PRACTICE BRIEF Climate-smart agriculture

Integrated Soil Fertility Management:

Contributions of Framework and Practices to Climate-Smart Agriculture

Overview of practice

Integrated Soil Fertility Management is a set of management practices aimed at combining organic inputs, fertilizers, improved germplasm and local practices, to suit context specific needs. ISFM delivers productivity gains, increased resilience, and mitigation benefits.

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Dries Roobroeck, Piet Van Asten, Bashir Jama, Rebbie Harawa and Bernard Vanlauwe

KEY MESSAGES

1 ISFM is a set of practices related to cropping, fertilizers, organic resources and other amendments on smallholder farms to increase production and input use efficiency.

2 ISFM benefits food security and incomes, enhances yield stability in rain-fed systems, and reduces GHG emissions from soils and fertilizers making it of value to CSA.

CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS
AGRA Growing Africa's Agriculture
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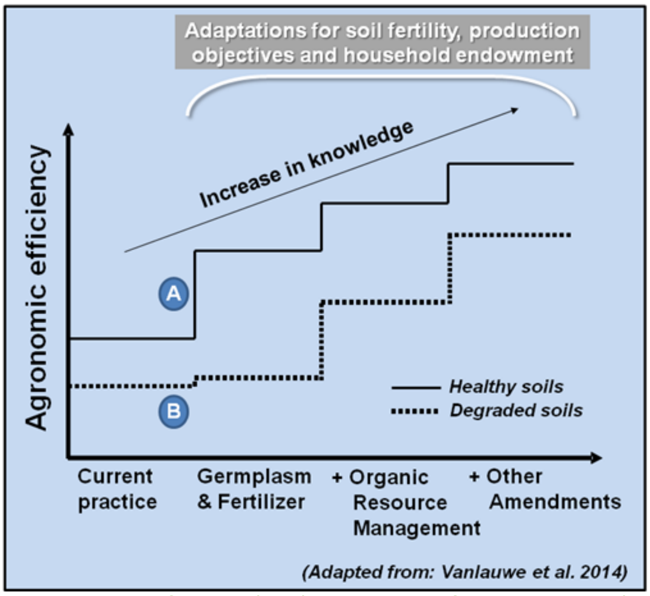
Overview of ISFM

More than thirty years of research on soil fertility and crop nutrition in the tropics has put forward strong evidence that fertilizer and organic inputs need to be addressed at the same time for successfully increasing agricultural production. Integrated Soil Fertility Management (ISFM) builds on this notion and was originally defined as*: 'A set of soil fertility management practices that necessarily include the use of fertilizer, organic inputs, and improved germplasm combined with the knowledge on how to adapt these practices to local conditions in aim of maximizing the agronomic use efficiency of the applied nutrients and improving crop productivity. ISFM seeks that all inputs are managed following sound agronomic practices'* (Vanlauwe et al., 2010). The primary indicator of agronomic efficiency here is the production of food per unit of input next to others like fodder and biomass. Figure 1 shows the ISFM framework with entry points of interventions on different farming practices and their expected benefits on the efficiency of crop production.

ISFM focuses in the first place on the germplasm of crops and use of inorganic fertilizers. The entry point on germplasm addresses selection of varieties and crop agronomy, such as spacing and planting date. Interventions on fertilizer use, in turn, target the formulation, placement, rate and timing of inorganic fertilizers. The second entry point of ISFM addresses organic resource management, such as inputs of crop residues, compost, manure or biochar to soils, as well as rotation or intercrop systems with N-fixing legumes and the use of plant-promoting micro-organisms. The third entry point of ISFM, other amendments, addresses other limitations to productivity such as soil acidity, micro-nutrient deficiency, erosion, soil compaction or pests and diseases.

Importantly, ISFM aligns practices with biophysical and socio-economic conditions at farm and plot level (Vanlauwe et al., 2014). The influence of soil fertility on benefits of ISFM practices is shown in Figure 1 with pathway A illustrating healthy soils where interventions on germplasm and fertilizer immediately cause agronomic efficiency to increase. Pathway B, on the other hand, illustrates degraded soils where organic resource management and other amendments are required before crop production can be brought to satisfactory level. The adaptation of practices dictated by ISFM warrants short- and long-term increases in agronomic efficiency under different farming conditions. The various features of the ISFM framework give a unique ability for decision-making on sustainable intensification strategies in smallholder farming systems.



(Adapted from: Vanlauwe et al. 2014)

FIGURE 1 ISFM framework with entry points of interventions and benefits on the efficiency of crop production according to soil health status

Benefits of ISFM

Research provides substantial evidence that practising ISFM can be of great benefit to production and livelihoods of farmers, the resilience of cropping systems to climatic change impacts, and mitigation of greenhouse gas (GHG) emissions derived from fertilizer or soil. Yet to date most studies have assessed impacts of ISFM on individual dimensions of Climate-Smart Agriculture (CSA). A 20 year trial in Nigeria by the International Institute of Tropical Agriculture (IITA) is one of the few that provides information about benefits of ISFM on all three dimensions of CSA (Vanlauwe et al., 2005).

The study consisted of a maize-cowpea rotation with reduced rates of Nitrogen Phosphorus Potassium (NPK) fertilizer to maize crops and input of N-rich organic residues. Figure 2 shows the relative changes in maize grain productivity, grain yield variability and soil C content in the ISFM system as compared to when applying no inputs or exclusively fertilizers (in brackets). The ISFM practice of combining fertilizers with organic inputs resulted in an average maize productivity of 2.8 tonnes per hectare whereas 1.7 ton ha-1 when exclusively fertilizers were used. Cowpea in turn yielded on average 1.2 ton ha-1 under the ISFM system whereas 0.7 ton ha-1 when no organic inputs were made.

The study further showed that the variability in maize grain yields between growing seasons was reduced tremendously when fertilizer and organic inputs were combined. In the ISFM system maize grain yields varied on average by 0.4 ton ha-1 per year whereas by 1.1 ton ha-1 yr-1 when fertilizers were used exclusively. The soil C content at the end of the 20-year trial period was almost double in the ISFM system than under other farming practices, illustrating that organic inputs mitigate soil CO2 emissions.

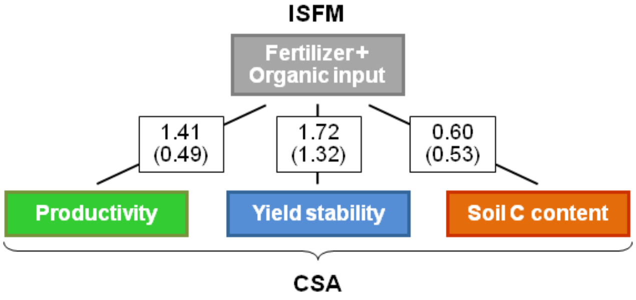


FIGURE 2 Benefits of ISFM for CSA illustrated by the relative changes in different indicators of a maize cropping system when combining fertilizers and organic inputs as compared to applying no inputs or exclusively fertilizers (in brackets).

Challenges to adoption of ISFM

Despite the significant benefits of ISFM for food security, household income and environmental protection, the adoption of practices by farmers is usually low and incomplete, especially in African smallholder systems.

The adoption of ISFM by farmers faces challenges related to: i) high transaction costs of farming inputs affecting access and price (Alene et al., 2008), ii) low awareness of the benefits of ISFM due to weak information transfer (Lambrecht et al., 2015), iii) credit facilities required for initial investment (Dercon & Krishnan, 1996), iv) aversion to risks associated with production and markets (Wik et al., 2004), v) availability and cost of labour (Roumasset & Lee, 2007), vi) land size and property rights (Goldesten & Udry, 2008), vii) social capital such as farmer associations, enabling institutions, and degree of trust, norms and values (Wossen et al., 2015), viii) diagnosis of soil fertility and long-range rainfall forecasts (Maro et al., 2013), and ix) availability of organic residues and competition by livestock (Rufino et al., 2011).

In order to scale out ISFM across African smallholder farming systems there is a need to strengthen research on and dissemination of practices at local, national and international levels. At the same time there is great need for high-resolution information on soil fertility to customize practices and maximize the benefits of ISFM, as well as decision-support tools that consider resource endowments and production objectives of farm households.

Where can ISFM be practiced?

The ISFM framework provides farming strategies for a large range of soil fertility conditions and cropping systems. Certain ISFM interventions have seen large scale adoption across sub-Saharan Africa: i) micro-dosing fertilizer in combination with manure management and water harvesting for cereal-legume systems in dry savannas such as the West African Sahel, and ii) targeted fertilizer application in combination with organic inputs for maize-legume intercropping and rotational systems in moist savannas, which cover about 615 000 km2 across sub-Saharan Africa. Recently ISFM systems have been developed for intensification of cassava (Vanlauwe et al., 2012), rice (Oikeh et al., 2010) and banana cropping in tropical agroecosystems (Wairegi et al., 2014). In slash-and-burn systems such as the Congo Basin, ISFM has great potential to address soil nutrient depletion and forest encroachment. Moreover, although the ISFM framework focuses on African smallholder farming, its practices offer solutions for other agricultural systems.

Contribution to CSA pillars

How does ISFM increase productivity, farm livelihoods and food security?

The first entry point of ISFM contributes to intensification of crop productivity through improved varieties and healthy seed systems that address pests and diseases, soil nutrient depletion and/or other biophysical limitations in cropping systems (Pypers et al., 2011; Shiferaw et al., 2008). ISFM enhances fertilizer use efficiency by promoting adoption of: i) incorporation of urea into the soil that reduces volatilization losses, ii) banding of fertilizers on soils that strongly absorb P that enhances the nutrient availability to plants, and iii) point placement of inorganic inputs in cereal crops that increases fertilizer recovery and reduces fertilizer requirements (Aune & Bationo, 2008). ISFM interventions on germplasm and fertilizer pay special attention to the price and access of inputs for farmers.

Input of stover residues in a millet cropping system as part of ISFM intervention on organic resource management –the second entry point

– has demonstrated increase of total biomass yield by more than seven times, while neutralizing acidity and reducing export of K, Ca and Mg (Bationo et al., 1996). Figure 3 shows the benefits of rotating local and improved climbing beans on the productivity and fertilizer efficiency of maize crops resulting from N fixation by legumes (Vanlauwe et al., 2012). The third entry point of ISFM addresses practices such as the application of lime, input of missing nutrients, deep tillage, and/or targeted use of pesticides or herbicides that contribute to tackling specific limitations that curtail crop production.

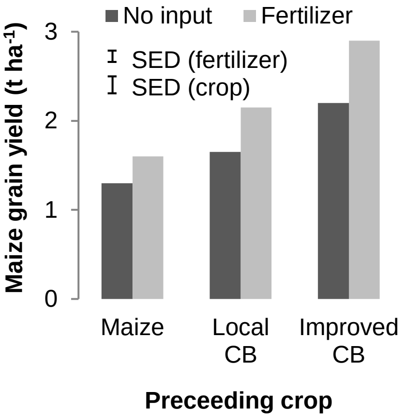


FIGURE 3 Benefits of legume rotation on maize grain productivity and fertilizer efficiency. CB = climbing beans. SED = standard error of difference (Adapted from: CIALCA, 2011)

A large-scale evaluation in moist savannas of Nigeria has demonstrated that an ISFM system consisting of maize and soybean rotations with strategic use of NPK fertilizers returned approximately 130 USD per hectare more than the conventional practice of maize mono-culture (Akinola, 2009). Greater net income of the ISFM system was attributed to lesser production costs and favourable market prices of soybean (Rusike et al., 1999). The respective increases in crop production and household income as a result of practising ISFM were further shown to significantly benefit the intake of calories and proteins by farmers.

How does ISFM help adapt to and increase resilience to climate change impacts?

ISFM strengthens the resilience of crop production to climate change impacts. Interventions in germplasm focus on tactical decisions such as the use of early maturing varieties or timing of planting in line with rainfall predictions. The first entry point of ISFM further addresses strategic fertilizer practices that increase differential fertilizer use efficiency under low and high rainfall. For instance, timing of N fertilizer inputs during periods with low water stress increases crop production under poor rainfall conditions (Piha, 1993).

Organic resource management practices as part of the second ISFM entry point provide important benefits for the water use efficiency of crops by enhancing water retention and reducing evaporation. Figure 4 shows the long-term trends in total biomass productivity of millet crops when combining fertilizer and input of stover residues as opposed to the exclusive use of fertilizers (Bationo, 2008). This study illustrates how organic resource management practices support greater crop productivity under low and high rainfall owed to improved water and fertilizer use efficiency. Leaving stover on the land during annual fallow periods traps windblown soil. Crop diversification through mixing of annual and perennial crops also contributes to addressing climate impacts on agricultural production and food security (Lin, 2011).

The third entry point of ISFM strengthens the resilience of cropping systems by disseminating practices such as tied ridging, contour ridging, stone row alignment and growing crops in zaï pits or basins that enhance water harvesting and prevent soil erosion (Nicol et al., 2015). By combining a range of practices and aligning them with the assets and objectives of farmers, the ISFM framework provides effective solutions for protecting crops from climate variability in the short and long term. Intensification of crop productivity by practising ISFM enhances the availability of fodder for rearing livestock which offers an important security to bridge periods of food scarcity thus strengthening the resilience of smallholder farming households to climate change impacts.

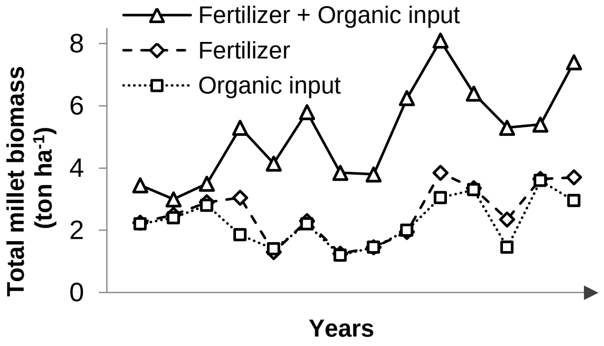


FIGURE 4 Long term millet production under different management practices. (Adapted from: Bationo et al. 1996)

How does ISFM mitigate greenhouse gas emissions?

Practising ISFM mitigates GHG emissions by reducing losses of N fertilizers and soil C to the atmosphere. The recovery of N fertilizers by crops and retention of nitrate in soils are two of the most important indicators of N2O emissions in tropical farming systems (Hickman, 2011). Fertilizer micro-dosing where inputs are applied to individual planting pockets, as per the first entry point of ISFM, increases the recovery of N by crops tremendously (Sime & Aune, 2014; Kisinyo et al., 2015). ISFM interventions on organic inputs further contribute to enhancing fertilizer uptake of crops as well as its retention in soils due to processes that balance nutrient immobilization and release (Chivenge et al., 2009). A study on fertilizer responses in grain-legume rotations systems demonstrated that N benefits from greengram, pigeonpea or cowpea were equal to a fertilizer N input of 16, 19 and 25 kg N per hectare (Marandu et al., 2010). Substituting an input of 10 kg urea-N per hectare directly mitigates emissions of 20 kg CO2 equivalent for manufacturing the fertilizer (Bernstein et al., 2007). A reduction of fertilizer inputs by 10 kg N ha-1 is by default accounted to lessen N2O emissions from soils in equivalence of 60 kg CO2-eq per hectare (Smith et al., 1997).

ISFM practices related to organic inputs benefit the conservation and restoration of soil C stocks thereby mitigating CO2 emissions from soils. For example, inputs of stover residues by maize farmers reduce soil C losses by 10 to 20 tonnes of C per hectare over a period of 20 years (Zingore et al., 2005). Figure 5 shows how practising ISFM conserves soil C stocks compared to when no inputs or exclusively fertilizers are applied. ISFM further aligns organic input practices with soil type, climatic conditions and availability of resources at farm and plot level to address differences in the effectiveness of practices at different sites.

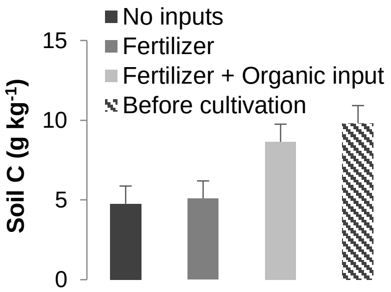


FIGURE 5 Effect of different maize farming practices on soil C content 20 years after cultivation.(Adapted from: Vanlauwe et al. 2005)

Costs and funding for ISFM

The financing of ISFM practices relies largely on the capital and assets of individual farmer households. Improved varieties and mineral fertilizers require a significant investment with quality germplasm costing between 20 and 100 USD per hectare per season for annual crops. Fertilizer inputs of ISFM systems range from 30 to 300 kg, costing between 50 to 300 USD per hectare per season. ISFM interventions on organic input and other practices increase labour costs by 5 to 20% in annual cropping systems.

The higher net return for farmers when practising ISFM contributes to relieving capital constraints for investments in agriculture. At the same time, various measures can be taken along the value chain to address bottlenecks in the financing of ISFM: i) reward agro-dealers, credit agencies and other actors who provide ISFM services, ii) provide loans to intermediary traders with in-built strategies to avoid default, iii) offer kick-start subsidy programs that address seasonal credit and cash constraints, iv) enable duty-free importation of fertilizers and agro-minerals, and v) create tax benefits for the multiplication of legume seed and production of organic inputs.

It is estimated that a five-year program to scale up ISFM practices on fertilizer and organic resource management in Sahelian drylands would need an initial investment of approximately 40 million USD (Vanlauwe). Doing the same for ISFM practices in grain-legume systems of moist savannas in western, eastern and southern Africa would require an initial investment of about 60 million USD. Basic research and pilot projects for developing ISFM practices in smallholder cassava and rice systems will respectively cost 4 and 5 million USD over a period of five years. Initiatives to bring ISFM to scale depend on funds from national governments, international development programs, private investors and charitable donors.

Metrics for CSA performance of ISFM

The contributions of ISFM practices to sustainable intensification and food security can be monitored and evaluated through regular measurement of indicators of crop production, agronomic efficiency and soil nutrient balances at farm and landscape level. Benefits of practising ISFM on income of farming households can be assessed by farm-gate analysis of value-cost ratios and net return. Monitoring of volumes, operations and services on different markets can be used to assess impacts of ISFM on value chains. The contributions of ISFM practices to improving the livelihood of farmers can be evaluated using indicators of nutrition, health and gender at household and societal levels. Benefits of practising ISFM on the resilience of crop production to climate change can be assessed by indicators related to the stability of production, water use efficiency and soil conservation at farm and landscape levels. Evaluating the impact of ISFM on GHG emissions from soils can be done through metrics addressing input and agronomic efficiency of fertilizers, as well as soil C stocks at farm and landscape level in combination with default emission factors.

Interaction with other CSA practices

ISFM practices on fertilizer use are embedded on the principles of '4R' stewardship (right source, right rate, right time, right place) that forms the basis of site-specific nutrient management. The ISFM framework has informed the CSA practice of coffee-banana intercropping in combination with fertilizer inputs to counteract nutrient depletion. Furthermore, ISFM interventions on organic resource management related to input of crop residues and crop rotation are shared with Conservation Agriculture.

Case study: "Enabling adoption of ISFM practices in Malawi"

Since 2012 the Clinton Development Initiative (CDI) and Alliance for a Green Revolution in Africa (AGRA) have been running a program to scale up ISFM in Malawi[34]. The system combines maize-soybean rotations with strategic use of inorganic NPK fertilizers and inoculation of legume with elite Rhizobium strains. An out-grower contractual model is used in which commercial farms act as anchors for enabling better access of smallholder farmers to information, seed, fertilizer, credit and output markets (Figure 6). The anchor farms provide training of master farmers on ISFM practices and help in farmer organization. Three years into the program a monitoring and evaluation has recorded the following achievements:

- Maize grain yields have increased from an average of 2.0 to 4.6 tonnes per hectare, and soybean yields from 0.7 to 1.3 tonnes per hectare.
- More than 18,000 smallholder farmers have adopted the ISFM practice with about 50% of the beneficiaries being women.
- A total of 9,906 hectares of land have been converted to the ISFM system.
- Training of more than 30,000 farmers on ISFM practices of whom nearly 50% are women.

Important transformations were observed at the farm level such as building of permanent homes and purchase of solar panels. Some farmers stopped growing tobacco cash crops in favour of soybeans due to the better farm gate prices of legume commodities. Adopters of ISFM appreciate the benefits to soil fertility and crop productivity.

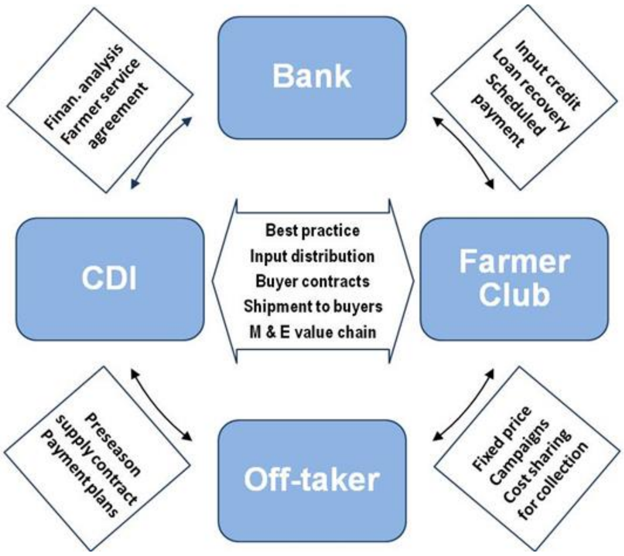


FIGURE 6 Framework of interactions between farmer clubs with anchor farmers, the Clinton Development Initiative (CDI), produce off-takers and banking partners

An important lesson from the program is the need for close partnerships with lending institutions to avoid inefficient borrowing schemes and to improve loan repayment policies. The high rate of adoption achieved by the program illustrates that the anchor farm model has great potential for scaling up ISFM practices because it brings together the different actors in the value chain. Some public financing is needed to support and accelerate activities such as farmer organization, extension and outreach. This is where most of AGRA's financial support has been invested.

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Authors

Dries Roobroeck, International Institute of Tropical Agriculture, Nairobi, Kenya

Piet van Asten, International Institute of Tropical Agriculture, Kampala, Uganda

Bashir Jama, Alliance for a Green Revolution in Africa, Accra, Ghana

Rebbie Harawa, Alliance for a Green Revolution in Africa, Nairobi, Kenya

Vanlauwe Bernard, International Institute of Tropical Agriculture, Nairobi, Kenya

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