resources in tropical soil fertility management has evolved alongside the changes in the guiding paradigms. In the context of the external input paradigm, organic resources were given little attention and were certainly not felt essential for sustainable crop production (Table 1). Confirming this paradigm, Sanchez (1976) stated that, when mechanisation is feasible and fertilisers are available at reasonable cost, there is no reason to consider the maintenance of soil organic matter (SOM) as a major management goal.

Although organic inputs had not been new to tropical agriculture, the first seminal synthesis on organic matter management and decomposition was not written until 1979 (Swift et al. 1979). Between 1984 and 1986, a set of hypotheses was formulated based on two broad themes, 'synchrony' and 'SOM' (Swift, 1984, 1985, 1986) building on the concepts and principles formulated in 1979. Under the first theme, the O(rganisms)–P(hysical environment)–Q(uality) framework for organic matter (OM) decomposition and nutrient release (Swift et al. 1979), formulated earlier, was elaborated 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. It is also interesting to note that, during this period,

organic resources were seen mainly as sources of nutrients, and more specifically N (Table 1). During the 1990s, the formulation of the research hypotheses relating to residue quality and N-release led to a vast amount of projects aiming at validation of these hypotheses, both within TSBF and other research groups dealing with tropical soil fertility. This information has been instrumental in permitting proper evaluation of the sustainability and efficiency of systems based on the organic input paradigm.

Table 1. The changing role of organic resources in tropical soil fertility management.

Period	Soil fertility management paradigm	Role of organic resources
1960s	External input paradigm	Organic matter plays a minor role
1980s	Biological management of soil fertility; LISA	Organic matter is a source of nutrients
1996	Second paradigm – combined application of organic resources and mineral fertiliser	Organic matter fulfils other important roles besides supplying nutrients
Now	Integrated soil fertility management	Organic matter management has social, economic, and political dimensions

A significant part of the work dealing with organic resource management aimed at fine-tuning procedures for organic resource quality determination. Short-term N availability from organic resources was

initially related mainly to their C:N ratio. Efforts to fine-tune organic resource quality assessments were derived from feed-quality assessments, traditionally used in the field of animal science. Examples are the determination of the fibre components of organic resources in terms of hemicellulose, cellulose, and lignin following various modification of the Van Soest fractionation scheme (Van Soest 1963; Van Soest and Wine 1968). Soluble polyphenols (King and Heath 1967) also became standard indicators of organic resource quality, as these appeared to strongly affect the short-term release of mineral N, mainly from leguminous organic resources that commonly have a rather high N content (e.g. Palm and Sanchez 1991). Further work indicated that soluble polyphenols are also very diverse (Harborne 1997) and react differently with proteins in organic resources. The protein-binding capacity, also originating from animal science, was found to be more sensitive in predicting mineral N release than the total soluble polyphenol content (Handayanto et al. 1997). Recently, spectroscopic approaches are being validated for their potential to determine organic resource quality (Shepherd et al. 2004).

Two major events further accentuated the relevance of decomposition processes to tropical soil fertility management. Firstly, a workshop held in 1995, on the theme ‘Plant litter quality and decomposition’, resulted in a book summarising the state of the art in 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 (Fig. 1; Palm et al. 2001). ORD contains information on organic resource quality

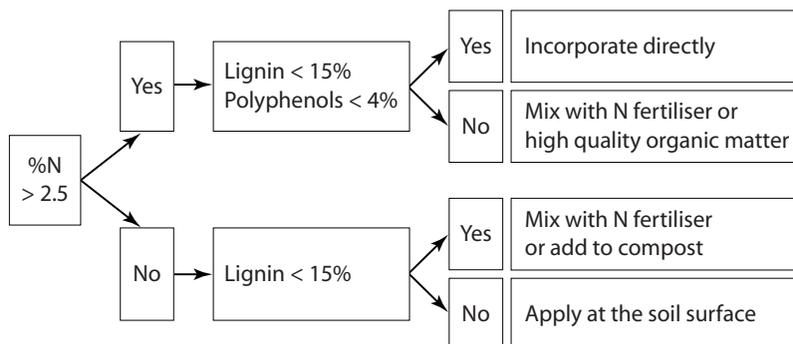


Figure 1. The decision-support system for organic matter management. Source: Palm et al. (2001).

parameters including macronutrient, lignin and polyphenol contents of fresh leaves, litter, stems and/or roots from almost 300 species found in tropical agro-ecosystems. 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 (Fig. 1). Recently, a farmer-friendly version of the DSS has been developed by Giller (2000).

The DSS recognises the need for certain organic resources to be applied together with mineral inputs, consistent with the second paradigm. Organic resources are seen as inputs complementary to mineral fertilisers, 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 (Table 1; Vanlauwe et al. 2002a). The potential for positive interactions is treated in more detail below.

Finally, the ISFM paradigm has also led to increased emphasis on the social, economic, and policy dimensions of organic input management (TSBF 2002).

The Technical Backbone of ISFM: Optimal Management of Organic Resources, Mineral Inputs, and the Soil Organic Matter Pool

Optimal management of the soil resource for provision of goods and services requires the optimal management of organic resources, mineral inputs, and the SOM pool (Fig. 2). Each of these resources contributes to the provision of goods and services individually, but, more interestingly, these various resources can be hypothesised to interact and generate added benefits in terms of extra crop yield, an improved soil fertility status, and/or reduced losses of nutrients.

Impact of individual factors on the provision of goods and services

Numerous studies have looked at crop responses to applied fertiliser in SSA and have reported substantial increases in crop yield. Results from the FAO Fertilizer Program have shown an average increase in maize grain production of 750 kg ha⁻¹ in response 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 fertiliser recommendations exist for most countries, but actual application rates are nearly always much lower, and in many cases zero, due to socioeconomic constraints rather than technical ones. For a variety of reasons, fertilisers are expensive in SSA; for example, prices were \$7.5 per 50 kg bag of urea in Germany versus \$13–17 per 50 kg bag in Nigeria in 1999 (S. Schulz, pers. comm., 2000). This is further aggravated by the lack of credit schemes to purchase these inputs, as there is often a large interval between fertiliser purchase and revenue collection from selling harvested products. Mineral inputs have relatively little potential to enhance the SOM status, which is central to the provision of many soil-based ecosystem services (Vanlauwe et al. 2001a). In the case of N fertiliser, they may even contaminate (ground)water resources when not used efficiently. The production of N fertiliser itself requires a substantial amount of energy, usually derived from fossil fuels, and contributes to the CO₂ load of the atmosphere.

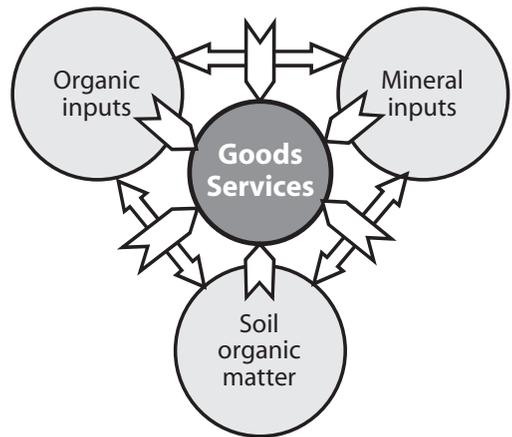


Figure 2. The goods and environmental services generated by the soil are the result of the management of organic resources, mineral inputs, and the soil organic matter pool, and the interactions between these various factors.

In cropping systems with sole inputs of organic resources, short-term data reveal a wide range of increases in maize grain yield compared with the control systems without inputs (Fig. 3). 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 (Fig. 3). With higher soil fertility status, the maximum increases observed were proportionally lower, falling to virtually nil at control grain yields of about 3000 kg ha⁻¹. Thus, 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 (Vanlauwe and Sanginga 1995; Cadisch and Giller 1997). Other problems are low and/or imbalanced nutrient content, unfavourable quality, or high labour demand for transporting bulky materials (Palm et al. 1997).

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 potentially positive impact on the environmental service functions of the soil resource. 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 such as buffering the atmospheric CO₂ loads or favouring water infiltration in the soil through a better soil structure (Fig. 4).

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

The second paradigm initiated a substantial effort to evaluate the impact of combined applications of organic resources and mineral inputs, as positive interactions between both inputs could potentially result in added benefits (Fig. 5). Two hypotheses that could form the basis for the occurrence of such benefits were formulated by Vanlauwe et al. (2001a): The “direct hypothesis” postulated that: ‘Temporary immobilisation of applied fertiliser N may improve the synchrony between the supply of and demand for

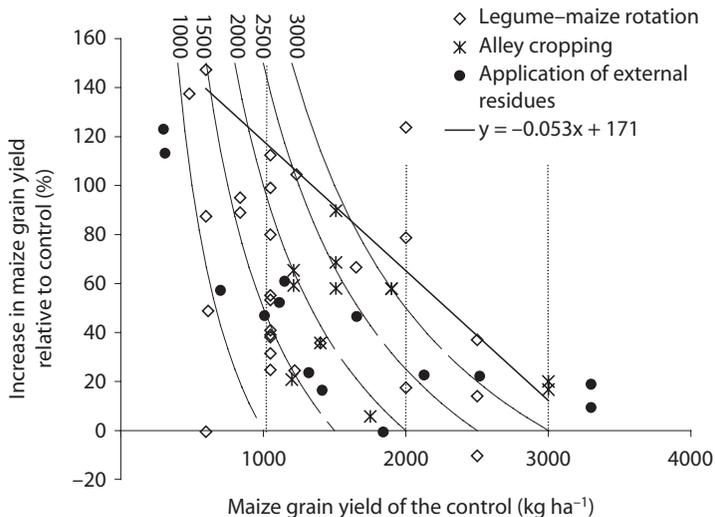


Figure 3. Increase in maize grain yield relative to the control in cropping systems based on organic matter management (legume-maize rotation, alley cropping, systems with application of external organic matter) without inputs of fertiliser N as influenced by the initial soil fertility status, expressed 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).

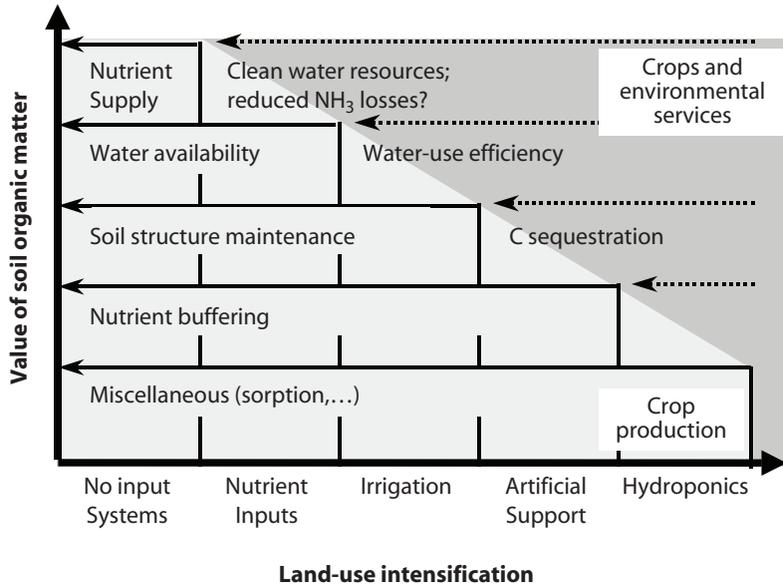


Figure 4. From the crop production point of view, the relevance of soil organic matter (SOM) in regulating soil fertility decreases (plain horizontal arrows) as natural capital is being replaced by manufactured or financial capital with increasing land-use intensification. From an integrated soil fertility management 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).

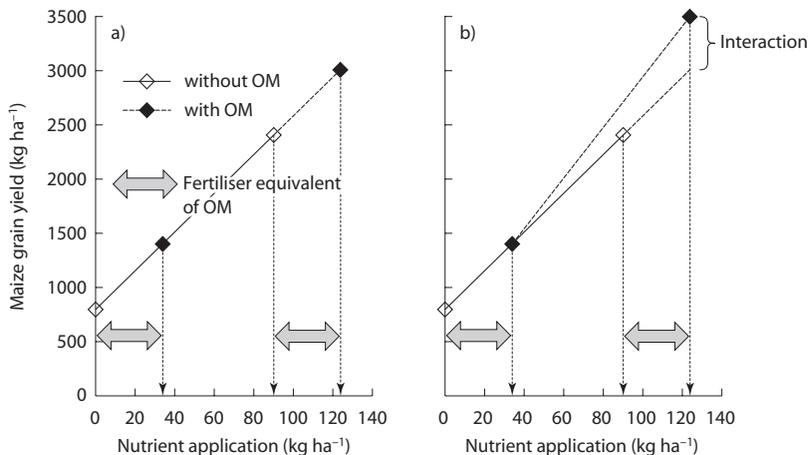


Figure 5. Theoretical response of maize grain yield to the application of a certain nutrient as fertiliser in the presence or absence of organic matter. The interaction effect is indicated on the graph. It is assumed that the applied nutrient rates belong to the linear range of the response curve. Source: Vanlauwe et al. (2001a).

N and reduce losses to the environment'. The 'indirect hypothesis' was formulated for N supplied as fertiliser and proposed that: '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 recognises 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 predict 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 fertiliser, Vanlauwe et al. (2002b) concluded that direct interactions between OM and fertiliser-N exist not just in the laboratory but also under field conditions. The importance of residue quality and ways in which organic inputs are incorporated into soil to the magnitude of these interactions was also demonstrated. In a multi-locational trial with external inputs of organic matter, Vanlauwe et al. (2001b) observed added benefits from the combined treatments at two of the four sites, which experienced serious moisture stress during the early phases of grain filling. The positive interaction in these two 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 subsurface placed) and constitutes evidence for the occurrence of mechanisms supporting the indirect hypothesis. Although more examples supporting the indirect hypothesis can be found in literature, 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 optimise the efficiency of external inputs. On the other hand, when applying organic resources and mineral fertiliser 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 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 results in positive relationships between SOM content and fertiliser use efficiency. On the other hand, SOM also releases available N that may be better synchronised with the demand for N by the plant than is fertiliser N, and consequently a larger SOM pool may result in lower fertiliser N use efficiencies. 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 fertiliser and the topsoil organic C content and supports the latter hypothesis (B. Vanlauwe et al., unpublished data). Other reports show higher use efficiency of N fertiliser (H. Breman, pers. comm.) and P fertiliser (A. Bationo, pers. comm.) for homestead fields with a higher SOM content.

Finally, application of organic resources is the easiest way to increase SOM. 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 sometimes large differences in SOM found 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/mineralisation 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 (Fig. 1). The 'C stabilisation potential' could be an equivalent index to the N fertiliser 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.

From Theory to Practice: Implementation of ISFM Practices at the Farm Level

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

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), introducing an organic matter production phase in a cropping system creates prob-

lems 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, and thus have a great potential to become part of such cropping systems (Sanginga et al. 2001). Additional advantages to the substantial amount of N fixation from the atmosphere associated with growing high biomass producing legumes in rotation with cereal include 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., and improved soil physical properties. These processes

Table 2. Place and time of production of organic matter (fallow species) relative to crop growth and the respective advantages/disadvantages of the 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’. Source: adapted from Vanlauwe et al. (2001a).

Place and time of organic matter production – example of farming system	Advantages	Disadvantages
Same place, same time – alley cropping	<ul style="list-style-type: none"> – ‘Safety-net’ hypothesis (complementary rooting depths) – Possible direct transfer from N₂ fixed by legume species 	<ul style="list-style-type: none"> – 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	<ul style="list-style-type: none"> – ‘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 	<ul style="list-style-type: none"> – 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	<ul style="list-style-type: none"> – Utilisation of land/nutrients otherwise not used – No competition between fallow species and crops 	<ul style="list-style-type: none"> – 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

yield benefits to a cereal crop beyond available N but are often translated into N fertiliser equivalency values. Obviously, values greater than 100% should be expected sometimes.

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.

Soil fertility gradients

There is a substantial amount of evidence that the soil fertility status of the various fields within a farm can be quite variable, often leading to gradients in which soil fertility decreases as one moves away from the household (Table 3). These gradients are commonly caused by long-term, site-specific soil management by the farmer, and have a considerable influence on crop yield (Fig. 6). 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, for example, farmers will preferably grow sweet potato on the most degraded fields, while bananas and cocoyam occupy the most fertile fields (Tittonell 2003). As such variations in soil fertility status are likely to affect the use efficiency of mineral

inputs (see above), the potential growth of legumes, and other important processes regulating ISFM options, it is important to take such gradients into account when formulating recommendations for ISFM. One important condition of such recommendations, however, is that these should be related to local classification systems for soil fertility evaluation, as smallholder farmers are unlikely to analyse their soils before deciding on their management. The existence of different fields with varying soil fertility status at the farm level is also likely to determine which are the optimal spatial and temporal niches within a farm to produce organic resources.

Beyond the soil: links with other realms of capital

So far, this paper has focused mainly 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, all of which contribute to their decision-making about 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 villages in Western Kenya, relatively wealthy farmers spend US\$102 on farm inputs per year compared with US\$5 for relatively 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 not only use mineral fertilisers more than do poor farmers, but also use a wider range of soil management practices. Farmer production objectives, which depend on a whole set of biophysical, social, cultural, and economic factors, also take into account the fertility gradients existing within their farm boundaries.

Table 3. Soil fertility status of various fields within a farm in Burkina Faso. Home gardens are near the homestead, bush fields furthest away from the homestead and village fields at intermediate distances. Source: Prudencio et al. (1993).

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

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 different ecosystem service 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 the above information needs to be synthesised in a quantitative framework, and (ii) that framework needs to be translated into a format accessible to the end users. The level of accuracy of such a 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, although both tools are needed as they serve different purposes. 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 about the technologies targeted. Van Noordwijk et al. (2001) prefer the term ‘negotiation support systems’ to avoid any connotation that the ‘decision support systems’ has the authority to make decisions that will then be imposed on the various stakeholders. In an INRM context, it is recognised that different stakeholders may have conflicting interests about certain specific soil management strategies, and that a certain level of negotiation may be required. Whatever the terminology, it should be clear that any single ‘decision’ aid is only one source of the wide range of information required by farmers to make their decisions.

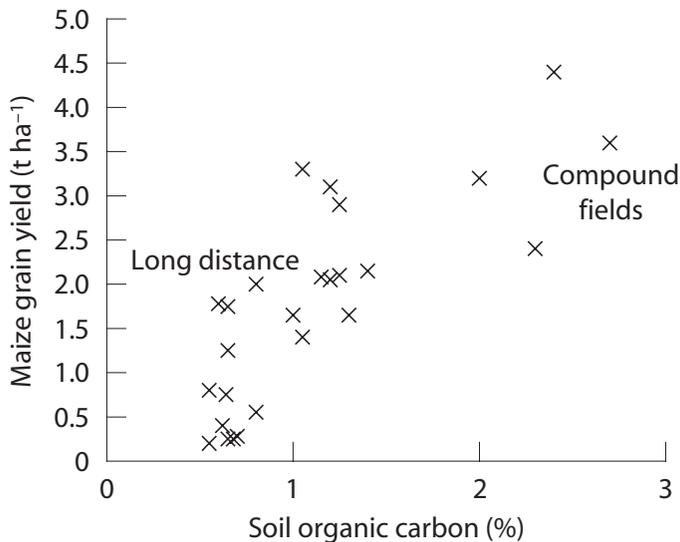


Figure 6. Relationship between the soil organic carbon content and maize grain yield for a set of fields varying in distance from a homestead in northern Nigeria. Source: Carsky et al. (1998).

In particular, the final format of the decision aid should take into account the realities in the field. Some of these realities are: (i) large-scale soil analyses are not feasible, so local soil quality indicators need to be included in decision aids, as farmers use these to appreciate existing soil fertility gradients within a farm; (ii) conditions within farms vary as does the availability of organic resources and fertiliser, 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.

Looking Ahead: the Future of the Science of Organic Resource Management

The following conclusions can be drawn from the material presented in this paper:

- (i) The perceived role for the contribution of organic resources in tropical soil fertility management has changed considerably over the years. Currently, organic resources are valued at a par with mineral inputs, as it is recognised that both inputs play essential but different roles in maintaining or improving soil fertility.
- (ii) ISFM involves the management of three sources of nutrients: soil-derived, organic-resource-derived, and fertiliser-derived. Interactions occur between these, and managing individual inputs and their interactions is an essential component of the ISFM research and development agenda.
- (iii) Organic resources are often not sufficiently available at the farm level. Improved germplasm of commonly grown crops that addresses various constraints to higher yields, is a valid entry point for targeting soil fertility depletion. Germplasm that generates multiple benefits is likely to be adopted more easily and potentially tackles several constraints simultaneously.
- (iv) There are no panaceas or solutions that will be optimal everywhere all the time. There is considerable variability between fields within a farm and between farmers within a community (e.g. different access to resources). Therefore, it is very important to identify the appropriate niches for specific ISFM

interventions. Such niches will have not only biophysical, but also economic and social dimensions. (v) Any recommendations for ISFM need to have a local soil knowledge basis, as this is the knowledge farmers are using to decide on the management of the resources (labour, fertiliser, organic resources etc.) available to them.

Future legume research and development could emphasise the following:

- (i) A considerable amount of information is available on ISFM interventions. There is an urgent need to synthesise this information to increase the impact of use and avoid duplication of effort. Syntheses should take the form both of databases and predictive models.
- (ii) The role of markets in creating added capital at the farm level is essential. ISFM options will have a greater chance of being adopted if they provide extra resources (labour, improved use efficiency of inputs etc.) to the farmer.
- (iii) It is essential to identify biophysical, social, and economic niches at the farm scale to introduce organic resource production options, as, under most conditions, organic resources are in short supply. Special attention should be given to multipurpose options.
- (iv) Much emphasis is often placed on maintaining the SOM. It remains a big question at what level SOM is needed to maintain the crop production and ecosystem service roles of SOM. To increase SOM usually involves a lot of investment in labour and land and, consequently, efforts to determine such threshold levels are essential. The role of organic resource quality in such endeavours should receive the attention it needs.
- (v) Further exploration of the detail and value of local knowledge systems and how these correlate to formal knowledge is essential in disseminating ISFM interventions.

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