Closing Crop Yield Gaps in sub-Saharan Africa through Integrated Soil Fertility Management

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Background

In sub-Saharan Africa (SSA), the yields of the main cereal crops have stagnated at less than 25% of potentially attainable yields while the per capita food production has continued to decrease over the last 5 decades. In many parts of SSA cereal crop yields are estimated < 1.5 ton ha^{-1} while the actual potential is more than 5 tons/ha. The low yields are largely attributable low use of organic and mineral nutrient resources, which has also resulted in negative nutrient balances (Smaling et al., 1993; Jager et al., 2001). Low crop yield trends also hold for grain legumes whose average yields have stagnated at about 0.7 ton ha^{-1} against a potential of up to 3 tons ha^{-1}. These low crop yields have led to increased food insecurity, poverty and malnutrition in most parts of SSA, which are likely to worsen as the population continues to grow. Insufficient nutrient application happens because inorganic fertilizers are often too expensive for most of the farmers, whilst organic resources are available in limited quantities. However, there is potential reducing the yield gap of most common cereal and legume crops through use of integrated soil fertility management (ISFM) technologies. ISFM has been 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, aiming at maximizing agronomic use efficiency of the applied nutrients and improving crop productivity (Vanlauwe et al., 2010). ISFM technologies can potentially produce better results when used in the context of 4R nutrient management stewardship. 4R nutrient management stewardship requires implementation of best management practices (BMPs) that optimize the efficiency of nutrient use based on the right source, rate, time and place of application. Selection of appropriate BMPs vary by location, and those chosen for a given farm are dependent on local soil and climatic conditions, crop, management conditions and other site specific factors. In the African context, successful implementation of such technologies requires involvement of all the key stakeholders in the food production value chain (farmer, extension agents, policy makers and market actors). This is the strategy IPNI and other key partners such as government departments, NARS, AGRA, and CGIAR centres are adopting to promote ISFM within the context of 4R nutrient management stewardship as affordable and more realistic option for boosting crop yields in SSA.

Approaches for closing the yield gaps with ISFM

Effective ISFM approaches are based on adapting crop and nutrient management practices to local soil, climatic and socio-economic conditions. The performance of different ISFM technologies are location specific and that significant and sustainable adoption of appropriate technologies is a function of farmers' access to appropriate inputs (fertilizer and seeds), access to appropriate information and availability of favourable output markets. This implies that successful promotion of ISFM should factor in the entire production value chain. Cases of how this strategy has succeeded in boosting crop yields and household incomes have been reported in southern Tanzania, western Kenya, central Kenya (caption 1) northern Ghana and Mali where through AGRA supported projects implemented by various National Agricultural Research Systems (NARS). The main strategies used to disseminate ISFM information included field days and radio programs, and improving farmers' access to quality seeds and fertilizers through support of agro-dealer networks and facilitating access to affordable credits and remunerative markets for surplus produce. As a result, farmers uptake of demonstrated ISFM technologies increased by over 100%, while yields of maize, sorghum, pigeon peas and other crops under demonstration increased by between 100 and 300%. Similar approaches and success stories have been reported in eastern, western and southern Africa by teams of scientists from Wageningen University, CIAT, IITA and other partners while working under the auspices of N2Africa Program.

Caption: ISFM performance on maize and legume in central Kenya

Impact of ISFM Intervention

Case 1: *Impact of cereal-legume intercropping on maize and grain legume yield in western Kenya*

The Kenya Agricultural Research Institute (KARI) established 136 maize-legume intercrop demos in western Kenya in 2010 through support of AGRA. The demos show-cased intercrops of maize with common beans, soybeans and groundnuts in Emuhaya, Kakamega, Mumias and Gem Districts. Phosphorus fertilizer was applied at a rate of 20 kg P ha^{-1} at planting while nitrogen fertilizer was applied as top-dress at a rate of 60 kg N ha^{-1}. The conventional practice was establishment of intercrop of maize and legumes with no fertilizer. Across the four districts, improved cereal-legume intercrop technologies increased maize yield by between 2.8 and 3.3 tons/ ha (300%) (Figure 1). In addition, farmers harvested between 1.0 and 1.3 tons of legume grains in comparison to the baseline of 0.7 tons/ha. The maize and legume grain produced this way were sufficient to meet anual food requirements of farming households and leave a surplus valued at >1,200 US$ per year.

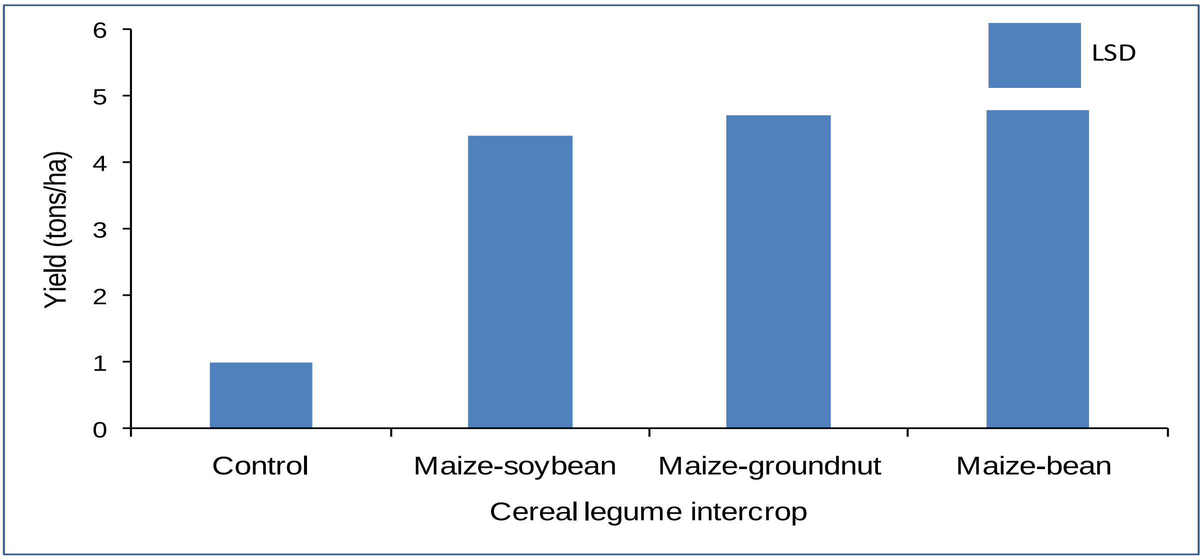

Figure 1: Effect of maize-legume intercropping on maize yield over three consecutive seasons in the farmers' fields

Case 2: ***Impact of nutrient combination on yields of maize and soybean in western Uganda***

In 2010, the Millenium Village Project (MVP) in partnership with Isingiro District Local Government launched on-farm demonstrations show-casing good agronomic practices with various levels of manure and fertilizer combinations for boosting soybean and maize yield in western Uganda. A total of 200 mother demos of maize-soybean rotations were established and monitored for 4 seasons. Average crop yields varied with treatment and seasons. For both maize and soybeans the farmers practice yielded significantly lower grains than the plots that were applied with various combinations of organic and inorganic fertilizers in all the seasons. Maize crop yields for plots with organic and inorganic fertilizers ranged between 1.9 and 4.0 tons/ha which was between 50 and 200% higher than farmer practice. Of all the interventions, maize yields were highest with the 25 Kg P + 79 kg N in each of the two maize cropping seasons. Across the two soybean cropping seasons, average soybean yields from the improved technology plots ranged between 1.2 and 1.8 tons/ha; this was between 50%-100% higher yields than the farmer practice (Figure 2). Contrary to the huge drought related decline (about 50%) in maize yield in 2011, the decline in soybean yield as a function of the same drought was less than 20%. These differences in impacts of drought on maize and soybean reflects a need for crop diversification especially in rain fed agriculture as a way of ensuring food security even when the rainfall is in adequate.

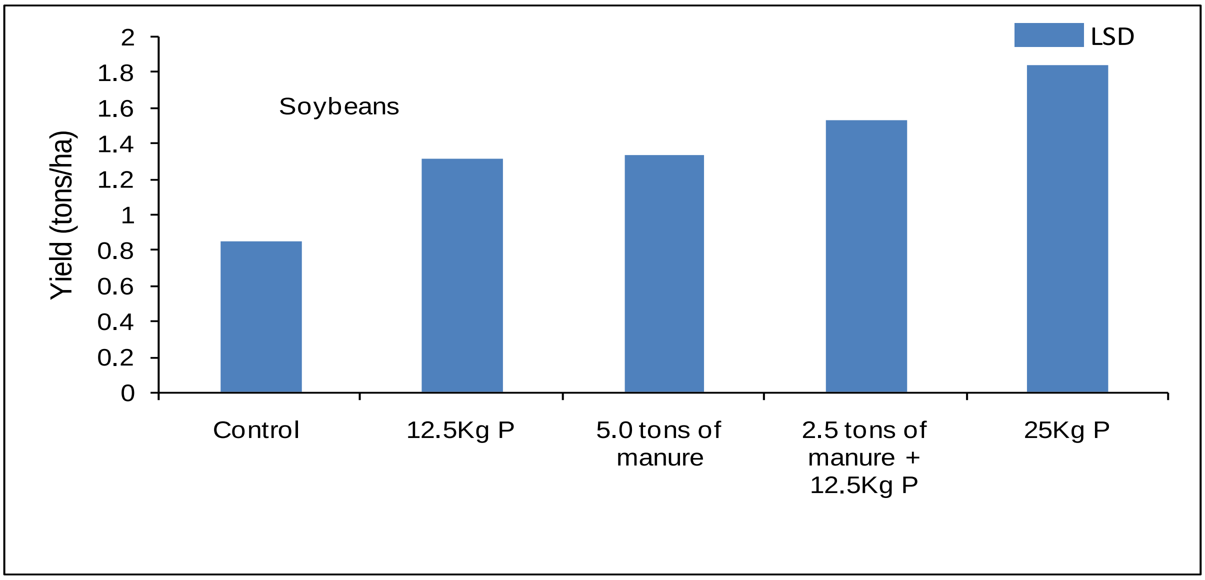

Figure 2: Effects of varying nutrient combinations on soybean production in western Uganda for the period 2010-2012

Case 3: ***ISFM in the context of soil fertility gradient in Zimbabwe***

In simulation exercise carried out by teams from Wageningen and CIAT to assess the impact of ISFM at village scale (Rufino et al., 2010), information from ISFM experiments, soil types, livestock feeding and manure management was combined and used to design a strategy to restore the fertility of unproductive soils and boost crop yields in north-east Zimbabwe. In a baseline scenario which represented current management with small amounts of NP fertilizers (between 5–50 kg N ha^{-1} y^{-1} and 2–17 kg P ha-^{1} y^{-1}), the village reached food self-sufficiency for its 66 households (about 330 people) only in years of good rainfall. In an alternative scenario using principles of ISFM, small rates of fertilizers (30 kg N and 15 kg P ha^{-1} y^{-1}) were applied to the home fields and crop residues were incorporated. Mid- and outfields received a full NP fertilizer rate (60 kg N and 30 kg P ha^{-1} y^{-1}), and all of the available manure (2–4 t ha^{-1} y^{-1}). This continuous addition of small amounts of manure (2–4 t ha^{-1} y^{-1}) and fertilizers increased maize yields in the mid- and outfields from 0–0.5 to 1–3 t ha^{-1}. At the village scale, this represented more than double the amount of grain needed for food self-sufficiency plus extra feed for the livestock of the village.

Case 4: ***Effect of fertilization and inoculation on soybean yields***

Soybean trials were conducted in Kenya, Uganda, Tanzania, Rwanda and Malawi for 3 consecutive years between 2009 and 2012. The trials evaluated for the effect of basal P application and inoculation on soybean yields. The treatments were: Farmer practice (no inputs), 20 kg P ha^{-1} and 20 kg P ha^{-1} + inoculation. The results suggested that planting soybeans with P fertilizer without inoculation could increase soybean yields by approximately 100% relative to the farmer practice.

By moving a step further to inoculate the seeds that were planted with basal P application, soybean yields increased further by up to 70% above the yields for P without inoculation. Other studies have shown that legume yields can even be boosted further by supplying limited doses of N at the establishment stage. This is crucial for meeting N demand prior to nodule development. Following full nodulation, the effect of externally supplied N on the performance of N fixing legume is limited.

Economic impact of ISFM

Economic analysis carried out on data from 10 projects from across eastern, southern and western Africa yielded benefit-cost ratio values of more than 2 (Table 1). Benefit-cost ratio is a good indicator of financial attractiveness of an intervention (CIMMYT, 1988; Kaizzi et al., 2012). Opportunity cost for resource poor people with little access to money is often 100% of the actual value due to other high priority uses of available funds and other investment opportunities (CIMMYT, 1988). Therefore, benefit-cost ratio of more than 2 is required for an investment to be attractive in SSA (CIMMYT, 1988; Kaizzi et al., 2012). A benefit-cost ratio of 1 implies that the returns are equal to the inputs and therefore there is no livelihood improvement from investment, while a value of less than 1 implies losses of human, financial and capital resources. This implies that the ISFM technologies demonstrated by the aforementioned projects were financially attractive.

Table 1: Effect of ISFM on performance of different crops and financial attractiveness

Country	ISFM Intervention	Crop	Yield Change (tons/ha)	*Benefit-Cost ratio
Kenya (Western)	Maize-Legume Intercrop	Maize	+4 (300%)	1.8-2.2
Uganda (Isingiro)	Improved seeds + fertilizer + crop rotation	Soybean	+1 (100%)	2.0-2.3
Tanzania (SHT)	Improved seeds + fertilizer + Maize-legume rotation	Maize	+4.5 (300%)	2.1-2.5
Ghana	Maize -legume rotations + improved seeds + fertilizer	Soybean	+1.5 (150%)	2.3-2.7

*Benefit cost ratio of more than 2 shows financially attractive technologies

Integrating of ISFM principles in farming systems

Comprehensive work on how ISFM technologies can be integrated into the African farming systems has been done over the last two decades by groups of scientists from CIAT, IITA, ICRISAT, IPNI, IFDC, ICRAF and NARS. The results show that the ISFM principles should be applied within the existing farming systems (Vanlauwe and Zingore, 2011). Two examples clearly illustrate the integration of ISFM principles in existing cropping systems in SSA: (i) dual purpose grain legumes-maize rotations with P fertilizer targeted at legume phase and N fertilizer targeted at the cereal phase in moist savannah agro-ecozones (Sanginga et al 2003) and in Western Kenya (AGRA, 2012), and (ii) micro-dose fertilizer applications in legume-sorghum or legume-millet rotations with retention of crop residues and water harvesting techniques in semi-arid agro-ecozones (Bationo et al.,1998). As for the grain legume-maize rotations, application of appropriate amounts of mainly P to the legume phase ensures good grain and biomass production, the latter in turn benefiting a subsequent maize crop and thus reducing the need for external N fertilizer. As for the micro-dose technology, spot application of appropriate amounts of fertilizer to widely spaced crops like sorghum or millet substantially enhances its use efficiency with further enhancements obtained when combined with physical soil management practices aimed at water harvesting

Challenges and policy requirements for increased adoption of ISFM

Although a lot of evidence exist in regards to the potential of ISFM to boost crop yields, the uptake of ISFM technologies has remained low. An essential condition for adoption of ISFM is access to quality farm inputs, access to appropriate information and produce markets. Quality assurance for the fertilizer and seeds that farmers acquire from the markets is very crucial. Most countries have laws to curtail adulteration of inputs but the level of enforcement differs with countries. Farmer organizations like UNFFE in Uganda and KENFAP in Kenya have been established to improve farmer access to inputs and to verify quality of inputs in the market.

To a large extent, ISFM adoption is driven by availability and access to appropriate inputs (Vanlauwe and Zingore, 2011) within accessible distances. In SSA, sustained input availability has worked well in some parts of Kenya, Uganda, Tanzania and Malawi especially when there are workable policies to support private-public partnership relationships through public support to establishment and management of private agro-dealer networks. Access to inputs cannot work in these countries, where over 50% of farmers are classified as extremely poor unless innovative input financing mechanisms are established to stabilize the input supply and demand. Over the last two decades the input prices have more than doubled while the employment rates and incomes have declined. The majority of smallholder farmers can therefore not afford sufficient inputs. There is a need for intervention by states through support of mechanisms for lowering input costs such as smart subsidies and tax relief on agricultural inputs. Further, policies that can boost availability of affordable financing such as low interest rates on credits advanced to farmers and support for establishment of revolving funds will improve farmer access of inputs and use of ISFM.

In addition to issues related to inputs, most farmers lack technical capacity to implement ISFM technologies independently. They therefore require effective extension services to understand which technologies work under different conditions. At present, in most African countries the ratio of extension staff to farmers is about 1:1000 against the recommended ratio of 1:400. But even the ability of available extension staff to offer quality extension services is often constrained by various capacity challenges. Policies that could boost the capacity and quality of extension services through improved recruitment rates, in service training and provision of tools for extension are crucial. Within this extension package it is also possible to make use of innovative extension approaches like mobile phones and radio programs.

Finally, farmers will not sustainably invest in yield boosting technologies when market for surplus is not available. Good markets serve to provide resources that can be used for purchasing inputs and pay back for the initial input credits. Often good markets for surplus produce in SSA are not accessible by farmers. As a result, it is estimated that approximately 30% of food produced in SSA is wasted before reaching the market (Lynd and Wood, 2011).. To boost crop yield with ISFM, there is a need for public investment in the areas of access to market through provision of information on availability of remunerative markets, market research, promotion of value addition and reduction of market barriers.

Conclusion

Integrated soil fertility management technologies are capable of closing or at least reducing the yield gaps for most crops that are grown in SSA. The challenges that need to be dealt with for this technology to succeed in closing these yield gaps across many countries and regions include: ensuring access to information on what works where and improving access to input and output markets.

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