Introduction

ISFM and the African farmer

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 (DeVries and Toennissen 2001). Poor soil fertility and nutrient depletion continue to represent huge obstacles to securing needed harvests. Improving access to fertilizers is a necessary countermeasure, particularly when farmers develop skills in selecting which fertilizers are required and how to best derive benefits from their application. ISFM as defined in the Foreword represents a means to overcome this dilemma by offering farmers better returns to investment in fertilizer 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.

Better managing soil fertility is an imperative for sub-Saharan Africa. Pedro Sanchez (1997) reinforces this view by identifying 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 resulting from food insecurity threatens the very fabric of social stability in the poorest countries. Several technological breakthroughs have emerged in Africa over the past decade that, once effectively disseminated, offer the means to reverse this ominous picture. Never before has there been a more advantageous opportunity to reinforce the role of the agricultural research and development community in addressing the full suite of soil fertility, food production and land degradation problems in Africa.

Smallhold farming systems in Africa are undergoing a profound transformation from subsistence farming to mixed-enterprise, market-oriented agriculture. This transition is in some cases abrupt, as when smallholders are recruited into large out-grower schemes, but in most cases it is subtle as households more fully recognize that their household needs cannot be satisfied by farming in isolation, and they make stepwise adjustments to improve their production and marketing skills (Woomer *et al.* 1998). A brief account of the origins and history of smallhold farming allows this transformation to be better placed into perspective.

Smallhold farming, where a large household permanently and intensively cultivates a small area of land, is a recently-developed phenomenon. Africa, especially East and Southern Africa, has undergone a series of pastoralist migrations from West and northern Africa (Oliver 1982). Once new lands suitable for agriculture were secured, these migrants farmed relatively small portions of land, and practiced long-term, grazed fallow rotation as a means of replenishing land productivity. Farmers cultivated a wide variety of indigenous crops and gathered traditional green vegetables and indigenous fruits. Livestock were viewed as wealth and complex patterns of communal grazing and gift giving developed around them. As population densities increased, a larger proportion of land was placed into cultivation and fallow intervals decreased until, in the most densely populated areas, communal grazing ceased.

At the earliest stages of European and Arab contact, new crops were introduced from tropical America and rapidly adopted by cultivators, particularly maize, beans, groundnut and cassava, allowing for greater intensification of land use. Interrupting this process in many parts of East, West and Southern Africa was the invasion of colonialist farmers who displaced Africans from the best agricultural lands and, in many cases, forced them to become labourers on large plantations (Odingo 1971). This invasion was short-lived, ending for the most part with independence and leaving behind a mixed legacy of new cash crops, farming methods, infrastructure and land tenure. On the other hand, many traditional crops and farming practices were lost and land reallocation was somewhat irregular. It is within this backdrop that today's small-scale farming households developed.

Newly-independent African governments sought to jumpstart their economies into the 20th Century through the development of parastatal boards regulating agriculture and infant industries (Eicher 1999). These boards were intended to improve commodity markets and provide a basis for taxing agriculture. Their highest priority was to reinforce export crops, such as coffee and tea, as a means of securing foreign currency for industrial development and many of the basic needs of smallholders became overlooked in the process. This lack of commitment to the poorest is partly responsible for the failure of the Green Revolution to take root in Africa in the 1970's (Okigbo 1990) and led to chronic food insecurity and episodic famine in the following decades.

African governments established agricultural extension services, marketing boards, farmers' associations, credit schemes, faculties of agriculture and national research institutes, principally toward the benefit of richer farmers. The services of these bodies were weakened during the economic crises of the 1980s when budget deficits and inflation prevailed. Many parastatal boards fell into mismanagement as well (Alexandratos 1997). Donor institutions imposed structural adjustment programs that resulted in dismantling or privatizing parastatal bodies and liberalizing the agricultural economy. Unfortunately, many of these reforms did not achieve the desired growth as private sector investment failed to materialize, leaving little to fill the rural services vacuum (Eicher 1999).

During these four decades, little changed for the smallhold farmers except their numbers increased greatly, their farm size diminished, their resource base degraded and seasonal food shortages intensified. Governance has improved in Africa as a result of democratization and market reform during the 1990s, but these gains did not result in the expected benefits among small-scale farming households, and in many cases the lives of the poorest farmers worsened. Some smallholders grew demoralized, others migrated to urban areas but the majority sought to make the best of their difficult situation.

The future of small-scale farming households largely rests in their ability to rapidly seize new production and marketing opportunities and the corresponding actions by national planners and development agencies to better empower farmer collective action. Hindrances beyond smallholders' control persist, notably weak rural road and utilities networks that in turn result in high costs of farm inputs and 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 smaller farms. Even the frontline extension agents lack sufficient educational materials and financial resources to assist their nearest clients (Lynam and Blackie 1994).

Several signals of real advances and promise of improvement in the lives of small-scale farming households exist. The ominous, decades-long trend of agricultural stagnation in Africa may have ended based upon steady improvement in crop-based agricultural growth rates over the past decade (Omamo 2006). Other real advances include greater access to improved crop varieties, better soil and pest management (Conway and Toenniessen 2003), rapid growth and expansion of services to members of farmer associations and the emergence of out-grower networks addressing specialty export markets (Stringfellow *et al*. 1997).

In order to complete these gains, rural prosperity in Africa requires that land managers make flexible use of ISFM knowledge and technologies in order to produce and market more food while improving their agricultural resource base (Vanlauwe *et al*. 2006). ISFM knowledge is not rigid, rather it involves adjustable application of basic principles in land management. Important features of ISFM with particular relevance to African small-scale farming systems include 1) the judicious application of purchased fertilizers, 2) the efficient management of available organic resources, 3) wider integration of nitrogen-fixing legumes into cropping systems and 4) the conservation of soils and their biota and organic matter. ISFM practices are derived from combining these elements in a manner that is both site-specific and locally acceptable. Amplifying knowledge of ISFM requires capacity building from the grassroots through the professional levels. Furthermore, developing better land management technologies necessarily involves private sector participation in designing and distributing farm inputs.

Our knowledge of Africa's soils is relatively small compared to the hundreds of millions small-scale farmers who make their living from its management (Table 1). In our attempts to fill this knowledge gap, however, numerous practical achievements have occurred, 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 (Giller 2002). 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 cereal-based cropping and livestock rearing (Woomer *et al*. 1999). Despite their high cost and competing demands for scare cash, farmers are learning to access mineral fertilizers and to use them in a judicious manner. It is within this agricultural setting that ISFM is taking hold in Africa through the more effective combination of organic and mineral inputs to soil and directing them toward more profitable use.

The redirection of soil management practice is best conducted in conjunction with the adoption of improved crop varieties that have been specially bred to meet rural household needs (DeVries and Toennissen 2001). In this way, new cropping systems that involve 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 success in ISFM in a manner that rapidly attracts a variety of land managers and empowers even the poorest farming households to become innovative adaptors (Woomer *et al*. 2002).

While the goal of ISFM, to deliver nutrients to crops in a resource-, labor- and cost-effective manner remains constant, the means to achieve ISFM varies within different agro-ecological

Table 1. Selected characteristics of agro-ecological zones in sub-Saharan Africa. Lowland areas are <800 meter above sea level (masl), mid-altitude areas between 800 and 1200 msal and highland areas >1200 masl. Lengths of growing period are <150 days for dry areas, 150-270 days for savannas and >270 days for forest areas. After: FAO (1995); FAO/IIASA (2000); FAO/IIASA (2002).

Agro-ecozone (% of the area)	Appropriate ISFM Technologies	Major soil orders (FAO system)	Major nutrient-related constraints
Lowland dry savanna (36%)	Micro-dosing, 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, Acrisols	Soil acidity, low available soil P
Mid-altitude moist savanna (7%)	Cereal-legume rotation and intercrops; Conservation Agriculture, slope management	Ferralsols, Nitisols	Soil acidity, low available N and P
Highland moist forests (7%)	Intercrops and rotations, slope management	Ferralsols, Andosols	Soil acidity, low available soil P

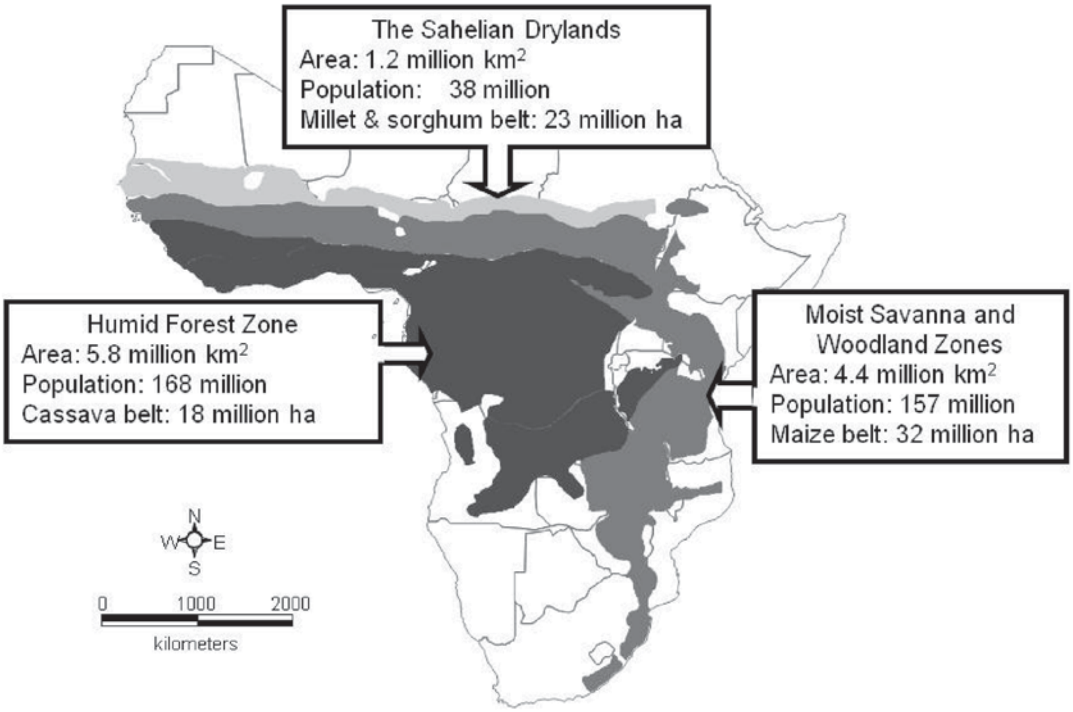

Figure 1. A summary of the characteristics of the zones and cropping systems warranting investment in ISFM.

zones (AEZs) and cropping systems. Different ISFM technologies are required to address the range of soil characteristics occurring in various AEZs in sub-Saharan Africa (Table 1). The coverage and additional information on some of these zones is presented in Figure 1.

Different soil fertility management technologies may be grouped in terms of effectiveness and potential for widespread adoption (Figure 2). Technologies appearing in Quadrant A (Figure 2) have reduced potential in terms of their productivity gains and adoption by small-scale farmers. Vermicomposting is practical at an industrial scale for the production of organic fertilizer and potting mixture, but the domesticated epigeic earthworms are not widely available and their high-quality organic feeds have more immediate alternative uses. Municipal and human wastes may also be transformed into organic fertilizers but they are bulky and their use may pose public health concerns. Lengthy experience with alley farming, where crops are grown between alternating rows of pruned trees, suggests that root crops and sandy soils are poorly suited to this system. Live fences on small plots or farms often result in excessive above- and below-ground competition with field crops. Despite these disadvantages, these technologies may prove useful under many circumstances, particularly the use of vermicomposting and municipal wastes in urban agriculture (see Chapter 4), but it is not otherwise advised to build a major soil fertility management program around them alone.

Technologies in Quadrant B (Figure 2) are attractive to small-scale farmers but usually do not result in farm-level benefits. Use of low quality crop residues or insufficient and improperly handled livestock manures in absence of mineral fertilizers provide too few nutrients for substantial gains in field crop production (see Chapter 4). Domestic composting may improve the nutrient concentration of organic resources, but its supply is usually insufficient and best directed toward home gardens or high value crops. Rotating or intercropping cereals and legumes produces crops needed by the household but production levels are usually low unless some form of nutrient replacement is practiced. In the same way, the production of stress-tolerant and nutrient-efficient crop varieties provides little in degraded soils, but they respond well to improved soil fertility management (see Chapter 15). The technologies in this quadrant

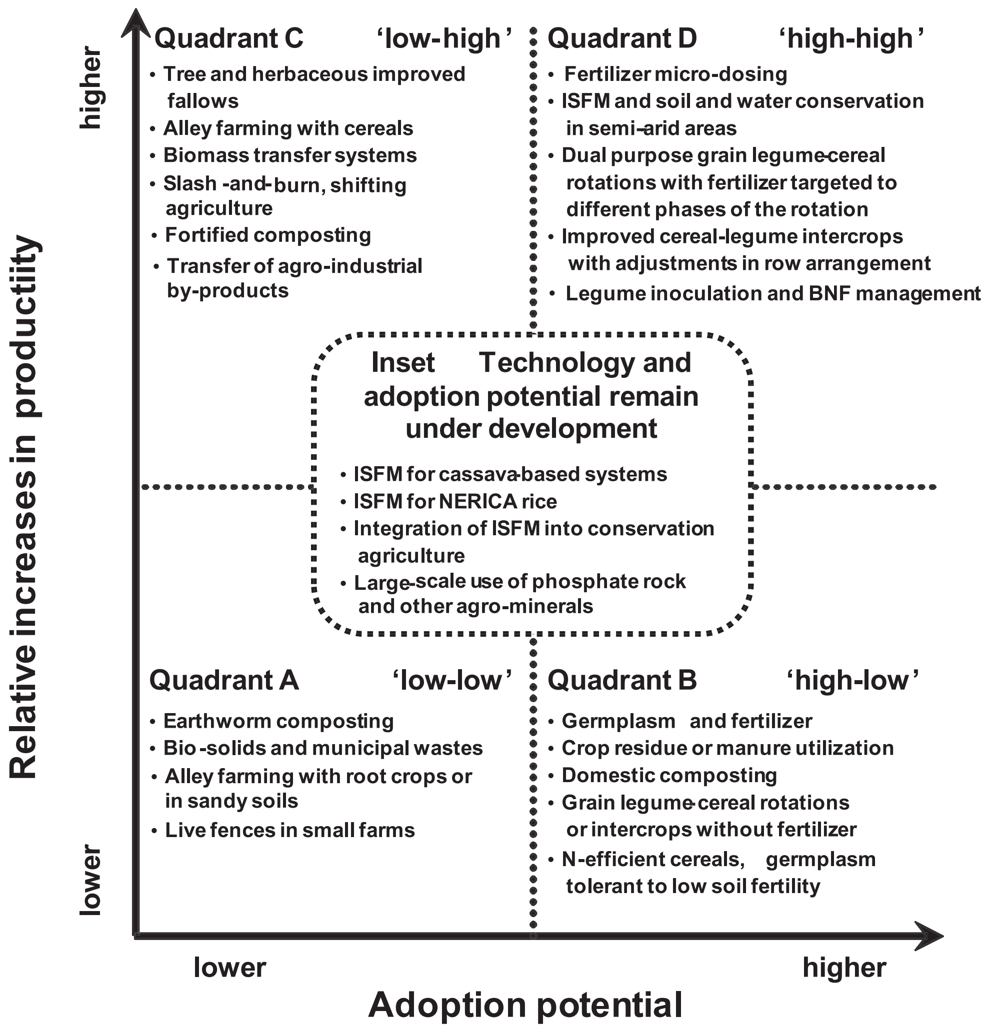

Figure 2. The relative adoption potential and contribution to soil fertility enhancement for various tested soil fertility management interventions. Adapted from A. Adesina (personal communication).

must not be dismissed as failures because they remain attractive to farmers, rather strategies must be employed to integrate them with more productive resource management approaches (see Chapter 11).

Practices presented in Quadrant C (Figure 2) have proven abilities to increase nutrient supply and improve both crop productivity and nutrient use efficiency, but they remain unattractive to farmers for a variety of reasons. Improved fallows require that lands be withdrawn from crop production, labor be redirected and that farmers invest in relatively expensive seed. Alley farming with nitrogen-fixing trees and cereals works, but requires intensive management and the sacrifice of some cropland. Biomass transfer systems, where organic resources are recovered, transported and applied, redirects nutrients to croplands but at the expense of other areas and requires large commitment of labor at a time with competing demands (see Chapter 4). Shifting agriculture, especially slash-and-burn, produces short-term benefits but at much greater environmental cost and is feasible only where population pressures are extremely low (see Chapter 9). Fortified composting involves the addition of fertilizers, agro-minerals and manures to bulky crop residues, and their partial decomposition, resulting in a high quality organic fertilizer, but requires hard work, cash investment and time to transform these materials that could be otherwise applied directly during field operations (see Chapter 4). This practice is, however, extremely practical in higher value horticultural enterprises. Similarly, agro-industrial wastes are useful as soil inputs, mulch or compost ingredient and are often free for the taking, but their bulk and difficulties in transport make them unavailable to most farmers (see Chapter 6). Indeed, the challenge to make more practical advantage of technologies appearing in Quadrant C is to target them to the correct smallholder clients while reducing their comparative disadvantages to others.

Technologies capable of delivering rapid benefits to large numbers of farmers in sub-Saharan Africa are presented within Quadrant D (Figure 2). Fertilizer micro-dosing involves spot placement of fertilizers, sometimes timed to rainfall in split applications. In semi-arid areas, ISFM practices may be strategically combined with water harvesting, usually through the creation of mini-catchments within the field (see Chapter 7). Combining cereals and grain legumes through rotation, intercropping and relays, and proving these crops with strategically applied mineral fertilizers and organic inputs are a key to ISFM and food security in Africa (see Chapter 6). In the case of crop rotations, additional information is required on optimal crop sequencing, and for intercropping, adjustments must be made in row spacing, orientation and crop combinations (see Chapter 8). In many cases, biological nitrogen fixation by field legumes can be increased through inoculation with elite strains of their microsymbiont rhizobia made available to the host through improved delivery systems (see Chapter 5). Much of this book is devoted to describing the refinement and dissemination of technologies falling within this quadrant.

Technologies with equally large potential but require further understanding or development before comprehensive ISFM packages may be built around them occur in the Inset of Figure 2. Management strategies for cassava and rice will certainly require mineral fertilizers and greater reliance upon nitrogen-fixing legumes, but additional research is needed before site-specific management practices are formulated (see Chapter 9). Conservation Agriculture shares many common features with ISFM, however, it was designed around large-scale mechanized agriculture and difficulties exist in applying its more restrictive provisions to small-scale agriculture (see Chapter 10). The larger-scale mining, processing and distribution of indigenous agro-minerals is an indispensable component of rural development in Africa and in some cases these materials are already being used as a replacement for more expensive, imported mineral fertilizers. Most agro-mineral deposits remain undeveloped or under-utilized, however, and coordinated efforts are required to design local, national and regional strategies for their better deployment (see Chapter 3). Again, substantial portions of this book address how to unlock the potential of technologies and materials belonging to this category. It is important to note that all of the technologies presented in Figure 2 have important roles within various farming systems in Africa and their refinement and adoption can contribute positively to site-specific application of ISFM.

Practical examples of ISFM

Two practical examples illustrate how ISFM works and can be improved upon. In West Africa, for example, farmers have adopted the micro-dose technology (Figure 2) that involves strategic application of small doses of fertilizer (e.g. 4 kg P ha^{-1}) and planting seed of improved crop varieties (Tabo *et al.* 2006). This rate of fertilizer application is only one-third of the recommended rates for the area. As a result of adoption, micro-dosed grain yields of millet and sorghum were increased by between 43 and 120% in pilot areas of Burkina Faso, Mali and Niger**.** The incomes of farmers using this practice improved by 52 to 134%. Small amounts of fertilizers 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 broadcast, result in more efficient nutrient uptake (Bationo and Buerkert 2001). In addition, the number of farmers using fertilizers following introduction increases. This success story has shown that adoption of micro-dose technology requires supportive and complementary innovation and market linkage. Production gains of millet and sorghum are obtained through the combination of micro-dosing in conjunction with water harvesting through the establishment of *zaï* pits (small, shallow water catchments) and the placement of manure, crop residues and composts into each pit (see Chapter 7). Accompanying soil conservation methods include half-moon furrows, stone bunds and tied ridges which conserve water and increase nutrient use efficiency. These measures extend the favorable conditions for soil infiltration after runoff, and the pits are particularly beneficial during more severe storms when the organic inputs absorb excess water and act as a subsequent moisture reservoir for the crops (Reij and Thiombiano 2003). This approach also restores crusted and compacted soils as well. This ISFM technology is being rapidly adjusted and adopted in the Sahel and has equal potential in other dryland farming areas.

Another example is drawn from the Guinea savanna of West Africa where improvement in the use of fertilizer nitrogen is achieved through the addition of organic inputs to soils. A straightforward series of managements was installed at several locations with sandy soils and low soil nitrogen and organic matter where 90 kg ha^{-1} of nitrogen was applied as urea fertilizer, farmer-available organic resources or an equal combination of both (Vanlauwe *et al.* 2001a). A basal addition of phosphorus fertilizer (30 kg P ha^{-1}) was included within all managements. Organic resources varied between sites depending upon their availability, were largely composed of tree leaves and twigs but also consisted of livestock and green manure at some locations.

Mineral N applied as urea at 90 kg N resulted in much higher yields than when the same amount of N was applied as a mixture of either surface mulched or incorporated organic inputs (Figure 3). When the two materials, mineral fertilizer and organic inputs (OI) were combined, however, strong positive interactions occurred, with maize yields comparable to those achieved from twice the level of mineral fertilization. This effect was mainly attributed to greater fertilizer use efficiency resulting from improved soil moisture conditions but contributions from mineralized nutrients other than N and P cannot be excluded. The nitrogen uptake from urea (15 to 43%) was much greater than that of the applied organics (8-10%), although the urea N alone provided relatively low agronomic use efficiency (13 kg grain per kg N). Improved moisture relations are also suggested by performance of maize in the surface mulched compared to the

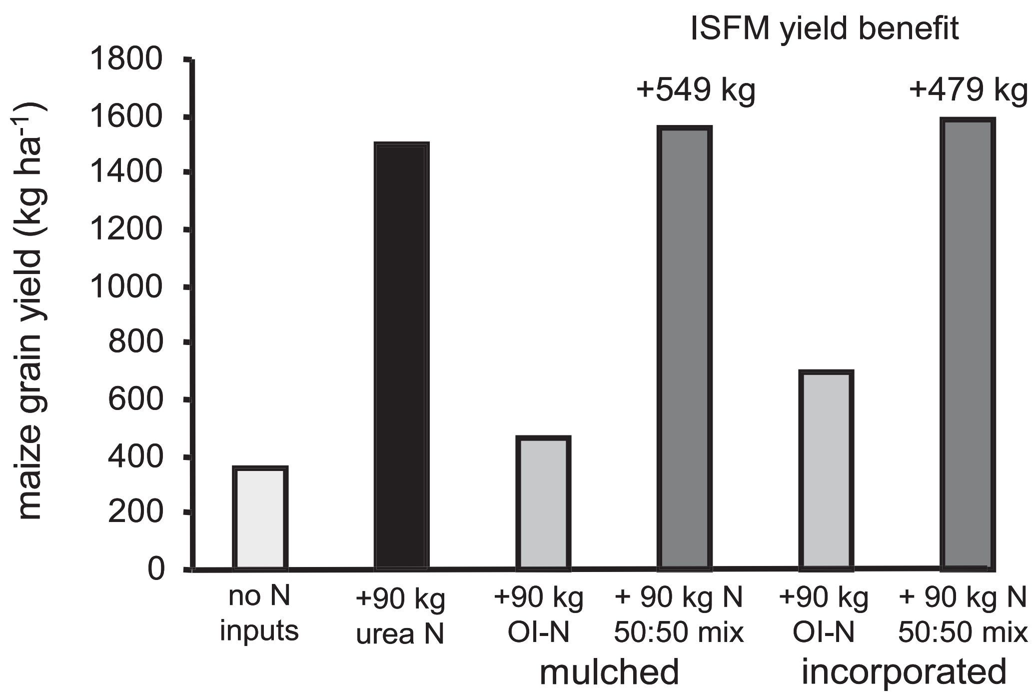

Figure 3. Interactions between mineral fertilizer and farmer-available organic inputs (OI) result in greater nutrient use efficiency (after Vanlauwe *et al.* 2001).

incorporated management (Figure 3). Overall, practicing ISFM required $56 less purchased inputs, involved several hours more field labor and resulted in an additional 514 kg maize grain ha^{-1} worth about $136. This example illustrates how crop yields may be improved through the application of relatively small amounts of mineral fertilizers combined with organic resources, supporting the feasibility of reducing fertilizer recommendations to smallhold practitioners of ISFM (see Chapters 2 & 12). While this example is drawn from experimental evidence in Benin, Cote D'Ivoire, Nigeria and Togo, any farmer may obtain the benefits of interactions between mineral fertilizers and organic inputs through the recovery of vegetation along farm boundaries and its application to croplands.

Realizing ISFM in Africa

The strong potential for achieving greater institutional involvement in soil fertility management, and extending needed technologies to more farmers greatly assists in 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 since the Structural Adjustment Programs made fertilizer 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 that assess soil management capabilities. Success must be expressed by impact indicators, such as yield increases, increased fertilizer sales, numbers of ISFM adopters and improved agronomic efficiency of applied nutrients. The ISFM technologies presented in Figure 2 are useful to formulate strategies for intervention and direct future investment (see Chapters 14 and 19).

One of the greatest strengths of ISFM is its ability to integrate local suitability, economic profitability, adoptability, and sustainability in developing improved land management recommendations. Constraints to improved targeting of soil fertility input recommendations in SSA include the use of over-generalized blanket recommendations that do not take into consideration farmers diverse socio-economic and biophysical conditions, misdirected 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 poor access to credit (see Chapters 2 & 12). If we assume for the moment that the degree and types of nutrient limitations are recognized and that technologies to ameliorate these conditions are identified, then the next important step is to devise strategies that facilitate the delivery of technologies to needy farmers. These technologies must be packaged into products and field operations that are recognizable, available and affordable to farm households (see Chapter 14). Policy interventions and marketing strategies can improve farmers' access to improved technologies but these will remain under-utilized if they appear over-priced or are perceived as risky (Chapter 19 and 20). The following points relate to the understanding and promotion of ISFM technologies among farmers at the grassroots level.

1. **Combine the strategic application of fertilizers and farmer-available organic resources in a manner that increases nutrient use efficiency and makes fertilizer use more profitable.** Fertilizer use must not be viewed as a standalone option for the management of soil fertility and the application rates recommended to farmers are too often beyond their means (see Chapter 2). Combining agro-minerals and organic resources also accelerates nutrient release (see Chapter 3). The elegance of ISFM is that it improves the efficiency of mineral fertilizer use through its combination with organic resources while producing longer-term beneficial environmental impacts (see Chapter 5). Organic resources vary in their nutrient contents and mineralization characteristics, and some even result in short-term immobilization of soil nutrients if not applied properly, so ISFM practitioners concerned with

the best use or processing of different quality materials require specialized knowledge (see Chapter 4).

2. **Optimize improved germplasm, water use efficiency and agronomic practices within new soil fertility management recommendations.** Studies have shown that introduction of a cash crop, such as cowpea, soybean or high value vegetables, into a cropping system can greatly boost the use of fertilizer by smallhold farmers and increase yields of succeeding food crops. The Oslo Conference on the African Green Revolution highlighted the role of crop diversification in optimizing farmer returns and as a principle of risk management to protect those returns. In addition, new crop varieties have been bred recently for drought tolerance, pest and diseases, and adaptation to low soil fertility and there is need to accelerate their adoption by smallhold farmers through ISFM practices.

3. **Keep recommendations and demonstrations simple.** On-farm trials and community demonstrations that are designed by agricultural scientists are too often overly complex, distracting farmers from their intended messages. ISFM is necessarily knowledge intensive and special attention must be placed upon capturing its findings into simplified field operations. Researchers who install large, replicated, randomized experiments in farmers' fields that are intended to host instructional field days risk confusing their clients. More information and better feedback is conveyed through simpler roadside field demonstrations and on-farm technology trials (see Chapters 11, 12 & 13).

4. **Work through existing organizations and networks.** Working with existing farmer associations and their umbrella networks to promote ISFM use offers several advantages. To a large extent, these farmer groups formed as a means of better accessing information and technologies in absence of adequate support from agricultural extension. These groups represent a ready-formed audience for technical messages, will collectively undertake independent technology evaluation and provide necessary feedback on the technologies (see Chapter 18). Larger organizations offer farm input supply services to their members, allowing them to purchase fertilizers in bulk or on credit, and pass savings to 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 ISFM products (see Chapters 6, 14 & 20).

5. **Adhere to market-led and value chain addition paradigms.** Improved profitability and access to market can motivate farmers to invest in new technology, particularly the integration of improved crop varieties and soil management options. This observation 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-adverse farmers unable or unwilling to invest in additional inputs (see Chapters 19 & 20). When working in the market-led mode, agronomists will no longer assume that additional produce resulting from technical adoption will necessarily benefit the household, nor will economists assume that demand created through market innovations will automatically be filled. Agricultural value chains place farm planning, field operations and produce marketing into a holistic context that permits the innovations necessary to improve farming enterprises, including farmer's investment in ISFM products, to be more readily identified and compared (Sanginga *et al.* 2007).