

Integrated Soil Fertility Management:

Contributions of Framework and Practices to Climate-Smart Agriculture



Field trials with ISFM-based maize and soybean rotations at 6 weeks after planting. The taller crops have received fertilizers micro-dosing while the shorter crops have not.

Overview of practice

Integrated Soil Fertility Management combines agronomic practices relating to crops, mineral fertilizers, organic inputs and other amendments that are tailored for different cropping systems, soil fertility status and socioeconomic profiles.



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KEY MESSAGE

- 1** ISFM interventions are built on the premises of increasing productivity and profitability for smallholder farming systems. Practising ISFM has further shown to enhance the stability of yields under adverse rainfall oscillations. Lastly, important reductions in greenhouse gas emissions can be made through ISFM owing to greater uptake of N fertilizers by crops and soil C sequestration.
- 2** A number of ISFM practices have been successfully brought to scale, each of which leading to major improvements of livelihoods and land use. What's more, these programs illustrated that access of farmers to quality inputs, information, off-takers and credit is of huge importance to achieve effective adoption of ISFM.



RESEARCH PROGRAM ON
Climate Change,
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Food Security



Overview of ISFM

More than thirty years of research on soil fertility, crop nutrition and socioeconomics in smallholder farming systems of sub-Saharan Africa has shown that combined interventions on fertilizer and organic inputs are prerequisite for achieving sustainable intensification. Integrated Soil Fertility Management (ISFM) builds on this notion and is 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). Any of the interventions is required to increase the efficiency and profitability of food production as related to use of land, labour, fertilizer inputs and financial investments.

The first entry point of ISFM is focusing on the agronomy of crops and inorganic fertilizers. Interventions on germplasm involve the selection of varieties, spacing and planting date. Interventions on fertilizer use respectively target the formulation, placement, rate and timing of inorganic nutrient inputs. The second entry point of ISFM targets interventions on organic resource management, including the return of crop residues, manure, compost and other types of organic wastes, next to rotation or intercropping with legumes and use of plant growth promoting micro-organisms. The third and last entry point of ISFM deals with any other amendments that may be needed to lift limitations to productivity such as soil acidity, micronutrient deficiency, erosion, soil compaction or pests and diseases.

By definition, ISFM prescribes that interventions have to be aligned with prevalent biophysical and socio-economic conditions at farm and plot level (Vanlauwe et al. 2014). Figure 1 gives a conceptual illustration of the responses in crop production and input use efficiency to different interventions for soils with contrasting fertility status. Pathway A on the graph represents healthy soils where interventions on germplasm and fertilizer immediately cause the agronomic efficiency to increase. Pathway B, on the other hand, serves as example for degraded soils where organic resource management and other amendments or practices are required before production can be intensified. By adapting practices to the myriad of farming conditions

ISFM warrants short and long term increases in production of food crops. The comprehensive features of the ISFM framework make it of great use for various actors ranging from farmers, extension agents and policy makers.

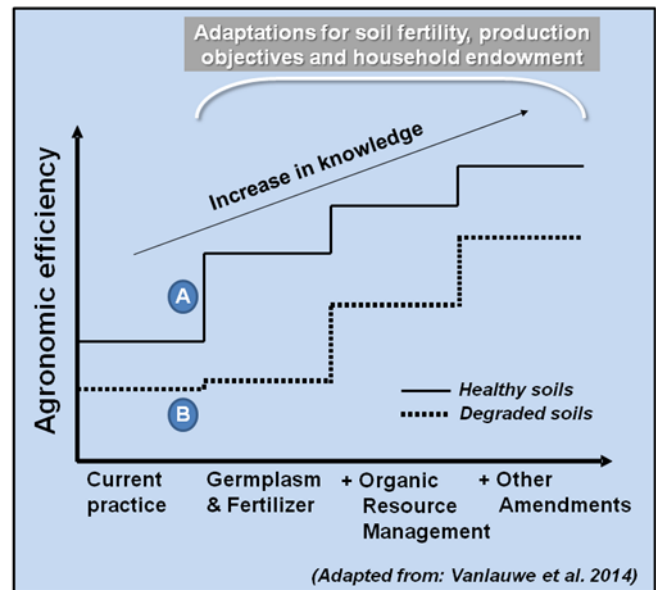


FIGURE 1 ISFM framework with entry points of interventions and benefits on the efficiency of crop production according to soil health status

Benefits of ISFM

Numerous ISFM-based practices have been studied and demonstrated significant benefits on productivity, profitability, resilience, and/or greenhouse gas (GHG) emissions as targeted in Climate-Smart Agriculture (CSA). Most studies however didn't assess the contributions of ISFM practices for all of the CSA dimensions at the same time. A 20-year study on the research farm of IITA* in south western Nigeria by Vanlauwe et al. (2005) is one of the few having the information needed for a comprehensive assessment of the benefits from ISFM for CSA.

The top panel in Figure 2 presents the average maize grain productivity that was achieved under different input of N-rich organic residues and/or nitrogen, phosphorus and potassium (NPK) fertilizers. When NPK fertilizers and organic inputs were combined maize grain yields were between 0.26 and 2.4 ton ha⁻¹ greater as compared to when the same inputs were applied separately. In the ISFM system maize grain yields remained well above 2 ton ha⁻¹ after 10 years of cultivation and with a reduced rate of N input whereas the maize productivity dropped to 1 ton ha⁻¹ in trials where exclusively fertilizers were used. Rotated cowpea crops, on the other hand, produced on average 1.2 ton ha⁻¹ in the ISFM system as

*International Institute of Tropical Agriculture

compared to 0.7 ton ha⁻¹ when fertilizers or organic inputs were applied separately. These results attest that practising ISFM generates sustainable increases of crop productivity and input use efficiency which ultimately benefit the livelihood of farmers.

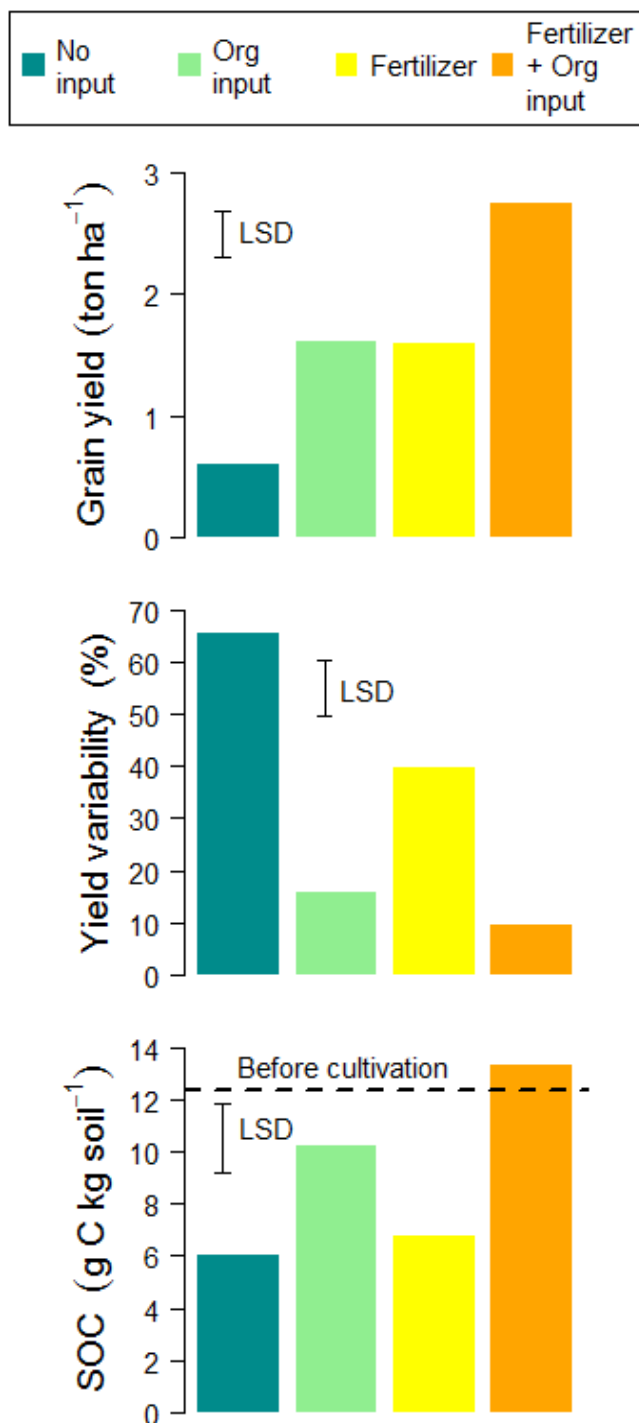


FIGURE 2 Productivity of maize grain, variability in maize yield in response to climate impacts and soil organic carbon (SOC) status after 20 years of cultivation for different input practices illustrating contributions of practising ISFM to the three dimensions of CSA. LSD = least significant difference. [Adapted from: Vanlauwe et al. 2005]

The middle panel in Figure 2 displays the proportional variability in maize grain yield that is ascribed to climate oscillations as calculated from the residuals of the regression in maize grain yields across all 20 growing seasons. In trials where fertilizers and organic inputs were combined the production of maize crops were significantly less impacted by oscillations in weather conditions as compared to when exclusively fertilizers were applied. Especially the organic inputs showed to play an important role in reducing the climate sensitivity of maize crops. The higher productivity and yield stability achieved in the ISFM system prove that the practices significantly strengthen the resilience of crops to climate change impacts. The bottom panel of Figure 2 summarizes the content of organic C in the top 5cm of soil at the end of the 20 year trials for different input practices. The dashed line in the graph depicts the soil organic C (SOC) content at the onset of the trials. When fertilizers and organic inputs were combined the SOC content was significantly greater as compared to when exclusively fertilizers or organic were applied. These results demonstrate that ISFM practices mitigate CO₂ emissions from soils whereby making important contributions to diminishing the GHG footprint of agricultural systems.

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 most important factors curtailing adoption are related to: i) high transaction costs of input and produce trading (Alene et al. 2008), ii) low awareness and common disbeliefs about the benefits of soil fertility management (Lambrecht et al. 2015), iii) shortage of credit facilities for making initial investments (Dercon & Krishnan 1996), iv) aversion to risks surrounding the profitability of inputs (Wik et al. 2004), v) cost and availability of labour (Roumasset & Lee 2007), vi) land size and property rights (Goldesten & Udry 2008), vii) weak social networks and pervasive distrust (Wossen et al. 2015), viii) lack of information about soil fertility and rainfall forecasts (Maro et al. 2013), and ix) scarcity of organic residues and competition for residues with 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 practised?

The ISFM framework provides farming strategies for a large range of soil fertility conditions and cropping systems. Over the last decade several ISFM interventions have been brought to scale across various agro-ecological zones, in specific: i) micro-dosing of fertilizers combined with manure management and water harvesting for cereal-legume systems in dry savannas of the West African Sahel, and ii) targeted fertilizer application combined with organic inputs for maize-legume intercropping and rotational systems in moist savannas of Eastern and Southern African. In the last couple of years efforts have been made to tailor-make ISFM practices for crops like cassava (Vanlauwe et al. 2012), rice (Oikeh et al. 2010) and banana (Wairegi et al. 2014) that are grown throughout the Tropics. Because ISFM practices are designed to curb soil nutrient depletion they have great potential for reducing deforestation in slash-and-burn systems across the larger Congo Basin. As explained in this brief many of the ISFM principles are shared with other sustainable agricultural practices and thereby applicable to different cropping systems, geographies, climates and economies.

Contribution to CSA pillars

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

Each entry point of ISFM is making different contributions to increasing the productivity and profitability of agricultural systems. In the first place ISFM is focussing on the management of crops what respectively involves the timing and spacing of planting up to dissemination of elite varieties and healthy seed systems. Such interventions on germplasm are very important for pushing up yield potentials as well as combating pests and diseases (Pypers et al. 2011; Shiferaw et al. 2008). On top of this, ISFM embeds different fertilizer practices that have been proven to enhance nutrient uptake and productivity of crops such as micro-dosing, deep placement, banding, and harmonizing of inputs with rainfall and nutrient demands (Aune & Bationo 2008). Throughout all of the ISFM

interventions on germplasm and fertilizers a lot of attention is being paid to the cost and profitability of external inputs as well as related market risks.

A study of 10 years on millet cropping at the research station of ICRISAT* in the semi-arid belt of Niger has demonstrated that mulching of stover residues along with input of NPK fertilizers generated a total biomass productivity that was between 2 and 7 times larger than when the same inputs were applied separately (Bationo et al. 1996). It was further found that the ISFM practice gave rise to major improvements of soil acidity, nutrient export and water productivity. Figure 3, in turn, is summarizing the benefits of common bean rotations, NPK fertilizers and farmyard manure on the productivity of maize crops (Vanlauwe et al. 2012). The third entry point of ISFM respectively involves practices to tackle further limitations to crop production, for instance liming to address soil acidity, input of sulphur, calcium, zinc and other nutrients to counteract deficiencies, deep tillage to resolve soil compaction, and use of pesticides or herbicides to combat severe insect and weed infestations.

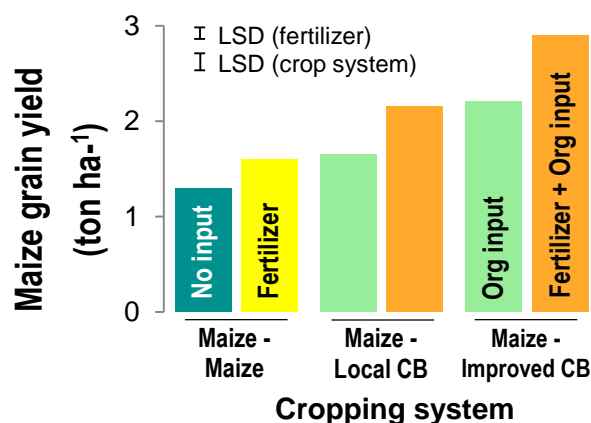


FIGURE 3 Maize productivity for different cropping systems and fertilizer practices. Legend is given inside the bars. CB = climbing beans. LSD = least significant difference. [Adapted from: Vanlauwe et al. 2012]

Monitoring of a large-scale pilot program across the moist savannas in Nigeria calculated that an ISFM system of maize and soybean rotations along with strategic use of N and P fertilizers gave a net return of 539 USD ha⁻¹ as compared to 422 USD ha⁻¹ for maize mono-cropping with similar rates of fertilizer inputs (Akinola 2009). The greater profitability of the ISFM system is attributed to lower production costs and better retail prices for soybean. It was further shown that the gains in food production and income from practising ISFM significantly benefited the intake of calories and proteins by farmers.

*International Crops Research Institute for the Semi-Arid Tropics

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

Interventions under each of the three ISFM entry points make different contributions to strengthening the resilience of crop production to climate impacts. Practices on germplasm and crops respectively involve tactical decisions such as use of early maturing and drought tolerant varieties, or harmonizing of planting time with rainfall predictions. At the same time, the first ISFM entry point is disseminating strategic fertilizer practices that minimize the risk of input loss to adverse weather. Such interventions for instance exist of interspersing N fertilizer inputs across periods when soils have optimal water content what significantly benefits N uptake by crops under a large range of climates (Piha 1993).

The ISFM principle of combining organic inputs and fertilizers makes important contributions to reducing the sensitivity of crop production to climate impacts. Figure 4 gives the proportional variability in total millet production that was exhibited under different input practices as calculated from the residuals of the regression in yields over the 10 growing seasons from the study at ICIRISAT mentioned in the previous section (Bationo et al. 1995). In trials where fertilizers and organic inputs were combined production of millet crops was significantly less impacted by oscillations in weather conditions as compared to when exclusively fertilizers or organic inputs were applied. Next to this, diversifying crops through intercropping and rotation as promoted by ISFM is decreasing the risk of crop failure on food security (Lin 2011).

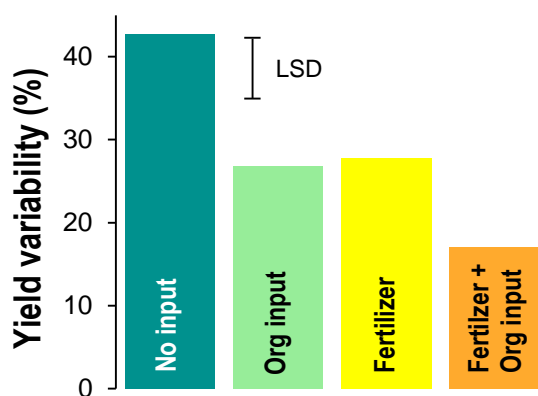


FIGURE 4 Variability in total millet production in response to climate impacts under different input practices. LSD = least significant difference. [Adapted from: Bationo et al. 1995]

The third entry point of ISFM contributes to increasing the climate resilience of agricultural systems by disseminating practices that enhance water harvesting and prevent soil

erosion such as tied ridging, contour ridging, stone row alignment and growing crops in zaï pits or basins (Nicol et al. 2015). By including a variety of practices and aligning them with the assets and objectives of farmers, the ISFM framework is able to provide effective solutions for reducing the sensitivity of crop production to climate impacts over the short and long term. Lastly, the increases in crop productivity achieved by practising ISFM provide more fodder for rearing livestock which helps bridging periods of food scarcity and hence strengthens the resilience of farming households to climate change impacts (Weindl et al. 2015).

How does ISFM mitigate greenhouse gas emissions?

Practising ISFM offers different benefits to mitigate GHG emissions from agricultural systems. Fertilizer micro-dosing, disseminated under the first ISFM entry point, has been shown to significantly increase the recovery of N by crops (Sime & Aune 2014; Kisinyo et al. 2015). Greater recovery of N fertilizers by crops, and retention of nitrate in soils, are two of the most important indicators for reduced emissions of nitrogen oxides in tropical farming systems (Hickman 2011). Combining fertilizers and organic inputs also enhances fertilizer uptake and retention by balancing immobilization and release processes (Chivenge et al. 2009). A study in moist savannas of Tanzania demonstrated that maize crops retrieved between 16 and 25 kg N ha⁻¹ from rotated greengram, pigeonpea and cowpea crops (Marandu et al. 2010). Substituting a urea input of 10 kg N ha⁻¹ cuts emission from manufacturing by 20 kg CO₂ (Bernstein et al. 2007). Based on default emission factors decreasing N fertilizer inputs by 10 kg ha⁻¹ is expected to mitigate N₂O emissions from soils by 60 kg CO₂ equivalent ha⁻¹ (Smith et al. 1997).

Combining fertilizers and organic inputs benefits the conservation and build-up of soil C stocks, hence mitigating CO₂ emissions from soils. A study in Zimbabwe demonstrated that the practice of incorporating stover from maize crops reduced soil C losses by 10 to 20 tonnes of C per hectare over a period of 20 years (Zingore et al. 2005). Figure 5 presents results from 10 year trials across a range of soil types in Kenya showing that the soil organic C content was between 0.2 and 0.5% higher when fertilizers and manure were combined as compared to when exclusively fertilizers were used. Input of stover conversely didn't sequester as much C in all of the soil types.

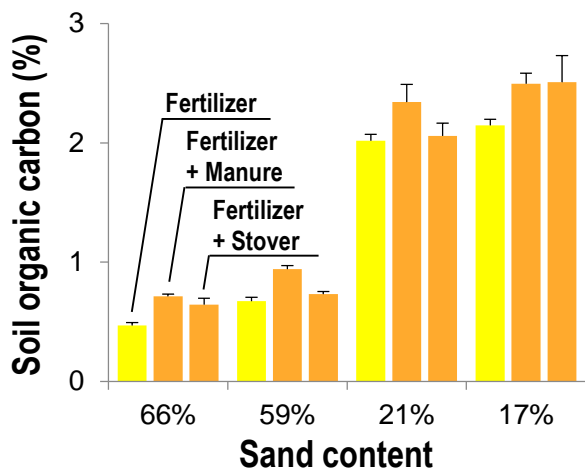


FIGURE 5 Soil organic C content after 10 years of cultivation with different input practices across sites with varying soil texture. Error bars are standard error. [Adapted from: Vanlauwe, Unpublished data]

By aligning organic resource management with soil type, fertility level, climatic conditions and availability of resources the ISFM framework seeks to reach sustainable solutions for crop production at landscape farm and plot level.

Costs and funding for ISFM

The financing of ISFM practices by farmer households relies largely on their individual capital, assets and availability of labour. 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 of ISFM practices is benefiting further investments of farmers into agricultural technologies. At the same time, various measures can be taken along the value chain to address bottlenecks in the financing of ISFM: i) support business incentives from 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) in state 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 2013). Doing the same for ISFM practices in grain-legume systems of moist savannah 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

There is a range of approaches and indicators that can be used for evaluating contributions of ISFM practices to each dimension of CSA at different operational scales. On the one hand, long-term and/or multi-locational trials have to be made that compare different practices for gathering quantitative and mechanistic information about how ISFM is benefiting food security, resilience and GHG mitigation. Such in-depth studies are however restricted to plot and farm level because they call for relatively intensive management and monitoring. Benefits of ISFM on crop productivity can respectively be captured through direct measurements or allometric estimation. The profitability of ISFM systems can be analysed through farm-gate analysis of value-cost ratios and net returns. Next to that, indicators of nutrition, health and gender have to be used for mapping changes in livelihood of farmers brought about by ISFM practices. The resilience of crop production to climate impacts and benefits of ISFM, in turn, are reflected by the stability of production and water use efficiency. Mitigation of GHG emissions as a result of ISFM practices can be assessed directly through gas flux measurements or indirectly using information about fertilizer usage and the efficiency of crop uptake next to measurement of soil C stocks in combination with emission factors. Lastly, data from plot and farm level studies can be made into process-based models to enable large scale assessments and scenario analysis of the benefits of ISFM by monitoring the area of land under specific practices.

Interaction with other CSA practices

ISFM practices on fertilizer use are embedded on the principles of '4R' stewardship (right

source, right rate, right time and 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. The system combines maize-soybean rotations with strategic use of inorganic NPK fertilizers and inoculation of legumes with N-fixing bacteria. 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 ton ha⁻¹, and soybean yields from 0.7 to 1.3 ton ha⁻¹
- 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

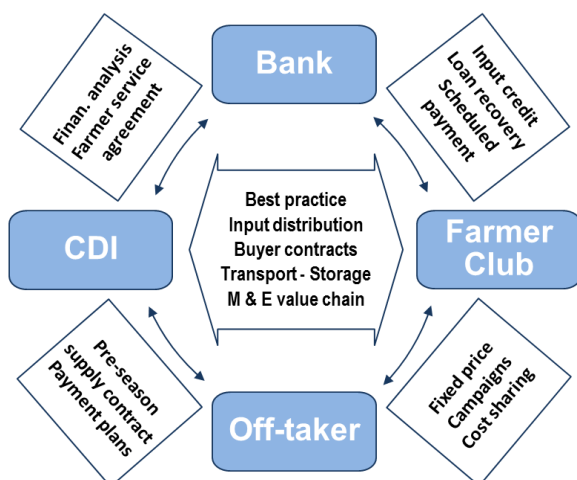


FIGURE 6 Framework of interactions between farmer clubs with anchor farmers, the Clinton Development Initiative (CDI), produce off-takers and banking partners

One of the most important lessons learnt from the program is the need for enabling partnerships with credit providers to avoid inefficient borrowing schemes and improve loan repayment policies. The high rate of adoption that was achieved by the program illustrates the anchor farm model has a great potential for scaling up ISFM practices owed it bringing together the different actors in the value chain. Some public financing is needed to support and accelerate activities like farmer organization, extension and outreach. This is where most of AGRA’s financial support has been strategically invested.

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