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Popular myths around soil fertility management in sub-Saharan Africa

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Abstract

The aim of this paper is to demystify some of the popular myths related to tropical soil fertility management that have gained hold in the development community and are often being promulgated by NGO's and development agencies in the tropics. Negative nutrient balances at farm scale or at larger scales are very often presented as proof that soil fertility is at stake in SSA. However, nutrient balances at plot and farm section scale are not always negative. In areas with large nutrient stocks, short-term nutrient mining is fully acceptable. Fertilizer use continues to face considerable controversy in SSA. In this paper, we demonstrate that fertilizers rarely damage the soil; that fertilizers are being used in SSA, often with favourable value-to-cost ratios; and that fertilizers do not cause eutrophication in SSA. Rock phosphates are abundantly present in SSA but most are poorly soluble. Adding these phosphates to compost heaps does not enhance the short-term availability of their P. Although organic inputs are essential soil amendments besides fertilizer, organic inputs alone cannot sustain crop production due to limitations in their quality and availability. Organic resources can also potentially stimulate harmful pests and diseases. Legumes are often advocated as important sources of organic matter but not all legumes fix nitrogen, require inoculation, or are a source of free nitrogen, as even green manures require land and labour. Certain grain legumes with high N harvest indices do not improve soil fertility, but remove net amounts of N from the soil. These myths need correction if we are to harness the role of science in the overall goal of assisting farmers to address the acute problems of poor soil fertility for smallholder farmers in SSA.

Keywords: Biological N fixation; Fertilizer; Legumes; Nutrient balances; Organic resources; Rock phosphate

1. Introduction

Soil fertility in Africa is at stake! (Smaling et al., 1997). It is widely acknowledged that poor soil fertility is the principal constraint to production in smallholder farming in Africa. Many development projects run by Government agencies and non-governmental organizations (NGO's) address the problem of poor soil fertility, but often on the basis of incorrect assumptions. We, as authors of this paper, are soil scientists actively involved in both research and debate concerning the problems of soil fertility in Africa. We often visit development projects and are involved in discussions with farmers, development workers, politicians and policy makers, both those belonging to donor agencies and the recipient countries. Arguments repeatedly come to the fore in these discussions that are not supported by our research experience or by the scientific literature.

The aim of this paper is to demystify some of the popular myths related to tropical soil fertility management that have gained hold in the development community and are often being promulgated by NGO's and development agencies in the tropics. We focused on myths in the context of the Integrated Soil Fertility Management (ISFM) paradigm, currently adapted by the science community dealing with tropical soil fertility management. ISFM has been defined as 'The development of adoptable and sustainable soil management practices that integrate the biological, chemical,

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physical, social, cultural and economic processes that regulate soil fertility' (CIAT et al., 2001). Technically, ISFM advocates the utilization of locally available resources, the combined application of organic resources and fertilizer, and enhancement of the use efficiency of both inputs (Vanlauwe, 2004). We do not claim complete understanding of all of the issues nor do we claim to cover all misconceptions related to appropriate soil fertility management. Rather we feel that many decisions made on investment in initiatives that are intended to address the problem of soil fertility are actually based on mis-information. Misunderstandings need correction if we are to achieve the overall goal of assisting farmers to address the acute problems of poor soil fertility for smallholder farmers in Africa. Other topical and contested issues, such as the dangers of nitrate in drinking water (see Addiscott and Benjamin, 2000; Addiscott, 2005) are predominantly problems of affluent countries and will not be considered here.

2. Myths surrounding nutrient balances

Nutrient balance studies of smallholder farming systems in Africa have received considerable attention since the papers of Smaling, Stoorvogel and colleagues appeared in the early 1990's (Stoorvogel and Smaling, 1990; Smaling et al., 1993; Stoorvogel et al., 1993). Whilst these studies have been highly influential in raising attention to the problem of soil fertility in Africa, nutrient balances are often been mis-interpreted and misused.

2.1. Myth: nutrient balances are always negative

Even in resource-limited smallholder agriculture not all fields are continuously mined; some fields have very positive nutrient balances, usually through concentration of nutrients from other parts of the farm (Scoones, 2001; Tittonell et al., 2005). This arises from the diversity of plot management, as most organic resources and mineral fertilizers are used on the home gardens and infields, and rarely on the outfields further away from the homestead. The development of gradients of declining soil fertility with distance from the homestead may not be a deliberate form of management, but probably an inevitable consequence of the limited availability of cattle manure and other nutrient resources. Preferential application of nutrients to the infields and home gardens ensures good crop yields in these limited areas, and saves labour in terms of the distance the nutrients are transported.

2.2. Myth: nutrient balances can be used to derive crop fertilizer requirements

During an emergency meeting concerning food shortages in Malawi in the mid 1990s, an international scientist presented a study based on agricultural statistics at national scale. The aim of the meeting was to consider approaches to increasing agricultural production and the need for fertilizers was of particular concern. The scientist had analysed crop exports from Malawi and concluded that the largest problem in Malawi was potassium because when crop exports of K were compared with fertilizer inputs the balance was highly negative. Conversely, a series of more than 1600 nutrient response trials conducted throughout Malawi failed to find evidence for the need for K fertilizers anywhere in the country (MPTF, 1997). A similar conclusion was reached in a study based on widespread soil sampling and analysis who found no evidence for K deficiencies (Matabwa and Wendt, 1993). The reason that the soils in Malawi can support yields without additional K fertilizers is that the K stocks in the soils are large and can provide sufficient K for crop growth. In Europe, some soils contain sufficient K to sustain production for hundreds of years (Holmqvist et al., 2003).

This example demonstrates that soil nutrient mining is a sensible option for farmers. As long as farmers do not see responses in crop growth and yield when fertilizers are applied they would be foolish to invest in importing extra nutrients! If stocks of available nutrients are high, yields of 3 t ha^{-1} of maize can be obtained without added fertilizers (Esilaba et al., 2001). Of course sustained nutrient removal will eventually mean that nutrients have to be replaced, but the speed with which nutrients are depleted depends on the yields of crops and the amounts of nutrients removed in relation to the nutrient stocks. The major conclusion is that nutrient balances cannot be used to indicate sustainability or to indicate fertilizer requirements without consideration of the stocks of the nutrients in the soil. Moreover, if a nutrient-balance study indicates a deficit (i.e. an overall removal of nutrients) then simply supplying that amount of nutrients in the form of mineral fertilizers will not lead to a balanced nutrient budget. Particularly in the case of N, the fertilizers added will be subject to unwanted losses, largely through leaching.

3. Myths surrounding fertilizers

Many studies in SSA have demonstrated the close links between increased crop production per unit area and fertilizer use. It is therefore surprising that this route for improving crop production has received stronger headwinds in SSA than elsewhere in the world, especially as crops react to fertilizer in SSA as they do elsewhere in the world.

3.1. Myth: fertilizers damage the soil

We quote from a recent MSc examination paper at a university in Northern Europe concerning the management of soil fertility in Africa: "*Using artificial fertilizers on a large scale in Africa will mean that smallholder farmers become dependent on countries in the North. Fertilizers destroy the soil structure and soil life. Yields will decline*

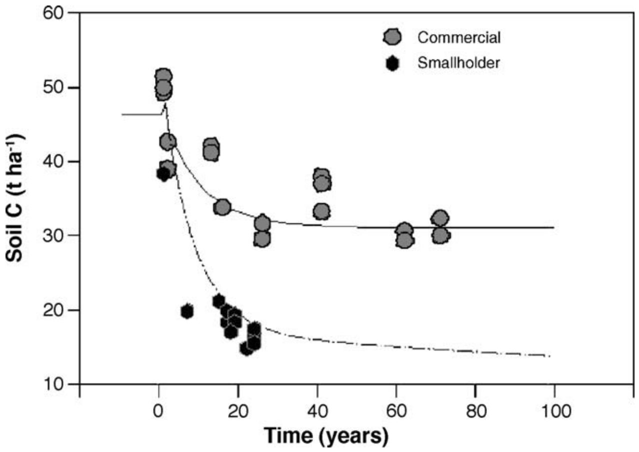

Fig. 1. Changes in soil organic C along cultivation chronosequences after forest clearance on a red clay soil (local classification 5E; FAO class Chromic luvisol) in Zimbabwe under commercial or smallholder agriculture. Source: Zingore et al. (2005).

drastically for smallholder farmers and in the long-term more and more fertilizer will have to be used as the soil becomes further damaged." It is particularly worrying that we have heard Government ministers in African countries suggest very similar things: that fertilizers damage the soil. This is patently incorrect, as we know of no evidence that fertilizers will lead to decreases in yields or that they can damage soil structure or soil life. In fact, the opposite effects are generally found as fertilizer use increases crop yields and thus increases the amount of organic matter returned to the soil through roots and potentially through crop residues. Comparison of long-term changes in soil organic matter after forest clearance in Zimbabwe revealed that equilibrium contents of soil C under 'high-input' commercial agriculture were 32 t C ha^{-1}; almost twice as much as the 18 t C ha^{-1} on the same soil type under 'low-input' smallholder agriculture (Fig. 1). The larger amounts of organic C in the soils under commercial agriculture result from continuous maize production of some 8 t ha^{-1} due to large additions of NPK fertilizer (roughly 150 kg N ha^{-1}, 30 kg P ha^{-1} and 30 kg K ha^{-1}), compared with continuous maize production of about 1.2 t ha^{-1} without fertilizer under smallholder management. Maintenance of soil organic matter is critical for both soil structure (in most soils) and soil life, and this example from Zimbabwe supports the conclusion that mineral fertilizers will improve soil structure and soil life where they lead to increases in the soil organic matter stocks. An analysis of several long-term trials in West Africa also revealed that the organic C contents of plots with fertilizer application are usually comparable to, or slightly higher than, the C contents of plots without addition of external inputs (Table 1).

The most common case where repeated use of mineral fertilizers can cause problems of soil fertility is the potential for acidification with ammonium-based N fertilizers. Where ammonium sulphate or urea N are used repeatedly in soils with poor buffering capacity, acidification of the soil will occur (Table 1). This is due to the release of H^+ through the process of nitrification of NH_4^+ to NO_3^-. If due attention is taken to ensuring that any pH changes are corrected by liming, then such acidification can be avoided. In enclosed laboratory incubations with soil, addition of ammonium sulphate can cause a temporary suppression of soil respiration, but subsequently can lead to increased respiration from maize stover due to alleviation of N limitation (Sakala et al., 2000). Such experimental observations indicate that negative effects of mineral fertilizers on 'soil life' are probably localised, short-term effects due to high-localised concentrations of nutrients or salts. The long-term effects of fertilizers on increased soil organic matter are likely to stimulate biological activity in soils.

3.2. Myth: fertilizers are not used in Africa as they are too expensive

Statements abound in the literature concerning low-external-input management of agriculture in Africa, such as 'fertilizers in Africa are not used by smallholder farmers in Africa as they are too expensive', but such statements are simplistic and hard to support. Many studies of farming systems in Africa reveal that fertilizers are used on some crops, though often only by the wealthier farmers, or on crops specifically grown for sale (e.g., Mapfumo and Giller, 2001; Tittonell, 2003). In some cases investigations reveal that a large proportion of farmers do use fertilizers, although often in limited quantities. Results from a survey with 200 farmers in two villages in the northern Savanna of Nigeria revealed that more than 90% of farmers used fertilizers but up to 81% of the fields received less than half of the recommended 120 kg N ha^{-1} because of high costs due to removal of subsidies and inefficient marketing systems (Manyong et al., 2001). The actual benefit-cost ratios for fertilizer use are most often favourable. 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) for West African countries varied between 1.1 and 8.9, usually above the required minimum ratio of 2. These ratios are likely less in a number of countries after the economic reforms during the late 1980s, early 1990s as the fertilizer-to-crop price ratios have substantially changed, depending on the nature and extent of the reforms across countries (Kherallah et al., 2002). In countries like Ethiopia, Kenya, and Zimbabwe, these ratios have decreased while in others, these ratios have more than doubled (e.g., Benin, Nigeria) or increased by at least 50% (e.g., Zambia, Senegal) (Kherallah et al., 2002).

Although in certain regions, farmers do use fertilizer, the amounts of fertilizers used are limited for a variety of reasons. First of all, cash is often lacking at planting due to competing demands for other household needs such as food or school fees. This means that even if the fertilizer price is lowered, there may still be a problem with access to cash

Table 1
Differences in topsoil organic C, total N, and pH, as affected by application of various forms of N fertilizer[a]

Site (country)	Reference	Type of N fertilizer	Application rate (kg N ha^{-1})	Duration (years)	Organic C (g kg^{-1})			Total N (g kg^{-1})			Soil acidity (pH)		
					Minus fertilizer	Plus fertilizer	Difference	Minus fertilizer	Plus fertilizer	Difference	Minus fertilizer	Plus fertilizer	Difference
Zaria (Nigeria)	Addiscott (2005)	$(NH_4)_2SO_4$	24	15	3.1	3.4	+0.3	0.26	0.29	+0.03	6.0	5.4	−0.6
Ife (Nigeria)	Addiscott and Benjamin (2000)	$(NH_4)_2SO_4$	134	7	8.0	8.5	+0.5	NA[b]	NA	NA	6.3	5.2	−1.1
Many sites[d] (Ghana)	Aihou et al. (1999)	$(NH_4)_2SO_4$	101–330	4–7	NA	NA	NA	NA	NA	+0.33 to −0.40[c]	NA	NA	−0.6 to −0.2
Ibadan (Nigeria)	Bationo et al. (1986)	$(NH_4)_2SO_4$	150	5	8.7	10.5	+1.8	0.90	1.00	+0.10	5.8	4.5	−1.3
Ife (Nigeria)	Bationo et al. (2004)	$(NH_4)_2SO_4$	69	14	5.7	3.5	−2.2	NA	NA	NA	4.4	3.6	−0.8
Bouaké (Côte d'Ivoire)	Buckles and Triomphe (1999)	Urea	160–200	20	13.5	8.3	−5.2	1.20	0.61	−0.59	6.0	5.5	−0.5
Ibadan (Nigeria)	Bationo et al. (1986)	Urea	150	5	8.7	9.0	+0.3	0.90	0.80	−0.10	5.8	4.9	−0.9
Ibadan (Nigeria)	Carsky et al. (1998a)	Urea	60	14	5.9	5.8	−0.1	0.49	0.53	+0.04	5.7	5.4	−0.3
Ife (Nigeria)	Bationo et al. (2004)	Urea	69	14	5.7	8.0	+2.3	NA	NA	NA	4.4	3.5	−0.9
Ibadan (Nigeria)	Bationo et al. (1986)	CAN[d]	150	5	8.7	10.4	+1.7	0.90	0.90	+0.00	5.8	5.0	−0.8
Mokwa (Nigeria)	Carsky et al. (1998b)	CAN	31–188	12	3.1	3.3	+0.2	0.19	0.24	+0.05	5.0	5.0	0.0
Ife (Nigeria)	Bationo et al. (2004)	CAN	69	14	5.7	6.5	+0.8	NA	NA	NA	4.4	3.9	−0.5

[a] Source: Vanlauwe et al. (2001a). Data refer to long-term experiments in the West African moist Savanna zone.

[b] NA: Not available.

[c] Only a range of differences in absolute values is given for a series of 27 sites.

[d] CAN: Calcium ammonium nitrate.

when needed. Initiatives to provide fertilizers in small packs, which are more within reach of farmers' budgets often leads to more widespread use of fertilizer. Secondly, the relatively low sale price of staple cereal crops, or restricted local markets for staple foods also leads to restricted opportunities for investment (Koning, 2002). Thirdly, the lack of inadequate agricultural policy and transparent and competitive private markets also hampers more widespread use of fertilizers.

Besides these economic bottlenecks, technical issues also remain to be addressed. Farmers often indicate that using fertilizers 'makes crops more hungry' or that 'fertilizers damage the soil' but such statements are difficult to interpret. If yields are increased this will lead to greater extraction of nutrients from the soil and if inappropriate nutrient combinations are used, greater nutrient extraction may lead to depletion of stocks of other nutrients and eventually to declines in yields. The problem of unbalanced fertilization is exacerbated by the limited range of fertilizer blends that are available in many African countries, so that inappropriate nutrient combinations are used, particularly on food crops. The liberalization of fertilizer markets has led to the abandonment of regulations designed to prevent deficiencies of some nutrients. For example, in Zimbabwe all fertilizers for application before or at planting (basal fertilizers) were required by law to contain 4% sulphur, but the recent liberalization of the market has led to a wide range of products being available which do not contain S. Given the wide distribution of sandy soils in Zimbabwe, which have inherently small stocks of S, this is likely to lead to widespread S deficiencies in future.

3.3. *Myth: fertilizer recommendations are a useful tool in disseminating information regarding fertilizer use to small-scale farmers*

Fertilizer recommendations are often based on nutrient response trials that were conducted many decades ago, and on a rather limited range of trials in relatively few locations. In many countries, standard or 'blanket' recommendations exist where the same rules are applied for whole agro-ecological regions, or in some cases across the whole country. Comparing these recommended rates with application rates currently used by small-scale farmers reveals a complete lack of relationship (Table 2).

Table 2
Recommended and current fertilizer use in certain areas in sub-Saharan Africa[a]

Characteristics	Southern Benin	Northern Nigeria	Western Kenya
Recommended fertilizer rates at the national level			
N	60 kg ha^{-1}	120 kg ha^{-1}	AEZ[b]-dependent
P_2O_5	40 kg ha^{-1}	60 kg ha^{-1}	AEZ-dependent
K_2O	0 kg ha^{-1}	60 kg ha^{-1}	AEZ-dependent
Currently used fertilizer rate at the national level			
N	2.3 kg ha^{-1}	1.5 kg ha^{-1}	>4.9 kg ha^{-1}[c]
P_2O_5	1.1 kg ha^{-1}	0.4 kg ha^{-1}	>4.0 kg ha^{-1}[c]
K_2O	1.3 kg ha^{-1}	0.4 kg ha^{-1}	>0.5 kg ha^{-1}[c]

[a] Source: Vanlauwe et al. (2004).
[b] AEZ means agro-ecozone.
[c] Depending on the agroecological zone

Guidelines for fertilizer use need to be flexible. As highlighted above, the soil fertility status of the different production units in one farm is not equal and this is likely going to influence crop production and use efficiency of applied N fertilizer. Carsky et al. (1998a,b) have reported a clear positive relationship between the soil organic C content and unfertilized maize yields for a number of sites in Northern Nigeria. An interesting research issue is whether the returns to N fertilizer application are higher on soils with a high soil fertility status, such as the fields near the homestead, compared with soils with lower soil fertility status. Soil organic matter (SOM) contents are usually positively related with specific soil properties or processes fostering crop growth, such as cation exchange capacity, rainfall infiltration, or soil structure. In plots where any of the above constraints limits crop growth, a higher SOM content may enhance crop growth and by that the demand for N and consequently increase the fertilizer N 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.

Guidelines should also be related to the likely production within the season because of the variation in climates (particularly rainfall) that determines the potential for crop production in any given season. Piha and colleagues (1993, 1998) developed guidelines for fertilizer use with maize in environments where rainfall is unreliable that increased their agronomic and economic efficiency significantly. The basic approach is to apply only less mobile nutrients (P, K, S) and small quantities of N at or soon after planting and to apply the majority of the N as top-dressing when plant demand is maximal. Greater attention is needed to such flexible approaches to nutrient management for any given environment in relation to the yields that can be expected if nutrient limitations are removed. Such recommendations should be based on local soil quality indicator schemes rather than formal soil analysis as the latter is most likely not going to be accessible to small-scale farmers in sub-Saharan Africa. Such local soil quality indicator schemes provide indicators that farmers use to determine the soil fertility status of a specific plot within his/her farm.

3.4. *Myth: fertilizers cause eutrophication in Africa*

Although the major problem in Africa is nutrient shortage, there are well-known examples where excess nutrient inputs have led to eutrophication of lakes. The best-known case is that of Lake Victoria where eutrophication has led to problems of large mats of the water hyacinth

(*Eichornia crassipes*) and mineral fertilizers have been blamed as the major cause of eutrophication. This is highly improbable for a number of reasons. The limiting nutrient for plant production in most freshwaters is P, and yet P leaching from soils is minimal (particularly in P-fixing soils such as those found around Lake Victoria). Further, very limited quantities of fertilizers are used within the Lake Victoria basin. The most likely cause of eutrophication is the loading of nutrients in erosion deposits and organic matter draining as untreated sewage waste from the major cities close to Lake Victoria such as Kampala, Mwanza and Kisumu (http://www.worldagroforestry.org/sites/program1/specweb/Lake%20Victoria.htm). A similar situation has been demonstrated for a much smaller lake, Lake Manyame, which receives waste-water drainage from Harare (Motsi et al., 2002). Fertilizers can only be the principal causes of eutrophication where they are used in excessive quantities, and this is not the case in most of sub-Saharan Africa (Kherallah et al., 2002).

4. Myths surrounding rock phosphates

Vast areas of SSA experience moderate to acute P deficiency, which is for most regions the second most important plant nutrient after N. Soils in these areas usually contain quite large stocks of total P (Nwoke et al., 2004) but the availability for plants of these stocks is low. Contrary to N, biological means to enhance the availability of P are limited. SSA contains a lot of rock phosphate (RP) deposits (Roy and McClellan, 1986) and consequently, substantial efforts have been made to use these resources to address the P problems. The major problem with using RP is their low solubility under non-acid soil conditions. In fact, of all RP sources in SSA, only the RP's from Tilemsi (Mali), Matam (Senegal), and Minjingu (Tanzania) have a solubility in 2% citric acid exceeding 10% (IFDC, unpublished results). Consequently, although application of most RP's shows responses to crops minimally 3 years after application, their agronomic effectiveness is too low to generate interest by smallholder farmers who usually have a shorter term view on returns to soil management practices (Bationo et al., 1986). This warrants attention to ameliorate the short-term (within one growing season) availability of P from most RP's. Various chemical, physical, or biological means have been explored to achieve this, but also in this domain certain myths thrive.

4.1. Myth: adding RP to compost increases it short term P availability

Mixing RP with composts to enhance the immediate availability of P is advocated at the extension level in Mali and Burkina Faso. The dissolution of RP in the soil solution was described by Hammond et al. (1986), using fluoroapatite as an example:

$$\mathrm{Ca_{10}(PO_4)_6F_2 + 12H_2O}$$
$$\rightarrow \mathrm{10Ca^{2+} + 6H_2PO_4{}^- + 2F^- + 12OH^-}$$

Clearly, protons favour the dissolution of RP. However, the pH of composted organic resources of varying origin usually is near neutral or higher (Epstein, 1997) (Fig. 2), certainly not favouring the dissolution of RP. Looking at literature data, it is obvious that these theoretical considerations are confirmed, when considering the soluble P content of the compost itself or the crop response to applied compost enriched or not with RP (Table 3). Obviously, the total P content of all composts treated with RP does increase but one could wonder whether this is the most appropriate ways to apply RP on farmers' fields. Other problems with the use of RP, not specifically discussed in this paper, are their bulkiness (some sources have P contents below 10%, IFDC, unpublished data), low availability (even in countries having large deposits), and often high content of heavy metals.

5. Myths surrounding organic inputs

Fertilizers are very often referred to as either scarcely available or expensive inputs in the context of farming systems in SSA. While both these attributes can be questioned (see above), these perceptions have led to a strong focus on low external input, organic resource-based soil management strategies in SSA. It remains an open question whether the new researchable issues generated by the 'organic' approach (after all, the guidelines for management of fertilizers were basically known) pushed the tropical soil fertility research community towards OM production and management and away from relying on external inputs. Nowadays, in the research community, it is

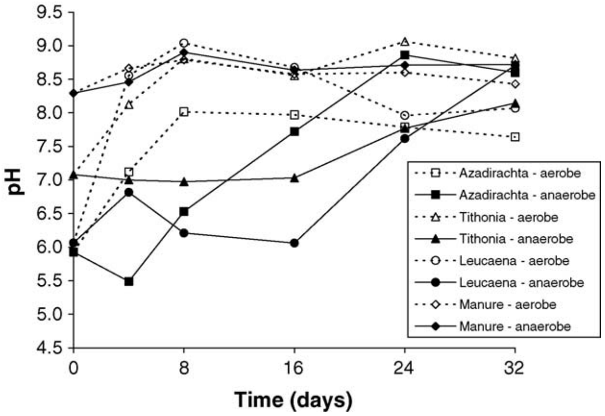

Fig. 2. Change in compost pH during a period of 32 days for aerobically (open symbols and dashed lines) and anaerobically (closed symbols and full lines) composted residues of *Azadirachta indica* (squares), *Tithonia diversifolia* (triangles), *Leucaena leucocephala* (circles), and farmyard manure (diamonds). Standard deviations of individual data points varied between 0.0 and 0.2 pH units ($n = 3$).

Table 3
Impact of additions of rock phosphates[a] to composts on available P or crop performance after application of these composts

Reference	Property measured	Without rock phosphate	With rock phosphate	Difference between treatments	Source of rock phosphate	Rate of rock phosphate addition
Lompo (1993)	Compost water soluble P compost	0.015%	0.017–0.018%	NS	Kodjari (Burkina Faso)	0.020–0.1 kg P kg^{-1} compost
Bationo et al. (2004)	Compost water soluble P	603 mg P kg^{-1}	466–752 mg P kg^{-1}	No level of variation given	Kodjari (Burkina Faso)	0.01 kg P kg^{-1} compost
Compaoré et al. (2001)	P concentration in soil solution	0.022 mg P l^{-1}	0.026 mg P l^{-1}	NS	Kodjari (Burkina Faso)	0.018 kg P kg^{-1} compost
Iruaga (1999)	Maize dry matter in pots after 7 weeks	44–45 g per pot	46–50 g per pot	NS	Hahotoe (Togo)	0.036 kg P kg^{-1} compost
Nyirongo et al. (1999)	Maize grain yield	1.72 t ha^{-1}	1.38–1.77 t ha^{-1}	NS	Tundulu (Malawi)	0.013 kg P kg^{-1} compost
Dhliwayo (1998)	Groundnut kernel yield	1.59 t ha^{-1}	1.59 t ha^{-1}	NS	Dorowa (Zimbabwe)	Unknown
Van den Berghe (1996)	Potato tuber yield	6.9–9.7 t ha^{-1}	7.5–10.6 t ha^{-1}	NS	Matongo (Burundi)	1 kg P per compost pit (1 m × 1 m × 2 m)

[a] Rock phosphates and experiment are all from various locations in sub-Saharan Africa.

acknowledged that the way forward for soil fertility management is to combine mineral and organic inputs (Vanlauwe et al., 2002). While fertilizers supply plant nutrients, OM is also a precursor for soil organic matter pool (SOM), which maintains the physical and physicochemical components contributing to soil fertility such as cation exchange capacity (CEC) and soil structure. However, in the development world, organic inputs are still often seen as a panacea for addressing soil fertility decline, although some organisations acknowledge the need for fertilizers (e.g., Worldvision, 1999). Another more practical reason for advocating the combined use of OM and fertilizer is that very often neither of them is widely available or affordable in sufficient quantities.

5.1. Myth: organic inputs can sustain crop production

While application of organic resources undoubtedly enhances crop production, relative (% increase relative to a control) and absolute (in extra kg ha^{-1} produced) increases in crop yields are often independently used to prove the impact of organic inputs on crop performance while a complete picture requires information on both parameters (Vanlauwe et al., 2001a). Organic inputs are not substitutes for mineral fertilizers as both inputs fulfil different functions. As a matter of fact, by definition, the term fertilizers applies to materials which contain at least 5% of one or more of the three primary nutrients in available form (Dudal, 2002), excluding most organic resources. While the main role of mineral inputs is to supply nutrients or correct unfavourable soil pH conditions, organic resources contain C, which drives all microbially and faunally mediated soil processes and finally replenishes the soil organic matter (SOM) pool.

The availability of organic resources is limited in most areas. Although there is a wide range of potential niches to produce organic resources within existing cropping systems (Table 4), 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. 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

Table 4
Advantages and disadvantages of organic matter production systems[a]

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

[a] Source: Vanlauwe et al. (2001a).
[b] Place and time of organic matter production and time of organic matter production relative to crop growth.
[c] Advantages and disadvantages with respect to soil fertility management and crop growth.
[d] 'Same place' and 'same time' mean 'in the same place as the crop' and 'during crop growth'.

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. Secondly, organic inputs are no substitutes for mineral inputs, first of all, because their nutrient release characteristics depend on their resource quality (Palm et al., 2001). N release from organic resources with a relatively low N, and high lignin and soluble polyphenol content is usually observed to be delayed, requiring proper targeting of these inputs to coincide with the crop requirements for nutrients. It is interesting to note that certain organic resources that are commonly seen to immobilise N during longer periods of time under controlled conditions do show positive impacts on crop growth under certain conditions which are not nutrient related, such as drought (Vanlauwe et al., 2001b) or wind erosion in the sahel (Bationo et al., 2004). It is also interesting to note that the most commonly found organic resources at the farm level, e.g., cereal stover or low quality farmyard manure, are materials of medium to low quality, again indicating the need for nutrient supplements through fertilizer inputs. Thirdly, the relative nutrient compositions of organic resources are not commonly matched to the nutrient ratios required by crops (Table 5). While cereal crop residues have a relatively good relative nutrient composition for maize production, their average N content is low, necessitating additional inputs of available N to counteract the N bound through immobilization (see above). Leguminous tree materials usually have a favourable N content but their N:P ratio is usually too high to supply sufficient amounts of P to the crops (Table 5). Note also that the relative nutrient contents are quite different for different crops so the combination of organic inputs and mineral fertilizer would need to address this. A further problem of reliance on organic inputs is the increased labour requirements that most approaches incur, and this is discussed below.

Table 5
N:P:K ratios of the harvested products of crops[a] and of two organic resources[b]

	N:P:K ratio
Harvested crop products	
Maize	100:21 (3)[c]:29 (5)
Cassava	100:17 (7):174 (81)
Yam	100:12 (3):107 (26)
Plantain	100:9 (1):224 (17)
Soybean	100:8 (1):27 (6)
Organic resources	
Cereal stover (rice, sorghum, maize)	100:19 (5):192 (128)
Leguminous trees/shrubs[d]	100:6 (3):44 (30)

[a] Source: Wichmann (1998). Crops important in SSA.
[b] Organic Resource Database (ftp://iserver.ciat.cgiar.org/webciat/ORD/. Organic resources commonly found in SSA.
[c] Values between brackets are standard deviations.
[d] Includes the following species: *Acacia* spp., *Albizia* spp., *Calliandra* spp., *Crotalaria* spp., *Flemingia* spp., *Gliricidia* spp., *Leucaena* spp., *Sesbania* spp., *Tephrosia* spp.

5.2. Myth: organic inputs decrease pest and disease attack

Whilst increasing the inputs of organic matter may often have beneficial effects on biological activity and lead to less pest and disease attack, effects are not always positive. Almost total yield loss was observed when maize was grown after incorporation of the good quality litter from a prolific *Sesbania sesban* tree fallow (Chikowo et al., 2004). The very poor growth of maize was due to a severe infestation with grubs of a cutworm (*Agrotis* sp.), which severed the maize roots. These effects were not seen in the control plots where maize had been grown continuously for 9 years.

6. Myths surrounding legumes

Biological N_2-fixation by legumes is an important source of N for many small holder-farming systems and has been extensively researched (Giller, 2001).

6.1. Myth: all legumes fix nitrogen

Although it is commonly assumed that the ability to fix N_2 is a major reason for the evolutionary success of legumes, this is now strongly contested. The legume family (the Leguminosae or Fabaceae) is comprised of three subfamilies: the Caesalpiniodeae, the Mimosoideae and the Papilionoideae. The Caesalpiniodeae is considered to be the oldest and ancestral subfamily from which the other sub-families diverged. All legumes have tissues that are rich in N compared with other plant families and yet only a quarter of the caesalpiniod legume species are able to nodulate (Sprent, 2001). It has been concluded that the ability to nodulate and fix N_2 developed to satisfy the strong demand for N in legumes, as N-rich tissues result in a greater capacity for photosynthesis per unit area of leaf (McKey, 1994). A restricted number of legumes in the other legume subfamilies are also unable to nodulate, but these appear largely to be cases where N_2-fixation ability has been subsequently lost, in the case of some *Acacia* species due to their adaptation to very dry environments (Sprent, 2001).

Some non-nodulating legumes are widely planted as ornamentals (e.g. *Bauhinia* spp., *Delonix regia*, *Senna* spp.) or are used as agroforestry trees for soil improvement (e.g. *Senna siamea*, *Senna spectabilis*). In southern Malawi a ‘food for work’ programme in the early 1990’s led to the extension and recommendation of alley cropping to more than 100,000 farmers. Most of the farmers were supplied with seedlings of *Senna spectabilis* as this species had been shown to give substantial benefits in promoting maize yields by efficiently recycling and concentrating of N and other nutrients around the emerging crop on fertile soils of the experimental stations. Unfortunately benefits were minimal on the infertile soils of smallholder farmers’ fields (Itimu, 1997), and yields were no better or worse than without trees. The reason that *Senna* was promoted in Malawi was largely due to the lack of sufficient supplies of seed of other N_2-fixing legume trees such as *Gliricidia sepium*, and severe damage to *Leucaena* from termites and the recently arrived psyllid. Under some circumstances *Senna* spp. have been observed to be suitable for rehabilitation of degraded soils. In Benin, the deep-rooting of *Senna siamea* allowed it to recover nutrients from deep soil horizons that were not explored by other legume trees (Aihou et al., 1999), provided there was a relatively rich subsoil (Vanlauwe et al., 2005). Thus some non-N_2-fixing legumes can sometimes be beneficial for soil fertility, but it is dangerous to assume that this is due to inputs from N_2-fixation without this being confirmed.

6.2. Myth: all legumes have a specific need for inoculation

Much research on the legume-*Rhizobium* symbiosis has focused on the need for inoculation with compatible and effective bacteria for legumes that are important in agriculture in temperate regions. Despite early papers that indicated widespread ‘promiscuity’ for nodulation of legumes with rhizobia (e.g. Wilson, 1944), it has often been assumed that virtually all legumes need to be inoculated. When the huge diversity of legumes in the tropics is considered an alternative conclusion is reached; that the ‘norm’ for legumes is to be promiscuous in nodulation with indigenous strains in the soil (Giller, 2001; Sprent, 2001). The majority of the inoculum industry is focused on soyabean. This important oilseed legume is an intriguing example where intensive breeding in North America, far from its centre of diversity, has led to selection of varieties that are highly specific (i.e. able to nodulate with only a restricted range of rhizobia) (Giller, 2001). Varieties of soyabean from Asia (Thompson et al., 1991), or those which have been through only a few selection cycles from Asian parental genotypes (Mpepereki et al., 2000) are able to nodulate with indigenous rhizobia in soils where they have never been grown and do not need inoculation. A breeding programme at IITA in Nigeria has been successful in re-introducing the ability to nodulate with indigenous rhizobial populations (Kueneman et al., 1984; Sanginga et al., 1996).

Three situations can be identified where legumes generally *do* need inoculation: (1) where compatible rhizobia are absent; (2) where the population of compatible rhizobia is small; (3) where the indigenous rhizobia are ineffective or less effective in N_2-fixation with the legume than selected inoculant strains. Although legumes that are newly introduced to a soil where they have never been previously grown may give increased yields with inoculation in the first season, some compatible rhizobia are often present. These rhizobia will multiply in the rhizosphere of a compatible host so that the population builds up and inoculation is not essential in subsequent seasons. If inoculants are available they are usually cheap in price relative to the other costs of production so that using inoculants is preferable to risking a loss in yield. However, development of ‘promiscuous’ varieties of legumes that are highly effective in fixing N_2 is preferable for smallholder farmers than reliance on legumes that need inoculation.

6.3. Myth: legumes are a source of free nitrogen

Biological N_2-fixation can contribute as much as 300 kg N ha^{-1} in a season through in grain legumes or legume green manures and exceptionally 600 kg N ha^{-1} in a year through tree legumes (Giller, 2001). Legume green manures and improved fallows have received considerable attention from researchers and development agencies in Africa, due to their capacity to improve the yields of staple cereal crops (Sanchez, 2002). However, all soil-improving technologies have a cost in terms of labour and land. The investment required to prepare land, sow, weed and plough under a green manure legume can often be considerable, particularly when the benefit of increased yield is generally realised only at the end of the growth of the subsequent crop. ‘‘Rules of thumb’’ that green manure legumes must yield at least 2 t ha^{-1} (roughly 50–60 kg N ha^{-1}), which is likely to give something close to 1 t ha^{-1} of extra maize grain (Gilbert, 1998), take into account the potential loss of land productivity, but not the extra labour invested. The labour required to turn under a prolific *Mucuna* green manure in Malawi was measured to be in excess of 80 person days ha^{-1} (Gilbert, personal communication).

Examples where green manures have achieved spontaneous diffusion in smallholder agriculture in the tropics are invariably where they have resulted in labour savings due to suppression of pernicious weeds (Carsky et al., 1998a,b; Versteeg et al., 1998; Buckles and Triomphe, 1999). Although such ‘windows of opportunity’ exist where green manures may be attractive for use by smallholder farmers, other factors often also play a role. In Benin, *Mucuna* or ‘green gold’ was rapidly adopted by more than 10,000 farmers (Manyong et al., 1999). However, when local NGO’s stopped purchasing seed for their promotion and extension programme in 1997 and the local market for *Mucuna* seed collapsed, the amount of *Mucuna* being grown declined rapidly (Manyong et al., 1999). Although farmers recognised the important role that green manure legumes can play in providing N and improving soil fertility for subsequent crops, these benefits were insufficient to justify the investment of land and labour. The creation of artificial markets for seed markets of green manure legumes has also been seen in other countries, for example, in Malawi where at one point *Tephrosia vogelii* seed was worth twice as much as grain of the staple legume *Phaseolus vulgaris* (Carr, personal communication).

6.4. Myth: growing legumes always leads to improvement in soil fertility

Apart from the fact that not all legumes can nodulate and fix N_2, as described above, many legumes do not contribute substantially to improving soil fertility. Where constraints such as deficiencies in P or K, or drought, limit legume growth, inputs of N from N_2-fixation will also be restricted. Even when legumes grow well, the contribution to soil fertility depends on the amount of N_2-fixed in relation to the amount removed from the system in the crop harvest, reflected in the N-harvest index (Fig. 3; Giller and Cadisch, 1995). Legumes grown specifically for soil fertility improvement, such as green manures or agroforestry trees, add the largest amount of N as little is generally harvested and removed from the field. There are large differences between grain legumes in the N-harvest index: creeping varieties of groundnut (*Arachis hypogaea*) and cowpea (*Vigna unguiculata*) tend to have low harvest indices for N. In contrast, high yielding varieties of soyabean (*Glycine max*) usually have high N-harvest indices and often are net removers of soil N (Toomsan et al., 1995).

Multi-purpose varieties of grain legumes such as cowpea and soyabean produce a lot of biomass while still giving reasonable grain yields (Mpepereki et al., 2000; Sanginga et al., 2001). For an equivalent grain yield of 2 t ha^{-1}, promiscuous soyabean varieties produced 150 kg N ha^{-1} in stover compared with new varieties that had only 40 kg N ha^{-1} in their stover. Yields of maize grown after the promiscuous varieties were generally double those of maize grown after the new varieties (Kasasa et al., 1999; Sanginga et al., 2004).

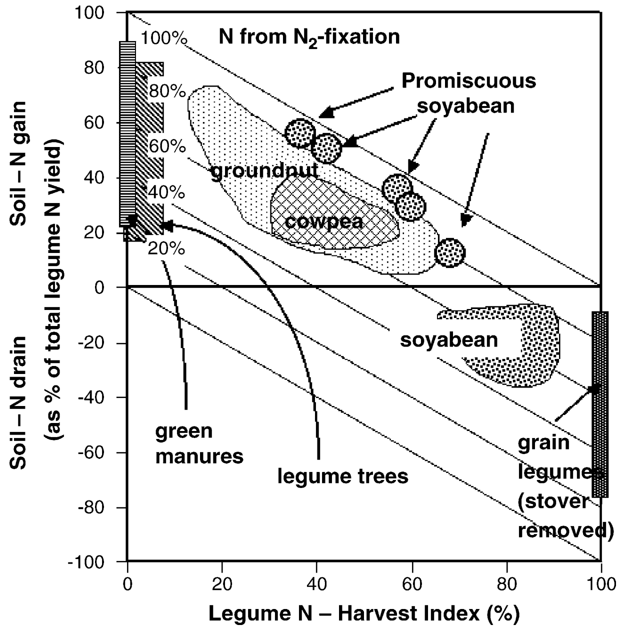

Fig. 3. The relationship between the %N from N_2-fixation and the N-harvest index for a range of green manure, agroforestry and grain legumes. See text for further explanation. Source: Giller and Cadisch (1995).

Yields of cereal crops are generally better in legume-cereal rotations than where cereals are cultivated year after year, and this effect is often seen even when legumes with a high N-harvest index is grown. Part of the explanation for the benefit of legumes on cereal yields can be attributed to the fact that they remove less N from the soil than a cereal crop as well as other effects such as breaking of pest and disease cycles. Farmers in Ghana, Benin and Kenya all report that cassava has a similar effect on improving soil fertility compared with continuous maize cultivation, presumably as cassava extracts less nutrients and returns more litter to the soil than continuous maize!

7. Concluding remarks

The currently accepted paradigm for tropical soil fertility management, Integrated Soil Fertility Management (ISFM), advocates the maximum use of locally available resources and the combined application of organic and mineral inputs, in an economically and socially acceptable way (Vanlauwe, 2004). Each of the keywords constituting this paradigm is associated with myths discussed above and these myths often form the basis of development activities related to improvement of the soil resource base. This is worrying not only because such activities are unlikely going to address the acute problem of soil fertility decline in SSA, but also because this may divert development resources away from interventions that are likely going to make a difference.

Some of the myths, highlighted in this paper, are the result of having a too narrow view or wrongly focused view on the overall impact of certain interventions on farmers' livelihoods. Green manures, for instance, may lead to substantial increase in crop production, but at the cost of land and/or labour. Nutrient removals by crops, for instance, are just one part of the equation determining the soil fertility status; nutrient stocks are equally important in delineating areas that require fertilizer inputs. The current move towards interdisciplinary evaluation (agronomic, economic, social) of soil fertility interventions is likely to counteract the creation of more myths.

Inappropriate communication is one of the major reasons sustaining some of the misconceptions regarding ISFM, that are addressed above. This emphasises that in research for development projects, the final products should not only be scientific papers in respected journals but also the translation of the messages in such documents in forms accessible to the development and policy community. Even when scientific papers have appeared refuting some of these myths, it can take a long time before this information filters through into more general textbooks. This leads to a long time lag before findings become generally accepted. Other reasons for the perpetuation of myths relate to ideological standpoints of the development partners and/or sponsors who are committed to particular approaches and reluctant to accept evidence that contradicts their stance. Our plea is for a more rigorous and critical evaluation of knowledge before interventions are tested with farmers. This could accelerate the development process and avoid researchers wasting time that farmers can ill-afford.

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