Sustainable Intensification of Maize-Legume based Systems: Lessons from SIMLESA

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Introduction

The "Green Revolution" (GR), a distinctly South Asian phenomenon, remains an epochal event in the history of agricultural development and achievement on the global stage. The success of the GR was made possible by the massive public sector investments in agricultural research and development (R&D) and support for credit, irrigation and input acquisition by farmers. It provides valuable lessons on how to achieve scaled productivity growth in agriculture and positive impact on the welfare of generations of people.

Sustainable intensification has become a major guiding principle in agricultural development. Sustainable agricultural intensification (SAI) can be defined as the production of higher amounts of agricultural output with only modest or no increases in the amount of resources required to do so while also avoiding some of the negative environmental impacts (Royal Society, 2009; Godfray et al., 2010). This focus on SAI is partly motivated by the accumulated evidence showing that historical successes in agricultural productivity growth from the GR in South Asia also generated negative environmental externalities, for example, groundwater depletion, soil-fertility degradation, and chemical runoff, as well as weak-outcomes for social and gender equity (e.g., Pingali and Rosegrant (1994); Pingali (2012). The nascent maize revolution in many parts of Asia today can rightly hope to not only trace the path of the past epoch of the wheat and rice based GR of the 1960s and 70s, but very crucially, also avoid some of the associated pitfalls. This paper will present evidence to show that the multiple goals of agricultural development (high-productivity, resource-conservation and food- security) can be simultaneously achieved. Based on a program-focused on SAI of maize-legume systems in East- and Southern Africa, we provide some emerging lessons that can guide the new maize revolution in Asia to achieve the multiple goals of food, feed, nutrition and environmental security.

Sustainable intensification of maize-based systems in East and Southern Africa: Program background

Improving the productivity and food security of maize-based farming systems using conservation agriculture (CA- based sustainable intensification strategies, is the main goal of Sustainable Intensification of Maize-Legume cropping systems for food security in Eastern and Southern Africa (SIMLESA) program. The program is funded by the Australian Centre for International Agricultural Research (ACIAR). It is managed by the International Maize and Wheat Improvement Center (CIMMYT) and implemented by national agricultural research systems in five partner countries – Ethiopia, Kenya, Tanzania, Malawi and Mozambique, with support from CIMMYT, Australian Universities of Queensland and Murdoch, Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), International Crops Research Institute for the Semi-Arid-Tropics (ICRISAT) and the Agricultural Research Center (ARC)-South Africa. Lessons from these five core countries are also implemented in spill-over countries – Botswana, Rwanda, South Sudan, and Uganda.

The program targets benefits to 650,000 farm-households by 2023 by increasing yield at least 30 percent and reducing the risk of crop failure (due to climatic changes and variability) by 30 percent. This will be achieved using five-interrelated objectives (see Figure 1) implemented under system integration, innovation platforms and impact orientation approaches.

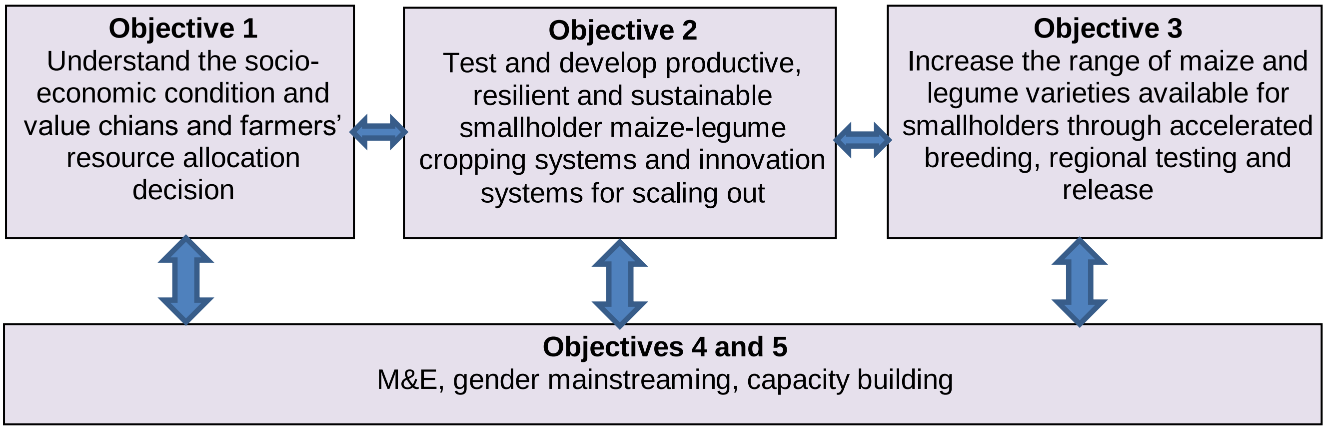

Figure 1. Objectives of SIMESA

Major findings and lessons

During the first phase of the program (2010 to2014) substantial knowledge and evidence has been generated and lessons learned on the performance of CA-based sustainable-intensification strategies and innovation platforms.

Conservation agriculture can improve crop productivity and incomes

Conservation agriculture (CA) is potentially a means of addressing the weaknesses of the GR without sacrificing productivity in the medium- or long-term. CA, in its strictest definition, is a crop- and resource-management system characterized by the principles of minimal soil disturbance and constant soil-cover through the use of crop residues and strategic crop rotations both in space and time (FAO, 2012). More generally, CA is a broad-suite of practices that, when applied in part, or in combination, can improve the sustainability of natural resource-use while increasing yields and/or reducing the costs of production (Hobbs, Sayre and Gupta 2008). Under both a strict-definition and a more general interpretation, CA has captured the imagination of agronomists, economists, and development practitioners, prospectively becoming a central pillar for sustainable intensification in smallholder production systems in developing countries. There is a growing body of agronomic evidence in support of CA's net-positive effects on the sustainability of intensive-smallholder systems. Understanding how and under what condition CA is working is one of the main tasks of the program. Over the last four-years, the program demonstrated various CA-based experiments in different villages to thousands of farmers.

Three-years of experimental data and results from Ethiopia, showed that the average grain maize yield can increase by about 5 percent to 18 percent under CA-based interventions, compared with the farmers' practice (Table 1). In Mozambique, the CA practices led to increased grain yields ranging between 13 percent to 33 percent (Table 2), while in Malawi, the increase in maize yield ranged from 3 percent to 21 percent in the mid-altitude agro-ecology, and 8 percent to 40 percent in lowland agro-ecology (Table 3). The highest increase in maize yield was achieved when CA was combined with maize-legume rotations.

Table 1. Average maize yield and CA options, kg/ha, Ethiopia

Sole maize with CA	3020
Maize-bean Intercropping with CA	2720
Maize-legume rotation with CA	3040
Farmers practice	2580

Source: Presentations at the country and regional annual review and planning meetings

Table 2. Mean maize yields (kg/ha) in mid-altitude agro-ecology of Malawi between 2010 and 2013.

Cropping system	**Maize yield (kg/ha)**
Conventional farmers practice	3743^{a}
CA Dibble maize sole no herbicide	3867^{ab}
CA Dibble maize sole + herbicide	4303^{bc}
CA Dibble maize-soya rotation	4524^{c}

Note: Means in the same column followed by different letters are significantly different at p<0.05

Table 3. Mean maize yields s in Sussundenga and Gorongosa districts of Mozambique- 2010 and 2013

Cropping system	**Yield (kg/ha)**
Conventional. Farmer practice	1487^{a}
CA basins maize/cowpea intercrop	1686^{ab}
CA jab planter maize sole maize	1734^{bc}
CA basins maize sole	1812^{bc}
CA basins maize-cowpea rotation	1972^{c}

Note: Means in the same column followed by different letters are significantly different at p<0.05

The experimental results are consistent with the results obtained using large-household-survey-data in Ethiopia and Malawi. In Ethiopia, the empirical evidence (based on the counter-factual framework of intervention evaluation), using 900 farm households, showed that the adoption of CA-options increased net-maize income by about 9 percent to 35 percent compared with non-adoption of these options (Figure 1). This increases further, to 26 percent to 137 percent when CA practices were adopted in combination with complementary inputs (e.g., improved maize varieties). The highest income was obtained when both CA practices were combined with use of improved maize varieties (Figure 1).

A similar pattern emerged in Malawi, using a survey that sampled 1,925 farm-households. The analysis showed that the performance of CA options significantly-improved when they combined CA with improved maize varieties (Figure 2).

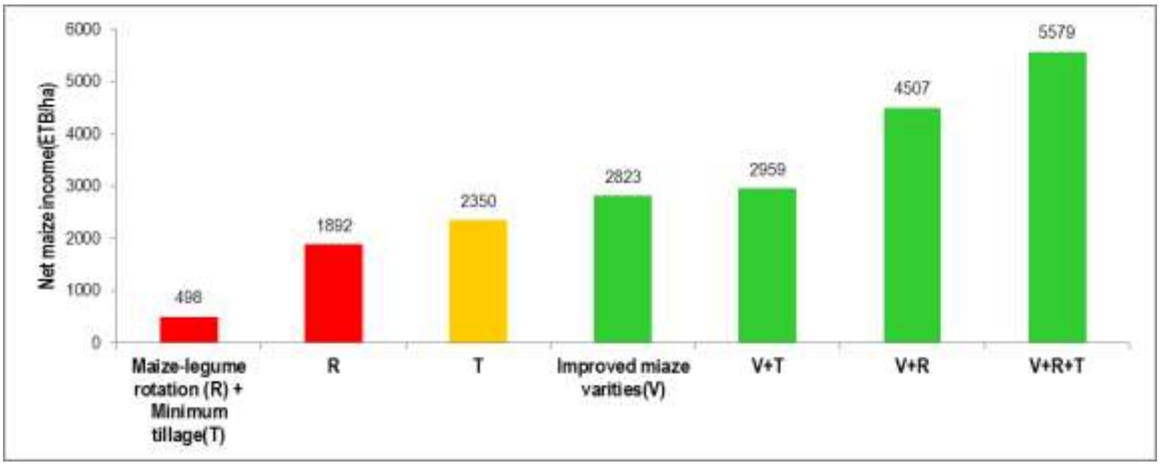

Figure 1. Impact of CA on maize income in Ethiopia

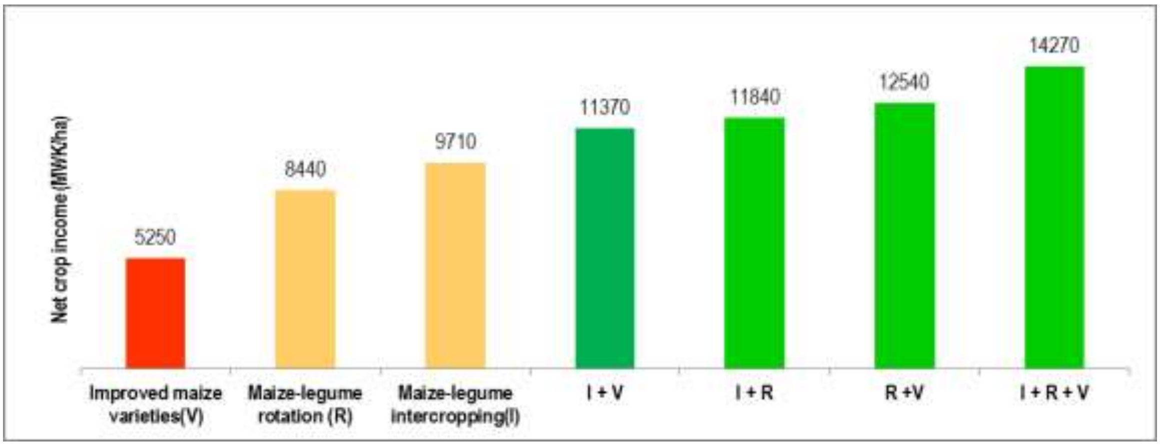

Figure 2. Impact of CA on maize income in Malawi

Conservation agriculture improves ecosystem services

One of the major reasons CA is advocated, is because of its positive impact on ecosystem services. Maize – legume intercropping increased the total nitrogen in the preceding year compared with planting only maize (Figure 3). CA options also increased water-use efficiency overtime (Figure 3-4). In Mozambique and Ethiopia, the highest-water use efficiency is achieved when CA options are combined with maize-legume intercropping system. The CA options further reduced soil degradation by 34 percent to 65 percent (Table 4).

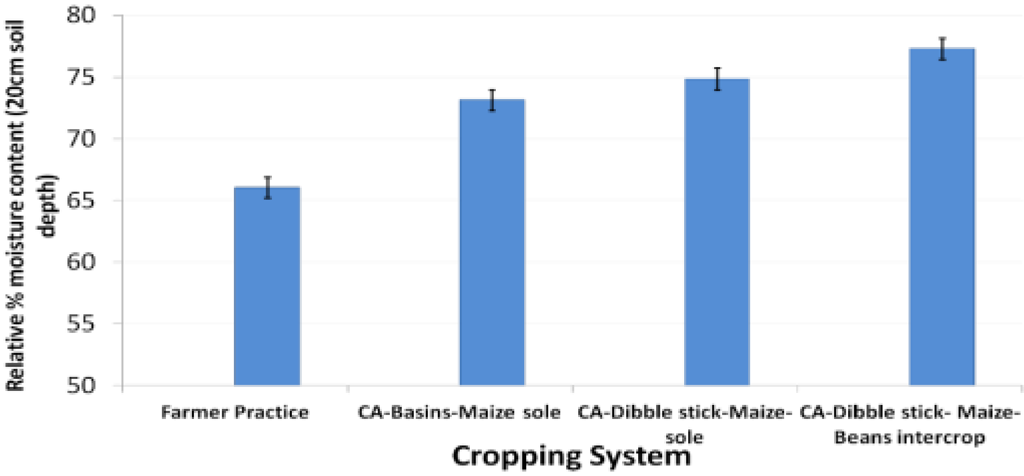

Figure 3. Soil moisture effects of CA-based cropping systems in Mozambique, Angonia district, 2012

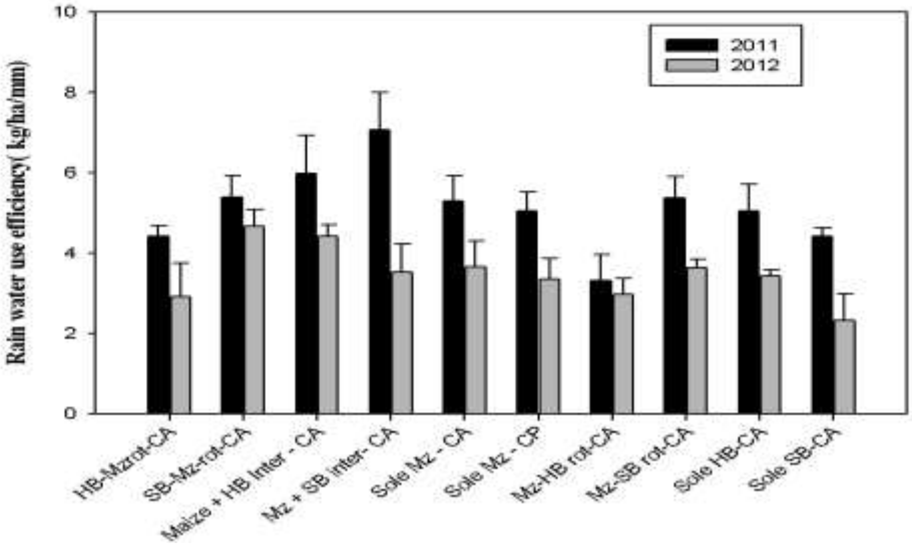

Figure 4. Effects of CA-based cropping systems on rain water use efficiency in Ethiopia.

Table 4. CA options and soil loss in maize plots in 2011/12, Ethiopia

Treatments	**Soil loss (ton/ha)**
Sole maize under farmers' practice	5.21
Maize-haricot bean intercropping under conservation agriculture(CA)	1.80
Sole maize + mulch+ CA	1.95
Maize-haricot bean intercropping with farmers practice	2.71
Maize-haricot intercropping under farmers practice	3.44

Source: Degfa (2013)

Empirical results using large-household survey data in Malawi and Ethiopia revealed adoption of CA options either by keeping constant or reducing the use of agro-chemicals. In Malawi, the average reduction in pesticide application ranges from 0.4 liters to 0.6 liters per acre while the average N-fertilizer use was reduced by 3kg/acre to 6 kg/acre for those who did not participate in the fertilizer subsidy program (CIMMYT Mimeo, 2013). Subsidy beneficiaries use more nitrogen (N) fertilizer when adopting CA options. This result highlights the confounding effect of subsidies on other land management practices and an additional consideration for policy makers when forming and maintaining the implementation of fertilizer subsidy programs. In Ethiopia, the use of CA options reduced N-fertilizer use or at least kept it constant without significantly-affecting income from maize. The highest N-fertilizer reduction (20 kg N/ha) was achieved in CA options that combined legume-maize rotation, minimum tillage and local maize varieties. However, minimum tillage increased the use of chemicals but when used in combination with legume-maize rotations, it had an insignificant impact on chemical use (Teklewold et al. 2013).

Conservation agriculture options play a role of risk management strategies

Reducing production risk is co-equal to increasing productivity in smallholder farmers' setting. In the absence of formal-risk-management strategies, the CA option can serve as risk-management strategies by diversifying the production system. Empirical analysis using the aforementioned household survey data in Malawi, has shown that CA options have the capacity to improve farmers' resilience by reducing the probability of crop failure (downside risk) and cost of risk (Kassie et al. forthcoming). Higher-risk-reduction was achieved when CA options are used jointly (Figure 5).

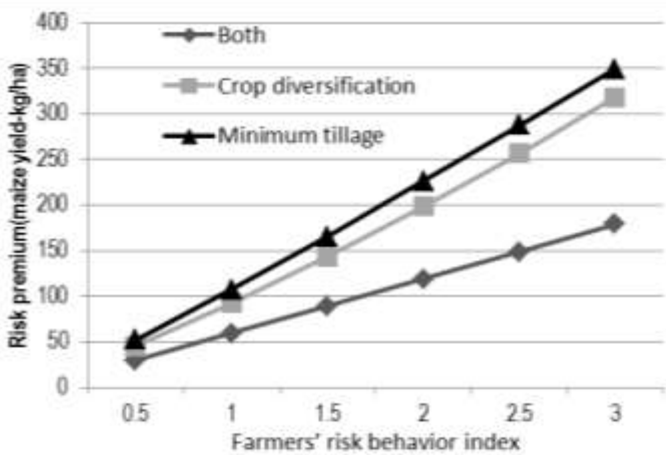

Figure 5. CA options impact on production risk
Note: crop diversification refers to maize legume intercropping and rotations.

Lessons from the maize variety selection and release under SIMLESA

When the SIMLESA program was designed by African and Australian scientists, a more diverse range of maize varieties became available to smallholders. This was identified as one of the key program outputs. Farmer-participatory variety selection (PVS) was selected as a novel approach to fast-track the release of varieties needed for maize-legume cropping system intensification. Accordingly, 396 on-farm PVS trials were conducted among SIMLESA target communities in all the five countries from 2010 to2013. Released and pre-release of maize varieties generated by various CIMMYT projects, such as Drought Tolerant Maize for Africa (DTMA), Water Efficient Maize for Africa (WEMA) and others, were used for the PVS. Thereafter, maize varieties that met the requirement of the agro-ecologies of the targeted farming systems and farmer preferences, were fast-tracked for release and seed production scaled. Subsequently, the varieties were integrated in conservation agriculture-based maize-legume cropping systems and promoted as part of a more productive, sustainable and risk-resilient livelihood system. Uptake and adoption of the newly- released varieties were facilitated through the establishment of widespread demonstration plots. Farmers' field days based on the demonstration plots, were organized in which government officials, community leaders, seed company representatives, research and extension staff participated. Different channels of information dissemination such as brochures, fact sheets, radio and television programs were used to promote the new varieties. In addition to farmer participation in PVS, various field days were organized to expose farmers and relevant partners to the new maize varieties and production technologies under evaluation. In Ethiopia alone, at total of 4,750 participants attended the maize-variety-promotion field days over the past four years. Among these, at least 25 percent of the participants were women. Novel approaches, such as purposeful inclusion of female-headed households and women in male-headed households, were used to involve women in field demonstrations and to participate in the field days. These efforts have enhanced participating women's skills and awareness, and developed the confidence of farmers to take up the new technologies.

Most of the varieties released with the SIMLESA program support were adopted by seed growers of the respective countries. Well-designed seed production planning systems called "seed roadmaps" were developed for selected varieties released previously and during the period of SIMLESA program for seed production scaling up. Accordingly, more than 23 tons of breeder seeds (Table 5) were produced by various research centers in the target countries and supplied to seed growers to stimulate seed production and dissemination systems. Seed companies were encouraged to produce required quantifies of basic- and certified- seeds to meet the requirements. For instance, during the 2012 to 2013 cropping season, a private seed company from Mozambique, Semente Perifeita, selected a hybrid released by the Mozambican Institute of Agricultural Research (IIAM), SP1, and produced 300 tons of certified seed. Foundation seeds used to produce the certified seed has been produced and supplied by IIAM. Over the past four-years, a total of 340 tons of basic seeds and 4,056 tons of certified seeds were produced and disseminated in the region with the involvement of 25 seeds companies. The quantity of certified seed produced under this program can plant an estimated area of 150,000 ha of land.

Table 5. Different classes of seed produced (tons) by each of SIMLESA program implementing countries

Countries	Breeder	Foundation	Certified
Ethiopia	5.7	277.0	3114.7
Kenya	4.3	11.3	23.4
Malawi	7.2	20.0	230.0
Mozambique	4.9	18.1	318.0
Tanzania	1.1	13.8	370.0
Total	23.2	340.2	4056.1

The main lesson from the varietal work under SIMLESA, is that *building on existing work and networks to create multi-stakeholder coalitions* in seed systems can have significant results and can hasten the movement of varieties through the pipeline and reduce the time from research station to laboratory to commercialization and farmer use. Without these institutional collaborations and the synergies involved, the time lag would be long with the attendant-productivity-losses and reduced capacity of the maize systems to keep pace with economic and environmental changes.

Capacity building

When SIMLESA was launched in 2010, the need for building sustainable agricultural research and development capacity was acknowledged right from the start. Investment in the training of the next generation of African agricultural scientists was a priority given the decline in capacity building during the past 10 to15 years.

As a result, more than 3,000 agricultural scientists from Eastern and Southern Africa have been trained and mentored in a variety of areas of the maize and legume production value chain. Furthermore, SIMLESA has succeeded in engaging more than 40,000 farmers, almost half of whom are women, through farmer-field days and exchange programs. While the SIMLESA capacity development efforts cover a variety of areas, a greater part of these focus on: CA principles and technologies; sustainable- and climate-smart agricultural productions systems; socio-economic dynamics of households and modelling; agricultural production system simulations; risk management; and gender mainstreaming and monitoring and evaluation in agricultural development.

SIMLESA's capacity-building initiatives target researchers, extension practitioners, farmers and other actors along the maize and legumes value chain. Other notable beneficiaries of the program's capacity-building measures have included young people who have been supported for postgraduate training and mentorship.

Innovation systems

Training on innovation platforms was conducted and practical support on their establishment and use was rendered in Kenya, Ethiopia, Malawi, Tanzania, Rwanda and Mozambique. The SIMLESA program has, as a result, been able to promote the comprehensive development of value chains and facilitate the adoption of sustainable agricultural intensification technologies by smallholder farmers. It has also managed to put gender issues on the innovation platforms. In this regard, the program will continue to support the establishment of innovation platforms in other partner countries in Eastern and Southern Africa.

Overall lessons for sustainable intensification of maize systems for Africa and Asia

Resource conservation and system diversification are key elements of CA-based SAI

The productivity (yield) advantages of CA-based practices compared to farmer-practices has been demonstrated in the SIMLESA program research. Further, it is worth noting that some of these benefits (including benefits of crop rotations) accrue progressively over time. The main message from these results is that resource conservation (especially labor resources) and system diversification (in space and time) are important if SAI is to be achieved in all maize systems in Asia. In a world of dwindling natural resources (labor, land, water), practices that conserve any or all of these are fundamental to SAI.

In fact, for CA to succeed and also to maintain a diversified farming system, the competition for residues in crop-livestock environments necessitates the need for research on integrated crops and livestock systems that enable CA and livestock to co-exist. How to achieve these competing demands, especially in maize systems that are designed to cater for feed, should be the subject of careful agronomic and economic analysis. In the Asian maize systems, these analyses should focus on optimal biomass yields to strike the right balance between residue and feed.

CA-based SAI provide a win-win proposition to farmers

The results from CA experiments, on-farm trials and socio-economic analyses clearly show that CA-based practices also reduce costs of production thereby promising win-win outcomes. The challenge is that the CA-based SAI although simple on the surface (legume intercrops, reduced frequency of tillage, residue retention) are actually *information and skill-intensive*. Therefore, the challenge to achieve SAI in Asian maize systems, will be similar to that in ESA, namely, the role of information, extension and adaptive research will continue to focus on how best to inform farmers about these techniques and their benefits in order to promote and achieve scaled adoption of best practices. In the end, the need to improve farmers' skills must be an integral part of SAI.

CA-based SAI provide ways for production risk mitigation

The management of risk (specifically the reduction of downside risk) is an important goal for poor farmers, most of whom operate in challenging environments.

Therefore, the SIMLESA program integrated risk-management and mitigation as equal components of the productivity objective. Yet enhancing productivity can also imply increased risk for farmers because it requires staking increased resources in an environment characterized by a number of uncertainties especially those related to climate and weather patterns. The evidence emerging from SIMLESA research activities suggests that CA-based practices can reduce the risk of crop failure without compromising yields thereby avoiding the classical high-risk, high-return (low-risk, low-return) tradeoff. This added advantage provides clear incentives for changing production patterns to focus on CA-based principles but also imply a big role for farmer education on risk related benefits. This is crucial if it is considered that some of these benefits accrue only in expectation and may therefore be difficult to appreciate due to the abstract nature of these benefits.

For many rural households, food security depends on productivity enhancement through improved maize and legume varieties and CA-based intensification

In some of the results emerging from SIMLESA, the food security outcomes of households was tied to the acreage under improved maize and legume varieties. This fundamentally suggests that for the foreseeable future, the pathway to food security in ESA will pass through smallholder *productivity and technology improvement on owned-farms*. In locales where maize is a key staple, this direct pathway may be relevant. A somewhat longer pathway may be possible in those Asian environments where maize is primarily a feed crop. This alternative pathway will be the income and market-access pathway emerging from intensified maize-livestock systems producing feed-for-own-livestock or for sale. The intensification principles outlined in the SIMLESA program will remain valid in both food and feed maize systems in Asia.

Capacity building, mainstreaming gender and institutionalization of innovation platforms are necessary to enhance the development and transfer of CA-based sustainable intensification systems.

Conclusions

The emerging maize revolution in Asia, is coming at a time when sustainable agricultural intensification has gained international recognition. The CGIAR system, of which CIMMYT is part, recognizes this aspect of agricultural development as one of the guiding strategies for their R4D work. The SIMLESA program is an illustration of this approach. The main lesson emerging from the SIMLESA program is that enhanced productivity is an integral part of sustainability. As part of SAI, implementing resource-conserving production systems which also preserve some diversity in cropping patterns can have "win-win" outcomes in terms of improving yields and reducing risk while also reducing labor costs, input use and sustain the natural resource base. For the foreseeable future, crop production holds the key to food security in rural areas, either through direct household food supply or through enhanced incomes that improve access to food. The main lesson to help guide the Asian maize sector development is that the many goals of increasing yields, reducing risk, enhancing profitability and conserving resources can be achieved simultaneously without too many tradeoffs being made among these goals. Avoiding these tradeoffs will require the application of the CA-based SAI strategies outlines in this paper.

SIMLESA's take home message for Asia's maize-legume systems, is to craft and enhance a comprehensive integration of disciplines to generate the relevant options/technologies; bring on board functional stakeholders through innovation platforms for scaling adoption; mainstream gender and inclusive strategies and value chain analysis tools to create improved farmer-to-market linkages.

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