Closing the yield gap through integrated soil fertility management

Nteranya Sanginga

Paper prepared for presentation at the "The Scramble For Natural Resources: More Food, Less Land?" conference conducted by the Crawford Fund for International Agricultural Research, Parliament House, Canberra, Australia, 9-10 October 2012

Closing the yield gap through integrated soil fertility management*

Dr Nteranya Sanginga
International Institute of Tropical Agriculture

Abstract

African agriculture stands at a crossroads. Either food security in Africa will remain elusive with isolated successes fuelling a sense of false optimism in an otherwise dismal situation, or decisive action can be taken to assist small-scale farmers to grow more and more valuable crops. Excellent progress is being made in crop improvement and seed systems, and many crop diseases, particularly viruses and fungal leaf pathogens, no longer pose a major problem. Low soil fertility and nutrient depletion continue, however, to represent huge obstacles to securing needed harvests. Improving access to fertilisers is a necessary countermeasure; however, the low returns from unskilled use of these products present a major impediment to their adoption by most small-scale farmers. Integrated Soil Fertility Management (ISFM) is defined as: the application of soil fertility management practices, and the knowledge to adapt these to local conditions, which optimise fertiliser and organic resource-use efficiency and crop productivity. ISFM represents a means to overcome this dilemma by offering farmers better returns for investment in fertiliser through its combination with indigenous agro-minerals and available organic resources. Disseminating knowledge of ISFM and developing incentives for its adoption now stand as challenges before national planners and rural development specialists. Done efficiently, these will result in more productive and sustainable agriculture, improved household and regional food security and increased incomes among small-scale farmers.

> *The soil nutrient losses in SSA are an environmental, social, and political time bomb. Unless we wake up soon and reverse these disastrous trends, the future viability of African food systems will indeed be imperiled.*
> Dr Norman Borlaug, 14 March 2003, Muscle Shoals, Alabama, USA.

High world fuel and fertiliser prices, increasing production of biofuels and a declining human capacity for soil and natural resource research continentally continue to exacerbate the situation described by Dr Norman Borlaug in the quote above.

---

* This paper is coauthored by P.L. Woomer, and adapted from Sanginga N. & Woomer P.L. (Eds) (2009). *Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process*. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture. Nairobi. 263 pp.

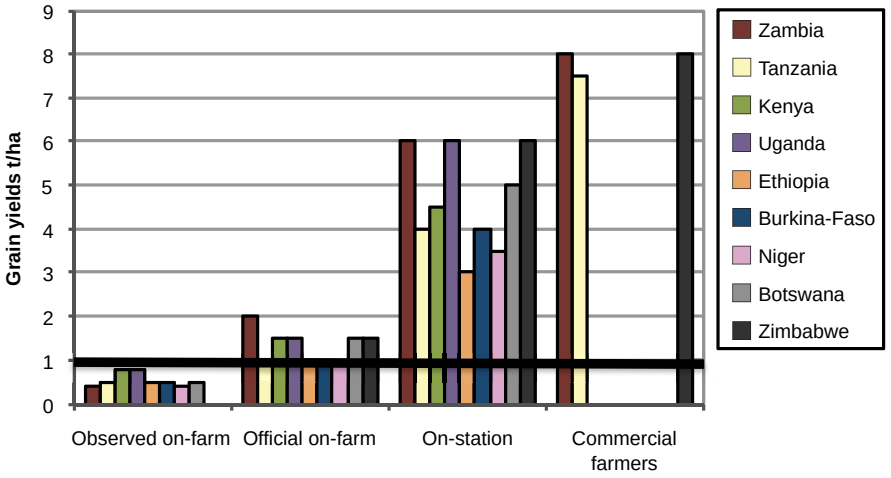

Figure 1. Reported maize grain levels in selected countries in sub-Saharan Africa, indicating the yield gap (heavy horizontal line).

There is, however, growing evidence that meeting this challenge in sub-Saharan Africa (SSA) will require more attention to soil fertility issues than was the case elsewhere. Farmers' fields are characterised by low inherent fertility and low use of inputs (Bationo et al. 2006). In most farmers' fields observed yields for most cereals hardly exceed 0.5 t/ha, yet a potential of 8 t/ha is attained in on-station trials and by some commercial farmers. As a result there is a great yield gap between the experimental station yields, farmers' potential yields and farmers' actual yields (Figure 1).

The high yield gap between farmers' potential and actual yields can be attributed to several constraints, mainly biological (varieties, weeds, disease and insects, water and nutrient deficiencies) and socio-economic (costs and benefits, access to credit and inputs, attitude, among others). Using models and different scenarios, the contribution of soil fertility to the yield gap can be determined. This calls for careful targeting of technology recommendations for potential and profitable soil fertility management, to address the diverse socioeconomic, biophysical and policy factors contributing to the low productivity.

Better management of soil fertility is an imperative for SSA. Pedro Sanchez (1997) identified soil fertility depletion on smallholder farms as the 'fundamental biophysical root cause of declining per capita food production in Africa' and advocated more integrated problem-solving approaches.

Despite these insightful observations the situation has only worsened. We face more than an economic problem because this potentially explosive situation threatens the very fabric of social stability in the poorest countries. In response, soil health issues are rising within the agendas of policymakers and donor agencies.

There has never been a better time to reinforce the relevance of soil fertility research in SSA. For instance, the Head of States during the African Fertiliser

Crops grown using conservation agriculture (left) and organic versus conventional nutrition (right) show the healthy-looking vigour produced by combining organic and mineral nutrition through integrated soil fertility management (ISFM).

Summit (AFS) conducted in Abuja, Nigeria, during 2006, recommended that fertiliser use be increased from the average 8 kg/ha to 50 kg nutrients/ha until 2015. The Bill and Melinda Gates Foundation and the Rockefeller Foundation through the Alliance for a Green Revolution in Africa (AGRA) have decided to invest in a soil health program as part of the African Green Revolution. The AGRA Soil Health Program will help build a foundation for agricultural sector growth by restoring African soil fertility through soil management and fertilisers that stably increase crop productivity by 50–100%.

AGRA believes that roughly half of the huge yield gap existing between SSA countries and the developed world will be closed through soil nutrients and improved agricultural practices; the other half through improved seed. African farmers, therefore, need better technologies, more sustainable practices, improved crop varieties and fertilisers to improve and sustain their crop productivity, and to prevent further degradation of agricultural lands.

African agriculture stands at a crossroads. Either food security in Africa will remain elusive with isolated successes fuelling a sense of false optimism in an otherwise dismal situation, or decisive action can be taken to assist small-scale farmers to grow more and more valuable crops.

Excellent progress is being made in crop improvement and seed systems. Many crop diseases, particularly viruses and fungal leaf pathogens, no longer pose a major problem. However, low soil fertility and nutrient depletion continue to represent huge obstacles to securing needed harvests. Improving access to fertilisers is a necessary countermeasure; but the low returns from unskilled use of these products present a major impediment to their adoption by most small-scale farmers.

The Integrated Soil Fertility Management (ISFM) paradigm as defined below represents a means to overcome this dilemma by offering farmers better returns for investment in fertiliser through its combination with indigenous agro-minerals and available organic resources.

Disseminating knowledge of ISFM and developing incentives for its adoption now stand as the challenge before national planners and rural development specialists!

Table 1. Changes in tropical soil fertility management paradigms and their effects on farm resource management over the past five decades.

Paradigm	Role of fertiliser	Role of organic inputs	Experiences
During the 1960s and 1970s			
External Input Paradigm: '1st Paradigm'	Use of fertiliser alone will improve and sustain yields.	Organic resources play a minimal role.	Limited success because of shortfalls in infrastructure, policy, farming systems, etc.
During the 1980s			
Organic Input Paradigm	Fertiliser plays a minimal role.	Organic resources are the main source of nutrients.	Limited adoption; organic matter production requires excessive land and labour.
During the 1990s			
Sanchez's 'Second Paradigm'	Fertiliser use is essential to alleviate the main nutrient constraints.	Organic resources are the entry point; these serve other functions besides nutrient release.	Difficulties in accessing organic resources hampered adoption (e.g. improved fallows).
During the 2000s			
Integrated Soil Fertility Management (ISFM)	Fertiliser is a major entry point to increase yields and supply needed organic resources.	Access to organic resources has social and economic dimensions.	On-going; several success stories.

The Integrated Soil Fertility Management (ISFM) paradigm

Based upon agricultural research findings across numerous countries and diverse agro-economic zones of SSA, a consensus has emerged that the highest and most sustainable gains in crop productivity per unit nutrient are achieved from mixtures of inorganic fertiliser and organic inputs (Vanlauwe et al. 2001). The ISFM paradigm results from lengthy investigation into the management of crop nutrition (Table 1). ISFM was derived from Sanchez's earlier Second Paradigm that relies

> *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.*

Thus, Sanchez recognised the need to combine essential organic inputs with fertilisers, but farmer-available organic resources are viewed as the main entry point (Sanchez 1994). Indeed, combining mineral and organic inputs results in greater benefits than either input alone, through positive interactions on soil biological, chemical and physical properties.

Adoption of the Second Paradigm by farmers was limited by the excessive requirement for land and labour to produce and process organic resources. Farmers proved reluctant to commit land solely to organic resource production at the expense of crops and income.

Integrated Soil Fertility Management (ISFM) may be defined as

> *the application of soil fertility management practices, and the knowledge to adapt these to local conditions, which optimize fertilizer and organic resource use efficiency and crop productivity. These practices necessarily include appropriate fertilizer and organic input management in combination with the utilization of improved germplasm.*

ISFM is not characterised by unique field practices but is rather a new approach to combining available technologies in a manner that preserves soil quality while promoting its productivity. ISFM practitioners do not merely recite this definition, but plan much of their annual field activities around it. Soil fertility management includes timely and judicious utilisation of pre-plant and top-dressed mineral fertilisers, but also the generation, collection, storage, enrichment and application of available organic resources and the maintenance and enhancement of beneficial soil organisms and processes.

The ISFM paradigm offers an alternative to the Second Paradigm by using fertiliser as the entry point for improving productivity of cropping systems. It asserts that substantial and extremely useful organic resources can be derived as by-products of food crops and livestock enterprises. ISFM also recognises the importance of an enabling environment that permits farmer investment in soil fertility management, and the critical importance of farm input suppliers and fair produce markets, favourable policies, and properly functioning institutions, particularly agricultural extension. Translating this knowledge into practical soil and land management strategies and empowering farmers through participatory technology development and adaptation is key to successful application of ISFM.

Current smallholder practice in Africa is too often exploitive, mining the soil of its nutrients and leading to degraded non-productive farming (Buresh et al. 1997). Simply introducing improved crop varieties and modest amounts of mineral fertiliser can improve crop yields but at a relatively low agronomic efficiency of nutrient use. Combining fertiliser addition with locally-available organic inputs, while retaining or enriching crop residues, improves nutrient-use efficiency and protects soil quality. Thus, several intermediary phases may be identified along the progression from farmers' current practice toward optimised ISFM (Figure 2). Complete ISFM comprises the use of improved germplasm, fertiliser, appropriate organic resource management and adaptations to local conditions and seasonal events. These adaptations lead to specific management practices and investment choices, and are iterative in nature, leading to better judgments by farmers concerning weed management, targeting of fertiliser and organic inputs in space and time, and choice of crop varieties.

Farmers' resource endowment also influences ISFM, as do market conditions and favourable policies promoting farm input supply. Local adaptation also adjusts for variability in soil fertility status and recognises that substantial improvements in agronomic efficiency of nutrient addition can be expected

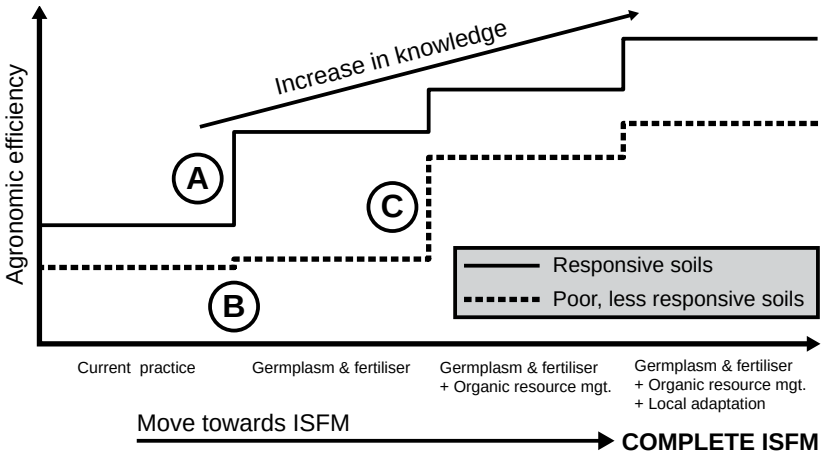

Figure 2. Conceptual relationship between the agronomic efficiency of fertilisers and organic resources, with current practice at left and full ISFM at right. At constant fertiliser application rates, yield is linearly related to agronomic efficiency.

on more responsive soils (A in Figure 2) while on poor, less-responsive soils, application of fertiliser alone does not result in improved nutrient use (B in Figure 2). Fertiliser is better applied in combination with organic resources (C in Figure 2). Additions of organic matter to the soil provide several mechanisms for improved agronomic efficiency, particularly increased retention of soil nutrients and water and better synchronisation of nutrient supply with crop demand, but it also improves soil health through increased soil biodiversity and carbon stocks.

ISFM is effective over a wide range of fertiliser application rates. It can greatly improve the economic returns from achieving the African Fertiliser Summit target through the increase in fertiliser agronomic efficiency, when its use grows from an average of 8 kg/ha to 50 kg nutrients/ha. ISFM also deters land managers from applying fertilisers at excessive rates that result in reduced agronomic efficiency and environmental pollution.

The approach advocated to improve the soil fertility status of African soils is embedded within the ISFM paradigm and will be achieved in large part. Maximum benefits from ISFM practices and technologies can only be obtained within an enabling context, where such factors as viable farm input supply and produce-markets, functional institutions and good policy are in place.

Assessment of ISFM technologies and targeting impact zones

Our knowledge of Africa's soils is relatively small compared to that of the hundreds of million small-scale farmers who make their living from soils management. In our attempts to fill this knowledge gap, however, we have made numerous practical achievements, often with land managers taking the lead. The management of available organic resources by smallholders seeking to diversify their operations and address new markets often demonstrates an intuitive understanding of nutrient recycling.

Most African farmers make innovative use of field and farm boundaries and collect useful organic materials from outside their farms, often by necessity, and then incorporate them into their major farm enterprises, particularly for cereal-based cropping and livestock rearing. Farmers have learned to access mineral fertilisers and to use them in a judicious manner, despite their high cost and competing demands for scarce cash. It is within this agricultural setting that ISFM is taking hold in Africa, leading to more effective combination of organic and mineral inputs to soil and directing them toward more profitable use.

Redirection of soil management practice is best conducted in conjunction with adoption of improved crop varieties that have been specially bred to meet rural household needs. In this way, new cropping systems involving higher yielding staple foods, grown in conjunction with new and improved legumes in rotations and intercrops, can raise the living standards of African small-scale farmers while improving the soils upon which their future depends.

The challenge now before the research and development community is how to replicate and expand isolated successes in ISFM in a manner that rapidly attracts a variety of land managers, and empowers even the poorest farming households to become innovative adopters.

Evaluation of earlier initiatives intended to improve soil fertility management practised by smallholder farmers shows that different interventions contribute in divergent ways to increased productivity and agronomic efficiency of inputs, and have contrasting potential for widespread adoption (Figure 3). Note that the interventions in the upper right quadrant ('High–high') of Figure 3 represent

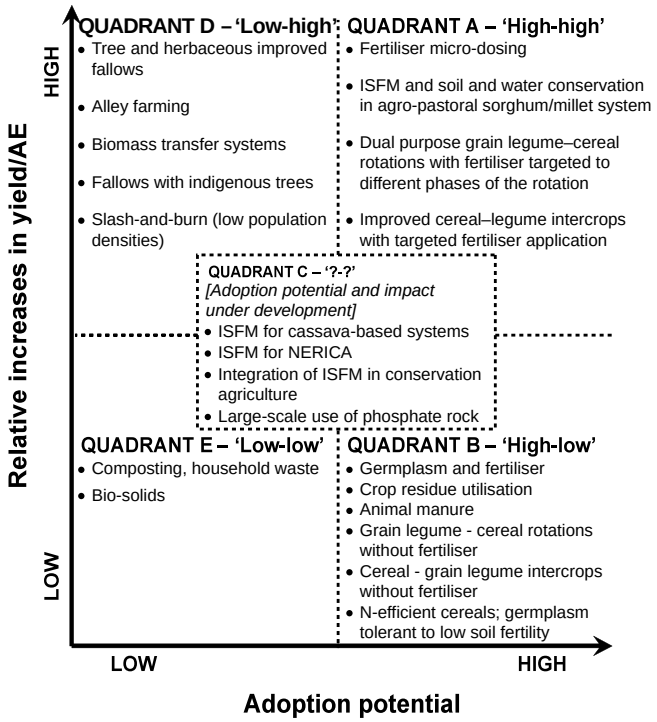

Figure 3. Relative adoption potential and contribution to soil fertility enhancement for various tested soil fertility management interventions. Adapted from A. Adesina (pers. comm.). AE = agronomic efficiency.

practices where complete ISFM as shown in Figure 1 is being successfully employed, and adopted in certain agro-ecological zones in SSA. Technologies in other quadrants are, to lesser or larger extents, moving towards complete application within ISFM. Practices listed within the central quadrant C could become utilised to great advantage, but there is at present limited knowledge on how to adopt ISFM into recommended practice. Note that the choice of winning technologies in the upper right position of Figure 3 is based upon their feasibility, accessibility, scalability and sustainability. Practices in Quadrants B, D, and E are not successfully used because either their adoption potential or their relative contribution to expanded use of mineral fertilisers in Africa is limited. Many current soil fertility management options fall within Quadrant B and a challenge before ISFM is to move these options into Quadrant A by overcoming their shortcomings in terms of nutrient supply and use efficiency.

The potential for both up-scaling, through various institutions dealing with soil fertility management, and out-scaling by reaching more farmers, greatly assists in better targeting future investment in ISFM.

Currently, the level of success of these practices is modest, for a number of reasons:

1. livelihood strategies are influenced by many other factors besides ISFM, making ISFM-specific success less visible,
2. developments in breeding have a stronger 'breakthrough' character because dissemination is more rapidly available and visible,
3. successes in ISFM are hard to come by because the Structural Adjustment Programs made fertiliser use unattractive to many farmers for several years, and
4. research and development efforts in the past lacked clear and consistent monitoring and evaluation tools to assess soil management capabilities.

Success must be expressed by impact indicators, such as yield increases, increased fertiliser sales, increased agronomic efficiency, and/or numbers of ISFM adopters.

The ISFM case in Figure 3 is useful in formulating strategies for intervention and direct future investment. The basic criteria for investments are: (i) proven successes because the farming system or technology has convincing impact and is ready for up-scaling; and (ii) likely successes where the farming system or technology may not have yet proved successful but is currently considered to be 'higher potential' because of soaring local, regional and world demand for agricultural products. One of the greatest strengths of ISFM is its capacity to integrate local suitability, economic returns/profitability, adoptability, and sustainability in developing improved land management recommendations.

While the goal of ISFM, to deliver nutrients to crops in a resource-, labour- and cost-effective manner, remains constant, the means to achieve ISFM varies within different agro-economic zones and cropping systems. Successful and potentially successful case studies mentioned above are located in different agro-ecological zones, which have different inherent soil-related constraints that need

Table 2. Selected characteristics of selected agro-ecological zones in sub-Saharan Africa (FAO 1995; FAO/IIASA 2000; FAO/IIASA 2002). Lowland, <800 m above sea level (masl); mid-altitude, 800–1200 masl; highland, >1200 masl. Growing periods are <150 days in dry areas, 150–270 days in savannas and >270 days in forest areas.

Agro-ecozone (% of the area)	Appropriate ISFM technologies	Major soil orders (FAO system)	Major nutrient-related constraints
Lowland dry savanna (36%)	Microdosing, Agro-pastoral interactions, Rock phosphate	Arenosols, Lithosols, Regosols	Low available soil P; soil acidity; low water holding capacity
Lowland moist savanna (17%)	Cereal–legume rotation and intercrops; Conservation agriculture	Lixisols, Ferralsols	S, Zn deficiency under intensive cultivation; low available N and P
Lowland humid forest (15%)	Cassava–legume intercrops, understorey & lowland rice management	Ferralsols, Arenosols	Soil acidity; low available soil P
Mid-altitude moist savanna (7%)	Cereal–legume rotation and intercrops; Conservation agriculture, slope management	Ferralsols, Arenosols	Soil acidity; low available N and P
Highland moist savanna (7%)	Intercrops and rotations, slope management	Ferralsols, Arenosols	Soil acidity; low available soil P

to be addressed, as outlined in the following sections and Table 2. Additional information on some of these zones is presented in Figure 4.

A broad and flexible approach to strengthening ISFM is envisaged which can result in large-scale impact in a relatively short time in the major intensification or impact zones in SSA. Improving and disseminating ISFM in drylands through improved fertiliser placement, manure management and water harvesting is key within the Sahel, an area characterised by extreme poverty and episodic famine. Enhanced use of fertiliser within cereal croplands, accompanied by deriving maximum benefit from nitrogen-fixing legumes grown as intercrops or in rotation, is an entry point for achieving food security and income generation in moist savannas and dry woodlands of eastern, southern and western Africa. Proven land management practices and, to a lesser extent, appropriate soil fertility products, are well established within these two agro-ecological zones of Africa, and it is only the lack of strategic planning and market development resources that impedes their widespread adoption.

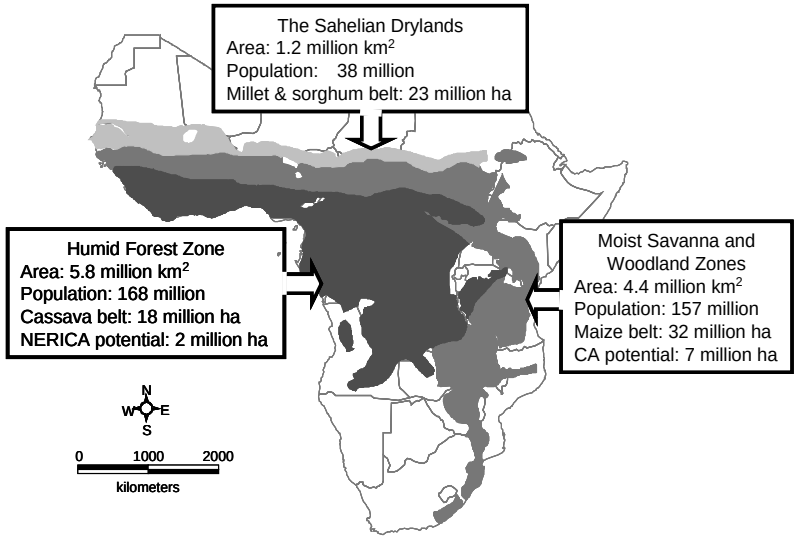

Figure 4. A summary of the characteristics of the zones and cropping systems warranting investment in ISFM.

ISFM guidelines are less developed within three areas: (i) the humid lowlands of Central and West Africa where root crops and banana are staple crops, (ii) within upland rice systems in conjunction with the growing importance of the New Rice for Africa (NERICA), and (iii) in conservation agriculture where soil quality improves with time but innovative uses of farm inputs are required.

Three accompanying developments are also necessary for the benefits of ISFM to become realised:

- improved capacity in the diagnosis and response to soil fertility constraints,
- greater access to farm input and commodity markets by small-scale farmers, and
- strategic policy adjustments that stimulate institutional and market response toward ISFM and its resulting crop surpluses.

All the above cannot be realised without reviving and strengthening human and financial resources.

There are constraints to improved targeting of recommendations on soil fertility inputs in SSA. They include:

- the use of over-generalised blanket recommendations that do not take into consideration farmers' diverse socio-economic and biophysical conditions,
- poor soil and crop management by farmers,
- lack of sufficient knowledge,
- limited access to responsive varieties,
- low and variable rainfall,
- limited access to stable produce-markets,
- limited financial means and access to credit.

If we assume for the moment that the degrees and types of nutrient limitations are recognised, and that technologies to ameliorate those conditions are identified, then the next important step is to devise strategies that facilitate the delivery of these technologies to needy farmers. These technologies must be 'packaged' into products and field operations that are recognisable, available and affordable to farm households. Clearly, policy interventions and marketing strategies can improve farmers' access to improved technologies but these will remain under-utilised if they appear over-priced or are perceived as risky. The following points, in the next section, relate to the understanding and promotion of ISFM technologies among farmers at the grassroots level.

Fertiliser as an entry point for ISFM

The recommendation of the Fertiliser Summit, 'to increase the fertiliser use from the current 8 to 50 kg nutrients/ha by 2015', reinforces the role of fertiliser as a key entry point for increasing crop productivity and attaining food security and rural well-being in SSA.

The impact of this target will, however, vary depending upon the agronomic efficiency of fertiliser, defined as 'the amount of output (such as crop yield) obtained per unit of fertiliser applied'. This rate varies across regions, countries, farms and fields within farms, and greatly affects the returns to the recommended 50 kg/ha (Prudencio 1993). Generally on responsive soils, where the applied fertiliser nutrients overcome crop nutrient limitations, substantial responses to fertiliser can be expected (Vanlauwe et al. 2006). On soils where other constraints are limiting crop growth (less-responsive soils), fertilisers alone in absence of other corrective measures result in relatively low agronomic efficiencies and small improvement in crop yield (Carsky et al. 1998; Zingore et al. 2007a,b).

Also important is the heterogeneity that exists between households within a community, translated in differing production objectives and resource endowments (Tittonell et al. 2005a,b; Giller et al. 2006).

The above factors co-determine the range of soil fertility management options available to the household. Ojiem et al. (2006) derived the concept of the 'socio-ecological niche' for targeting ISFM technologies, which must be embedded into local social, economic and agro-ecological conditions.

Fertiliser not only improves crop yields but it also increases the quantity of available crop residues useful as livestock feed or organic inputs to the soil (Bationo et al. 2004). Targeting phosphorus (P) application to legumes doubles crop biomass and increases the fertiliser agronomic efficiency of the next cereal crop (Vanlauwe et al. 2003; Giller et al. 1998). Similarly, strategic application of nitrogen (N) fertiliser improves the performance of most cropping systems, even N-fixing legumes. For example, application of small amounts of starter N to legumes stimulates root growth, leading to better nodulation and increasing the N contribution to a succeeding cereal crop (Giller 2001; Sanginga et al. 2001). More accurate timing and placement of top-dressed N during peak demand of maize greatly improves crop yield and agronomic efficiency (Woomer et al. 2004, 2005).

Mineral fertilisers are important within ISFM, but not as a stand-alone means to crop nutrient management. Within responsive soils, fertiliser is indeed a valid entry point for ISFM, while in the poorest soils organic resource management options must be implemented in conjunction with mineral fertiliser addition before sufficient crop responses are realised. This situation holds true under a number of soil conditions, including shallow sandy soils, degraded soils with collapsed physical structure and low soil organic matter, and highly weathered soils with toxic properties.

Fertiliser quality is often problematic. Manufacturers and blenders commonly lack the essential agronomic information to formulate appropriate nutrient compositions in fertilisers. Crop nutrient requirements depend on the environment, and change with time and intensifying crop production. Obtaining this information is hampered by ineffective linkages with experimental stations and lack of regular crop surveying. Loss of fertiliser quality through poor storage and adulteration, occurring mostly during repackaging, is another constraint and it greatly discourages farmer investments in fertiliser.

A major problem for effective utilisation of fertilisers and ISFM practices in Africa has been inability to deliver appropriate recommendations and accompanying inputs in the right form to smallholder farmers. Past fertiliser recommendations have been based on single major cash crops such as maize, tea and cotton, delivered in 'pan-territorial/blanket' form, failing to take into account the spatial variation in smallholders' resource endowment (soil type and condition, labour capacity, climate risk, etc.). There is need therefore to move away from 'blanket' recommendations and instead base guidelines for fertiliser use on the principles of ISFM, targeting dissemination programs to the specific crop production problems faced by farmers and their socio-economic circumstances and production goals.

Many fertiliser recommendations made to farmers are regarded as excessive, and rightly so. Fertiliser recommendations are generally based upon sound field trials, but too often they are formulated by optimising returns per unit area rather than per unit input. Gain per unit area is appropriate information for commercial production, but this approach is inappropriate to more limited investments in fertiliser by cash-poor farmers. These farmers are better positioned by maximising their returns per unit input (Figure 5). Recommended fertiliser rates based upon the greatest returns per unit input are usually 30% to 50% of those based upon unit area. This implies that if a farmer can afford to fertilise only one-third of the farm at the recommended rate per unit area, then she is better off by applying only one-third of that rate to the entire farm.

Nonetheless, it is critical that fertiliser recommendations be re-examined within this context and adjusted downward to levels better afforded by small-scale farmers. Different fertilisers may be managed in different ways particularly within the context of ISFM. Furthermore, fertiliser recommendations are only starting points in fine tuning a land manager's nutrient management strategy. More localised fertiliser recommendations are best developed, adjusted and validated through close collaboration between researchers, extension agents

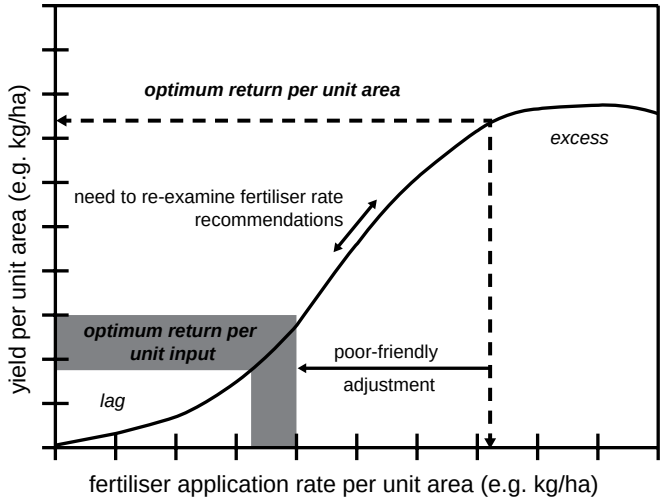

Figure 5. Fertiliser recommendations formulated for small-scale farmers should be based not upon maximizing return per unit area, as is customary, but rather optimizing return per unit fertiliser input.

and farms. Farmers must be empowered to undertake adaptive adjustments to local recommendations that meet the requirements of their individual farms and fields.

Several steps are required before fertilisers of the correct type are sufficiently available to smallholder farmers in Africa and become adopted within the context of ISFM. First, better diagnosis of soil and plant constraints by rural planners must be achieved so that the correct types and blends of fertilisers become marketed. Then the use of these fertilisers must become nested within ISFM recommendations targeted to a farmer's agro-ecological setting, production strategy and socio-economic conditions. To achieve this goal, human and institutional capacities must be directed towards finding integrated solutions to soil constraints that make best use of farmers' limited resources, and that balance the benefits of redirecting cash investment and labour.

Key considerations in devising ISFM strategies

Fertiliser advice must not only provide suggested types and rates but also offer guidelines on how to make adjustments in conjunction with the use of commonly available organic resources. For example, manure piles that are protected against nutrient loss need smaller amounts of mineral fertilisers to supplement them.

ISFM approaches may follow two parallel paths, one for strictly commercial production that optimises returns per unit area and another intended for resource-poor farmers that makes best use of limited fertiliser. Different resource endowment categories exist within a given farming community and the capacity of each category to invest in mineral fertilisers differs. Similarly,

households have different degrees of labour availability. Farmers producing cereals for markets should be offered one set of recommendations, and those who are seeking food security for the least cost could be offered another set where less fertiliser is used more efficiently.

Different ISFM recommendations can be forwarded for soil fertility niches within farms and for major topographies. Spatial heterogeneity within and across farms results from topography, nutrient and soil gradients and specialised niches, and these differences necessarily influence nutrient management. In many cases heterogeneity has been intensified during past management when, say, more resources may have been devoted to nearer or more productive fields. Separate practices are required for severely degraded and nutrient-depleted lands to allow farmers to rehabilitate their least productive fields in a resource- and time-efficient manner.

Localised fertiliser recommendations are best developed, adjusted and validated through close collaboration between researchers, extension agents, farmer associations and their members. Participatory research methods can guarantee farmers have a role in the formulation of recommendations, and reveal farmers' adaptive and adoptive responses to those recommendations and the impacts resulting from them. This approach is markedly different from top-down prescriptive approaches to fertiliser use where farmers themselves need to adjust recommended management practices to suit their farming conditions and household priority setting. However, the level of participation can vary, depending on the complexity of the knowledge underlying a specific intervention.

The craft of ISFM involves making the best use of affordable fertilisers, available organic resources and accessible agro-minerals. Better management of fertiliser calls for farmers to gain increased knowledge through information and training campaigns. Corresponding actions include promotion of fertiliser micro-dosing, water conservation, management of soil organic matter, better integration of legumes into farm enterprises and mobilisation of available agro-minerals. Lack of farmer knowledge on production, conservation and effective utilisation of organic resources is a major constraint and it needs to be addressed through information directed through a variety of sources.

Guidelines in ISFM practice cover generalised practices for different sorts of fertilisers, and more specialised approaches for specific categories of land and household resources. As recommendations become more localised, greater knowledge of ISFM is required. Ultimately, it is the responsibility of individual farmers as ISFM practitioners to make adjustments to local recommendations based upon their specific conditions. Examples of ISFM guidelines follow.

Combine the strategic application of fertilisers and farmer-available organic resources in a manner that increases nutrient use efficiency and makes fertiliser use more profitable

In West Africa, for example, farmers have adopted the 'microdose' technology that involves strategic application of small doses of fertiliser (4 kg P/ha) and seed (Tabo et al. 2006). This rate of fertiliser application is only one-third of the

recommended rate for the area. As a result of adoption of 'microdoses', grain yields of millet and sorghum were increased by between 43% and 120% in all the project study sites in Burkina Faso, Mali and Niger. The incomes of farmers using this practice increased by 52–134%. Small amounts of fertilisers are more affordable for farmers, give an economically optimum (though not technically maximum) response, and, if placed in the root zone of these widely-spaced crops rather than uniformly distributed, result in more efficient uptake (Bationo & Buerkert 2001). In addition, the number of farmers using fertilisers in the study sites dramatically increased. The successful experience has shown that adoption of microdose technology requires supportive and complementary institutional innovation and market linkage such as 'warrantage'.

Optimise improved germplasm, water use efficiency and agronomic practices within new soil fertility input recommendations

Studies have shown that introduction of a cash crop, such as cowpea or soybean or high value vegetables, into the cropping system can greatly boost the use of fertiliser by smallholder farmers and increase yields of succeeding food crops. The importance of crop diversification was emphasised at the Oslo Conference on the African Green Revolution, where it was noted that crop diversification can help in optimising farmer returns and, as a principle of risk management, protect those returns. Similarly new crop varieties have been bred recently for drought tolerance and adaptation to low soil fertility, and there is need to increase their adoption by smallholder farmers.

Keep recommendations and demonstrations simple

On-farm trials and community demonstrations that are designed by agricultural scientists are too often overly complex and this distracts farmers from their intended message. Integrated Soil Fertility Management is complex and knowledge-intensive and special attention must be placed upon capturing its findings into simplified field operations. Researchers who install large, replicated, randomised experiments in farmers' fields that are intended to host instructional field days risk confusing their clients. More information and better feedback is conveyed from simpler on-farm field demonstrations and technology trials.

Work through existing organisations and networks

Working with existing farmer associations and their umbrella networks to promote fertiliser use offers several advantages. To a large extent, these farmer groups formed as a means of better accessing information and technologies in the absence of adequate support from agricultural extension. These groups represent a ready formed audience for technical messages, which will collectively undertake independent evaluation of technologies and provide necessary feedback on them. Larger organisations offer farm input supply services to their members, allowing them to purchase fertilisers in bulk or on credit, and pass savings onto members. Farmer groups provide peer support to members, allowing them to undertake new and more complex field operations and investments. Other stakeholders, particularly farm input suppliers, also deserve attention during the planned promotion of fertilisers, but groups of potential fertiliser users must not be overlooked.

Adhere to market-led and value chain addition paradigms

The Market-Led Integration Hypothesis states that 'improved profitability and access to market will motivate farmers to invest in new technology, particularly the integration of new varieties with improved soil management options'. It is based in part upon the disappointing past experiences of developing and promoting seemingly appropriate food production technologies, only to have them rejected by poor, risk-averse farmers unable or unwilling to invest in additional inputs. This simple hypothesis captures a unifying breakthrough. When working in the market-led mode, agronomists will no longer assume that additional produce resulting from technical adoption, including the expanded use of fertilisers, will necessarily benefit the household; nor will economists assume that demand created through market innovations will automatically be filled. Value chain addition examines farm planning, field operations and produce-marketing, in a holistic context that permits the innovations necessary to improve farming enterprises, including a farmer's investment in fertiliser, to be more readily identified and compared.

A way forward

The future of small-scale farming households largely rests in their ability to rapidly seize new production and marketing opportunities, and corresponding actions by national planners and development agencies to better empower farmers' collective action.

Hindrances beyond smallholders' control persist: notably weak networks of rural roads and utilities which in turn result in high costs both of farm inputs and of marketable crop surpluses. Agricultural extension is sporadic at best and attempts at extension reform are largely ineffective. Much of this dilemma is related to improperly translated 'training and visitation' extension models because of the large numbers of extension clients resulting from increasingly small farms. Even the frontline extension agents presently in place lack sufficient educational materials and financial resources to assist their nearest clients (Lynam & Blackie 1994).

Recent reviews of the different stakeholders and partners involved in ISFM research for development in SSA point to the need to build capacity and to consolidate efforts at all levels — from farmers to researchers and policy makers.

To generate and deliver demand-driven knowledge and technologies, there is a need for a platform on ISFM supported by a Center of Excellence in SSA, to foster partnerships between advanced research institutions, national agricultural research and extension systems, and the private sector. The platform will support capacity-building and drive the generation of new knowledge and approaches to disseminate ISFM practices. Different mechanisms will be used, including consortia, and networks such as the African Network for Tropical Soil Biology and Fertility (AfNet) — a pan-African network that is able to mobilise 400 scientists who engage in ISFM research for development.

Funding for ISFM research needs to recognise the urgency for immediate action and for longer-term investment. At the heart of that support is a critical mass and diversity of soil scientists in SSA.

The platform will provide that mass, centred on the staffing of current institutions working on ISFM in SSA. In addition, laboratory facilities are urgently needed for the type of research described above. There is thus a crucial need for a targeted and committed investment in ISFM, in SSA and more widely, to enable and enhance the momentum that has already been achieved by the Bill and Melinda Gates Foundation, the Rockefeller Foundation and their partners.

Conclusion

In summary, ISFM aims at effective use of inputs by combining a number of components. ISFM practices involve:

1. judicious use of mineral fertiliser and agro-minerals, in terms of their form, placement and timing of application;
2. management of crop residues and other locally-available organic resources in a way that improves agronomic efficiency;
3. use of locally adapted germplasm that is resistant to local stresses and conditions, both biotic and abiotic; and
4. other field practices determined by local agricultural conditions, particularly pest and disease management, soil erosion control, moisture conservation and the enhancement of beneficial soil biota.

These considerations lead to a suite of field practices based upon past experience, current information and changing farming conditions. They will result in better soil fertility management — an essential component of rural development in Africa.

References

Bationo A. & Buerkert A. (2001). Soil organic carbon management for sustainable land use in sudano-sahelian West-Africa. *Nutrient Cycling in Agroecosystems* 61: 131–142.

Bationo A., Kimetu J., Ikerra S., Kimani S., Mugenda D., Odendo M., Silver M., Swift M.J. & Sanginga N. (2004). The African Network for Soil Biology and Fertility (AFNet): New challenges and opportunities. In: Bationo A. (Ed.) *Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa*. Academy Science Publishers, Nairobi, Kenya. pp. 1–23.

Bationo A., Waswa B., Kihara J. & Kimetu J. (2006). Advances in integrated soil fertility management in sub-Saharan Africa: Challenges and opportunities. *Nutrient Cycling in Agroecosystems* 76.

Buresh R.J., Sanchez P.A. & Calhoun F. (1997). *Replenishing Soil Fertility in Africa*. Soil Science Society of America Special Publication No 51. Madison, USA. 251 pages.

Carsky R., Jagtap S.S., Tian G., Sanginga N. & Vanlauwe B. (1998). Maintenance of soil organic matter and N supply in the moist savanna zone of West Africa. In: Lal R. (Ed.) *Soil Quality and Agricultural Sustainability*. Ann Arbor Press, Michigan, USA. pp. 223–236.

FAO (1995). *Fertilizer and Plant Nutrition Bulletin No. 12*. Food and Agriculture Organization of the United Nations, Rome.

FAO/IIASA (2000). Global agroecological zones 2000. Online database at http://www.Fao.org/ag/agl/Agll/Gaez/Index.htm. Food and Agriculture Organization of the United Nations, and International Institute for Applied Systems Analysis.

FAO/IIASA (2002). *Global Agroecological Assessment for Agriculture in the 21st Century*. International Institute for Applied Systems Analysis, Luxembourg.

Giller K.E. (2001). *Nitrogen Fixation in Tropical Cropping Systems*. Second Edition. Wallingford, UK: CAB International.

Giller K.E., Gilbert R., Mugwira L.M., Muza L., Patel B.K. & Waddington S. (1998). Practical approaches to soil organic matter management for smallholder maize production in Southern Africa. In: Waddington S.R., Murwira H.K., Kumwenda J.D.T, Hikwa D. & Tagwira F. (Eds) *Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe*. Soil Fertility Network and CIMMYT, Harare, Zimbabwe, pp. 139–153.

Giller K.E., Rowe E., De Ridder N. & Van Keulen H. (2006). Resource use dynamics and interactions in the tropics: Scaling up in space and time. *Agricultural Systems* 88: 8–27.

Lynam J.K. & Blackie M.J. (1994). Building effective agricultural research capacity: The African challenge. In: Anderson J.R. (Ed.) *Agricultural Technology: Policy Issues for the International Community*. Wallingford, UK: CAB International, pp. 106–134.

Ojiem J.O., De Ridder N., Vanlauwe B. & Giller K.E. (2006). Socioecological niche: A conceptual framework for integration of legumes in smallholder farming systems. *International Journal of Agricultural Sustainability* 4: 79–93.

Prudencio C.F. (1993). Ring management of soils and crops in the West African semi-arid tropics: The case of the Mossi farming system in Burkina Faso. Agriculture *Ecosystems and Environment* 47: 237–264.

Sanchez P.A. (1994). Tropical soil fertility research toward the second paradigm. *15th World Congress of Soil Science*. Acapulco, Mexico, pp. 65–88.

Sanchez P.A., Shepherd K.D., Soule M.J., Place F.M., Buresh R.J., Izac A-M.N., Mokwunye A.U., Kwesiga F.R., Ndiritu C.G. & Woomer P.L. (1997). Soil fertility replenishment in Africa: An investment in natural resource capital. In: Buresh R.J., Sanchez P.A. & Calhoun F. (Eds) *Replenishing Soil Fertility in Africa*. Soil Science Society of America & American Society of Agronomy. SSSA Publication No. 51.

Sanginga N., Okogun J.A., Vanlauwe B., Diels J. & Dashiell K. (2001). Contribution of nitrogen fixation to the maintenance of soil fertility with emphasis on promiscuous soybean-based cropping systems in the moist savanna of West Africa. In: Tian G. Ishida F. & Keatinge J.D.H. (Eds). *Sustaining Soil Fertility in West Africa*. SSSA Special Publication No. 58. Soil Science Society of America. Madison, USA. pp. 157–178.

Tabo R., Bationo A., Gerald B., Ndjeunga J., Marchal D., Amadou B., Annou M.G., Sogodogo D., Taonda J.B.S., Hassane O., Diallo M.K. & Koala S. (2006). Improving cereal productivity and farmers' income using a strategic application of fertilizers in West Africa. In: Bationo A., Waswa B.S., Kihara J. & Kimetu J. (Eds). *Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities*. Springer, Netherlands, pp. 201–208.

Tittonell P., Vanlauwe B., Leffelaar P.A., Rowe E. & Giller K.E. (2005a). Exploring diversity in soil fertility management of smallholder farms in Western Kenya. I. Heterogeneity at region and farm scale. *Agriculture Ecosystems and Environment* 110: 149–165.

Tittonell P., Vanlauwe B., Leffelaar P.A., Shepherd K.D. & Giller KE. (2005b). Exploring diversity in soil fertility management of smallholder farms in Western Kenya. II. Within farm variability in resource allocation, nutrient flows and soil fertility status. *Agriculture Ecosystems and Environment* 110: 166–184.

Vanlauwe B., Aihou K., Aman S., Iwuafor E.N.O., Tossah B.K., Diels J., Sanginga N., Merckx R. & Deckers S. (2001). Maize yield as affected by organic inputs and urea in the West African moist savanna. *Agronomy Journal* 93: 1191–1199.

Vanlauwe B., Bationo A., Carsky R.J., Diels J., Sanginga N. & Schulz S. (2003). Enhancing the contribution of legumes and biological nitrogen fixation in cropping systems: Experiences from West Africa. *Grain Legumes and Green Manures of Soil Fertility in Southern Africa: Taking Stock of Progress.* Proceedings of Soil Fertility Network Meeting, Vumba, Zimbabwe, pp. 3–13.

Vanlauwe B., Tittonell P. & Mukulama J. (2006). Within-farm soil fertility gradients affect response of maize to fertiliser application in Western Kenya. *Nutrient Cycling in Agroforestry* 76: 171–182.

Woomer P.L., Lan'gat M. & Tungani J.O. (2004). Innovative maize–legume intercropping results in above and below ground competitive advantages for under storey legumes. *West African Journal of Applied Ecology* 6: 85–94.

Woomer P.L., Tungani J., Odhiambo G. & Mwaura F.M. (2005). Striga management options in Western Kenya. *African Crop Science Conference Proceedings* 7: 479–484.

Zingore S., Murwira H.K., Delve R.J. & Giller K.E. (2007a). Influence of nutrient management strategies on variability of soil fertility, crop yields and nutrient balances on smallholder farms in Zimbabwe. *Agriculture Ecosystems and Environment* 119: 112–126.

Zingore S., Murwira H.K., Delve R.J. & Giller K.E. (2007b). Soil type, historical management and current resource allocation: Three dimensions regulating variability of maize yields and nutrient use efficiencies on African smallholder farms. *Field Crops Research* 101: 296–305.

Dr Nteranya Sanginga assumed the leadership of the International Institute of Tropical Agriculture in November 2011. He has a wealth of experience in agricultural research and development, particularly in applied microbial ecology, plant nutrition, and integrated natural resources management in Africa, Latin America, and South-East Asia. He was the Director of CIAT-TBSF and worked at the University of Zimbabwe, IAEA, and IITA where he served as principal scientist, head (soil microbiology unit), project coordinator, and program leader. He has trained more than 30 PhD candidates, who are now leaders in their countries. Dr Sanginga, from Democratic Republic of Congo (DRC), did his postgraduate training at IITA and PhD in Agronomy/ Soil Microbiology under a joint program with partners in DRC, Burundi, and Rwanda.

Email: N.Sanginga@cgiar.org