SECTION 3

HIGHLIGHTS FROM COUNTRY INITIATIVES

13 A systems research approach to the sustainable intensification of agriculture in Australia's northern grains region

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Key points

- There are significant similarities between the subtropical and tropical agroecologies of eastern and southern Africa and Australia.
- Evidence from SIMLESA field trials in eastern and southern Africa, and associated investments in Australia, suggest that conservation agriculture-based sustainable intensification in Queensland's semi-arid tropics has significant potential to reduce yield gaps, increase production efficiencies and improve risk management.
- ACIAR investments in Africa and Australia have produced significant benefits for African and Australian farmers and contributed to capacity building.

Introduction

Agricultural systems in high- and low-income countries are known to suffer distinctive problems. In low-income countries, the limited availability of resources (e.g. land, finance, labour and information) and the lack of access to inputs, product markets, services and infrastructure constrain the opportunities and incentives for smallholder farmers to change and improve their farming systems. In high-income countries, increases in the yield of traditional commodities are plateauing or decreasing, terms of trade continue to decline, high levels of farm debt constrain investment in more-productive technologies and investments in research and development continue to dwindle. In this chapter, we discuss these issues in relation to Australia's agriculture and propose that:

1. there is significant potential for conservation agriculture-based sustainable intensification (CASI) in Queensland's semi-arid tropics
2. there are still opportunities to bridge yield gaps[1] and increase production efficiencies in dryland cropping
3. there is need for research programs that are more transformative and generate new opportunities to diversify farming systems and sources of income in a changing climate.

These three points are discussed in terms of the lessons learned from SIMLESA and associated research investments in Australia.

Across the globe, most food production systems face, in one way or another, significant crises. In high-income countries such as Australia, these are crises of sustainability, profitability and lack of investment, which constrain the opportunities for CASI.

Since the Green Revolution in the 1960s, productivity gains in agriculture can be attributed to improvements in agronomy, breeding, the cropping system and their interactions. The significance of these productivity gains is reflected in the fact that, over the last 50 years, we have fed an additional 4 billion people with only an 11% increase in land area. We also know that future productivity gains are likely to be driven by further improvements across the same drivers. However, this task will require much larger efforts to achieve similar gains, particularly considering that yield trends over time for rice, wheat and maize are plateauing or declining (Grassini, Eskridge & Cassman 2018), and that the negative impacts of climate change are becoming more evident (Allen et al. 2018).

It is important to clarify that, in terms of total factor productivity, gains can emerge from combinations of increases and even reductions in farm output. For example, in Australia between 1977 and 2015, the total factor productivity of the broadacre industries grew by about 1.1% annually. This increase was primarily driven by reductions in input use (–1%) rather than increases in output growth (+0.1%). In comparison, in the US, farm-level total factor productivity has increased since the late 1940s, driven primarily by increases in total output (United States Department of Agriculture 2019). Other figures (Sheng, Ball & Nossal 2015) show that, in recent years, Australia's total factor productivity growth rate has slowed relative to that of Canada and the US. The poorer performance of Australia's agriculture sector, compared to that of Canada and the US, has been attributed to lower levels of investment in public research and infrastructure (Sheng, Ball & Nossal 2015).

1 Yield gaps are defined as the difference between farmers' yield and achievable rainfed yields from the application of optimum combinations of genotypes and management to site and expected seasonal conditions.

Historically, Australia's public investment in agriculture research and development contributed to almost two-thirds of the average productivity growth between 1952 and 2007 (Zhang, Chen & Sheng 2015). Structural changes in the sector also allowed more efficient farmers to increase agricultural total factor productivity (Sheng et al. 2016). Both factors have been associated with increased efficiency in the use of labour, land, capital, inputs and ultimately, increased farm productivity. Larger farms had greater capacity to invest in, and were better situated to benefit from emerging productivity-enhancing technologies like large machinery, control traffic and automation.

In 2017, cropping industries were the largest contributors (1.54%) to total factor productivity in Australia, followed by beef (1.3%), mixed livestock–cropping farms (0.9%) and sheep (0.3%) (ABARE 2019). However, total factor productivity growth for the cropping industries has not been homogeneous across the three Australian grain-cropping regions (western, southern and northern). Differences between regions are found in the growth of input and output markets. For example, the northern grains region had the lowest inputs growth (0.6%) and a slow output growth (1.9%), resulting in the lowest net total factor productivity growth (1.3%) of the three regions. There are multiple differences between regions (e.g. soils, climate, cropping system). For example, the southern and western regions have Mediterranean climates, while the northern region has more evenly distributed rainfall in its southern and central regions, and a predominantly summer rainfall environment in the north. Climate, particularly droughts, can modify the values of total factor productivity across regions, although climate conditions have been more severe in the western and southern regions (Australian Bureau of Agricultural and Resource Economics and Sciences 2019). The poor performance of the northern grains region could be primarily attributed to its low input growth, particularly fertilisers. Growth in the northern region was 1.3%, compared with 1.9% and 1.4% for the southern and western regions respectively (Grains Research and Development Corporation 2017).

In the northern regions of Australia, the grains industry has been characterised by sizeable yield gaps[2] (Clarke et al. 2019), small profit margins (Roxburgh 2017) and large-scale production systems that grow a limited number of commodities. Climate variability, poor terms of trade for traditional commodities and high labour costs have contributed to this condition. Market factors have also constrained large-scale farmers to produce a small number of commodities. The strategy of diversifying cropping systems would require better access and management of a diversity of input and output markets, as well as a wider range of transport, storage and export options and infrastructure for smaller volumes of high-value produces. Across the northern grains region, the high handling cost of exporting containerised produce has limited farmers' opportunities to diversify cropping activities and generated low-cost, large-scale, risk-averse rainfed farming systems (Figure 13.1).

Next, we will discuss these issues in reference to Australian agriculture and propose that:

1. there is significant opportunity to sustainably intensify agriculture in Australia's semi-arid tropics by reducing yield gaps and increasing production efficiencies in dryland cropping
2. there is a need for research programs that are more transformative and generate new opportunities to diversify farming systems and sources of income in a changing climate.

2 Yield gaps are defined as the difference between farmers' yield and achievable rainfed yields from the application of optimum combinations of genotypes and management to site and expected seasonal conditions.

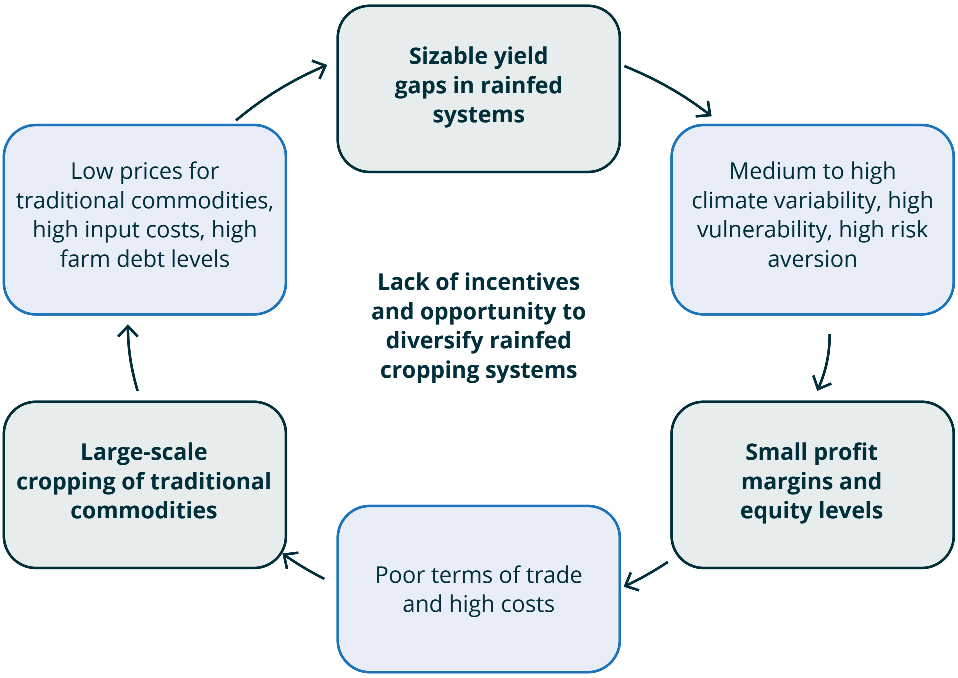

Figure 13.1 **Drivers of and constraints to farmer-led diversification of rainfed cropping systems in Australia's northern grain region**

Optimum crop designs to reduce yield gaps

In principle, crop production is a function of a crop's ability to capture resources, chiefly radiation and water, and the efficiency of the crop in converting these resources to dry matter and grain (Rodriguez & Sadras 2007). In Australia's northern grains region, both water availability and water use efficiency, and heat stress, are the main constraints to summer crop production. While water availability is determined by soil type, management, rotation and in-crop rainfall, water use efficiency is highly related to crop nitrogen availability (Sadras & Rodriguez 2010). Numerous interactions between water and nitrogen supply are well characterised, particularly in rainfed systems. For example, in environments where water limits crop growth, a reduced biomass early in the season, driven by lower than optimum levels of nitrogen supply, reduces the likelihood of water stress during critical periods around flowering later in the season. This has been described as the trade-off between yield potential and lower but more stable yields (Sadras, Roget & Krause 2003; Sadras et al. 2016). Heat stress at air temperatures above 38 °C, has also caused pollen sterility around the critical flowering stage and reduced the yield of summer crops (Singh et al. 2015). Management that staggers the flowering stage of crop development and the time of the season with a high likelihood of heat stress has provided important opportunities for farmers to drastically minimise yield reductions in the region.

An opportunity to reduce yield gaps and increase productivity can be found from the adoption of crop designs that are better adapted to site and expected seasonal conditions. Crop here refers to combinations of genotypes (G) and agronomic management practices (M) that best suit the environment (site and seasonal conditions, E) (Hammer et al. 2014). For example, even though there are only small variations between hybrids in terms of tillering potential, maturity and stay-green (Clarke et al. 2019), various combinations of hybrids and management practices, primarily plant density, resulted in 50% and 48% yield differences in sorghum and maize, respectively, across environments, yielding on average between 0.5 t/ha and 11 t/ha, respectively (Figure 13.2). Interestingly, the yield differences observed in Figure 13.2a and 13.2c translated into sixfold and fourfold increases in water use efficiency in both sorghum and maize, respectively (Figure 13.2b and 13.2d).

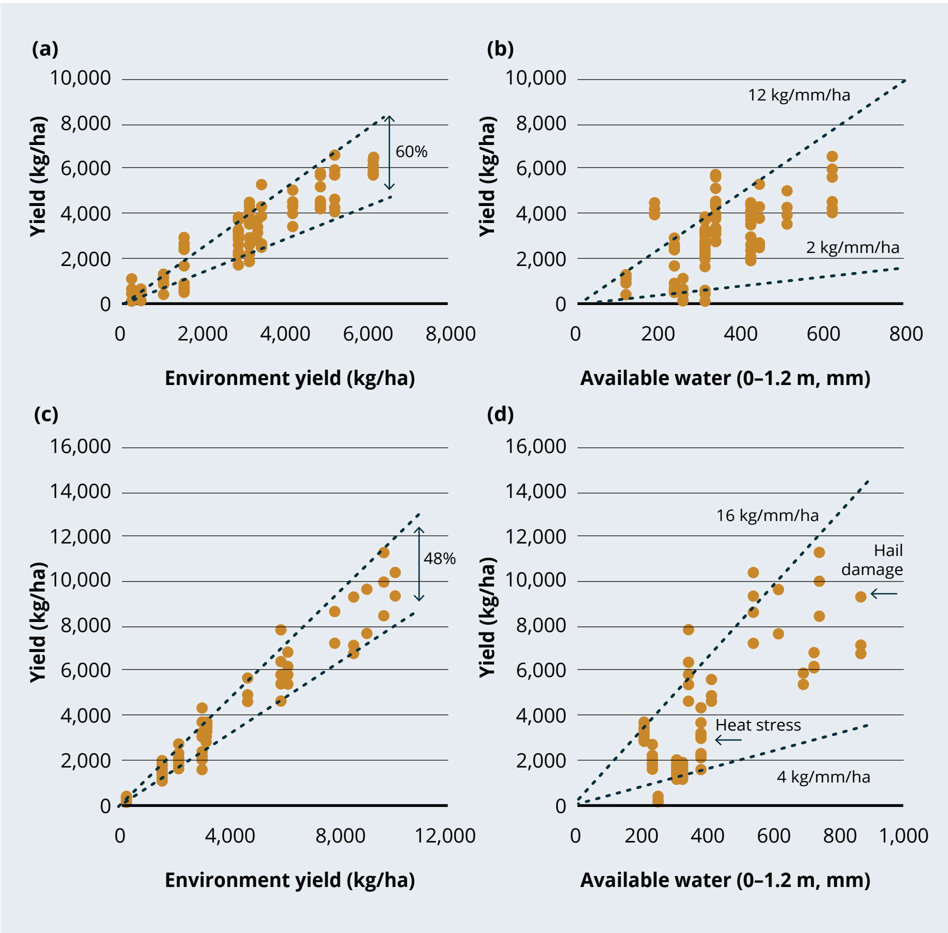

Figure 13.2 **Yield of sorghum (a and b) and maize (c and d) hybrids across management combinations (i.e. plant densities, row configurations, sowing times) versus the average site yield (a and c) and total available water (b and d) for on-farm trials across the northern grains region of Australia sown during the 2014–16 seasons**

Both sorghum and maize datasets were analysed in three stages:

1. exploring crop ecophysiological relationships between measured variables
2. using data-mining techniques
3. using linear mixed models to identify levels of significance in multienvironment (genotype and environment combinations and interactions) trials.

Using the results from on-farm trials, simple rules of thumb for farmers were developed using data-mining techniques (Figures 13.3 and 13.4). For example, the sorghum data consisted of 488 estimated treatment means (i.e. combinations of hybrids, row configurations, densities, sites and seasons). The median yield was 5.3 t/ha, with minimum and maximum treatment yields of 1.7 and 12.8 t/ha respectively (13.5% moisture content). Figure 13.3a shows that in the above-median yielding environments (>5.3 t/ha), the highest yields were obtained using plant populations higher than 50,000 plants/ha and high-yield potential hybrids. Figure 13.3b shows that in the below-median yielding environments (<5.3 t/ha), the highest yields were obtained in solid 1 m row configurations planted at 50,000–60,000 plants/ha.

The maize yield dataset also consisted of multienvironment G×M trials sown during the 2014–15 and 2015–16 seasons across the Liverpool Plain, east and west of Moree, the Darling Downs, Western Downs and central Queensland. Treatments included five factors: site, irrigation, row configuration, hybrid and plant density.

Soil moisture at sowing (initial soil water 0–1.2 m, mm) was the most important variable for determining maize yield under suboptimal growing conditions (below-median-yield environments) (Figure 13.4a). When the initial soil moisture at sowing was more than 184 mm in the 0–1.2 m of soil profile, there was only a 25% distribution of yields below the economic threshold, i.e. 3.5 t/ha. With less than 184 mm stored in the top 1.2 m of the soil, the crop was highly reliant on in-crop season rainfall. For example, most yields were below the economic threshold when soil moisture at sowing (initial soil water) was between 150 mm and 184 mm (18 sites), but 50% of the yields were lower than 3.5 t/ha when initial soil water was below 150 mm. In above-median-yield environments, crop configuration was the main variable dividing the population of treatment yields. Super-wide configuration had the lowest yields. Within the solid crop configurations, the highest yields were obtained with highly prolific hybrids. Among the non-prolific hybrids, the highest yields were obtained with the highest populations (i.e. ≥4,800 plants/ha).

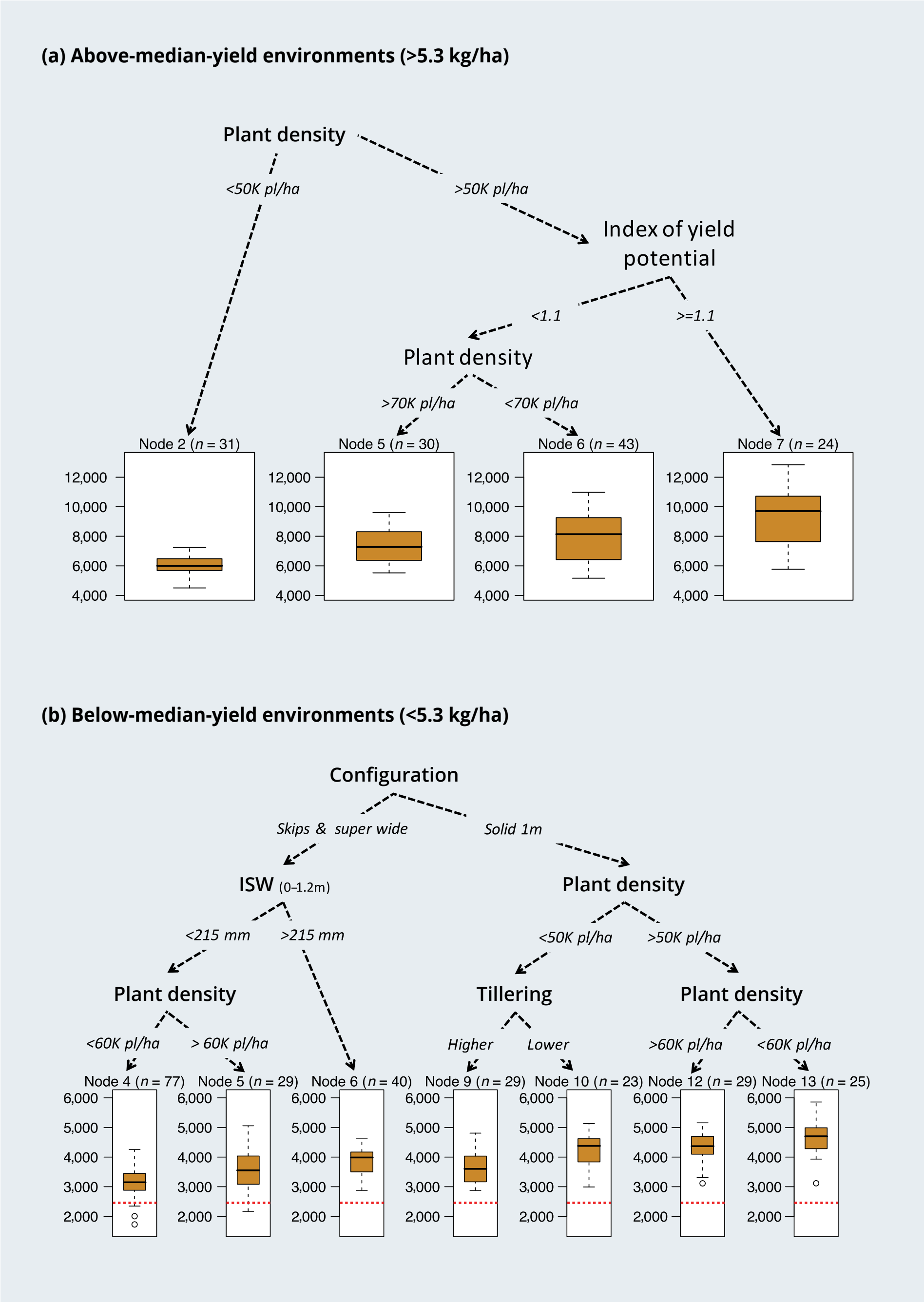

Figure 13.3 Rules of thumb to identify high-yielding crop designs (genotype and environment combinations) for sorghum production in high- and low-yielding environments

Notes: Genotype and environment rules separating yield levels for below-median and above-median (5.3 t/ha) yield environments. The dashed red line indicates the break-even yield of 2.5 t/ha.

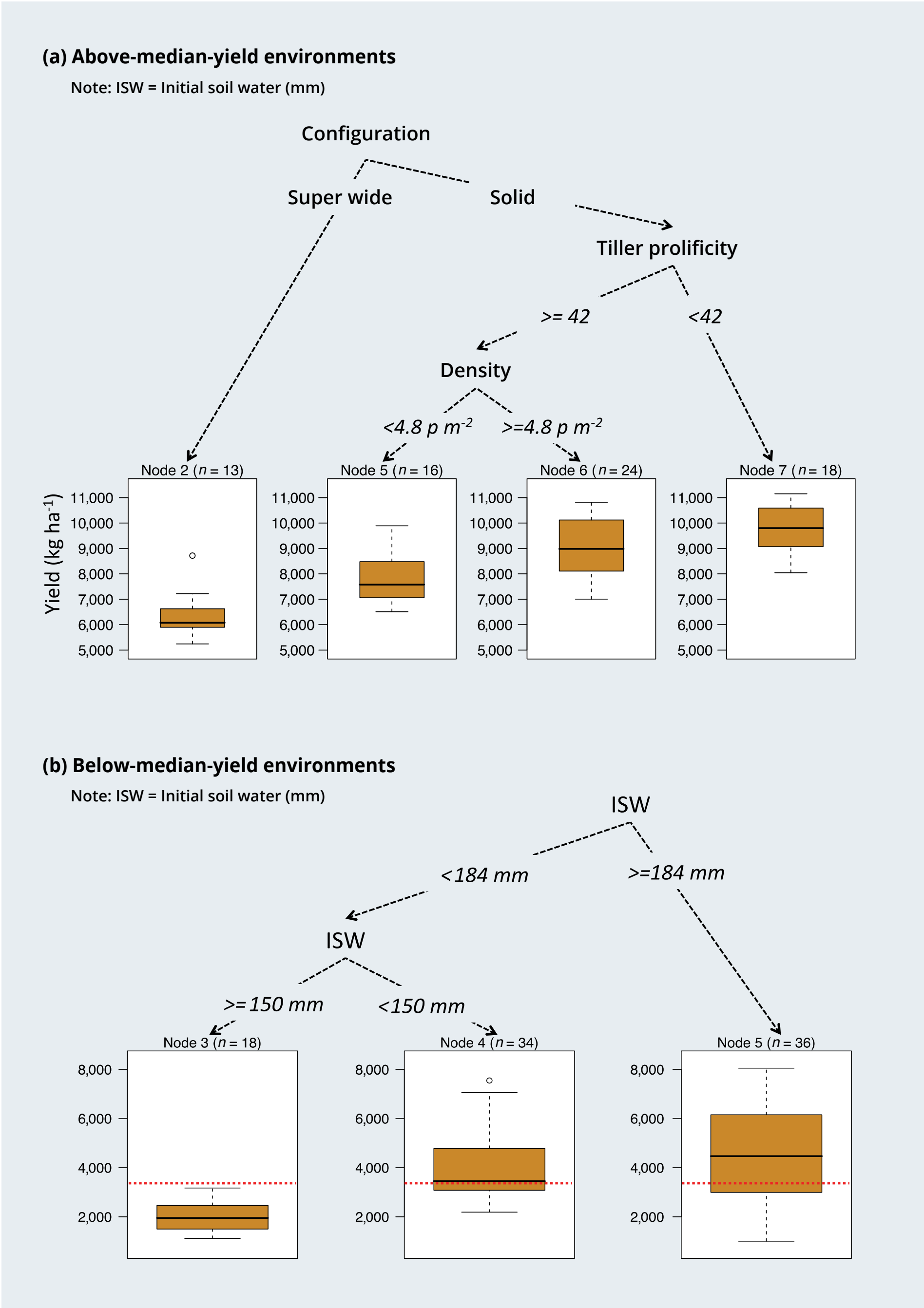

Figure 13.4 **Rules of thumb to identify high-yielding crop designs (genotype and environment combinations) for maize production in high- and low-yielding environments**

Notes: Genotype and environment rules for below-median and above-median-yield environments that discriminate high- and low-yielding treatments from a multienvironment trial across Australia's northern grains region. The dashed red line indicates a break-even yield of 3.5 t/ha.

These results show that management options, including plant population, row configuration and sowing date, affect the pattern of water use over the growing season and the final yield. The findings demonstrate that it is possible to identify the combinations of hybrid and management that maximise yields and profits, or minimise risks, for a given sowing environment. As shown above, crop yields can be highly variable under a climate that produces contrasting and changing sowing environments.

The main challenge in identifying optimum G×M combinations is predicting relevant attributes of the environment at the time of sowing. Inherent to dryland cropping is a high level of season-to-season and within-season climate variability. Australia has a long track record of valuable developments in climate sciences and applications (Hammer et al. 2014). Seasonal climate forecasts were created and used to inform likely seasonal conditions and practice change (see the farmer decision-support tool Climate Kelpie at http://www.climatekelpie.com.au). However, adoption remains low due to:

- the perceived low value of the existing skill in the information of seasonal climate forecasts
- the complexities associated with the multiple interactions between factors when managing biological systems (i.e. climate, soil and crop interactions) and their effect on the skill and value of crop yield forecasts)
- the challenge of understanding and communicating probabilistic information, especially by risk-averse farm managers and consultants.

We assessed our capacity to inform crop design under SIMLESA based on predicted sowing environments (i.e. the accuracy of seasonal climate forecasts). This was achieved by linking a tested crop model (APSIM) with a skilful seasonal climate forecasting system. Results showed that the seasonal climate forecast was reliable and skilful and, when linked with APSIM, the analysis could identify crop designs that increased farmers' profits (Rodriguez et al. 2018).

The value in skill depended on the baseline used for the comparison. When current farmers' practice was used as the baseline, linking APSIM sorghum and POAMA-2 increased average profits by A$143/ha and reduced or even eliminated downside risk (Table 13.1). When the baseline for the comparison was the highest yielding, static hybrid-by-management combination, the actual value of the additional climate information was, on average, A$17/ha/year, which is roughly equivalent to the benefits derived from Australia's sorghum breeding over the last 30 years (i.e. 2.1% per year, or 44 kg/ha/year). These results indicate that, even though the value of the additional climate information might seem small ($Value_{optSCF}$), its magnitude compares well with that derived from much larger and better-funded breeding programs. Much larger benefits ($Value_{optS}$) might be realised when using such insights in discussions with farmers on benefits and risk from increasing investments in dryland cropping to sustainably bridge productivity and profit gaps.

These efforts have made it possible to inform optimum crop designs to increase farmers' profits and reduce risks using reliable and skilful dynamic GCM models, interfaced with validated crop simulation models. The release of Australian Bureau of Meteorology's new higher resolution and more sophisticated ACCESS-S1 seasonal climate forecast system early during 2018 is likely to further increase the value of climate information when linked with crop simulation models like APSIM. However, to achieve those gains, improvements in downscaling techniques and real-time access to outputs from the Bureau of Meteorology's seasonal climate forecasts will be required. Further, this information needs to be translated and made available to decision-makers in a form that is understandable and usable.

Table 13.1 Mean profits from farmers' current practice and crop designs optimised based on simulation using climatology and profit gains from the optimised crop designs

	Soil type (PAWC)	Profit (A$/ha)			
		Farmers' current practices	Optimised	$Value_{opts}$	$Value_{optSCF}$
Capella	high	1,108	1,260	152	3
	medium	748	824	77	3
	low	544	600	56	4
Dalby	high	1,127	1,337	210	13
	medium	1,048	1,241	194	17
	low	795	913	118	12
Goondiwindi	high	866	1,092	226	16
	medium	841	1,011	170	63
	low	678	793	115	6
Moree	high	1,025	1,226	202	23
	medium	814	962	148	32
	low	373	427	54	19

Notes: PAWC = Plant available water content; $Value_{opts}$ = difference in profit between simulations of current farmers' hybrid-by-management combinations and a status (every year the same) optimised hybrid-by-management combination; $Value_{optSC}F$ = difference in profit between $Value_{opts}$ and the dynamically optimised hybrid-by-management combination informed by the POAMA-2 seasonal forecasts.

Increasing efficiencies of external inputs

In 2015, Australian sorghum production was worth A$647 million. In the same year, sorghum became the most economically important crop in Queensland. In the Darling Downs region, sorghum cropping has been the main summer cropping activity, using up to 37% of cropped area per year. Understanding what makes a successful sorghum farmer can help inform practice change, gaps in information and investment in research and development programs. With the objective of improving our understanding of the drivers for high sorghum yield, Roxburgh (2017) combined farmers' survey data and crop modelling approaches to derive relationships between farmers' level of investment, farm debt and productivity.

Results in Figure 13.5 are from interviews with farmers reporting on 74 sorghum fields sown between 2010–11 and 2013–14 in the Darling Downs (Queensland, Australia). Ten farms provided sufficient data on debt levels to be included in the analysis, with five farmers in each debt group.

The dataset included surveys from 13 farms and data from 75 sorghum fields grown between 2010 and 2013 across the Darling Downs. Results showed substantial differences in yield (3,882–7,112 kg/ha), water use efficiency (8–15 kg/mm/ha); nitrogen use efficiency (35–78 kg grain/kg N) and gross margin (397–930 A$/ha) between farmers' fields. Logistic regression analysis indicated that the best-performing fields were sown before early October and had higher application rates of nitrogen fertilisers (at least 80 kg N/ha).

However, farmers appeared less willing to invest in inputs (i.e. nitrogen fertilisers) and had lower variable costs when the farm had higher levels of debt per unit of farm area (Figure 13.5). The interviews found that farm businesses with debts of more than A$1,831/ha achieved lower sorghum yields (left branch in Figure 13.6a) and had lower sorghum gross margins (left branch in Figure 13.6b). From the results shown in Figures 13.5 and 13.6, Roxburgh (2017) concluded that farmers' decisions to invest in crop inputs were directly impacted by their level of indebtedness per hectare. Farm debt reduced the adoption of yield-increasing technologies. High levels of farm debt led to under-investment in nitrogen fertilisers, lower grain yields and lower gross margins compared to farms with less debt.

To quantify downside risk (i.e. the proportion of years in which sorghum yields were below a minimum profitable yield of 1.5 t/ha) of nitrogen fertilisation management decisions, an APSIM simulation and analysis using long-term climate records was conducted (Figure 13.7). A large diversity in sorghum yield, water use efficiency and nitrogen use efficiency was found among sorghum farmers' fields in the Darling Downs. These differences were largely associated with deficient agronomic management practices (i.e. sowing date, soil fertility differences and levels of nitrogen fertilisation). Downside risk was unchanged at around 20%, with more than twofold increases in the level of nitrogen fertilisation across a range of sowing times, while the likelihood of above-median and upper-tercile grain yields increased significantly. Raising awareness surrounding the incentives identified in this risk assessment might challenge farmers' current understanding of risk exposure and encourage investment in applying CASI practice in sorghum cropping. Results also emphasise the opportunity to increase sorghum yields and profits, and clearly show the need for more integrative farm-level studies to inform the relationship between farm debt levels and optimum crop management.

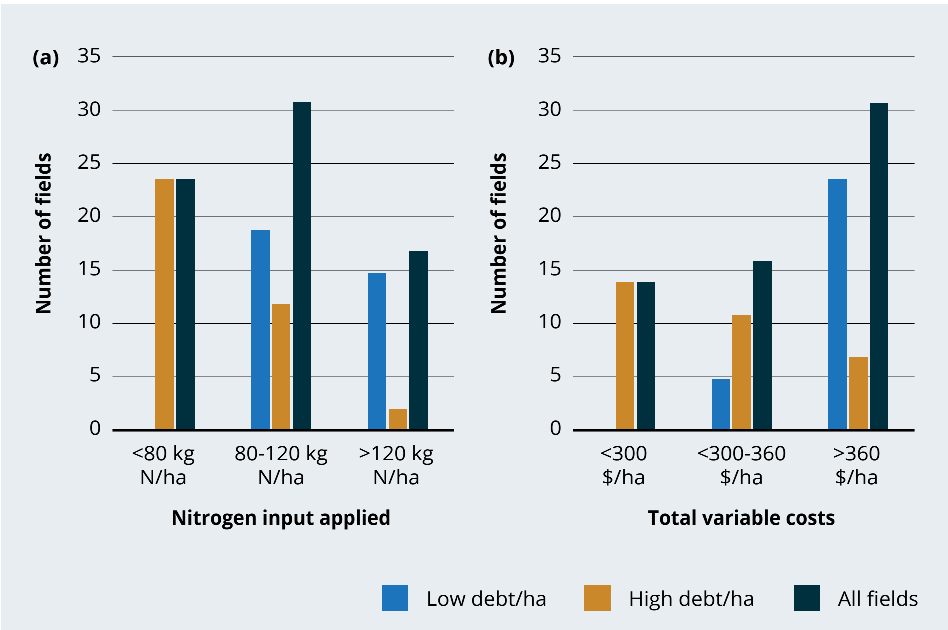

Figure 13.5 **(a) Use of nitrogen fertilisers and (b) total variable costs for farms with above- and below-mean debt.**

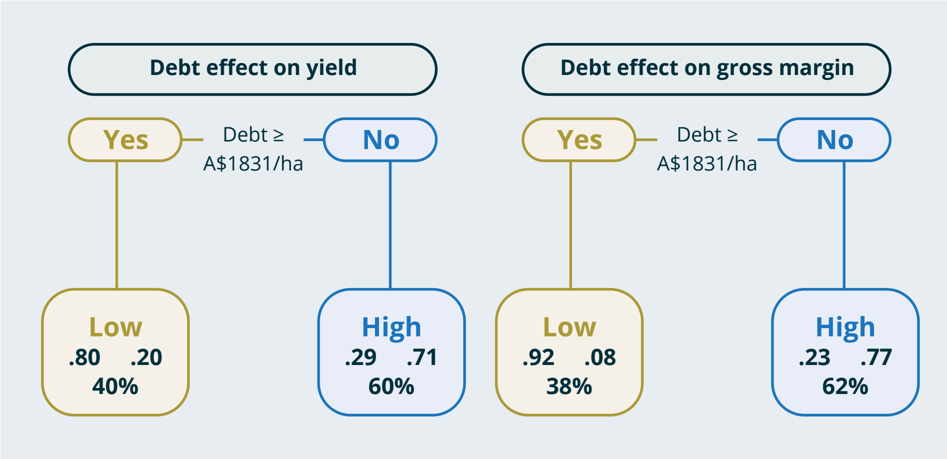

Figure 13.6 **Classification tree for the effects of farm debt on (a) sorghum yields and (b) gross margins**

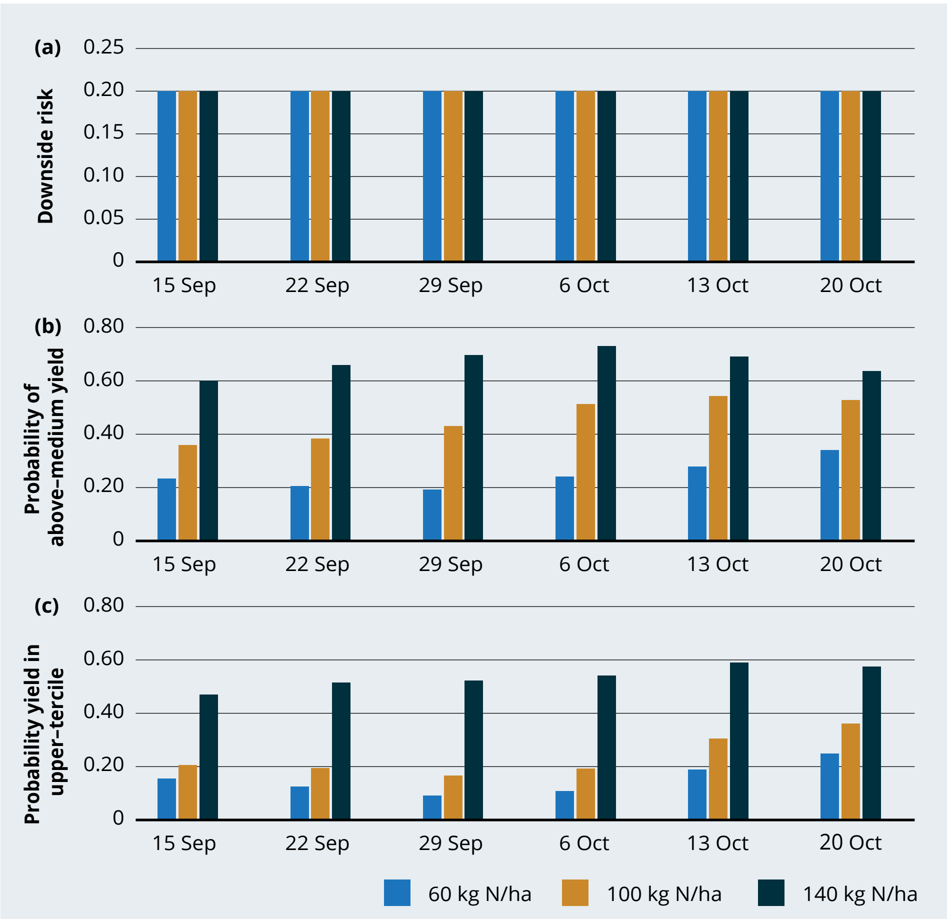

Figure 13.7 **Likelihood of achieving (a) yields lower than 1.5 t/ha, (b) above-median yields and (c) yields in the upper tercile**

New opportunities from a changing climate

In both Africa and Australia, climate change is leading to shifts in cropping patterns. Water stress and extreme heat during flowering times have been common abiotic stresses that limit yield in summer cropping across the northern grains region. Avoiding the overlap of sensitive crop stages around flowering with periods having a high likelihood of heat and water stress can help farmers reduce losses. Early sowing can also increase the likelihood of double cropping a winter crop after a short summer fallow. Previous research identified that maize and sorghum crops show significant cold tolerance and high-yield potential when sown in winter. Eighteen on-farm and on-station G×M trials were sown in a latitudinal transect between Breeza in the Liverpool Plains (New South Wales) and Emerald (central Queensland) to determine if sowing summer crops in winter is a feasible means of adapting the cropping system to a hotter and more variable climate.

Initial results on the emergence of sorghum planted at soil temperatures ranging between 10 °C and 27 °C at sowing depth showed that colder (<15 °C) and hotter soils (>22 °C) tended to reduce crop emergence between nil (no reduction) and 20% across a large range of hybrids. Reductions in crop emergence can be easily compensated for by increasing sowing rates, while the largest benefits arose with double cropping a high-value winter crop (e.g. chickpea) the following winter. Even though the results are encouraging, questions remain related to the:

- impact of cold soils on crop emergence and establishment
- predictive capacity of APSIM to simulate the practice
- likelihood and impact of early frosts
- effects on water use and water use efficiency
- implications for optimal cropping systems.

Conclusions

The results presented here show that there is significant value in linking crop simulation modelling and seasonal climate forecasting tools to inform optimum crop designs. However, increased efforts should be invested in simplifying and communicating complicated probabilistic risk management information to make it easier for farmers to use. It could also be inferred that productivity and farm profits would increase if the information increased farmers' confidence in decisions to invest in more-productive technologies (e.g. higher rates of nitrogen fertilisation). Ongoing climate variability and change will increasingly challenge farmers and researchers; however, it is also becoming clear that opportunities for significant changes in our cropping systems can be found. Even though more information is required, sowing summer crops in winter appears to be possible and profitable, and breeding companies have shown interest and are starting to develop hybrids with enhanced cold tolerance.

The common denominator in the work presented in this chapter has been the application of a systems research approach to conservation agriculture-based sustainable intensification of sorghum cropping systems in Australia by multidisciplinary teams of agronomists, crop physiologists, climatologists and socioeconomic scientists, in partnership with participating farmers and agribusinesses.

It is clear that future gains in the productivity, economic, environmental, social and human dimensions of farming systems in Australia and Africa need to be pursued through improvements in agronomy, breeding and the farming system, and their interactions. This is only feasible through the development of more transdisciplinary research programs.

In the case of both Africa and Australia, this will require the development of a coordinated series of research activities that address the challenges to intensify crop–livestock households along the early stages of the adoption and impact pathways. Research activities should include:

- ex-ante participatory identification and quantification of benefits and trade-offs, to target and prioritise interventions
- on-farm systems research to test the transformational potential of adopting single and multiple technologies in crop–livestock systems in collaboration with case study farmers
- development and testing of tools for farmers, such as climate information applications and services
- capacity building on the design of integrated farming systems, crop systems modelling, the use of climate applications to inform investment decisions on farm and along value chains, and engagement with policy.

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14 Achievements and prospects of CASI practices among smallholder maize–legume farmers in Ethiopia

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Key points

- Conservation agriculture-based sustainable intensification (CASI) practices considerably improved soil properties in maize–legume farming systems, resulting in increased crop productivity, reduced downside risk and increased farmers' incomes across diverse agroecological zones in Ethiopia.
- Crop residue retention, one of the components of CASI, greatly reduced soil loss by erosion and increased rainwater use efficiency in moisture-stressed areas.
- Partnerships between public and private actors enhanced variety selection, production, dissemination and utilisation of maize–legume seeds for food and feed.
- CASI includes many different practices that can be applied simultaneously for increased benefits. Dissemination needs the application of various extension methods, from individual mentoring to mass media messaging. CASI promotion can also be enhanced by introducing incentives for farmers such as subsidised seed or fertilisers and suitable farm implements.
- Crop residue retention is more difficult to maintain with free grazing livestock and it requires policy intervention at different levels, from community to national government.
- Follow-up research priorities include crop–livestock integration for climate-smart agriculture and risk and resilience with CASI practices.

Background

Maize and legumes are important sources of food and income for smallholder farmers in Ethiopia. Conventional farmers' practice, consisting of repeated tillage without crop residue retention and monoculture, has resulted in soil degradation. Field surveys, variety selection, on-station and on-farm experiments have been conducted across major cereal–legume farming systems of Ethiopia since 2010. The experiments were to evaluate the performance of conservation agriculture-based sustainable intensification (CASI) against conventional practice, and to select compatible legume varieties for the CASI systems. Variety selection was conducted through farmers' participatory techniques in different agroecological regions of Ethiopia. CASI practices included maize–legume intercropping; no tillage, no burning, previous year residue retention (mulch); recommended maize fertiliser rate (using compound nitrogen, phosphorus and sulfur fertilisers at planting and urea) applied to the maize; and legumes seeded at the middle of two maize rows simultaneously with maize. Conventional practices included frequent tillage (on average, four to five), sole cropping and no residue retained on the farm, and maize after maize rotations. Results showed that CASI conserved more soil moisture in multiple cropping and rotation systems compared with monoculture practice. Soil loss and sediment concentration were significantly reduced and rainwater use efficiency was higher in CASI compared with conventional practice. CASI practices improved soil bulk density, organic carbon, infiltration rate and penetration resistance, and crop productivity. Higher crop yields under CASI systems were achieved, particularly in years with low rainfall, indicating the resilience of the practices during stress seasons. Significant crop yield improvements, higher financial benefits and reduced risks of crop failure were established under CASI systems. Seed production of improved maize and legume varieties was considerably enhanced in major maize- and legume-producing areas of Ethiopia by involving public and private seed enterprises. In this regard, farmers' participatory variety selection techniques and variety selection criteria were instrumental in maize and legume variety dissemination and uptake. On-farm demonstrations and scaling out of CASI practices played a pivotal role in awareness creation, technology dissemination and adoption. Field days, exchange visits and agricultural innovation platforms were established and utilised for raising awareness of CASI practices. The most common practices to be adopted were intercropping followed by rotation, reduced tillage, residue retention and herbicide use. The involvement of multistakeholders in the scaling-out activities and piloting of CASI technologies across major maize–legume-producing areas will be instrumental in the dissemination of CASI technologies in the future. Unavailability of herbicides, shortage of improved seeds and livestock feed, and free grazing are challenges to the adoption of CASI practices in Ethiopia.

CASI is the issue of the day for Ethiopian crop production. Accordingly, conservation agriculture-based sustainable intensification constitutes cropping principles aimed at sustaining high crop yields with minimum negative consequences on the environment. In this respect, maize and legume farming has a critical position in Ethiopia (Food and Agriculture Organization 2014). Maize and major grain legumes are the main source of income for Ethiopian farmers. The indigenous cereal teff, wheat, sorghum and barley are also staple crops grown in the diverse agroecologies of Ethiopia. Maize is a strategic crop for food security, while legumes provide vital dietary protein and generate income. In Ethiopia, especially in the sites selected under SIMLESA, maize and legumes coexist and are planted in intercropping, crop rotation, relay and double cropping systems. While maize is a major crop, legumes are used as fertility-replenishing crops in maize–legume farming systems.

Importance of maize and legumes and their production challenges in Ethiopia

The production of maize and legumes is growing rapidly in area and volume of harvest, expanding into new frontiers in many parts of Ethiopia where these crops have not traditionally been grown (e.g. north-west, Central Rift Valley, eastern and southern regions). Maize is produced in major agroecologies of Ethiopia and is taking over indigenous crops, such as sorghum (Figure 14.1).

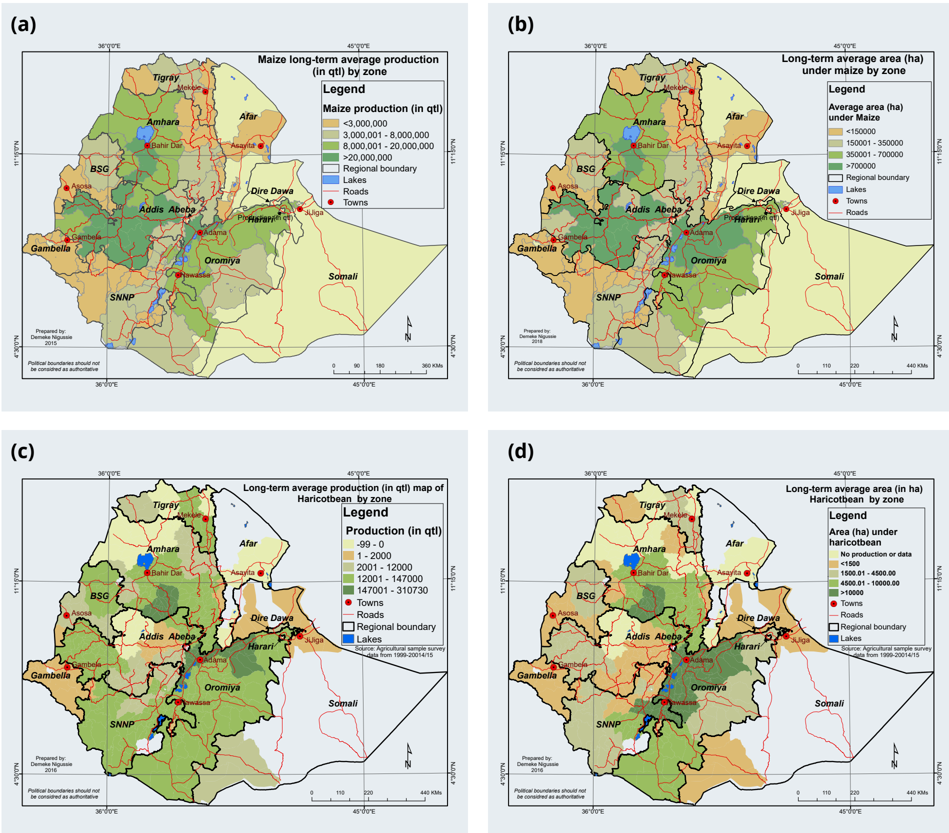


Figure 14.1 **Long-term average maize production in Ethiopia by (a) weight and (b) area; long-term average common bean production in Ethiopia by (c) weight and (d) area**

Note: Quintal (qt) = 100 kg

Between 1995 and 2016, maize production areas increased from 1.5 Mha to 2.1 Mha and production jumped from 2.0 Mt to 7.8 Mt (Central Statistical Agency 2017). Maize (*Zea mays* L.) is currently being produced by 10,863 million farmers in Ethiopia (Central Statistical Agency 2017). The legume species commonly grown in maize-based farming systems are common bean (*Phaseolus vulgaris* L.) and soybean (*Glycine max* L.). According to the Central Statistic Agency (2017), common bean (both red- and white-seeded) is produced by nearly 4.0 million households on 290,202 ha of land, with an annual production of 480,000 t grown over wider agroecologies in Ethiopia. Soybean is produced by 130,022 households on 36,636 ha with total production of 812,347 kg (Central Statistical Agency 2017). In addition, mungbean (*Vigna radiata*) and lupin (*Lupinus albus*) occupy land areas of 37,774 ha and 19,908 ha, respectively. Among the legume crops, common beans are important as a source of export earnings in Ethiopia. For instance, annual export from common bean was about US$132 million, and the price per tonne grew at a high average rate (7.09% per year) between 2006 and 2015 (Figure 14.2). Legumes are also important for improving soil fertility, as they fix nitrogen.

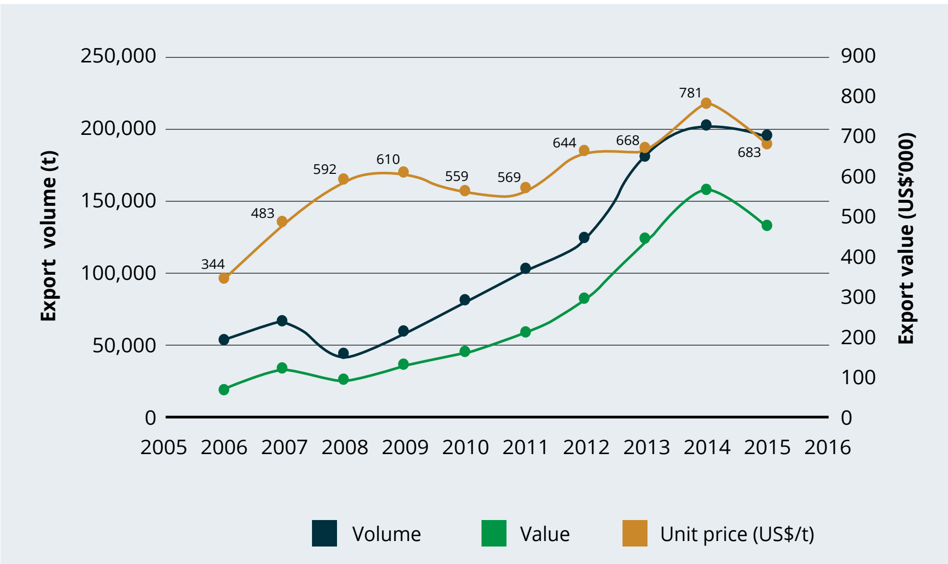


Figure 14.2 **Ethiopian common bean export volume, value and price per tonne, 2006–15**

In Ethiopia, a major countrywide drought occurs every 10 years, while the rate is as frequent as every three years in drought-prone areas such as the Central Rift Valley (Beshir & Nishikawa 2017). Monocropping, frequent tillage (four to five times before planting), and crop residue removal or burning are very common practices in maize-based farming systems of Ethiopia. Furthermore, 1.5 billion tonnes of soil is taken away annually by erosion, of which 45% is from arable land (Bewket & Teferi 2009; Gelagay & Minale 2016). The rate of soil erosion in Ethiopia (20–93 t/ha/year) is four times higher than that for Africa as a whole and 5.5 times higher than the world average. Soil erosion from crop lands costs Ethiopia about 1.5 Mt of annual grain production (Hurni et al. 2015). Lemenih et al. (2005) documented a continual decline in soil quality with increased frequency of tillage in Ethiopia, proving that the existing farm land management is not sustainable.

The same study further revealed losses of 50.4% soil carbon and 59.2% total soil nitrogen over 53 years of continual cropping, compared to the natural forest. Haileslassie et al. (2005) documented a depletion rate of 122 kg N/ha/year, 13 kg P/ha/year and 82 kg K/ha/year in Ethiopia. The same work showed that soil nutrient stocks across regional states in Ethiopia were diminishing, except in areas under vegetation. A recent study in north-western Ethiopia showed intolerable rates of soil erosion reaching 42 t/ha/year. The highest loss was recorded from cultivated lands on steep slopes (Molla & Sisheber 2017)

Another important pressure on farm land is the rapidly growing human population. The Ethiopian population is growing at an alarming rate (2.9% per year). The total population is currently 105.35 million and the young population (under 24 years of age) constitutes 63.6%. The majority of the population (79.6%) are rural residents (World Factbook 2017), whose livelihoods are primarily based on agriculture. Production and productivity of crops, including maize and legumes, are growing due to technological changes (e.g. new crop varieties, chemical inputs and improved agronomic practices). Climate change and variability have been posing challenges for soil productivity and crop production.

Although maize and legume are major staple crops in Ethiopia, they face multiple production constraints. The major maize production challenges are caused by continual monocropping and residue removal (Wakene et al. 2011). Large areas of highlands (>1,500 m above sea level) are affected by soil acidity. Accordingly, about 43% of the Ethiopian arable land was affected by soil acidity (Ethiosis 2014). Mesfin (2007) reported that moderately acidic soils (pH <5.5) influenced crop growth considerably and required intervention. The main factors giving rise to increased soil acidity in Ethiopia include climatic factors such as a high amount of precipitation (that exceeds evapotranspiration, which leaches appreciable amounts of exchangeable bases from the surface soil), temperature, severe soil erosion and repeated tillage practices, where the soil is intensively cultivated and overgrazed.

Maize is mainly cultivated by smallholder farmers who depend on animal traction power under rainfed conditions. Conventional tillage for maize production in Ethiopia involves ploughing three to four times until a fine seedbed is obtained and kept for two to three months prior to planting (Debele & Bogale 2011). This practice coincides with high and intense rainfall, leading to high soil erosion and resulting in increased soil acidity and low soil fertility. Soil and water erosion and acidity are the main problems today in western parts of the country. The largest areas of the western Oromia highlands are dominated by nitisols with high acidity (Mesfin 1998; Temesgen et al. 2011). Repeated application of acidic inorganic fertiliser could also enhance soil acidity, particularly in conventional systems. The nitrification is more enhanced in much-disturbed soil than that with minimum tilling. Nitrate leaching might be aggravated, which increases the concentration of H^+ in the soil solution. Past research indicates that the use of different agronomic management practices like crop diversification and intensification using rotation and intercropping, reduced frequency of tillage and residue retention can greatly improve soil acidity and increase soil fertility and productivity. Crop rotation and intercropping practices with conservation agriculture have improved and considerably enhanced soil fertility (Abebe et al. 2014).

The issues of food security in agrarian Ethiopia calls for sustained food production by improving and maintaining soil fertility and enhancing its moisture conservation capacity. Sustainable crop production systems need to be developed to address the challenges of depleting soil fertility, climate variability and growing population pressure in Ethiopia. The SIMLESA program, funded by ACIAR, was developed and implemented in five African countries (Ethiopia, Kenya, Malawi, Mozambique and Tanzania). SIMLESA activities were based on the principles of CASI. Since CASI practices may vary across areas based on soil types, moisture and slope, experiments were established across major agroecologies and data were obtained and analysed. CASI included simultaneous application of minimal soil disturbance, permanent soil cover using crop residues or living plants, and crop rotations/ associations (FAO 2014).

SIMLESA program objectives in Ethiopia

The SIMLESA program had the following major objectives for Ethiopia. Most objectives were common across the SIMLESA countries; however, forage production and a broader set of agroecologies were considered in Ethiopia:

1. characterising maize–legume (fodder/forage) systems and value chains and identifying broad systemic constraints and options for field testing
2. testing and developing productive, resilient and sustainable smallholder maize–legume cropping systems and innovation systems for local scaling out
3. increasing the range of maize, grain legume and fodder/forage varieties and their seeds for smallholders through accelerated breeding, regional testing and release
4. supporting the development of local and regional innovation systems and scaling out modalities and gender equity initiatives.

The following agroecologies were selected and research teams were established to meet these objectives.

Agroecologies

SIMLESA research activities were conducted in the drought-prone areas of Central Rift Valley and southern region, subhumid, high-potential maize-growing areas of western and north-western Ethiopia, and semi-arid areas of the Somali region. The research activities were conducted by different agricultural research centres located across diverse agroecologies (Table 14.1):

- the Central Rift Valley was managed by Melkassa Agricultural Research Center (MARC)
- the southern region was jointly managed by Hawassa Maize Research Subcenter of the Ethiopian Institute of Agricultural Research (EIAR) and Hawassa Research Center of Southern Agricultural Research Institute (Hawassa-SARI)
- western Ethiopia was managed by Bako Agricultural Research Center (BARC) and Pawe Agricultural Research Center (PARC)
- north-western Ethiopia was managed by Adet and Andessa Agricultural Research Centers of the Amhara Regional State Agricultural Research Institute (ARARI)
- the semi-arid areas of eastern Ethiopia activities were managed by Somali Region Pastoral and Agro-pastoral Research Institute (SoRPARI).

The long-term on-station trials included sole cropping of maize and legumes, maize–legume intercropping and maize–legume rotation.

Table 14.1 Research centres implementing CASI practices under the SIMLESA program in Ethiopia, 2010–17

Description	MARC	BARC	PARC	EIAR	ARARI	SoRPARI	Hawassa-SARI
Altitude (metres above sea level)	1,500	16,50	1,120	1,694	2,240	1,761	1,689
Latitude (North)	8°24′	9°6′	11°5′	7°03′	11°17′	24°27′	07°03′
Longitude (East)	39°19′	37°09′	36°05′	38°28′	37°43′	10°35′	38°30′
Annual rainfall (mm)	763	1,244	1,586	955	1,771	545	1,001
Average maximum temperature (°C)	28.4	27.9	32.6	27.6	25.5	28.2	27.3
Average minimum temperature (°C)	14	14.1	16.5	13.5	9	12.6	12.6
Average temperature (°C)	22	20.6		20.0	17.5		19.95
Soil type	andosol	ulfisols	nitisols	sandy loam	clay		vitric andosols
Soil pH	7.1–7.4	4.99		7.0	5.4–6.3		6.4–6.9
Agroecology	moisture stress	subhumid	hot humid	tepid to cool humid	mid-altitude	semi-arid	mid-altitude

Note: CASI = conservation agriculture-based sustainable intensification

Research teams

SIMLESA Ethiopia was implemented by multidisciplinary teams from the different agricultural research centres. Teams included agricultural economists, agronomists, breeders, entomologists, pathologists, weed scientists, agricultural extension and gender specialists. Agricultural economists were involved in the identification of production constraints to be addressed through CASI options for maize–legume production systems. Value chain and adoption monitoring surveys were categorised under Objective 1. This team was assisted by agronomists and breeders who validated the results of field surveys. Objective 2 was led by agronomists, who had a critical role in testing CASI practices across different agroecologies. The agronomists established long-term (since 2010) on-station and on-farm trials across diverse agroecologies in Ethiopia. The data obtained from the experiments were shared with the team of country program coordinators and scientists from the International Maize and Wheat Improvement Center (CIMMYT), who were providing technical support to Objective 2.

The third objective was spearheaded by maize and legume breeders who were assisted by socioeconomists and extension personnel working with farmers in selecting improved maize and legume varieties. The major task was the identification of farmer-preferred varieties using participatory variety selection (PVS). Both farmer criteria and scientific techniques were adopted to identify varieties suitable for target environments. For example, genotype-by-environment interaction analysis was used to identify maize varieties for adaptation to wider agroecological conditions. Similarly, grain and forage legume varieties that were suitable for intercropping with maize were identified and recommended for production under maize–legume cropping systems. Likewise, on-farm demonstrations and multistakeholder platforms were established to aid faster dissemination of information and technologies. Accordingly, selected maize and legume varieties and CASI practices across various agroecologies were promoted with the support of agricultural extensionists and gender specialists under the umbrella of Objective 4 of the SIMLESA program. Results of these research activities are highlighted in the following sections.

Based on research results under Objectives 1–3, demonstrations and scaling out activities were established in 29 districts located in 12 administrative zones across major maize- and legume-growing agroecologies of Ethiopia. The zones represented 31% of households involved in cereal and 30% in pulse crops production, and 44% maize and 27% and common bean production hectarage in Ethiopia (Table 14.2). The remaining sections present the findings, followed by conclusions and implications of the work done over seven years.

Table 14.2 Number of households, production areas of cereals, pulses and common bean in SIMLESA program areas, Ethiopia, 2016

Zone/Country	Cereal		Maize		Pulse		Common bean	
	Households (No.)	Area (ha)	Households (No.)	Area (ha)	Households (No.)	Area (ha)	Households (No.)	Area (ha)
Ethiopia	16,326,448	10,219,443	10,862,725	2,135,572	9,062,008	1,549,912	3,947,664	290,202
East Shewa zone	364,038	395,977	239,466	92,374	191,825	70,451	100,922	16,723
West Arsi zone	464,515	290,660	296,049	63,538	148,566	27,146	109,608	18,685
West Shewa zone	523,405	525,382	334,619	98,354	250,966	56,910	14812	–
Sidama zone	402,254	53,467	286,265	31,548	644,580	23,311	473,996	14,535
Hadiya zone	268,031	107,641	97,306	20,041	131,493	12,335	54,454	2,725
East Wollega zone	276,568	288,005	265,801	135,192	110,715	18,140	47,297	–
Jigjiga zone	86,773	66,421	48,813	21,314	–	–	–	–
Metekel zone	105,295	100,451	83,092	23,398	56,234	12,792	30,459	1,747
West Gojjam zone	616,949	517,671	597,312	212,557	302,291	72,631	36,046	10,763
Arsi zone	611,380	526,820	336,048	81,089	310,589	62,058	71,478	7,630
West Hararghe zone	858,249	222,401	589,968	39,808	348,120	12,632	285,645	5,178
Awi zone	265,691	228,836	247,508	69,659	94,482	25,047	3,697	0
Gurage zone	195,590	96,349	105,256	32,151	130,746	12,917	38,894	111
Alaba zone	61,395	38,924	58,658	19,898	30,128	1,812	28,638	1,626
SIMLESA program area total	5,100,133	3,459,007	3,586,161	940,919	2,750,735	408,182	1,295,946	79,724
Percentage of Ethiopia	**31**	**34**	**33**	**44**	**30**	**26**	**33**	**27**

Findings

Farming systems and household characteristics

The SIMLESA program in Ethiopia characterised the farming community from the national regional states of Oromia, Southern Nations and Nationalities and People's (SNNP) and Benishangul Gumuz. It laid the ground for targeted research on CASI cropping system intensification, in situ soil and water conservation and maize–legume variety selection and their dissemination. It included 53 communities constituting 576 households across nine districts in semi-arid agroecologies in the Central Rift Valley and its surroundings from SNNP to the subhumid high moisture area of western Ethiopia (Bekele et al. 2013). Later, in 2012, two regional states—Amhara from north-western and Somali from semi-arid eastern Ethiopia—were covered and the focus of research expanded to comprise forage production, as livestock keeping is an essential part of the maize–legume farming system in Ethiopia.

Farm households were composed of an average of seven members (the range was 4–15) of fairly equal number of male and female members. Female-headed households made up 14.3% of the total. Household heads had an average age of 39 (standard deviation = 12) with about four years of formal schooling. The number of households per kebele[3] averaged 746 (standard deviation = 290). The farm households owned small areas of land (1.29 ha), of which 90% (1.16 ha) was used for crop production and the remaining for residence and grazing (Bekele et al. 2013). The per capita land holding was 0.1 ha, making further land division difficult and sustaining food security through crop production challenging without intensification. The per capita land holding was 0.28 ha in 1995 in Ethiopia (Food and Agriculture Organization 2001), meaning there was a 35.7% reduction in just 15 years.

Regarding household labour in crop production and marketing, men and women participated in maize and legume land preparation, planting, weeding, harvesting and grain marketing. The proportion of men's involvement in field operations was higher in land preparation, planting and harvesting while the participation of women and children was greater in weeding. Marketing of grain harvest was a joint decision between couples, and neither of them had exclusive decision-making power (Bekele et al. 2013). This represented a positive move towards gender equity and equality, signalling the community's recognition of women's need to participate in the issues that affect a household's livelihood. This result is in line with that of Beshir, Habtie and Anchala (2008), who documented the practice of joint decision-making in resource use among farm households in crop–livestock farming communities of both Christians and Muslims in Adama district in the Central Rift Valley of Ethiopia. Other than crop farming, livestock constituted a large part of farm household livelihood: 77% of maize–legume-growing households owned cows, 87% had other livestock and 43% kept donkeys. The average holding of animals was 2.88 tropical livestock units[4] (TLU), among which cattle constituted 2.36 TLU (Mulwa et al. nd).

3 Kebele is the lowest administrative unit in Ethiopia.

4 One tropical livestock unit is equivalent to livestock weight of 250 kg. The conversion factor varies according to the livestock type: 1 ox = 1.12 TLU, 1 cow or heifer = 0.8 TLU, 1 sheep = 0.09 TLU, 1 goat = 0.07 TLU, 1 horse = 1.3 TLU, 1 mule = 0.90 TLU, 1 donkey = 0.35 TLU.

Financial viability of CASI practices

The relative advantage of a technology is a long-established criterion in agricultural innovation adoption. The level of relative advantage is usually expressed in financial profitability, status obtained or other values (Rogers 1983). The financial feasibility of different CASI maize–legume production practices across agroecologies were closely monitored and documented. The CASI maize–legume production practices were cost-effective with a higher benefit:cost ratio (3.79) in the Central Rift Valley of Ethiopia compared to the usual farmers' practice of continual sole maize monocropping. Similarly, in semi-arid areas of Jigjiga, a pastoralist/agropastoralist could earn 4.25 times more income by intercropping maize and common bean (Table 14.3). Similar results were attained from producing maize and common beans under CASI practices in other agroecologies. In Hawassa, CASI maize–legume production practices outperformed conventional practices, while the maize and common bean intercropping system was the most profitable production venture. In terms of financial viability, maize and common bean intercropping gave higher margins (3.33–6.08) across major agroecologies where the SIMLESA program has been executed (Table 14.3). Gross margins of maize production under conservation agriculture were 136% higher than maize produced under conventional practices in Hawassa.

Table 14.3 Benefit:cost summary of conventional practices versus CASI maize and legume production across major agroecologies in Ethiopia

Location	Conventional practices	CASI practices				Benefit: cost ratio (CASI sole maize vs conventional practice sole maize) (%)
	Sole maize	Sole maize	Maize–common bean intercropping	Maize–common bean rotation	Common bean–maize rotation	
Hawassa	3.48	4.75	6.08	4.99	6.36	136
Bako	3.67	4.49	3.33	3.90	3.67	122
Central Rift Valley	3.51	3.95	3.79	2.05	3.51	113
South Gojjam	1.95	2.97	–	–	–	152
Jigjiga	3.32	3.78	4.25	6.73	–	114

Notes: CASI = conservation agriculture-based sustainable intensification; figures are in terms of benefit to cost ratio from unit area (ha).

Among CASI maize and legume production practices, crop diversification gave multiple benefits. First, it enhanced productivity. Second, it downsized the risk of continual sole maize production on plots planted with improved varieties of maize using chemical fertilisers (Jaleta & Marenya 2017). With respect to drought risk reduction, CASI practices showed extra resilience during moisture-stress seasons. For instance, common bean rotation and intercropping with maize under CASI gave consistently higher yields than a similar cropping system under conventional practices in both drought-prone Central Rift Valley and subhumid, high-potential agroecologies in Ethiopia during a low rainfall season in 2012 (Merga & Kim 2014; Abebe et al. 2014). Moreover, CASI practices gave higher yield advantages under sole maize, compared to similar conventional practices in a drought year (Abebe et al. 2014).

In terms of financial benefit, Mekuria and Kassie (2014) illustrated that the highest income was obtained when conservation agriculture practices were combined with improved maize varieties (Figure 14.3). The same work substantiated that the maximum yield increase was realised by using crop diversification, minimum tillage and fertiliser application, where the minimum yield was obtained when only minimum tillage was adopted.

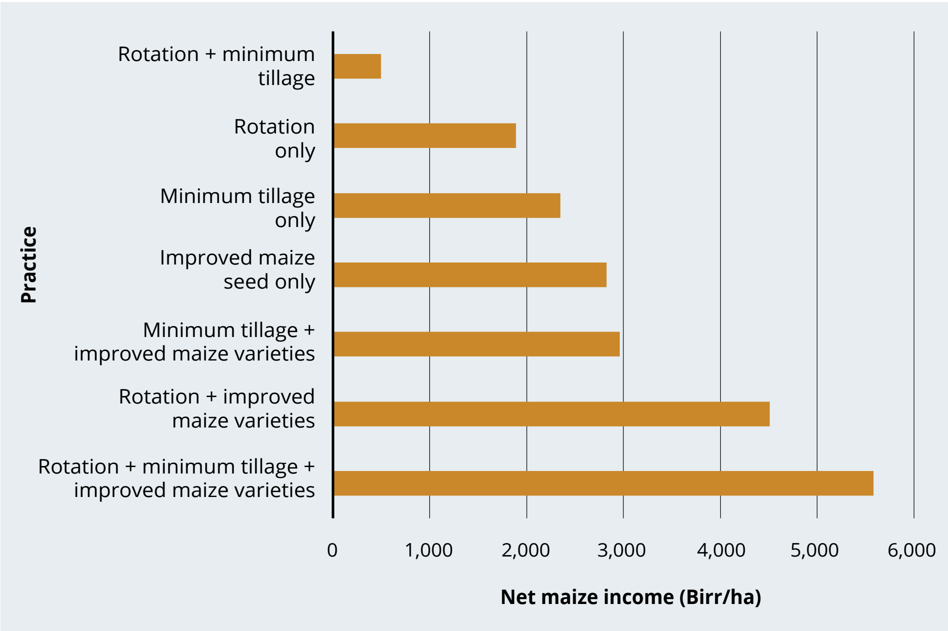


Figure 14.3 **Impact of agronomic practices on maize variety performance and net maize income in Ethiopia**

Source: Mekuria & Kassie 2014

Adoption status of sustainable intensification

Results of CASI-awareness raising efforts in SIMLESA study sites in southern Ethiopia revealed that 97% of the respondents were aware of SIMLESA's CASI technologies from on-farm demonstrations, attending field days, participating in exchange visits and media broadcasts. In this area, the most important practices adopted were intercropping, minimum tillage and improved maize and legume varieties (Getahun 2016). The awareness level of CASI practices was 71% in the Bako area. Teklewold et al. (2013) found that social networks and the number of relatives inside and outside the village positively affected the adoption of CASI technologies, particularly crop rotation and minimum tillage. SIMLESA demonstration plots and extension workers played pivotal roles in creating awareness of CASI practices.

Maize and legume varieties, and minimum tillage were the technologies preferred most by farmers in the Bako area in western Ethiopia. In southern Ethiopia (e.g. the Loka Abaya and Boricha areas), unavailability of herbicides, and shortage of improved maize varieties, foodlegume seeds and livestock feed were challenges associated with CASI adoption (Getahun 2016). Field days, exchange visits and innovation platforms were important means of awareness creation among farmers (Table 14.4). In Bako, an adoption monitoring study showed that 51% of the respondents knew of at least one CASI technology. The major CASI practices adopted, in order of decreasing awareness and use, were crop rotation, intercropping and minimum tillage. Major positive progress was noted from intercropping, residue retention, zero tillage or combinations of these (Table 14.4). In this study, farmers' preferences were, in order of decreasing importance, intercropping, crop rotation, crop residue retention and herbicide application (Figure 14.4).

Table 14.4 Farmers' awareness and use of CASI practices, Bako, 2013

CASI practice	Awareness	Ever used	Used after 2010	Change after 2010 (%)
Intercropping	95.5	26.0	11.0	42.3
Rotation	93.0	58.5	2.5	4.3
Minimum tillage	32.5	17.5	16.0	91.4
Residue retention	80.0	29.0	14.0	48.3
Reduced tillage	52.5	27.0	12.5	46.3
Chemical fertiliser	96.0	70.0	3.5	5.0
Herbicides	71.0	21.5	13.0	60.5
Hand weeding	100.0	98.5	0.0	0.0
Intercropping + minimum tillage + residue	29.5	12.5	11.0	88.0
Rotation + minimum tillage + residue	22.0	8.5	7.0	82.4

Notes: CASI = conservation agriculture-based sustainable intensification; *n* = 200

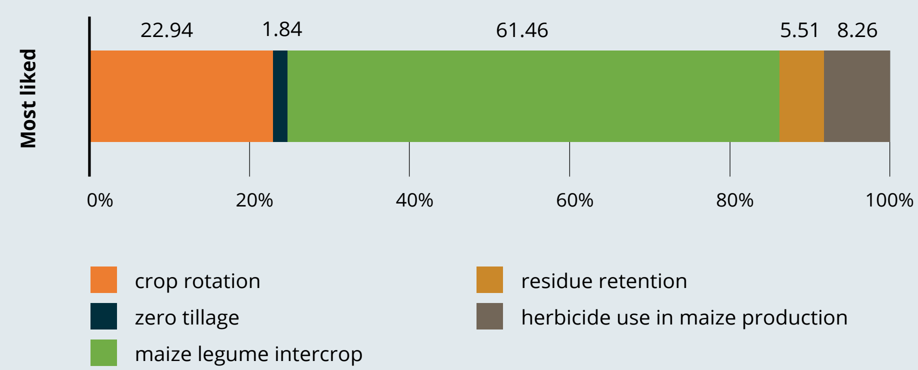


Figure 14.2 Ethiopian common bean export volume, value and price per tonne, 2006–15

In the Central Rift Valley, farmers reported to know and have used improved maize and common bean varieties. Among the farmers contacted, 12% were found to have experience in hosting the technologies as a member of an innovation platform. These groups are identified as first-generation adopters. Considering the distribution of varieties, Awash-1 (a haricot bean variety) and Melkassa-2 (a maize open-pollinated variety) are dominant among host and scaling-up farmers, whereas the Melkassa-2 and Nasir varieties were grown by many second-generation adopters (Table 14.5).

Table 14.5 Adoption of maize and common bean varieties by different categories of CASI farmers, Central Rift Valley, 2013

Crop	Crop variety	Category of farmer involved in CASI practices				Total No. (%)
		Host farmers No. (%)	Scaling-up farmers No. (%)	Second-generation adopters No. (%)	Third-generation adopters No. (%)	
Common bean	Awash-1	10 (18.5)	29 (53.7)	11 (20.4)	4 (7.4)	54 (100.0)
	Awash Melka	5 (17.2)	13 (44.8)	6 (20.7)	5 (17.2)	29 (100.0)
	Nasir	8 (14.5)	7 (12.7)	33 (60.0)	7 (12.7)	55 (100.0)
Maize	BH-540	1 (4.8)	5 (23.8)	9 (42.9)	6 (28.6)	21 (100.0)
	Melkassa-2	19 (15.2)	48 (38.4)	48 (38.4)	10 (8.0)	125 (100.0)
	Melkassa-4	–	7 (87.5)	–	1 (12.5)	8 (100.0)

Note: CASI = conservation agriculture-based sustainable intensification
Source: Adam, Paswel & Menale n.d.

Similarly, adoption of CASI practices showed that maize–bean intercropping, maize–bean rotation, minimum tillage, residue retention and their combination, fertiliser and herbicide application were adopted in the Central Rift Valley (Table 14.6). Maize–bean intercropping (34%), minimum tillage (28%) and crop rotation (24%) were widely practised by farmers. Host farmers were more likely to adopt maize–bean intercropping, while scaling-up participants were more likely to apply minimum tillage with fertiliser. Maize–bean rotation was popular among second-generation farmers and maize–bean intercropping was popular among third-generation farmers (Table 14.6).

Table 14.6 Awareness of CASI practices by different categories of farmers in the Central Rift Valley in 2013

CASI practice	Category of farmer involved in CASI practices				Total No. (%)
	Host farmers No. (%)	Scaling-up farmers No. (%)	Second-generation adopters No. (%)	Third-generation adopters No. (%)	
Maize–bean intercropping	19 (20.7)	34 (37.0)	25 (27.2)	14 (15.2)	92 (100.0)
Maize–bean rotation	14 (21.5)	16 (24.6)	32 (49.2)	3 (4.6)	65 (100.0)
Minimum/ zero tillage + fertiliser	8 (10.7)	42 (56.0)	16 (21.3)	9 (12.0)	75 (100.0)
Minimum/ zero tillage + residue retention	14 (77.8)	2 (11.1)	2 (11.1)	–	18 (100.0)
Minimum/ zero tillage + herbicide	6 (24.0)	8 (32.0)	9 (36.0)	2 (8.0)	25 (100.0)

Note: CASI = conservation agriculture-based sustainable intensification
Source: Adam, Paswel & Menale n.d.

Contribution of CASI practices in increasing yield and reducing downside risk

The major components of CASI practices include reduced tillage, residue retention, and crop association (rotation or intercropping of legume and maize). In the Central Rift Valley, maize was the most commonly produced food crop, sown in an average of 1.08 ha/household (46% of the crop land). Around 0.45 ha of land was allocated to common bean production. Both maize and legumes were grown mainly as a sole crop, with only a few households intercropping (randomly scattered) legume within maize (Abdi & Nishikawa 2017). Farmers produced maize continually under conventional practices, without crop residue retention on farm plots. The average highest maize yields obtained under CASI practices was 5.76 t/ha in the Central Rift Valley (Merga & Kim 2014), 5.55 t/ha in moist subhumid regions, and 7.0 t/ha in subhumid north-western Ethiopia.

The combination of major CASI practices increased maize and legume productivity (Merga & Kim 2014). In addition to productivity gains, adoption of CASI technologies reduced downside risks from shrinking investments to labour. Crop diversification, use of improved varieties and application of chemical fertilisers, along with CASI practices, gave the maximum yield. Abandoning the use of those technologies resulted in lower yields. Likewise, maize yield fell to a minimum if a farmer abandoned the application of both improved variety and chemical fertiliser (Jaleta & Marenya 2017). The risk of maize production was higher in the absence of crop diversification. The same study indicated that crop diversification, application of chemical fertiliser and use of improved crop varieties reduced the downside risk by 51%. In this case, crop diversification served two purposes: enhancing crop productivity and reducing downside risks.

Increased rainwater productivity under CASI practices

Higher soil moisture content in all soil horizons was recorded in the CASI common bean–maize rotation plot, followed by CASI sole maize, at both planting and harvesting times. The rainwater productivity of maize was significantly higher in CASI plots compared to conventional practices plots, even during the lowest rainfall year. In terms of rainwater productivity, the highest value (10 kg/mm/ha) was obtained from common bean–maize rotation followed by maize–common bean rotation (9.2 kg/mm/ha) and sole maize (8.2 kg/mm/ha) grown under CASI management practices, compared to the average value of 7.4 kg/mm/ha under conventional practices (Merga & Kim 2014).

Maize–legume intercropping systems under CASI had significantly higher rainwater productivity, compared to crop rotation systems or conventional practices. Soybean–maize intercropping under CASI in Bako used more water than conventional practices in growing seasons under a well-distributed rainfall pattern. However, under erratic and low rainfall regimes (below the annual average seasons), common bean/soybean–maize intercropping was more efficient and increased rainwater productivity and accumulated more yield (Abebe et al. 2014). Intercropping maize and common beans under CASI reduced yield loss (risk) typical of the short rainfall seasons. Additional yield gains of 38–41% from common beans were observed in the moisture-stressed season when rotated with and intercropped with maize under CASI, compared to similar practices under conventional practices (Abebe et al. 2014).

During moisture-stressed years, maize–common bean rotation under CASI was found to be more productive in the semi-arid Central Rift Valley. This was attributed to crop residue cover to minimise soil water evaporation, and enhanced soil moisture retention. Yields of maize intercropped with common beans were significantly suppressed in seasons with low rainfall, probably due to competition for soil moisture (Merga & Kim 2014). CASI cropping systems showed better rainwater productivity in all seasons. The difference was particularly high in seasons with low rainfall. This indicates that cropping systems under CASI were more resilient in semi-arid areas such as the Central Rift Valley. In 2013, the highest maize grain yield (5.76 t/ha) was recorded from the common bean–maize rotation under CASI, while the lowest maize grain yields (4.02 t/ha) were recorded from common bean–maize intercropping under conventional practices (Merga & Kim 2014). The yield from common bean–maize rotation was significantly higher than yield from all conventional practices. Growing common bean and maize under CASI at Melkassa produced 40% and 28% grain yield advantages over conventional practices, respectively. Similarly, the stover yield of maize increased by 25% under CASI compared to conventional practices, while that of common bean improved by 34% in a maize–common bean rotation (Merga & Kim 2014).

The same study showed that rainwater productivity—the ratio of grain or stover yield (kg) to rainfall amount (mm) from planting to physiological maturity of the crop—was affected by tillage and cropping systems in years when the rotation crop was maize. The rainwater productivity for maize grain yield with maize–common bean intercropping was 18% greater compared to maize monocropping. When the rotation crop was bean, rainwater productivity was sensitive to certain combinations of tillage practices and seasons as well as the type of cropping system. The rainwater productivity was 18% and 20% greater with maize–common bean intercropping compared to maize monocropping for maize grain and stover yield, respectively, when the rotation crop was bean (Liben et al. 2017).

Soil moisture and soil erosion

Research results from Central Rift Valley by Merga and Kim (2014) revealed that moisture content of soil horizons was significantly affected by tillage and cropping systems, based on data from four cropping seasons (2010–13). The same study recorded higher moisture content at a depth of 30–60 cm both during planting and after harvest. Common bean–maize rotation under CASI retained consistently higher moisture in all soil horizons. The soil under common bean–maize rotation had 34% higher soil moisture within the first 15 cm of soil depth compared to CASI with sole maize at planting. The lowest soil moisture content at harvest was observed in 2012 in the common bean–maize intercropping plots under conventional practices. This result is in agreement with the work of Erkossa, Stahr and Gaiser (2006) from the highlands of Ethiopia, who documented CASI's significant positive effect on soil moisture retention and soil fertility restoration.

Ethiopia suffers from soil erosion. This is the main driver of soil degradation and costs the nation millions of tonnes of food grains. Research results from the Bako Agricultural Research Center on the effects of different soil management practices on run-off, soil nutrient losses and productivity of crops show a 25.39% and 10.37% reduction in run-off from use of maize–common bean intercropping under CASI practices compared to maize mulch conventional practices (Table 14.7). Residue mulching not only reduced the surface run-off but also provided a cover to the soil surface, reduced soil detachment by raindrop impact and trapped the sediments carried by surface run-off. As shown in Table 14.7, treatments that received residue mulch under both conventional and minimum tillage reduced soil loss and sediment concentration in run-off. Soil loss reduction compared to the control were 97.9% for maize mulch conservation agriculture and 92.27% for maize mulch conventional practices. This might be attributed to the high sediment trapping capacity of the residue mulch (Degefa 2014).

Table 14.7 Effect of different tillage and management practices on soil loss at BARC

Treatment	Run-off depth (mm)	Sediment concentration (g/l)	Soil loss (t/ha)
Sole maize + minimum tillage (conservation tillage)	44.99[a]	667[a]	18.92[a]
Sole common bean (conservation tillage)	28.39[cd]	45.17[ab]	7.03[bc]
Maize–common bean intercropping (conservation tillage)	22.12[d]	38.23[ab]	4.69[bc]
Sole maize + mulch (conservation tillage)	34.13[cd]	62.63[a]	9.84[b]
Maize–common bean intercropping (minimum tillage)	35.88[cb]	27.8[b]	4.04[c]
Sole maize + mulch + minimum tillage	40.76[ab]	48.57[ab]	9.56[b]
Mean	34.38	48.18	9.01
CV (%)	13.93	3.77	33.37
LSD (0.05)	8.729	33.07	5.47

Notes: CV = coefficient of variation; LSD = least squares difference; values followed by a different superscript letter (a, ab, b, c, cb, and d) are significantly different across management treatments.
Source: Degefa 2014

CASI practices were found to be more effective in soil loss reduction in maize production plots in subhumid zone at Bako on Ulfisols. The soil loss difference was high for sole maize under conventional practices. CASI practices reduced soil loss in the range of 34–65%, compared to conventional sole maize production practices under more frequent tillage. The highest soil loss was registered under sole maize in conventional tillage (Table 14.8).

Table 14.8 **Ecosystem benefits of practices of CASI and conventional practices at BARC**

Practice	Soil loss (t/ha/yr)	Per cent	% reduction
Maize–common bean intercropping under conservation agriculture	1.8	35	65
Sole maize, mulch and minimum tillage	1.95	37	63
Maize–common bean intercropping and conventional tillage	2.71	52	48
Maize–common bean intercropping and conventional practice	3.44	66	34
Sole maize using conventional tillage	5.21	100	0

Note: CASI = conservation agriculture-based sustainable intensification
Source: Degefa 2014

Yield and seasonal rainfall variability

Experiments conducted in the Bako area in the subhumid agroecology and the Melkassa area under semi-arid conditions showed that CASI practices performed better during soil moisture stress years such as 2012—the year in which the lowest rainfall for 20 years was registered (Merga & Kim 2010; Abebe et al. 2014). Maize grain yield showed a decreasing trend under conventional practices, but an increasing trend under CASI across the cropping seasons 2010–13 (Merga & Kim 2014). The same study revealed that maize stover and common bean straw production was higher under CASI than conventional practices in the Central Rift Valley.

Associating maize yield with rainfall distribution and pattern during 2010–13 in Bako shows that maize grain yield substantially increased across cropping seasons. However, a yield reduction was observed in 2012, which might be attributed to the lowest average annual rainfall on record (Abebe et al. 2014). Moreover, reduced rainfall and erratic distribution during tasseling to silking stages resulted in unusually early maturity of the main crop maize, which could be a major reason for the yield reduction (Figure 14.5).

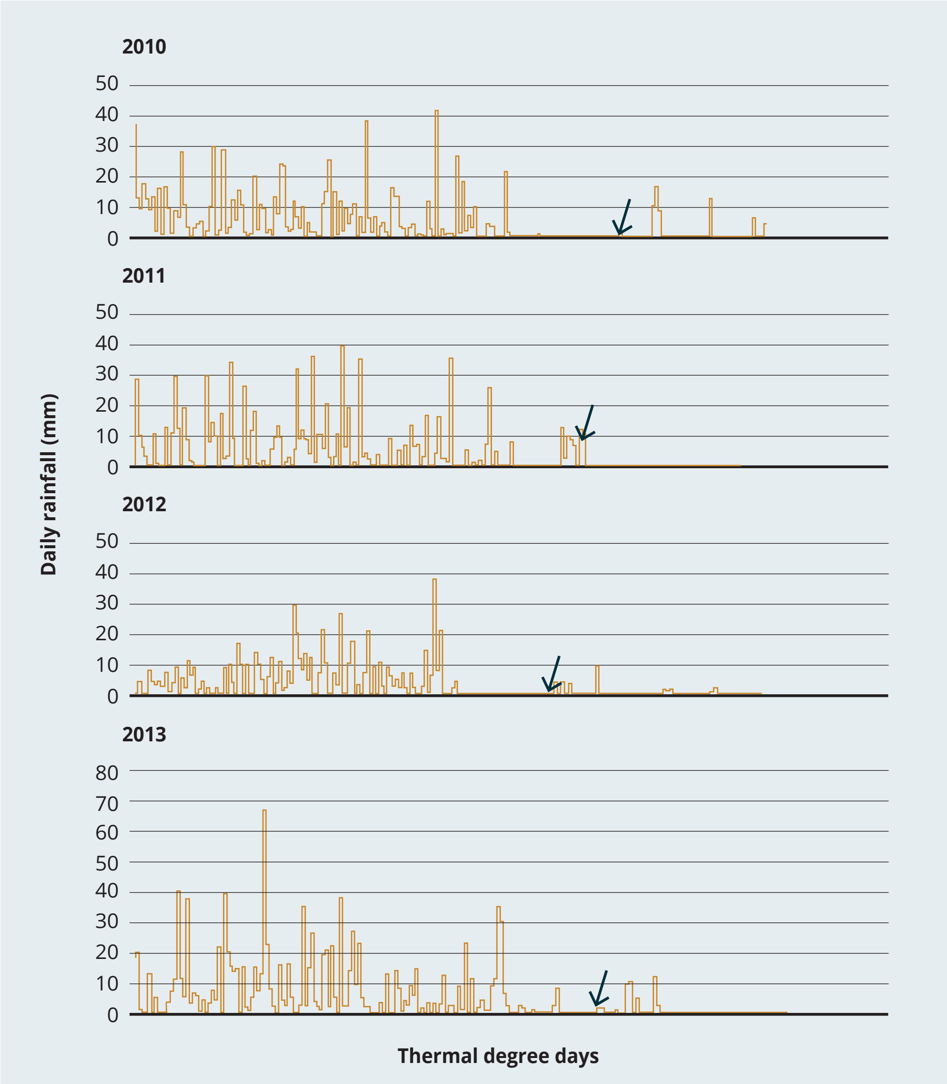


Figure 14.5 **Daily rainfall and thermal degree days during the common bean–maize cropping systems, 2010–13**

Note: Arrows correspond to physiological maturity stage of maize that affected the yield of the crop components.
Source: Adapted from Abebe et al. 2014

Grain yield, land productivity and income

In north-western Ethiopia, an experiment on intercropping of narrow-leaf lupine and white lupine with maize was conducted under two intercrop planting arrangements: single row and paired rows of legume between paired rows of maize. The results show that maize and narrow-leaf lupine intercropping with paired planting arrangements gave a 16% higher maize grain yield, 18% higher land equivalent ratio and 15% increases in net return compared to sole maize production (Assefa 2017).

The highest land equivalent ratio was also registered from single arrangement, and maize–white lupine with paired arrangement was associated to actual yield of the component crops in the intercrop system. However, in the maize–narrow-leaf lupine intercropping system, the yield gain of maize was associated with a yield loss of narrow-leaf lupine and the lowest land equivalent ratio (Table 14.9). On average, the intercropping system was 42% more productive as compared to sole crop production as measured by the land equivalent ratio. This result is consistent with previous findings (Saban, Mehmet & Mustafa 2008).

Table 14.9 **Effect of planting arrangements on grain yield and land equivalent ratio of maize–common bean/lupine intercropping in north-western Ethiopia**

Treatment		Maize grain yield (t/ha)	Legume grain yield (t/ha)	Land equivalent ratio
Intercrop	Planting arrangement			
Maize + common bean	Single row intercrop	5.86	0.79[a]	1.5[a]
Maize + common bean	Paired row intercrop	5.66	0.74[a]	1.4[ab]
Maize + narrow-leaf lupine	Single row intercrop	6.40	0.24[c]	1.3[b]
Maize + narrow-leaf lupine	Paired row intercrop	6.55	0.38[b]	1.4[ab]
Maize + white lupine	Single row intercrop	5.54	0.44[b]	1.4[ab]
Maize + white lupine	Paired row intercrop	6.24	0.47[b]	1.5[a]
Sole crop maize		5.66		
Probability difference		ns	*	**
CV (%)		6.91	25.83	14.70
Sole crop common bean			1.86	
Sole crop narrow-leaf lupine			2.12	
Sole crop white lupine			1.14	

Notes: Data were combined over sites (Jabitehinan and Mecha) and years (2012 and 2013). Numbers followed by different letters on the same column indicated significant difference at the 5% probability level. *, ** and *** are significant difference at probability levels of 0.05, 0.01 and 0.001, respectively.
Source: Assefa et al. 2017

Similarly, experimental results conducted in southern Ethiopia showed that adoption of CASI practices and technologies increased household return on investment in maize (32.6%) and common bean (49%) production, by growing common beans twice a year intercropping and relay cropping with the same maize crop. This is because the growth stages of both crops overlap. Common bean is planted as a second crop near maturity so maize is harvested while common bean is still growing in the field. This system of cropping increased the yield of common beans by 50% compared to that of conventional practice (Markos et al. 2017). Financial profitability of intercropping and the high preference of farmers for intercropping was documented across different agroecologies in Ethiopia (Merga & Kim 2014; Abebe et al. 2014). Field experiments conducted on 11 plots in southern Ethiopia showed that maize–common bean intercropping produced the highest maize and common bean grain and biomass yields. The performance of all the intercropping experiments was superior to sole cropping systems (Table 14.10).

Table 14.10 **Grain yield and biomass of maize and first belg common beans in permanent long-term SIMLESA plots in Loka Abaya and Boricha districts, 2015**

Treatment	Maize		Common bean		Land equivalent ratio
	Mean grain yield (t/ha)	Mean biomass (t/ha)	Mean grain yield (t/ha)	Mean biomass (t/ha)	
Maize/common bean intercropped in conventional tillage	7.66	15.33	0.07	0.1	1.47
Maize/common bean intercropped in CASI	8.54	16.44	0.1	0.15	1.77
Sole maize CASI	7.21	14.39	–	–	1
Maize/cowpea intercropped in CASI	8.04	14.28	0.07	0.14	1.53
Sole common bean under CASI	–	–	0.17	0.32	1
Common bean in rotation under CASI	–	–	0.15	0.17	1
LSD (%)	NS	NS	390**	580*	0.328*
CV (%)	15.07	16.86	13.3	8.27	9.4

Notes: CASI = conservation agriculture-based sustainable intensification; LSD = least squares difference; CV = coefficient of variation. *, ** and *** indicates statistical significance at 1. 5 and 10% levels respectively.
Source: Reports from SARI

Environmental sustainability

Retention of crop residues significantly reduced rainwater and wind erosion and also resulted in higher rainwater productivity in the semi-arid Central Rift Valley (Mega et al. 2014). Similarly, farmers hosting long-term CASI trials in the Central Rift Valley and southern Ethiopia often indicated that CASI plots experienced low or no erosion damages compared to conventional practice plots. A compelling illustration of this occurred when a heavy flood devastated crops in the Halaba district in southern Ethiopia during the 2016 cropping season. In that season, all crops under conventional practice were severely damaged by the heavy flood and no or very minimum flood damage was observed to crops and soils under CASI. Moreover, the benefit of crop residue retention was witnessed by farmers in the southern part of Ethiopia, where a cut-and-carry system was practised. In those areas, there was a clear indication that soil cover increased moisture retention. This agrees with the field experiment results from Melkassa (Merga & Kim 2014).

Moreover, an increase in the number of macrofauna in soil was recorded on plots in southern Ethiopia where maize–legume intercropping under CASI was practised. Macrofauna, particularly arthropods, decompose and humify soil organic matter, and function as ecosystem engineers. Macrofauna are essential in controlling the number of bacteria and algae. Certain macrofauna, such as termites, are responsible for processing up to 60% of litter in the soil (Bagyaraj, Nethravathi & Nitin 2016). Moreover, burrowing anthropoids such as termites improve soil porosity, facilitate root penetration, prevent surface crusting and soil erosion, and they facilitate the movement of particles from lower horizon to the surface, helping to mix the organic and mineral fractions of the soil (Bagyaraj, Nethravathi & Nitin 2016).

Results from the field experiments conducted in southern Ethiopia clearly show increased soil macrofauna with crop intensification compared to conventional practices (monocropping). The intensification system had a significantly greater number of termites, ants, millipedes and centipedes for all the cropping systems under CASI than those under conventional practices (Table 14.11). This increase was attributed to intercropping and residue retention under CASI.

Table 14.11 Soil macrofauna under CASI and conventional practices in southern Ethiopia, 2015

Treatment	Average number of soil macrofauna				
	Termites	Ants	Millipedes	Centipedes	Others
Maize and common bean intercropping under conventional practices	0.67	12.9	0.23	0.9	2.4
Maize and common bean intercropping under CASI	10.6	18.2	1.3	3	4
Maize and cowpea intercropping under CASI	2.8	42.8	0.1	1.3	4
Sole maize under CASI	0	24.2	0	1	3.3
Sole common bean under CASI	7.9	10.8	0	0.7	1.4
Common bean–maize rotation under CASI	1.4	11.4	0.3	1.7	4.3

Note: CASI = conservation agriculture-based sustainable intensification

Similarly, a markedly greater improvement in soil properties (bulk density, organic, carbon, infiltration rate and penetration resistance) and crop productivity was observed at Melkassa with CASI practices, suggesting superiority of the CASI system for improved soil quality and enhanced environmental sustainability in the semi-arid areas of Ethiopia (Merga et al. 2017, under review). The same study substantiated reduction in top soil bulk density in the semi-arid Melkassa area due to increased soil organic carbon (OC) as a result of residue retention and reduced soil compaction under CASI systems. Increased soil carbon (SC) and improved soil moisture contents were observed broadly, across contrasting areas of Ethiopia—the semi-arid Central Rift Valley and the subhumid moist Bako area (Liben et al. 2017; Abebe et al. 2014).

The lowest soil pH was recorded when maize was continually produced under conventional practices compared to CASI systems. Total phosphorus content of the soil was higher for common bean crops grown continually or in rotation with maize under CASI (Figure 14.6a). Higher percentages of organic carbon were recorded in maize–common bean intercropping, sole common bean and common bean–maize rotations under CASI, compared to conventional practices. Production of sole maize under conventional practices and CASI practices significantly reduced total nitrogen content of the soils whereas a significant improvement was observed with crop rotation and intercropping systems under CASI systems (Figure 14.6b).

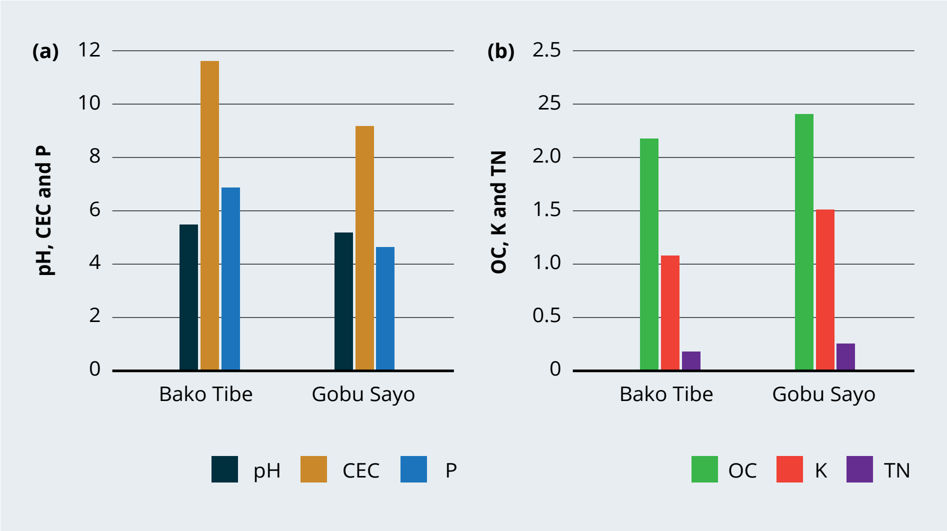


Figure 14.6 **Chemical properties of soil influenced by different cropping systems with tillage practices (across locations during 2010–12 cropping seasons)**

Notes: pH = soil pH; CEC = cation exchange capacity (cmol/100 g soil); P = phosphorus (mg/kg soil); OC = organic carbon (%); K = potassium (cmol/kg soil); TN = total nitrogen (%). Source: Abebe et al. 2014

Even though field evidence shows the superiority of CASI over conventional practices in improving environmental sustainability, free grazing is still a major challenge in many parts of Ethiopia, deterring residue retention and allowing ongoing soil erosion by rainwater and wind. It is imperative that alternative forage crop production or forage/feed supply systems are explored. It is clear that maize stalks are a major forage source for livestock. Maize stalk is given to animals from the early age of crop growth through maturity to post-harvest. This system of continual thinning of maize crop for feed may affect crop yield, as farmers thin throughout the growing period. A separate plot could be used for forage by planting maize densely and harvesting it before it dries up completely. This is an innovative practice among a few farmers in the Siraro area in West Arsi Zone. Policy intervention may be needed to establish local or community-based actions to control and minimise free grazing.

Maize, grain and forage legume varieties

With the objective of providing varietal options to farmers for maize, food and forage legumes, a participatory variety selection approach was employed by the SIMLESA program in different agroecologies in Ethiopia. Under Objective 3 of SIMLESA, numerous varieties were evaluated in different areas using farmers' and researchers' selection criteria, and farmer-preferred varieties were released for commercial production. Promising pre-release and released varieties obtained from ongoing breeding activities were evaluated under participatory variety selection trials. This has been found to be a reliable and quick approach to identifying farmer-preferred varieties for both sole cropping and intercropping systems. Witcombe et al. (1996) proved that participatory variety selection is a very quick and cost-effective method for identifying farmer-preferred cultivars, when a suitable choice of cultivars is presented.

Participatory variety selection of maize

In Ethiopia, a number of on-station and on-farm participatory variety selection and mother–baby trials of released and pre-release varieties were conducted beginning in 2010. These varieties were also generated by various CIMMYT programs, such as Drought Tolerant Maize for Africa, Water Efficient Maize for Africa, Improved Maize for African Soils and Nutritious Maize for Ethiopia. Participatory variety selection of maize was conducted in drought-prone areas of southern Ethiopia and identified that farmers' major selection criteria were grain yield, maturity and disease resistance. Furthermore, farmers also used more specific selection criteria such as cob size, bare-tip, grain size and drought tolerance. Based on these selection criteria, farmers identified Shalla, Abaraya and SC403 as the most suitable varieties for the drought-prone areas of southern Ethiopia (Table 14.12).

Preferences and priorities varied across genders, based on differences in their role in farming. Women generally participated more in planting, weeding, harvesting, seed and grain storage than men. Women (in both female- and male-headed households) played a major role in selecting maize varieties, while men played a more significant role in selecting the common bean (cash crop) varieties. This distinction is expected under these conditions, where men interact with the marketplace more than women do.

Table 14.12 Farmers' selection criteria for maize varieties in Borecha and Loka Abaya districts of southern Ethiopia, 2013

Criterion	Maize varieties ranked by farmers' criteria*					
	Abaraya	BH540	BH543	Shalla	SC403	MH130
Early maturing	4	5	6	3	2	1
Adapt to moisture stress area	3	6	5	2	4	1
Big cob size	2	4	5	1	3	6
No rotten cobs	3	6	5	2	4	1
Big seed size	3	4	5	1	2	6
Heavy seed weight	3	4	5	1	2	6
White seed colour	1	2	4	6	3	5
Full husk cover	2	1	5	6	3	4
Drought tolerance	2	6	3	1	4	5
Sum rank point	**23**	**38**	**43**	**23**	**27**	**35**
Overall rank	**1**	**1**	**3**	**4**	**5**	**6**

Note: * The lower the sum of the score, the more preferred the variety.

Another participatory variety selection trial of eight released maize hybrids was conducted in Jabitehinan and South Achefer districts of north-western Ethiopia, across eight environments. The three most important selection criteria used by the farmers were disease resistance, drought tolerance and high-yielding potential. Researchers also noted that grain yield and other important yield-related traits were used to identify desirable varieties. AMH851 and BH661, with respective mean grain yields of 7.8 t/ha and 7.4 t/ha, were identified as the most suitable hybrids for the region based on researchers' and farmers' selection criteria (Table 14.13). Farmers unanimously preferred these hybrids for better field performance, disease resistance, prolificacy and grain yield.

Table 14.13 **Days to maturity and yield of maize hybrids evaluated in Jabitehinan and South Achefer districts of north-western Ethiopia, 2012–13**

Hybrid	Days to maturity	Mean grain yield (t/ha)
BH542	154.0	5.67
BH660	174.0	6.69
BH673	174.7	7.07
BH545	156.0	7.14
AMH850	169.1	7.35
PHB3253	149.3	7.42
BH661	178.7	7.43
AMH851	171.6	7.80

Source: Elmyhun, Abate & Merene 2017

To further substantiate the selection criteria used by farmers and researchers, a GGE-biplot analysis was performed to identify the most ideal varieties for the area. The GGE-biplot analysis also identified AMH851and BH661 as the most ideal varieties of the hybrids evaluated (Figure 14.7).

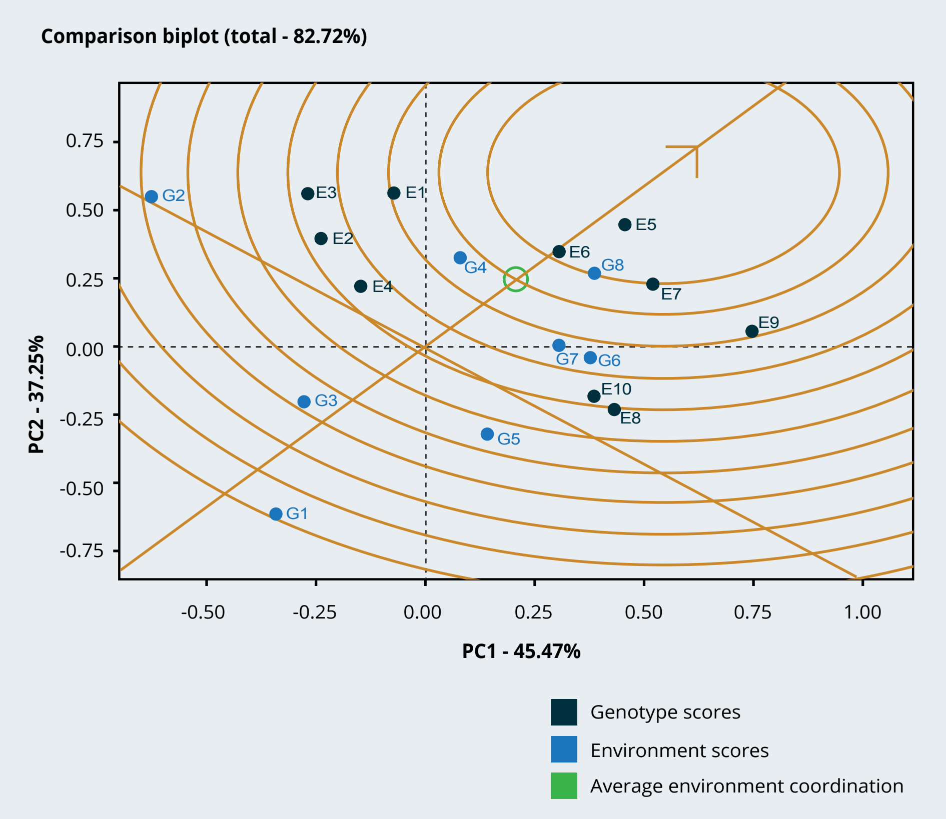


Figure 14.7 **Comparison of maize hybrids for their suitability in north-western Ethiopia**

Source: Elmyhun, Abate & Merene 2017

The choices made by farmers using these criteria are in agreement with the yield records of researchers. This shows that farmers' evaluation criteria agree with the measurements and analysis made by researchers. A combination of farmers' and researchers' selection criteria could be used for rapid selection of improved varieties, compared to the conventional selection approach of researchers, which takes longer. Similar selection criteria were used by Abebe et al. (2005), who identified the most desirable drought-tolerant maize varieties using a mother–baby trial approach.

Similarly, 19 commercial hybrids were evaluated across 11 environments under different management conditions that represent major maize-growing areas of the county (Wolde et al. 2018). Among the hybrids, BH546 (7.5 t/ha), BH547 (7.4 t/ha), P3812W (7.2 t/ha) and 30G19 (7.00 t/ha) were identified as the higher yielding and most stable hybrids. The grouping pattern of the hybrids observed in this study suggests the existence of two closely related maize-growing mega-environments (Figure 14.8). The first was represented by Bako and Pawe, in which Pioneer hybrids P3812W and 30G19 were the winner varieties. The second mega-environment was represented by Hawassa, Haramaya, Melkassa and Tepi, and hybrids BH546, BB547 and BH661 were the ideal varieties. The other hybrids were either unsuitable for or non-responsive to the test environments used. Arsi-Negelle was an outlier environment that was not suitable for any of the hybrids studied. However, to confirm the patterns observed in the current study, additional multilocation and multiyear data would be needed.

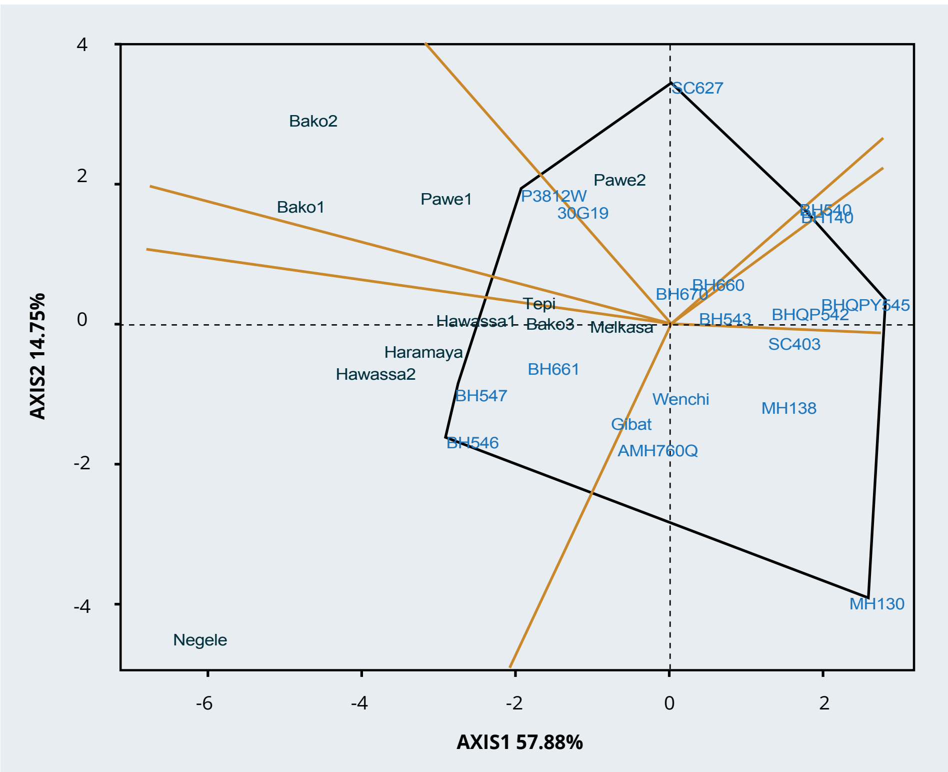


Figure 14.8 **Maize-growing mega-environments constructed using genotype plus genotype-by-environment biplot for 19 maize hybrids evaluated across 11 environments**

Source: Wolde et al. 2018

A series of variety evaluation trials resulted in the identification of best-bet maize varieties for scaling up. A total of 12 maize varieties were identified. Of these, seven varieties (BH546, BH661, BH547, MH138Q, MH140 and Gibe-2) were released during the SIMLESA phase. Some varieties, such as BH546 (erect and narrow-leaved) and MH130 (short plant stature), were identified as being suitable for intercropping with different legume species. In addition, these varieties had higher grain yield than the previously released varieties. These varieties were then scaled out to reach a larger number of farming communities in target areas.

Participatory variety selection of grain legumes

Participatory variety selection trials of common bean varieties were conducted in the dry to moist agroecologies of southern Ethiopia. Farmers identified Hawassa-Dume, SER119 and SER180 as suitable varieties for Hawassa Zuria and Badawacho districts (Table 14.14). Farmers' selections were mainly based on seed size, early maturity, market demand and grain yield. Selections based on researchers' evaluation criteria also identified Hawassa-Dume, Nasir and SER-180 as the most desirable varieties in Hawassa Zuria and Badawacho districts. The selected varieties are being widely taken up and produced in southern central areas of Ethiopia. In general, 13 high-yielding and stress-tolerant legume varieties (7 common bean and 6 soybean) were released or recommended for further promotion. The varieties were developed with the support of Tropical Legumes II and III (TL-II and TL-III), and ongoing government-funded projects.

Table 14.14 Farmer evaluation criteria and ranking of nine common bean varieties at Hawassa Zuria and Badawacho districts in southern Ethiopia

Variety	Criteria								Hawassa Zuria		Badawacho	
	SS	EM	Mkt	Yld	DisR	SSRFS	BM	colour	Sum	Rank	Sum	Rank
Dume	4	4	5	4	4	4	3	4	32	1	33	1
SER119	3	3	5	4	4	3	4	5	31	2	32	2
SER180	3	3	4	4	4	3	4	4	29	3	26	3
SER176	2	2	2	4	4	2	3	3	22	5	25	4
SER125	3	2	2	3	4	2	3	4	23	4	24	5
SER48	3	2	2	3	4	2	3	3	20	7	24	5
SER118	3	2	2	3	4	2	3	3	22	5	23	7
SER78	3	5	2	1	1	5	2	2	21	8	21	8
Nasir	4	1	1	4	2	1	4	2	19	9	19	9

Notes: SS = seed size; EM = early maturity; Mkt = market demand; Yld = high yield; DisR = disease resistance; SSRFS = suitability to short rainfall farming system; BM = bean stem maggot. Scoring: 5 = highly preferred, 1 = least preferred.

Participatory variety selection of forage legumes

The SIMLESA program focused on CASI maize–legume cropping systems. In addition to minimum or no-tillage, effective weed control and maize–legume intercropping or rotation, CASI necessitates retention of adequate levels of crop residues and soil surface cover to improve soil quality. In Ethiopia, crop residues are used as alternative sources of animal feed, as livestock keeping is an essential part of maize–legume cropping systems. For example, where the livestock population is high, challenges of residue retention have been identified as the major bottleneck in adoption of conservation agriculture.

The encroachment of crops on traditional pasture lands, and the lack of appropriate forage/fodder species, compelled farmers to increasingly rely on crop residues for fodder. Therefore, systems for production and supply of forage crops need to be in place to enable farmers to retain crop residues in their fields. The SIMLESA expansion program in Ethiopia addressed issues related to fodder and forages in mixed crop–livestock systems in addition to SIMLESA's main objectives.

Several forage legume species were evaluated on-farm and on-station across different ecologies in SIMLESA's hosting centres in Ethiopia. The prime selection criteria included rapid growth and groundcover, shade tolerance (suitability for intercropping) and high biomass yield. Accordingly, two cowpea accessions (Acc. 17216, Acc. 1286) and varieties (black-eyed pea and Kenkey) of cowpea and one lablab accession (Acc.1169) were selected for further scaling up. A well-organised and structured field evaluation was undertaken on sweet lupine genotypes in north-western Ethiopia. In this region, lupine is used for multiple purposes, such as human consumption, green manuring and forage. It can be produced on soils of low fertility with minimum agronomic management practices.

Four sweet lupine varieties were evaluated for dry biomass and seed yield on one research station and farmers' fields across different locations over several years. The varieties showed an average dry biomass yield ranging from 3.5 to 4.0 t/ha and seed yield ranging from 1.7 to 2.7 t/ha. Among the varieties, Sanbabor and Vitabor showed superior field performance across all test environments and had acceptable levels of crude protein (Figure 14.9 and Table 14.15). These two varieties were officially released and registered in 2014 for use by the farming community. This was the first release of sweet lupine varieties in Ethiopia.

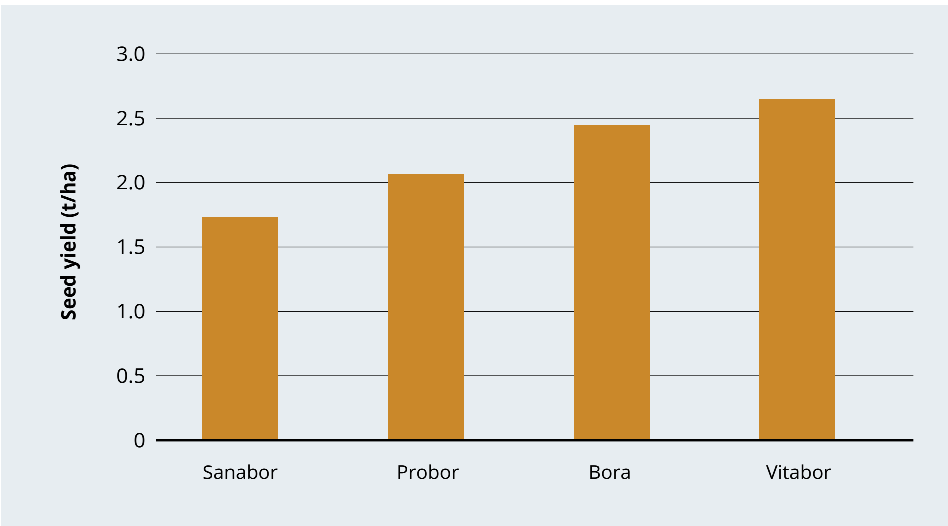


Figure 14.9 Seed yield of sweet lupine varieties evaluated across Ethiopia

Table 14.15 **Traits of Sanabor and Vitabor sweet lupine varieties**

Variety	Seed yield (t/ha)		Crude protein (%)	Maturity (days)	100 seed weight (g)	Height (cm)
	On-station	On-farm				
Sanabor	3.7	3.1	35	140	16.0	90
Vitabor	3.8	2.8	32	141	13.8	78

In another experiment, 12 white lupine accessions obtained from local collections were evaluated for seed yield at six different locations in north-western Ethiopia during the 2014–15 main growing season. The accessions included (as designated by the Ethiopian Biodiversity Institute) Acc. 242281, Acc. 238996, Acc. 238999, Acc. 236615, Acc. 239029, Acc. 239007, Acc. 242306, Acc. 239003, Acc. 239045, Acc. 239032, Acc. 207912 and a local accession. The seed yield ranged from 1.60 t/ha (Acc. 239045) to 2.44 t/ha (Acc. 238996), with a grand mean of 1.94 t/ha. Acc. 238996 (2.44 t/ha), local accession (2.22 t/ha), Acc. 239003 (2.12 t/ha) and Acc. 239029 (2.07 t/ha) had a higher seed yield (Table 14.16). Of all the environments, Debre Tabor (3.72 t/ha) and Injibara (3.43 t/ha) showed higher seed yields, whereas Dibate (0.75 t/ha) and Mandura (0.40 t/ha) had lower seed yields than the other locations (Table 14.16).

Table 14.16 **Mean grain yield of 12 white lupin landraces tested across six locations in Ethiopia**

Accessions	Mean grain yield (t/ha)						Mean
	Fenote Selam	Merawi	Debre Tabor	Injibara	Dibate	Mandura	
Acc. 242281	1.98	0.33	4.91	3.14	0.69	0.41	1.91
Acc. 238996	2.70	1.71	4.23	4.58	1.01	0.42	2.44
Acc. 238999	2.69	1.03	3.29	2.50	0.75	0.34	1.77
Acc. 236615	1.47	1.42	2.88	2.96	0.62	0.32	1.61
Acc. 239029	2.15	2.03	3.98	3.11	0.84	0.33	2.07
Acc. 239007	2.40	0.80	3.17	3.90	0.66	0.44	1.90
Acc. 242306	1.90	1.81	3.37	3.17	0.72	0.36	1.89
Acc. 239003	1.58	1.56	4.17	4.04	0.82	0.56	2.12
Acc. 239045	1.71	2.02	2.74	2.08	0.69	0.37	1.60

Seed production and dissemination of selected maize and legume varieties

Seeds of selected maize and legume crops were produced by different stakeholders and distributed to the farmers. Well-designed seed production planning systems, called seed road maps, were developed for selected varieties released before and during the SIMLESA program for seed production and scaling up. Bako, Hawassa and Melkassa Agricultural Research Centers were responsible for the production and supply of early generation seeds, while public and private seed companies and farmers' cooperative unions, such as Meki-Batu, were involved in the production and marketing of certified seeds. Two private seed companies (Anno Agro-Industry and Ethio VegFru PLCs) and four public seed enterprises (Amhara Seed Enterprise, Ethiopian Seed Enterprise, Oromia Seed Enterprise and South Seed Enterprise) were very active in seed production of maize hybrids identified by SIMLESA.

More than 30 t of breeder seeds were produced and supplied to seed growers to stimulate the seed production and dissemination systems. The seed companies were encouraged to produce required quantities of basic and certified seeds. Over the last seven years, nearly 300 t of basic seeds and 6,500 t of certified seeds (80% hybrids and 20% open-pollinated varieties) were produced and disseminated with the direct and indirect support of the SIMLESA program. The quantity of certified seeds produced under this program could plant 260,000 ha. Considering an allocation of 0.5 ha land for maize and a family size of seven people per household, the seed produced contributed to the food security of 520,000 households and more than 3.64 million people.

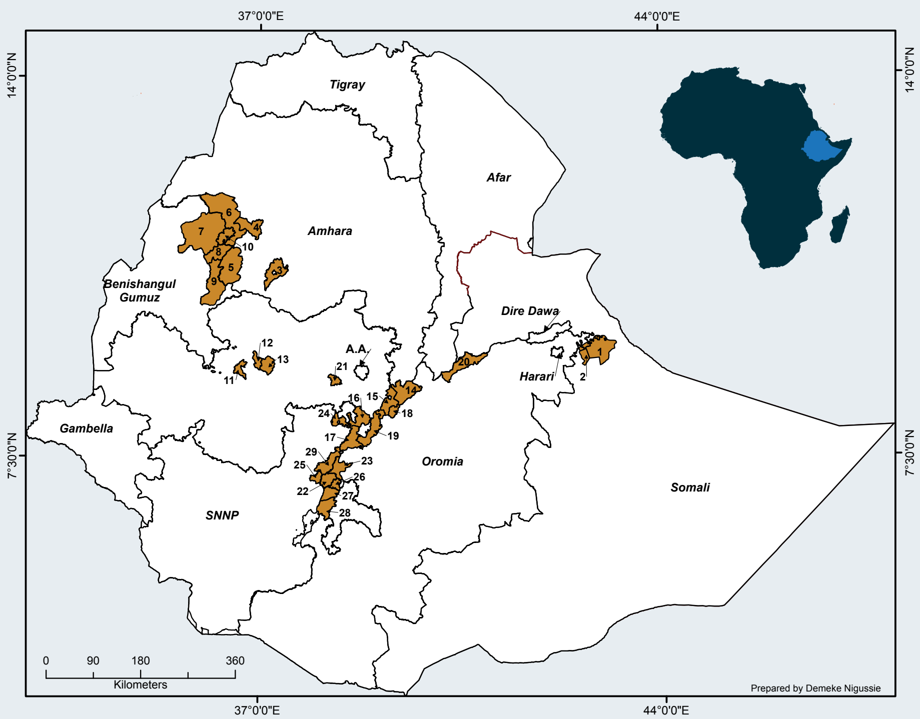
Taking SIMLESA output lessons to scale

On the basis of field research results from long-term on-station and on-farm trials across contrasting agroecologies, CASI practices tested by SIMLESA activities proved to be technically feasible and financially viable for smallholder farmers. These technologies were taken up for large-scale dissemination using different scaling-up and scaling-out approaches. In the first stage, demonstrations of best-bet technologies were conducted across varying agroecologies where SIMLESA hosting centres were operating. In collaboration with local extension institutions, CASI practices were promoted in villages through field days, exchange visits, printed extension materials and audiovisual media. A number of field days, demonstrations and training sessions were organised and 16,683, 1,564 and 3,596 stakeholders attended these events respectively over the period of seven years. Printed extension materials (leaflets, manuals, pamphlets and posters) were produced and disseminated. Audio and visual tools (TV and radio broadcasts) were also used for wider coverage of the scaling-out efforts. The media messages were broadcast in a number of languages, including Amharic, Afan Oromo and Somali.

Based on these experiences, a grant agreement was made with agricultural and natural resources departments in the zones to handle the dissemination of CASI practices using Ethiopia's highly structured and well-established extension system. Seven zones of agricultural and natural resource departments from Oromia, Amhara and SNNP regional states were involved in the SIMLESA-based best-bet practices scaling-out activities (Figure 14.10). These regional states represented the first three major maize- and legume-producing and densely populated regions, and constituted 80% of the population and 50% of the land mass. They contributed up to 96% of the production of maize–legumes (Central Statistical Agency 2015). In most cases, the identified scalable conservation agriculture best-bet practices and technologies under the scheme included:

- reduced/minimum tillage
- maize–legume intercropping
- legume–maize rotation
- herbicide application for weed control.

The financial and technical feasibility of these technologies and practices have been proven across the different agroecologies.



SIMLESA project area districts

1. Jijiga	6. Jawi	11. Wayu Tuqa	16. Dugda	21. Ilu Gelan	26. Hawassa Zuria
2. Gursum	7. Dangur	12. Gobu Seyo	17. Adami Tulu Jido K.	22. Siraro	27. Boricha
3. Jabitenan	8. Mandura	13. Bako Tibe	18. Dodota	23. Shala	28. Loko Abaya
4. South Achefer	9. Dibate	14. Boset	19. Zeway Dugda	24. Meskan	29. Halaba
5. Guangua	10. Pawe Spe.	15. Adama	20. Meiso	25. East Badawacho	

Figure 14.10 Major districts of the SIMLESA program implementation areas in Ethiopia

SIMLESA outputs also led to initiatives by the federal and regional offices of the agricultural and natural resource department to promote and scale out CASI best-bet practices in places where they best fit and enhanced the productivity and sustainability of maize and legume-based production systems. These include:

- The scaling out of maize–lupine intercropping in Amhara regional state. The local bureau of agriculture and natural resources included the practice in its extension package. Extension manuals were prepared in English and Amharic for extension agents and farmers.
- Reduced tillage initiatives by the Oromia Bureau of Agriculture and Natural Resources.
- The development of recommendation domains and manuals to practise CASI technologies in selected districts. The Federal Ministry of Agriculture established a unit to promote climate-smart agriculture and CASI practices tested by SIMLESA Ethiopia.
- The establishment of a country-level conservation agriculture taskforce to coordinate initiatives promoting the application of conservation agriculture practices by different institutes and organisations.

Gender roles in maize–legume production

A study on gender in the Central Rift Valley of Ethiopia showed that women contributed to household decision-making across maize and common bean value chains (Table 14.17) on issues of access to and control of tangible and non-tangible assets. The data show that the gap between men and women farmers' access to agricultural information was diminishing (as expressed by farming-related information from extension workers) and several important decisions were reportedly made jointly by both spouses.

Table 14.17 Access to resources and decision-making in Central Rift Valley in Ethiopia (*n* = 61)

Description	Gender/measure	Average/count
Age of the household head (years)		39 (±13)
Type of household	male-headed	54
	female-headed	7
Mode of main farmland acquisition	inheritance	39
	village allocation	21
	both	1
Land user decision-maker	men/husbands	32
	women/wives	6
	joint (spouse)	22
	husband's father	1
Male farmer usually obtains farming-related information from extension agent	yes	42
	no	19
Female farmer usually obtains farming-related information from extension agent	yes	36
	no	25
Women grow separate plots	yes	6
	no	54
Main decision-maker to grow maize	man	26
	woman	6
	joint	29
Main decision-maker to grow common bean	man	25
	woman	6
	joint	25

Source: Own field study, April 2017

Gender roles in maize and common bean production

Many crop production activities were jointly performed by men and women. Marketing was done by men and women, although the volume was higher for men while women sold lesser volumes at farm gate and village markets. Concerning control over crop production resources, the majority of households made joint decisions. Women controlled the income from crop sales in one-third of households, showing improvement in this aspect from what was commonly perceived as low or insignificant. There is, however, limited access to and control over productive resources (land and labour) among women in male-headed households. Likewise, access to extension services, training and market information was less common among female-headed households than male-headed households. This may hinder technology adoption, contributing to low production and productivity that may lead to limited market participation by women. Attention should be given to women in training and extension service provisions.

Women's and men's preferences and priorities varied. More women (both in female-headed and male-headed households) preferred maize (the major food crop) than men, while more men preferred common bean. Although maize and common bean were the major crops for food and cash, these crops are sold solely as grain in local markets to middle men or consumers. There was little opportunity to add value to maize and common bean through product processing, which could involve more women and youth. This needs attention from researchers and development practitioners. Decision-making about crop production (including seed selection, seed storage, land reparation, planting, disease and pest control, weeding, residue incorporation, harvesting, storing transporting and marketing) primarily involved adult males, with fewer adult females and children. Adult women participated more in planting, weeding, harvesting, seed, grain storage and marketing. Children contributed more during planting, weeding, harvesting and land preparation of maize and common bean production.

Conclusions

CASI practices in maize–legume systems across the different agroecologies in Ethiopia proved to be environmentally friendly and economically feasible. Maize grain yield was consistently higher under CASI systems compared to conventional practices. CASI practices considerably improved soil quality in terms of bulk density, organic carbon, infiltration rate and penetration resistance. As a result of improved soil quality, increased crop productivity was recorded across different agroecological conditions of Ethiopia. Likewise, a higher level of soil organic carbon was achieved in maize–common bean intercropping, sole common bean and common bean–maize rotations under CASI systems, compared to similar practices under conventional practices. Maize–legume intercropping systems under conservation agriculture considerably increased rainwater productivity. Both intercropping and conservation agriculture increased rainwater productivity, which translated into higher grain and stover yield advantages.

CASI was found to be vital for soil conservation by reducing soil erosion by water and wind. Crop residue retention with conservation agriculture reduced soil loss by nearly 100%. Reduced run-off from CASI fields resulted in higher rainwater use efficiency in moisture stress areas. Maize–legume production intensification proved to have multiple benefits in Ethiopia, including enhanced productivity, reduced downside risk in maize production on plots planted to improved maize and/or chemical fertiliser, and higher financial returns. The highest income was obtained when conservation agriculture practices were combined with improved crop varieties, which is directly correlated with CASI and crop system diversification.

A number of maize and legumes were selected and utilised by involving public and private partners in seed production and dissemination. Involvement of farmers in participatory variety selection was instrumental. Participatory variety selection was a tool to develop confidence among farmers as well as seed producers, which sped up the uptake of improved varieties. Farmers' variety selection criteria proved to be consistent with objective measurements adopted by breeders.

Adoption monitoring indicated that awareness of CASI technology was high. This was a result of hosting on-farm demonstrations, attending field days, participating in exchange visits and listening to media broadcasts. The most important CASI practices adopted by farmers were intercropping, minimum tillage and improved varieties. Improved varieties and minimum tillage were the technologies liked by most smallholder farmers. However, there were still challenges that hindered adoption of the technologies developed through SIMLESA, such as unavailability of herbicides, shortage of improved seed and livestock feed. There were also biophysical conditions, such as sealing of soils, which reduced the benefits of CASI practices in some parts of Ethiopia. More importantly, open grazing was a challenge for residue retention. This would need policy interventions at many different levels, from community to higher decision-making bodies.

CASI practices had a positive influence on sustainable crop production. Intercropping maize with common bean under CASI showed the high potential of avoiding crop production risks under variable and short rainfall, including drought years. Intercropping was more profitable than other CASI and conventional practices. In terms of labour demand, CASI reduced total oxen draught power compared to conventional practices, mainly due to reduced/minimum tillage and intercropping.

Many crop production activities were jointly performed by men and women. Marketing was done by men and women, although the volume was higher for men because women did less at the farm gate and village markets. Most households made joint decisions about crop production resources. Women controlled the income from crop sale in a reasonable proportion of households, showing improvement on previous reports of women's involvement (low or insignificant). Women in male-headed households, however, still had limited access to and control over productive resources (land and labour). Likewise, access to extension service, training and market information was less common among women than men. This may hinder technology adoption, contributing to low production and productivity that may lead to limited market participation by women. This calls for greater focus on women in training and service provision activities. Men's and women's preferences for crop production varied. Women (in both female- and male-headed households) had a stronger preference for maize (the major food crop) and men had a stronger preference for common bean.

Maize and common bean were the major food and cash crops in SIMLESA intervention areas. The crops, however, were sold solely as grain in local markets to middle men or consumers. There was little opportunity to add value to the crops through product processing, which involved more women and youth. This needs the attention of researchers, development practitioners and policymakers.

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15 Intensification of maize and legumes in Kenya

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Key points

- Conservation agriculture-based sustainable intensification (CASI) experiments were started in Kenya for maize and legumes with the objectives of increasing rainfed productivity by 30% and reducing downside risk by 30% for 100,000 small-scale households in one decade.
- Farmers identified their preferred maize, legume and pasture/fodder varieties and tested them under CASI practices and other agronomic practices and varieties. The yields of maize and legumes tripled and quadrupled among collaborating and neighbouring farmers respectively, compared to other farmers.
- Farmers realised labour savings of up to US$250/ha compared to conventional tillage methods of growing crops.
- CASI resulted in significantly more soil water at various depths and at harvest time, lower soil bulk density and higher microbial populations compared to conventional tillage.
- Profitability and sustainability of CASI and the advantages of innovation platforms in experimentation, solving farmers' problems and linking farmers to markets were evident lessons from this program.
- There is a need to embed CASI in Kenya's Climate Smart Agriculture Strategy to realise the benefits of increased farm profitability and environmental sustainability, and to also formulate supportive policy for innovation platforms to support farmers to address production constraints and link them to markets.

Introduction

For decades, maize and bean yields in Kenya have remained low, at 25% and 20% of potential yields, contributing to production risks for farmers. The SIMLESA program activities started in 2010 to address this problem. The objective was to increase productivity of maize and legumes by 30% and reduce downside risk by 30% in one decade for target communities. Key activities of the project were:

- participatory variety selection
- agronomic trials
- gender mainstreaming
- the development of innovation platforms.

An initial characterisation of maize and legume cropping systems was carried out to identify target communities. Participatory variety selection trials evaluated newly released and pre-release varieties of maize (47 varieties), legume (39 varieties), and fodder (12 varieties). Agronomic trials were conducted to evaluate and identify best-performing conservation agriculture-based sustainable intensification (CASI) practices. Production levels were compared for specific CASI practices for maize, legume and fodder production:

- zero tillage
- zero tillage with *Desmodium*
- furrows and ridges.

Farmers identified 14 maize, 23 legume and seven fodder varieties from the participatory variety selection trials, which they endorsed. Participating farmers also expressed support for all conservation agriculture options. Thirteen innovation platforms were initiated to build research capacity, support experimentation and scaling out of farmer-selected technologies and practices. Short-term training of Kenya Agricultural and Livestock Research Organization (KALRO) staff, partners and long-term training of four KALRO scientists was carried out.

Farmers shared information on the benefits of conservation agriculture-based sustainable intensification (CASI) practices. Gender mainstreaming was carried out through training of scientists and partners, resulting in more female participants than male participants. Maize and legume yields among participating and neighbouring farmers increased threefold and fourfold respectively when compared to non-participating farmers. Several scaling-out methods were tested and demonstrations were found to be the most effective. By 2017, poverty levels in the counties in which trials were implemented had not changed significantly compared to 2010. Proven technologies and CASI practices can be scaled out at economic corridor levels and more broadly to help meet production and poverty alleviation goals.

What was the situation in 2010?

Kenya has a surface area of 580,397 km^2 and a population of 50 million people (Worldometer 2017). The people are comprised of 42 ethnic groups, with the six largest ones accounting for 80% of the population. The country lies between 4.5°N and 4.0°S and 34°E and 42°E, spanning a highly varied agroecological zonation from coastal and inner lowlands to alpine. The coastal region and the area surrounding Lake Victoria experience a tropical climate.

The area on the slopes of Mt Kenya and Mt Elgon experience a temperate climate. A total of 18.4% of the land is high- and medium-potential, 8.5% is semi-arid and 53% is arid land. Twenty per cent of the land is very arid (Adimo 2017). Forty-nine per cent of the land is agricultural. The agriculture sector is the main driver of Kenya's economy and livelihoods for the majority of Kenyans. The sector contributes 26% directly to the gross domestic product, and a further 25% indirectly through linkages with agrobased and associated industries (KALRO 2017).

Maize is adaptable to a wide range of climate conditions, and is the most extensively grown crop in Kenya. Depending on variety, maize is grown in areas with as low as 750 mm rain per year to areas with as high as 2,200 mm rain per year (Kogo et al. 2019). Seventy-five per cent of the crop is produced by small-scale farms (less than 25 acres) located in all areas of Kenya where farming is carried out and 25% by large-scale farms located mainly in Trans Nzoia, Nakuru, Bungoma and Uasin Gishu counties (Kirimi 2012). Maize growing accounts for 56% of cultivated land in Kenya (Chumo 2013). It is grown by 98% of rural farm households (Government of Kenya 2011) and has a per capita consumption of 88 kg per year (Ariga, Jayne & Njukia 2010). Maize production by rural farm households has most typically been intercropped with legumes with little or no crop rotation (Micheni et al. 2015).

The most important legumes in Kenya, based on production volume, have been common beans, pigeonpea, cowpea and soybean, in order of decreasing importance. Legumes are a rich source of protein, typically eaten with maize, and have supplemented cereal carbohydrates to improve the nutrition profile of Kenyan diets. Legume and maize cropping systems have also complemented one another. For instance, beans have been harvested earlier than maize, providing a source of food and income before maize is ready for consumption. In 2010–14, maize and beans production satisfied 90% and 86% of demand, with the balance being imported. Pigeonpea and cowpea, however, exceeded consumption volumes by 75% and 60% respectively. As the most important crops in terms of production volume, and a main source of food and income for smallholder farmers in Kenya, maize and legumes provide a good entry point for improving land productivity, food security and welfare of farmers.

Average yields of maize and beans in Kenya in 2010 were 1.6 t/ha for maize and 0.5 t/ha for beans (Ouma et al. 2013). These yields were especially low relative to their potential yields of over 6.0 t/ha for for many drought-tolerant maize varieties (Abate et al. 2015) and 2.5 t/ha for beans (Karanja et al. 2008; Micheni et al. 2015). The yield gap has been attributed to low adoption of improved varieties and agronomic practices, declining soil fertility and poorly distributed rainfall, among other factors (Muricho et al. 2011). In 2011, 67% of farmers from western and eastern Kenya SIMLESA clusters planted hybrid maize while 31% planted lower-yielding recycled seed. Forty-four per cent of female farmers and 28% of male farmers from the same communities planted recycled maize seed that had been recycled by women and men for 11 and 8.5 seasons, respectively (Muricho et al. 2011). Most of the hybrid seed planted by farmers were older, less-productive hybrid varieties than more recently developed and released varieties.

In 2010, prior to their involvement in the SIMLESA program, many households practised management strategies with little production potential. Average fertiliser and seed rates were 40% and 47% of recommended levels, respectively. Farmers normally did not apply fertiliser on legumes. Only 1% of the farmers practised zero tillage on their farms. The major production constraints reported by households from western Kenya in 2011 were related to markets and soil fertility, such as high prices of fertiliser, lack of availability of fertiliser at the right time and lack of credit to buy fertiliser.

In eastern Kenya, farmers ranked drought and seed-related constraints as the most important maize production constraints. About 54.3% of households where SIMLESA activities were carried out had a daily per capita expenditure below the internationally defined poverty line of US$1 per day (Muricho et al. 2011). The Kenya SIMLESA program evaluated these production factors to identify opportunities for production gains and develop targeted strategies to support adoption. In 2017, the poverty levels (Answers Africa 2017) were the same as 2011 because SIMLESA and other KALRO-developed technologies had not been scaled out widely enough to have an impact on productivities and the incomes of farming communities.

Maize is the leading source of carbohydrates and legumes are the leading source of protein to the Kenyan population. However, most farmers practise mixed farming, where different crops and livestock are raised on the same farm. The types of crops grown and livestock kept depend very much on the agroecologies, but the number of different crops grown and livestock types kept are usually large. This is exemplified by KALRO Kitale research in the Mandate region, which found that 34 different crops, with many different varieties or cultivars, were grown and nine different livestock types kept (Nkonge et al. 1997). Many of the crops and livestock types are of little national economic value.

Some crops are grown for export purposes and others for local consumption. Livestock production is mainly for local consumption.

Crops grown mainly for export

Tea is the leading export earner for the country. It is grown in about 110,000 ha in the western and eastern highlands of Kenya, where there is adequate rainfall and low temperatures. Sixty per cent of the tea is produced by about 260,000 small-scale farmers, while large-scale tea estates produce the balance (Smart Farmer Kenya 2017).

Horticultural crops, mainly vegetables (spinach, cabbages, broccoli and kales), fruits (lemons, grapes, oranges and pineapples) and flowers (roses and orchids) are the second-largest agricultural enterprise in terms of foreign exchange earnings for Kenya. About 70% of the total revenue is accounted for by flowers alone.

Coffee in Kenya is typically grown on rich volcanic soils that are located at elevations of between 1,500 m and 2,100 on the slopes of Mt Kenya and Mt Elgon. As of 2015, coffee exports from Kenya made up approximately 20% of the country's total export earnings.

Crops grown mainly for local consumption

Irish potato is the second most important crop in Kenya after maize, in terms of consumption. It is grown by more than 800,000 farmers generating more than 50 billion Kenyan shillings (KSh) to the country within the local market (Soko Directory 2017). The crop is produced mainly in 13 counties of Kenya, including Bomet, Bungoma, Elgeiyo-Marakwet, Kiambu, Meru, Nakuru, Narok, Nyandarua, Nyeri, Taita-Taveta, Trans Nzoia, Uasin Gishu and West Pokot (Potato Farming in Kenya 2017). These counties have a temperate climate suitable for potato growing, with rainfall of 850–1,200 mm per year and altitudes of 1,500–2,800 m above sea level.

Wheat is the second most important cereal grain in Kenya after maize. Wheat farming in Kenya is largely done for commercial purposes on a large scale. Kenya is self-sufficient in the hard varieties of wheat, but is a net importer of the softer varieties. Wheat is mainly grown in the Rift Valley, in areas with altitudes ranging between 1,200 m and 1,500 m above sea level, and annual rainfall varying between 800 mm and 2,000 mm, with up to 2,500 mm on higher grounds (Shawiza 2016).

Rice is Kenya's third staple cereal after maize and wheat. Rice farming in Kenya is estimated at 33,000–50,000 Mt, while consumption is 180,000–250,000 t. About 95% of rice in Kenya is grown under irrigation in paddy schemes managed by the Kenya National Irrigation Board in eastern Kenya and Nyanza provinces. The remaining 5% is rainfed.

Livestock and crops sectors contribute 46% and 54% respectively to the agricultural gross domestic product. In Kenya, most meat and milk production is from cattle, goats and sheep and, to a small extent, camels. Poultry for meat and egg production is also an important sector and both indigenous and commercial chickens are kept.

Exotic dairy cattle for milk production are kept by both small-scale farmers and large-scale farmers who produce 80% and 20% of the milk respectively. Approximately 90% of the red meat consumed in Kenya comes from pastoralists who keep most of the indigenous cattle, sheep, goats and camels (Farmer & Mbwika 2012).

What did SIMLESA do?

Program objectives

To identify practices to enhance household maize and legume production systems, the International Maize and Wheat Improvement Center (CIMMYT) and regional networks with financial support from ACIAR formulated a CASI research program. The aim of the program was to increase the productivity of maize and legume-based farming systems under rainfed conditions by 30% and reduce the downside risk by 30% in at least 100,000 households in Kenya in one decade.

The program evaluated three principles of conservation agriculture:

- minimum soil disturbance
- crop residue retention on the soil surface
- crop rotation.

Minimum tillage and residue retention on the soil surface have reduced soil erosion from rainwater and wind and improved soil moisture retention, alleviating the adverse effect of low or poorly distributed rainfall for farmers in Kenya (Mo et al. 2016). Crop rotation has minimised the build-up of disease and insect pests in the soil and increased soil fertility. It is used to reduce pests and diseases in cropping systems and give better distribution of nutrients in the soil profile. Farmers opted to grow maize and legumes as intercrops instead of rotation as a way of intensification, due to the small sizes of their farms. Thus, maize was intercropped with legumes every season.

To achieve the program's set targets, research and scaling-out activities were planned and implemented under five broad themes:

- evaluate the dynamics and performance of CASI options for maize–legume production systems, value chains and impact pathways
- test and adapt productive, resilient and scalable CASI options for sustainable smallholder maize–legume production systems
- increase the range of maize, legume and fodder/forage varieties available to smallholder farmers
- support and development of local innovation platforms for scaling out
- build research capacity.

Program sites

Embu, Meru and Tharaka Nithi counties in eastern Kenya and Bungoma and Siaya counties in western Kenya were identified as the major maize and legume production areas with the greatest potential for increased yield. Strategic partnerships were established and historic production data were collected to characterise the maize and legume production systems in these regions and identify target communities.

A baseline study was conducted using primary data from farming households and secondary data from Ministry of Agriculture Livestock and Fisheries and other development organisations. Collection of primary data involved a three-stage sampling procedure to select the study households. First, the districts were purposively selected. Second, administrative divisions were randomly sampled. In the selected divisions, 88 villages were sampled, proportionate to the number of villages in the division. For the sampled villages, a random sample of households was selected proportional to the number of households in the villages. In total, 613 households comprising 494 male-headed households and 119 female-headed households were sampled. Enumerators were trained and involved in the collection of primary data through face-to-face personal interviews of household heads or, in their absence, senior household members well versed in farming activities. A structured questionnaire was used under the supervision of socioeconomists from the Kenya Agricultural Research Institute's Kakamega and Embu centres.

Data were collected regarding demographic and socioeconomic profiles of the households, resource endowments, adoption of maize and legume varieties, crop and livestock production systems, and input and output markets. The data were analysed by simple descriptive statistics (percentages, cross tabulations and means) to discern general characteristics of the data using the Statistical Package for Social Scientists (SPSS). Non-parametric analysis of the variables was done to test significance across the different comparison groups using chi-square and *t*-tests. Factor and cluster analysis methods were used to establish farm typologies using R-software.

Four clusters in each of the regions (eastern and western Kenya) were selected as research sites based on a review of historic production data and household surveys. Kyeni (Embu county) and Mweru (Meru county) in humid areas were identified in eastern Kenya. Two other sites, Mariani (Tharaka Nithi county) and Mworoga (Meru county) were earmarked for trials in subhumid ecologies in the same region. Likewise, Bumula and Kanduyi in Bungoma county in humid zones, and Karemo and Liganwa in Siaya County in the subhumid area were identified in western Kenya (Figure 15.1).

In these eight clusters, communities were further characterised through key informant discussions involving 302 female and 301 male farmers. The selected sites had maize and legumes as major enterprises and good potential for agriculture, with well-drained soils and relatively high rainfall of 1,100–1,600 mm per year, although poorly distributed (Jaetzold et al. 2005a, 2005b, 2006). Other regions in eastern and western Kenya had a bimodal rainfall pattern and two cropping seasons per year. The sites were densely populated and the majority of farmers practised mixed farming.

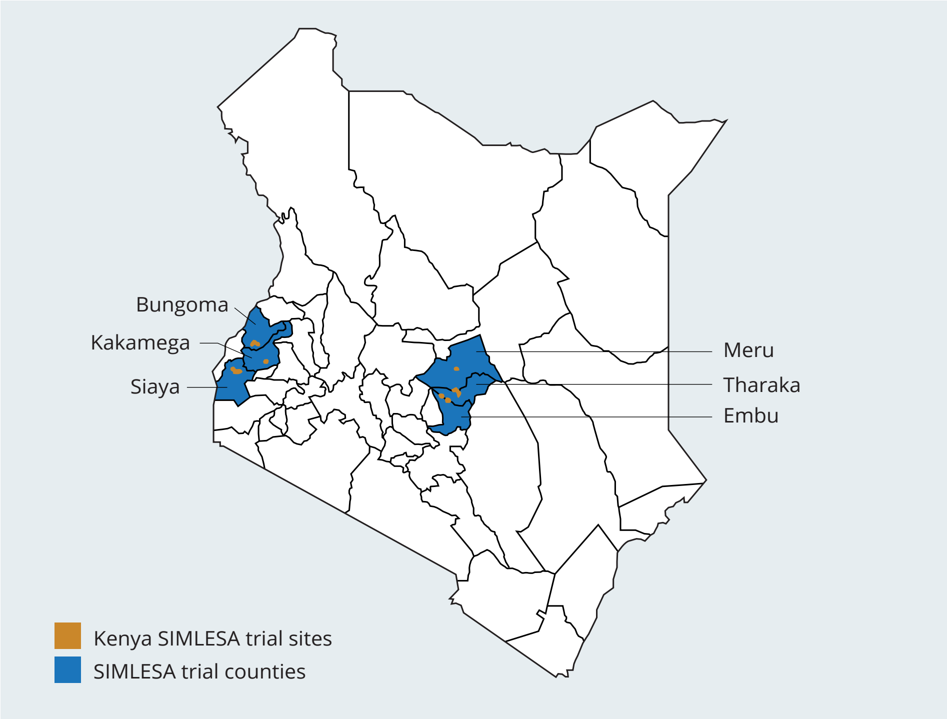

Figure 15.1 **SIMLESA trial sites in western and eastern Kenya**

Implementation

The Kenya SIMLESA program commenced implementation in 2010. At this stage, discussions were held with farmers and other key stakeholders, including provincial administration, Ministry of Social Services, Kenya Seed Company, Kilimo Salama Crop Insurance Company and Organic Africa (an input stockist). The discussions were focused on explaining the objectives and establishing roles and responsibilities for participatory field research activities.

The 2010 baseline survey included information on crop types and varieties grown, access to agricultural inputs and services, broad systemic constraints and options for field testing. These data established benchmarks against which the progress of program interventions could be evaluated. The survey findings were discussed in meetings with research and extension partners from the Ministry of Agriculture, farmers and community leaders. Farmers' views were solicited and included in the research agenda. Possible solutions to agricultural constraints were discussed and agreed upon in a participatory manner. Farmers and other stakeholders agreed to introduce and test new and more-productive maize, legume and pasture varieties under participatory variety selection trials, in which farmers selected preferred varieties using their own criteria.

Maize and legume varieties were tested as intercrops, a practice which was already popular among the farmers and under additional CASI practices. Six farmers per cluster were initially identified by other farmers to host experimental plots on their farms. The experimental plots were to be used for variety and CASI system testing, demonstrations, exchange visits and for learning purposes by other farmers within and beyond the sites. To address nonagronomic challenges, other stakeholders along the value chain were included as members of innovation platforms.

Participatory variety selections

More-productive newly released and pre-release maize, legume and fodder varieties were identified from the national research programs (Drought Tolerant Maize for Africa, International Maize and Wheat Improvement Center, International Crops Research Institute for Semi Arid Tropics, International Livestock Research Institute, Tropical Legumes 2, seed companies and Egerton University) in a participatory manner with farmers. A total of 47 maize[5], 39 legume[6] and 12 fodder[7] varieties were tested under the participatory variety selection approach. Multiple crops were evaluated in participatory variety selection trials. These included maize varieties under intercrops with common bean, pigeonpea, soybean, peanut and cowpea. These were tested under CASI systems in farmers' fields. Fertiliser was applied according to KALRO recommendations. Trials were carried out by farmers with support from research and extension providers. Evaluations were carried out separately by female and male farmers, and reports compiled. Researchers conducted separate evaluations. Data were triangulated to identify the best-performing varieties. The same studies were conducted on research stations.

The varieties preferred by farmers were used by researchers and seed companies to produce seed following well-defined seed road maps, which provided neccessary agreements with seed companies on the amount of seed to be produced for farmers within a specified period (Table 15.7). Basic seed was produced by researchers and given to seed companies to multiply seed for farmers.

Testing CASI options

Four CASI treatments were selected by farmers, researchers and extension staff for testing (Table 15.1).

1. Zero tillage that involved no land tillage, only making seed and fertiliser holes at specified spacing. Weeds were controlled using herbicides. Over 75% of the crop residues were left on the surface of the plots at the end of the season.
2. Zero tillage + *Desmodium* that involved no land tillage, only making seed and fertiliser holes at specified spacing. *Desmodium* was interplanted to control weeds and provide fodder for livestock. Over 75% of the crop residues were left on the surface of the plots at the end of the season.
3. Furrows and ridges that involved making furrows and ridges at the start with little maintenance in the follow-up seasons. Weeds were controlled using herbicides. Over 75% of the crop residues were left on the surface of the plots at the end of the season.
4. Conventional tillage that involved ploughing, harrowing and at least two stages of hand weeding to control the weeds. All crop residues were removed from the plots at the end of the season.

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5 **Maize varieties tested under participatory variety selection** KALRO Embu: KH500–39E, KH500–38E, KH631Q, Embu 225, Embu 226, Embu Synthetic, KDV1, KDV5, KDV6, DK 8033, MZ 1202(H529), 12 ML 1, Pioneer 2859W, Pioneer 30G19
KALRO Kakamega: KSTP 94, KH633A, IRWS 303, KAK SUT2, KM0403, H520, H624, KM0221, KH533A, GAF 4, DH014, KM0111, KM0311, KM1001, H527, KM0404, KM0406; commercial varieties: DK8031, H513, DH04, WH105, WH505; farmers' varieties: Nya Uganda, Obabari, Sipindi, Duma 49, Namba nane, Panadol, DK 8031, H614, Duma 43, H624, H513

6 **Legume varieties tested under participatory variety selection** KALRO Embu: bean (KAT B9, KAT B1, KATX 56, KATX69, Embean 14, KK8, KK15, Embean 7, Embean 118, Chelelang, KKRII05/Cal 130, Ciankui, Tasha, KAT RM-01, KKRII05/cal 14B); pigeonpea (KAT60/8, ICEAP 00554, 00040, 00850, 00557, KAT60/8, CPL 87091); cowpea (K80, M66, KVU-27–1); farmers' varieties: bean (Mwitemania); pigeonpea (Kendi, Ndombolo)
KALRO Kakamega: bean (KK8, kk071, kk072, kk15, kk20, Emben 14, KAT B9, KAT B1, KATX 56, KATX69, KK Rosecoco, KK Red Bean 16); soybean (SB19, SB 25, SB3, EAI3600); peanut (ICGV-SM 99568, ICGV-SM-12991, ICGV-SM-90704); farmers' varieties: beans (Nya seje, Rosecoc); peanut (Red Valencia)

7 **Fodder varieties tested under participatory variety selection** Sorghum (E6518), vetch, *Calliandra calothyrsus*, *Morus alba* (mulberry), *Leucaena trichandra*, *Brachiaria decumbens* (Basilisk), *Brachiaria brizantha* (Toredo), *Brachiaria brizantha* (Piata), green-leaf *Desmodium*, silver-leaf *Desmodium*, *Dolichos lablab*, dual-purpose cowpea

Recommended rates of fertiliser were applied in all treatments. For maize, 60 kg N and 60 kg P205 were applied per hectare. For legumes, 20 kg N was applied per hectare.

Table 15.1 **Tillage methods selected by farmers for testing**

Tillage method	Land preparation	Weed control	Residue management	Example
Zero tillage	only seed and fertiliser holes made	herbicides used as needed	over 75% retained on soil surface	
Furrows and ridges	furrows/ ridges made at the start and maintained thereafter with minimal repairs	herbicides used as needed	over 75% retained on soil surface	
Zero tillage and *Desmodium* intercrop	only seed and fertiliser holes made	herbicides used at first season before planting	over 75% of maize and bean residue retained on soil surface, *Desmodium* fed to livestock	
Conventional tillage	land dug by hand followed by planting of seed and fertiliser	two hand weeding sessions	all residue removed and fed to livestock	

Adoption monitoring of SIMLESA technologies

Adoption of technologies and practices in SIMLESA was evaluated through surveys carried out by the Adoption Pathways Project in collaboration with SIMLESA scientists. The Adoption Pathways Project was supported by the Australian International Food Security Centre. In 2012–13, the first adoption survey was carried out. The objective of the survey was to estimate the number of farmers who had heard of and adopted SIMLESA technologies or practices since 2010. A snowball/chain sampling technique was used. The method started by interviewing first-generation farmers (i.e. host farmers), members of innovation platforms and agricultural extension officers in SIMLESA clusters. The first-generation farmers and agricultural extension officers provided a list of second-generation farmers (i.e. farmers they had trained in issues related to SIMLESA activities, or who had participated in the field days or visited experimental plots, and were practising SIMLESA technologies). The second-generation farmers supplied a list of other farmers who were implementing SIMLESA activities. A total of 4,503 farmers were interviewed. A second adoption study was undertaken in late 2015 in eastern Kenya, within the program sites in the three counties of Embu, Meru and Tharaka Nithi. A total of 100 female and 76 male farmers were interviewed.

Capacity building

Building credentials

Researchers and partners were trained in different areas and disciplines as listed below. Training was conducted by the program locally, while other sessions were held in Tanzania, Zimbabwe and by the Agricultural Research Council of South Africa. Apart from short courses, one Kenyan received support to enrol in an Master of Science and three Kenyans received support to enrol in PhD programs and conduct SIMLESA research. Of the three PhD programs, one student successfully graduated in July 2015.

Gender mainstreaming

Four female and two male scientists were trained in four gender mainstreaming workshops in 2011 and 2012. Each training took a week, on average, and included a field practical. Scientists trained others and, with the trainees, recorded gender-responsive and gender-sensitive data during planning, implementation and evaluation of technologies. Documentation of five gender study cases of good practice was carried out (CIMMYT-ACIAR 2013).

Monitoring and evaluation training

Four researchers built their capacity in monitoring and evaluation in four training workshops in 2011 and 2012. The trainings were carried out in Kenya and Tanzania and lasted about three days each. Researchers used their acquired skills to develop gender-responsive key performance indicators that were used to monitor the progress of SIMLESA program implementation.

APSIM model training

Two officers were trained on crop systems research in farm typology modelling and the Agricultural Production Systems sIMulator (APSIM) model. Crop simulation models were used to calibrate data from targeted areas to assess the production, profitability and riskiness of certain identified production strategies. Data for the calibration of the APSIM model were obtained from existing national climatic databases, and supported by soil and cultivar information.

What did we learn?

Baseline survey and farming systems characterisation

Of the 613 households that were interviewed, 119 were female-headed and 494 were male-headed. Farming was the main occupation (74.2%) of the household heads. The average farm size in the five counties (Embu, Meru, Tharaka Nithi, Bungoma and Siaya) was 1.20 ha/household and this did not differ significantly between the counties. The crops grown by most farmers were maize and legumes. About 76% of the surveyed households fed crop residues to their livestock and 65% used livestock manure on their farms. This flow of resources across crop and livestock systems required an integrated approach to crop and livestock research.

The three most important maize production constraints reported by the surveyed households were high fertiliser prices, drought and high prices of improved seeds. This informed ongoing research into alternative sources of crop nutrients, high-yielding and drought-tolerant maize and legume varieties and strategies to increase access to affordable seed (e.g. community-based seed production).

The statistics that summarise the entire SIMLESA research area population provided a broad understanding of household production systems in Kenya (Table 15.2). Household typologies were developed to understand the diversity and major sources of socioeconomic disparity among the population of SIMLESA farmers. Households fell into one of six farm typologies based on factors identified from baseline survey data and focus group discussions (Figure 15.2) (Wilkus, Roxburgh & Rodriguez 2019). As a result of the factor and cluster analysis method used to establish typologies, households within a farm typology had similar socioeconomic characteristics. These similarities suggest that households within the same typology would benefit from similar technologies. CASI technologies were therefore evaluated and developed for specific typologies that could be targeted when promoting technologies.

Table 15.2 Household characteristics in Kenya

Cluster variables	Frequencies (%) or cluster medians (standard deviations)			
	1	2	3	*P*-value[a]
Western Kenya				
Farm size (ha)	3.0 (3.9)	1.5 (1.1)	1.3 (1.3)	>0.000***
Household size (adult male equivalent)	4.5 (2.0)	2.4 (0.7)	2.5 (1.4)	>0.000***
Sheep or goats (head)	4 (3.7)	1 (1.3)	2 (2.3)	>0.000***
Household assets (KSh1,000)	44 (115)	19 (35)	11 (17)	>0.000***
Sampled population (%)	40	40	20	-
Female-headed (%)	18	16	30	0.118
Reliant on cropping (%)	23	24	23	0.950
Reliant on off-farm work (%)	71	78	82	0.083.
Reliant on non-cropping farming (%)	31	24	23	0.222
Age of household head (years)	53 (14)	42 (14)	58 (15)	0.653
Highest education of household head (years)	8 (3.9)	8 (2.9)	2 (2.1)	>0.000***
Household income (KSh1,000)	143 (913)	60 (325)	37 (203)	0.000***
Eastern Kenya				
Farm size (ha)	1.5 (1.4)	2.1 (1.3)	5.4 (3.7)	>0.000***
Household size (adult male equivalent)	2 (0.7)	3.6 (1.4)	3.5 (1.5)	>0.000***
Maize area (ha)	0.2 (0.2)	0.1 (0.2)	0.6 (1.1)	>0.000***
Sheep or goats (head)	3 (1.7)	3 (2.0)	8 (3.6)	>0.000***
Cattle (TLU)	0.5 (0.5)	1.4 (0.7)	1.4 (1.0)	>0.000***
Sampled population (%)	60	29	11	-
Female-headed (%)	23	17	9	0.036*
Reliant on cropping (%)	51	51	59	0.759
Reliant on off-farm work (%)	66	66	44	0.047*
Reliant on non-cropping farming (%)	26	26	35	0.434
Age of household head (years)	45 (15)	52 (12)	54 (14)	>0.000***
Highest education of household head (years)	7 (4)	8 (4)	7 (4)	0.865
Household income (KSh1,000)	67 (211)	134 (1,789)	225 (440)	0.027*

Notes: TLU = tropical livestock unit. 1 TLU is equivalent to livestock weight of 250 kg. The conversion factor varies according to the livestock type: 1 ox = 1.12 TLU, 1 cow or heifer = 0.8 TLU, 1 sheep = 0.09 TLU, 1 goat = 0.07 TLU, 1 horse = 1.3 TLU, 1 mule = 0.90 TLU, 1 donkey = 0.35 TLU. a = ANOVA test (*, **, *** for *P*-value <0.05, 0.01 and 0.001 respectively).

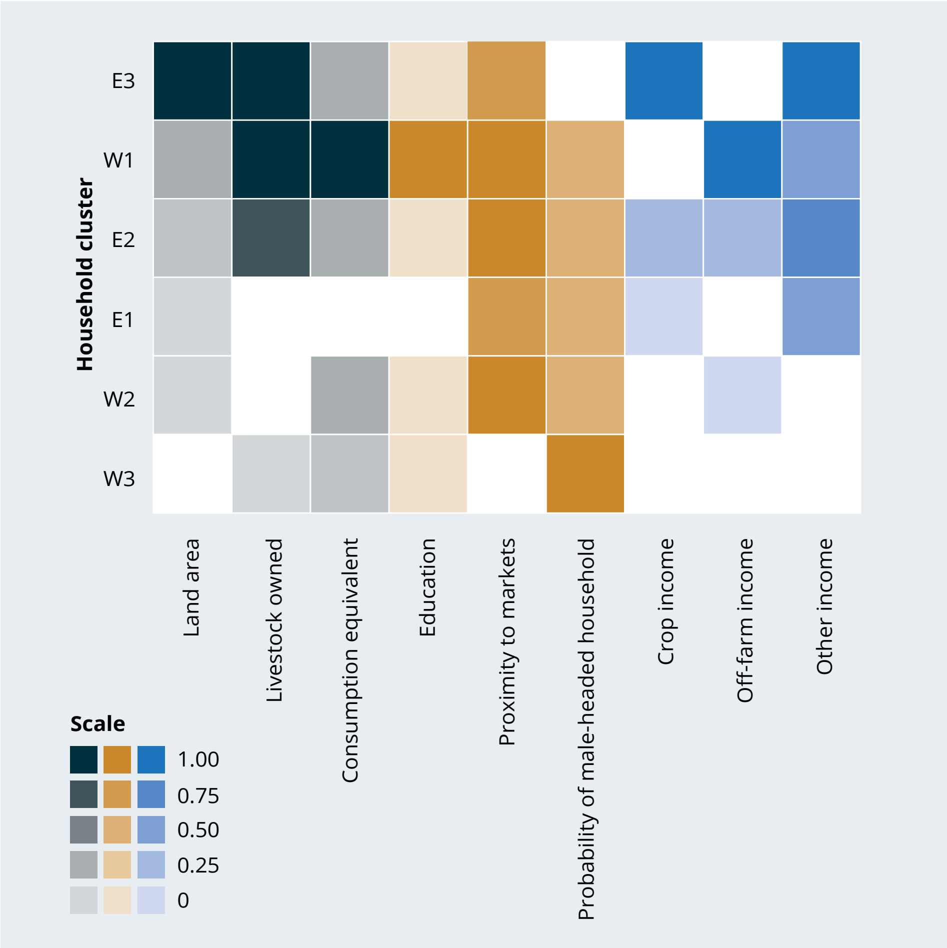

Figure 15.2 **Heat map of the characteristics and livelihood strategies of farmer groups from western (clusters W1, W2 and W3) and eastern Kenya (clusters E1, E2 and E3)**

The intensity of colour indicates the value of the farm system variable for a household group relative to other groups (0–1, light to dark, respectively). Three types of farming system variables were used: food availability levels (black), social mobility factors (orange) and sources of income generation (blue). Food availability variables were the median values for land area, tropical livestock units and consumption equivalents within each group. The social mobility factors were median education level (years of formal education), proximity to markets (walking minutes) and the probability of being a male-headed household within the group. Income generation components were median income levels from crop sales, off-farm activities and other non-crop farm sales.

Source: Wilkus, Roxburgh & Rodriguez 2019

Participatory variety selection trials

Farmers identified 14 preferred maize varieties (Table 15.3) in participatory variety selection trials from the 47 varieties tested. Farmers preferred varieties for different reasons, and female and male farmers did not always rank varieties the same way.

Table 15.3 Maize varieties selected and endorsed by farmers

Variety	Hybrid/OPV	Source	Reasons for selection
Eastern Kenya			
PHB 30G19	hybrid	Pioneer Seed Company	high yields (>5 t/ha), double cobs, well-filled grains and low ear placement
PHB P2859W	hybrid	Pioneer Seed Company	early maturity (approximately 120 days), high yields (>5 t/ha), drought-tolerant
KH500–39E	hybrid	KALRO	high yields (4.5–5 t/ha), well-filled cobs, heavy grains, good husk cover
KH500–38E	hybrid	KALRO	moderately high yields (4.5–5 t/ha)
H529	hybrid	Kenya Seed Company	high yields (>4.5 t/ha), good roasting and cooking qualities
DK 8031	hybrid	Monsanto	high yields (>4.5 t/ha)
Emb 225	OPV	KALRO	high yields (>4 t/ha), early maturing, drought-tolerant, good roasting quality
Emb 226	OPV	KALRO	early maturing
KDV 1	OPV	KALRO	early maturing, drought-tolerant, high yields
KDV 5	OPV	KALRO	early maturing (up to 90 days), high yields (>4.0 t/ha), drought-tolerant
KDV 6	OPV	KALRO	early maturing (<95 days), high yields (>4.0 t/ha), drought-tolerant
Western Kenya			
H520	hybrid	Kenya Seed Company	high yields, big cobs, not dented, white kernels
KH633A	hybrid	KALRO	early maturing
KSTP 94	OPV	KALRO	tolerance to striga weed, high yield

Note: OPV = open-pollinated variety

Farmers endorsed 24 legume varieties (Table 15.4) from the 42 varieties tested. Criteria for endorsing a given variety included early/medium maturity, grain colour, high grain yield and level of disposal (consumption/marketing).

Table 15.4 Legume varieties endorsed by farmers

Variety	Legume type	Source	Reason for selection/preference
Chelalang	bush bean	Egerton University	high yields, early maturing
KK Rosecoco 194	bush bean	KALRO Kakamega	high yields, tolerant to root rot, appealing colour
Ciankui	bush bean	Egerton University	early maturing, high yields, fast cooking
Tasha	bush bean	Egerton University	early maturing, disease- and insect-tolerant
KK Red Bean 16	bush bean	KALRO Kakamega	high yields, tolerant to root rot, appealing colour
KK8	bush bean	KALRO Kakamega	high yields, tolerant to root rot
KK15	bush bean	KALRO Kakamega	high yields, tolerant to root rot, good for food security because of low marketability
Embean 14	bush bean	KALRO Embu	high yields, early maturity, good taste, very marketable
KAT X69	bush bean	KALRO Katumani	high yields, withstands heavy rains, marketable
Ndombolo	pigeonpea	local (Meru) variety	high yields
Kendi	pigeonpea	local (Meru) variety	highly drought-tolerant, cooks fast, high yields, withstands heavy rains, marketable
KAT 60/8	pigeonpea	KALRO Katumani	high yields, withstands heavy rains
ICEAP 00554	pigeonpea	ICRISAT	high yields, withstands heavy rains, marketable
ICEAP 00850	pigeonpea	ICRISAT	high yields, withstands heavy rains
ICEAP 00040	pigeonpea	ICRISAT	early maturity, high yields
ICPL87091	pigeonpea	ICRISAT	large-seeded, high yields, withstands heavy rains
ICGV 99568	peanut	ICRISAT	large grain, good for roasting, good taste
ICGV 90704	peanut	ICRISAT	large grain, good for roasting
ICGV12991	peanut	ICRISAT	good for butter processing
SB 19	soybean	CIAT	high yields, does not lodge
M66	cowpea	KALRO Katumani	dual purpose, high yields, good for intercropping, highly drought-tolerant, cooks fast
M80	cowpea	KALRO Katumani	dual purpose, resistant to aphids, highly drought-tolerant, marketable
KVU-27–1	cowpea	KALRO Katumani	dual purpose, moderately resistant to aphids, highly drought-tolerant, marketable

Testing of fodder/forage crops for feeding livestock started in 2015 with the aim of providing alternatives to maize and legume crop residues. Out of 12 fodder varieties that were tested and promoted, seven varieties were preferred by farmers (Table 15.5). From the set of preferred varieties, three different *Brachiaria* varieties were distributed to 54 women and 27 men farmers in eastern Kenya by December 2016. Preliminary *Brachiaria* feeding trials by farmers showed increased milk production from 0.5 l/day to 1.5 l/day. Biomass yields for *Brachiaria* grasses were 50% more than that of Napier grass.

Table 15.5 **Fodder varieties endorsed by farmers**

Variety	Type	Source	Reason for selection/preference
Brachiaria decumbens (Basilisk)	fodder	ILRI	high biomass, easy to carry compared to Napier, high milk increase, good in soil conservation
Brachiaria brizantha (Toredo)	fodder	ILRI	high biomass, easy to carry compared to Napier, high milk increase, good in soil conservation
Brachiaria brizantha (Piata)	fodder	ILRI	high biomass, easy to carry compared to Napier, high milk increase
Calliandra calothyrsus	fodder	KALRO	3 kg of fresh *Calliandra* had the same effect as 1 kg of dairy meal in milk production (Paterson, Kiruiro & Arimi 1999)
Leucaena trichandra	fodder	KALRO	milk increase when fed to dairy cattle, palatable and liked by animals, easily adaptable, drought-tolerant
Morus alba (mulberry)	fodder	KALRO	milk increase when fed to the dairy cattle, palatable, liked by animals, easily adaptable, drought-tolerant
Desmodium	fodder	KALRO	substitute for maize residue, increased milk production

Results from maize, legume and fodder varieties selected and endorsed by farmers showed that farmers' preferences are highly variable and could not be satisfied by a few varieties. Yield, early maturity, drought tolerance, insect- and disease-tolerance, colour of grain, volume of grain that fills a 50 kg or 90 kg bag, cooking qualities, taste and marketability were characteristics that different farmers valued when selecting varieties. Farmers did not value characteristics the same way. Female and male farmers' selection criteria were not always similar. While women tended to value qualities that impacted the end user, like taste, cooking and roasting qualities and grain colour more than yield, men were more concerned with yield as it translated to higher returns. Fodder forage species were equally appreciated by female and male farmers for their fast growth rates and higher biomass.

CASI practices endorsed by farmers

Irrespective of management practice, maize and beans yields of the SIMLESA program participants and neighbours of participants were significantly higher (4.5 t/ha and 2.0 t/ha respectively) than yields of nontrial farmers (1.6 t/ha and 0.5 t/ha respectively). This was attributed to the use of more-productive newly released varieties, correct rates of fertilisers, correct seed rates, timely control of weeds and control of disease and insect pests. This increase in yield represented 300% for maize and 400% for beans in the SIMLESA clusters and the neighbouring farms.

Maize and bean yields obtained under zero tillage, furrows and ridges and conventional tillage were not significantly different (Figures 15.3 and 15.4).

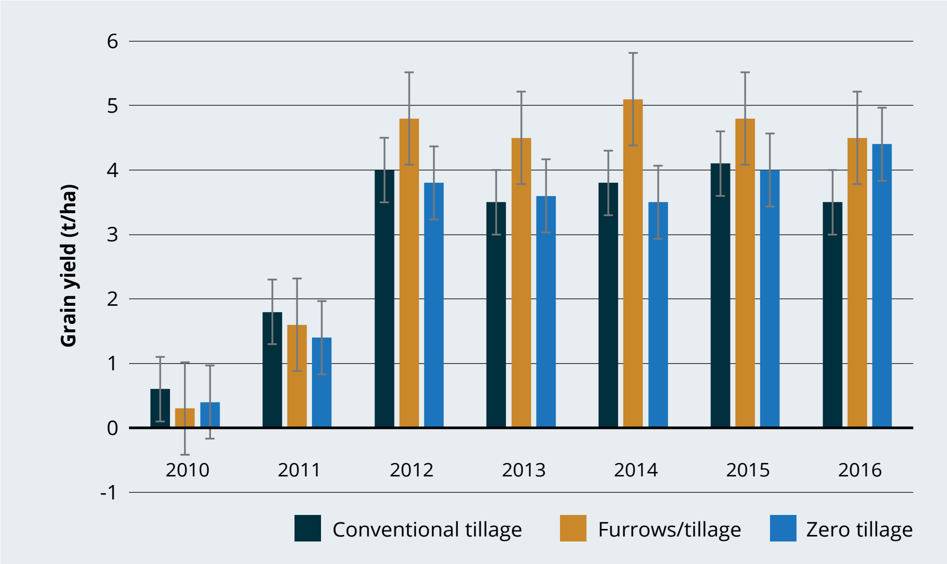

Figure 15.3 **Average annual maize grain yield under different tillage practices in eastern Kenya SIMLESA sites, 2010–16**

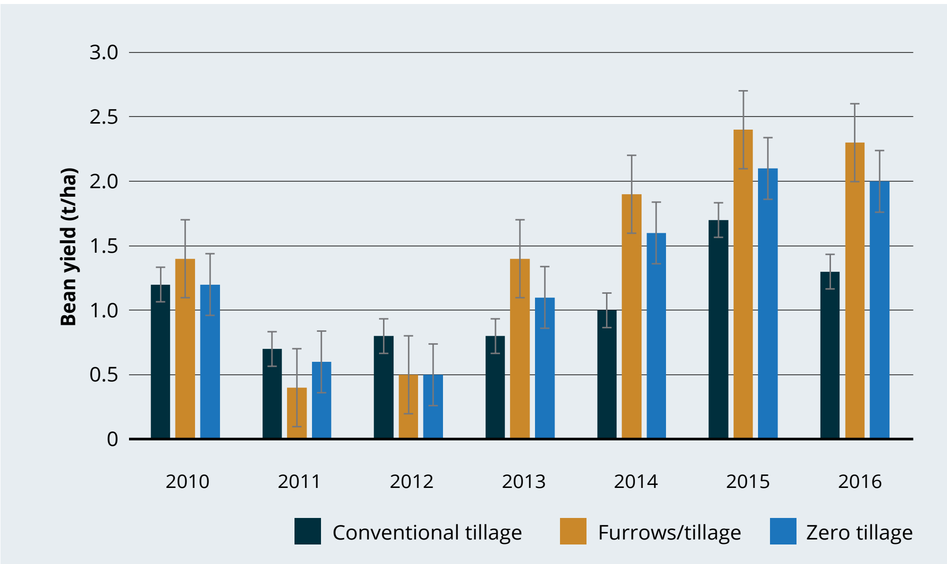

Figure 15.4 **Average annual bean yield under different tillage practices in eastern Kenya SIMLESA sites, 2010–16**

Returns on labour, and therefore profitability, CASI practices were significantly higher than conventional tillage. Labour costs associated with zero tillage and furrows and ridges were US$800–$1,200/ha (Figure 15.5). Conventional tillage in eastern Kenya involved hand digging before planting followed by two hand weeding sessions. In CASI systems (zero tillage and furrows and ridges), herbicides replaced hand digging and weeding. The cost of furrows and ridges were only significantly higher than zero tillage in the first season (2010), when the furrows were newly made. However, yield levels under zero tillage compared to furrows and ridges were not significantly different for each season from 2010 to 2016. Although the yields of maize for different tillage methods were not significantly different, farmers realised much higher returns from zero tillage and furrows and ridges due to their higher labour cost saving.

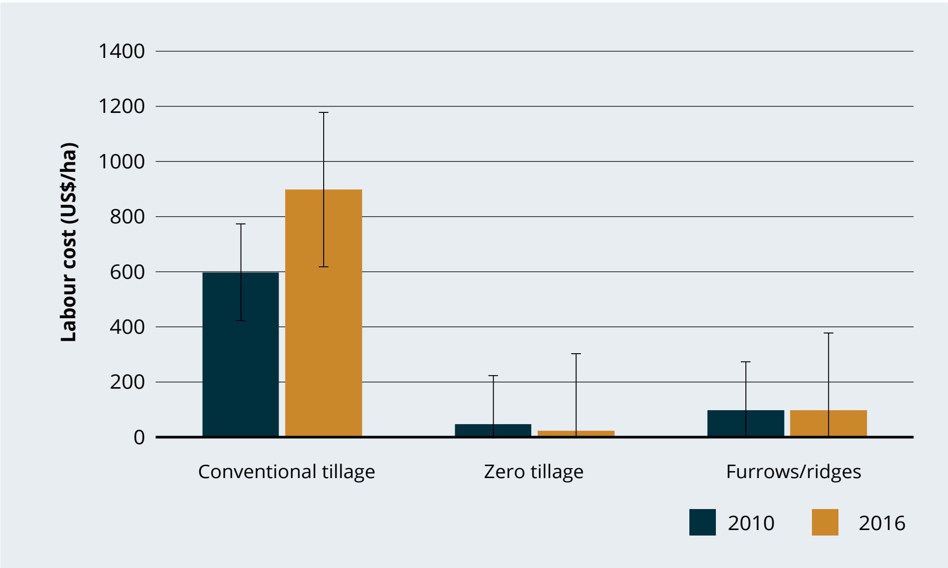

Figure 15.5 **Labour costs of different tillage practices in eastern Kenya**

The average crop water use efficiency for the three tillage methods is shown in Figure 15.6. The first year of experimentation did not have mulches on the CASI plots. This may be why CASI treatments did not have an advantage over the conventional tillage practice on moisture capture. Enhanced crop water use efficiencies were observed later under the CASI treatments, during subsequent years of the study. This is when adequate residues had accumulated under the CASI treatments and therefore more moisture retention was achieved. All seasons from 2011 recorded significantly higher crop water use efficiency (above 7.0 kg/ha/mm) for the furrow and ridge treatment compared to less than 6.1 kg/ha/mm for conventional and zero tillage systems. Related studies showed that utilisation of resources by crops is greatly affected by weeds when the crop and weeds compete for light, nutrients and moisture. Better weed control under the CASI treatments, using pre- and post-emergence herbicides, might have greatly improved crop water use efficiency.

The effect of three tillage practices on soil moisture at 0–15 cm soil depth at harvest time was tested for six seasons in the semi-arid areas of eastern Kenya. In the fourth season, the tillage methods were already significantly different from each other, with the furrows and ridges retaining the highest amount of moisture.

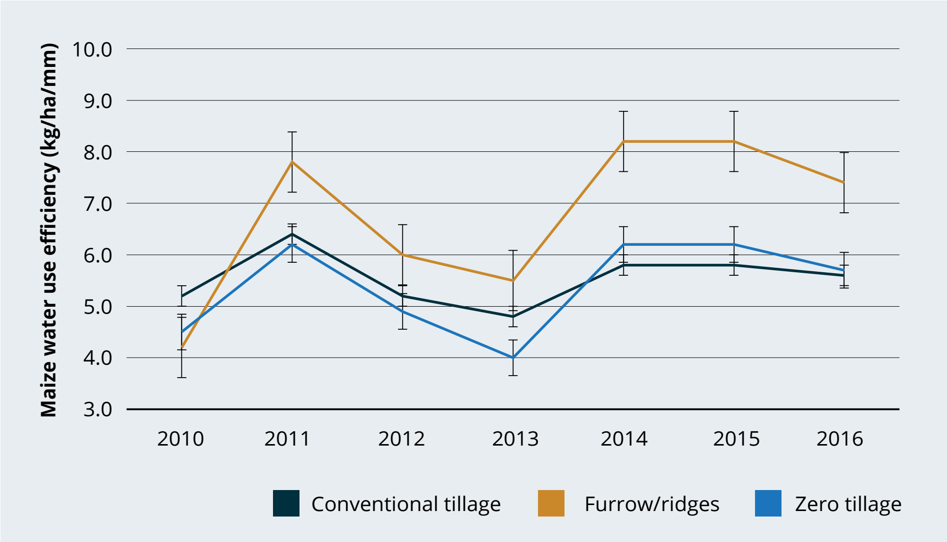

Figure 15.6 **Effect of tillage practices on crop water use efficiency in eastern Kenya**

Maize and legumes on furrows and ridges were more tolerant to drought than in zero tillage or conventional practice. This was explained by the higher average moisture levels of furrows and ridges compared to zero tillage or conventional practices. Residual moisture could be exploited by growing a short-maturing and less-water-demanding crop, such as cowpea, leading to increased productivity.

Furrows and ridges had significantly lower bulk density than either zero tillage or conventional tillage (Figure 15.7). Lower bulk density increased crop yield.

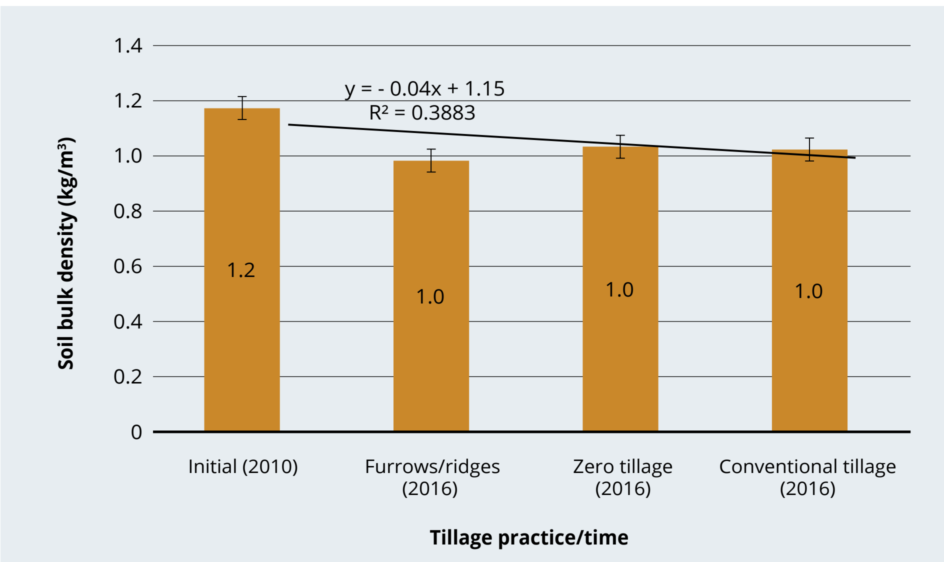

Figure 15.7 **Effect of tillage practice on soil bulk density in eastern Kenya, 2010 and 2016**

Farmers expressed positive impressions of all three CASI practices that were evaluated in farmers' experimental plots. Preferences tended to depend on the gender of the farmer. Female farmers preferred zero tillage over the other CASI practices because it decreased labour demand. In contrast, male farmers preferred furrows and ridges over the other CASI options because it performed the best under drier conditions.

What was the impact?

Innovation platforms

By 2014, the number of innovation platforms had grown to 13 and the stakeholders who were members had grown to more than 40. The innovation platforms that were developed contributed to high levels of farmer involvement in research and knowledge-sharing. Farmers were involved from the initial stage of program implementation in the identification of farming challenges and opportunities, and in selecting farmers to act as hosts for agronomic trials. After establishing trials, farmers and members of the local innovation platforms were instrumental in conducting seasonal monitoring and evaluation with the aim of quantifying the effects of CASI practices on crop performance, soil fertility improvement and weed management. Farmers arranged and hosted field days for wider scaling out of SIMLESA technologies and knowledge as well as training other farmers on CASI principles and practices. Farmers shared information on the benefits of CASI practices.

The partnerships developed under the innovation platforms contributed to:

- exchange of agricultural knowledge from research to farmers
- ongoing management and evaluation of technologies (i.e. adaptive learning)
- scaling out of crops and livestock technologies
- exchange of supply-and-demand information between farmers and input and output markets.

These functions of social networks facilitated rapid community mobilisation, networking, synergy creation and self-driven interventions. Within the innovation platform framework, farmers and other stakeholders acted as agents of change, filling the gap of the limited extension services and increasing awareness of improved technologies, increased adoption, increased scaling out and productivity. Dialogue within the innovation platform framework increased community visioning with set targets for improved productivity and marketing, and created opportunities for producers to spearhead field days, education tours and other scaling-out activities.

Scaling out of technologies and practices in SIMLESA was carried out through demonstrations, farmer field days, exchange visits, agricultural shows, innovation platforms, partner extension systems, seed road maps, partner non-government organisations, faith-based organisations, community-based organisations and selected partners through competitive grant systems. The various components that were scaled out are shown in Table 15.6. Most of the set targets were exceeded.

Table 15.6 Scaling out of SIMLESA technologies and activities

Research aspect	Target by 2016	Achieved
Number of farmers reached	11,500 farmers	7,000 women; 11,000 men
Number of farmers who adopted SIMLESA technologies	958 women; 4,082 men	2,066 women; 1,401 men
Number of maize–legume farming communities selected	48	51
Number of communities characterised on socioeconomic and biophysical profiles	15	72
Number of long-term trials established	2	5
Number of best-bet options tested	4	6
Number of best-bet options selected for scaling out	2	3
Number of farmers trying out conservation agriculture-based experiments on their own fields documented	340	2,669 women; 1,766 men
Number of new maize varieties identified and evaluated	no target	47
Number of new maize varieties endorsed through participatory variety selection procedures	3	14
Amount of seed of new maize varieties produced and distributed to partners	0.15 t	8.25 t
Number of new legume varieties identified and evaluated	no target	42
Number of new legume varieties endorsed through participatory variety selection procedures	2	23
Amount of seed of new legume varieties endorsed through participatory variety selection procedures	0.3 t	12.71 t
Number of new fodder varieties identified and evaluated	no target	12
Number of new fodder varieties endorsed by farmers	no target	7
Number of seed companies the country team working with	no target	8
Number of innovation platforms formed	8	13
Number of functional innovation platforms	8	11
Number of farmers reached by innovation platforms (approximate)	no target	1,600
Number of farmers reached through field days	12,000	11,497 women; 7,405 men
Number of exchange visits conducted	approx. 6	4
Number of stakeholders participating in exchange visits	149 women; 191 men	156 women; 169 men

Development of seed road maps

To provide enough quantities of seed of the maize and legume varieties selected by farmers, scientists from KALRO agreed on seed road maps with seed companies and provided them with basic seed to multiply for farmers. The amount of seed produced through the seed road maps is shown in Table 15.7. The seed companies that participated in seed road maps and the varieties they multiplied are shown in Table 15.8.

Table 15.7 Seed road maps showing the type and amount of seed produced

	2010–11	2011–12	2012–13	2013–14	2014–15
Breeder seed production	EML 1: 40 kg	EML 1: 450 kg			1.16 t
Pre-basic and basic seed production	EML 2: 200 kg EML 3: 200 kg	EML 1: 4.5 t EML 2: 2 t EML 3: 2 t	EML 1 × EML 2: 6 t		1.2 t pre-basic 1.8 t basic All by KSU
Certified seed production				Production: 17 t of KH 500-39E in March 2014	55 t • 25 t (Freshco) • 30 t (KSU)
Maize: breeder seed	0.375 t	0.125 t	3.672 t	1.0 t	0.045 t
Maize: certified seed	1.5 t	12.4 t	0.436 t	162 t	202 t
Legumes: breeder seed	0.684 t	0.630 t	1.212 t		
Legumes: certified seed					29.4 t

Table 15.8 Key seed companies and partners

Seed company	Seed multiplied
Mogotyo Plantations	KH500-39E maize
Frescho Seed Company	KH500-39E, KH633A, KH631Q, KDV 6 maize varieties
KALRO Seed Unit	KH500-39E maize, KSTP 94 maize and legume seed
Kenya Seed Company	HB520 maize variety
Bubayi Products Limited	KK8 bean variety
Leldet Seed Company	Peanut
Western Seed Company	KK8 and KK15 bean varieties
One Acre Fund	KK8 and KK15 bean and SB191 soybean varieties
ICRISAT	Peanut breeder seed (1.0 t) given to KALRO by ICRISAT

A competitive grant system approach was adopted to exploit the comparative advantages of partners to reach higher numbers and ensure that at least 100,000 households were reached by SIMLESA technologies and practices in one decade from the start of the program. Four partners were competitively selected out of 29 that expressed interest to scale out SIMLESA technologies (Table 15.9).

Table 15.9 Targets to be reached by partners in the competitive grant system

Partner	Technologies to scale out	Coverage	Targets
National Council of Churches of Kenya	new maize and legume varieties	Embu, Kitui, Meru and Tharaka Nithi counties	• 30,000 households reached out • 10,500 households applying the technologies on their farms by May 2018
	agri-innovation platforms	Kitui and Tharaka Nithi counties	• 2 agri-innovation platforms established by May 2018
	information sets	Embu, Kitui, Meru and Tharaka Nithi counties	• 30,000 information sets (brochures, SMS, billboards, radio transcripts and outreach programs, audio visual content and programs) by May 2018
Mediae Company	SIMLESA sustainable intensification options	filming for content to be carried out in Embu, Kakamega, Kitale, Kitui, Machakos, Meru, Tharaka Nithi and Uasin Gishu counties	• intensification options aired on Citizen TV in Shamba Shape Up Series 7 covering 5,000,000 farm households throughout Kenya with 400,000 expected to benefit directly by April 2018
Egerton University	new legume and maize varieties and conservation agriculture-based technologies and practices	Busia, Kakamega, Siaya and Vihiga counties	• at least 30,000 households and users reached with 7,500 applying on their farms by August 2018 • at least 30,000 information sets (brochures, SMS, billboards, radio transcripts and outreach programs, TV content and programs) developed and disseminated • at least 350 next user partner staff engaged and supporting the processes above
Frescho Kenya Limited	maize varieties (KDV 6, KDV 1, KH 500-33A, KH 500-39E, KH500Q, KH600-14E); beans (KAT X56, KAT B1); sorghum (Gadam, Seredo); green grams (N26); cowpea (K80/M66); *Dolichos lablab* (DL 1002)	Embu, Meru, Tharaka Nithi, Bungoma, Kakamega and Siaya counties	• reach 30,000 households with distribution of free samples of maize and legume varieties for farmers to try on their farms • reach 36,000 farmers in farmers' fairs and field days • target 80% of the farmers and households to embrace and continue with the technologies and farming methods

Mobile phone system for the delivery of information to farmers and agribusinesses

Mobile phone numbers of recipients of SMS messages were collected and entered into an Excel spreadsheet and loaded into the established website being managed from Australia by the Queensland Alliance for Agriculture and Food Innovation. An initial target of 2,000 farmers from western Kenya were loaded and tested. The number of farmers in the network was increased progressively to 20,000 recipients who received and sent messages.

Adoption rates of SIMLESA technologies

The adoption survey carried out in 2012–13 found that the adoption of CASI practices in program sites in eastern Kenya (4,503 households) increased dramatically from less than 1% when the program began in 2010 to 58% in 2013 for zero tillage and 38% for furrow and ridge tillage systems. The survey also established that more women were adopting zero tillage practices than men, while more men were adopting furrow and ridge practices. At least 50% of the host farmers were planting new varieties beyond the exploratory trial plots. Among the legumes, 71% of farmers were growing Embean 14, which was more popular among female farmers. Its preferred attributes were good taste, high yields and good price compared to other varieties.

By 2016[8], a number of farmers beyond the targeted SIMLESA households had heard of and adopted SIMLESA technologies and practices based on knowledge gained from SIMLESA participants. Adoption patterns suggested that the most common and effective approaches of disseminating program technologies and practices were visits to demonstration sites (96.6% of respondents), attending field days (73.7%) and exchange visits (39.2%). The most popular crops were DK 8031, KDV 6 maize varieties and Embean 14 bean variety, known by 44.3%, 20.7% and 15.5% of respondents, respectively. Furrows and ridges, residue return and fertiliser use were known by 30.4%, 18.7% and 13.4% of respondents, respectively.

What should we do next?

SIMLESA households realised the potential benefits of the more-productive technologies and practices. However, these benefits have not been fully realised by the broader community. The main task that we need to engage with between 2020 and 2030 is to scale out the proven technologies at corridor and higher levels using approaches that have been found to be effective, such as demonstrations, field days and exchange visits.

Current seed supplies are also too low to meet demand if the households that were reached by SIMLESA wish to adopt improved varieties. Future efforts will need to address this supply constraint. Options include multiplication by farmers or by seed companies.

Farmers and other partners can be supported as they continue to apply SIMLESA technologies and practices on their farms. Leaflets and booklets about SIMLESA-developed technologies and practices can also support wider knowledge dissemination. This can achieve the desired impact and improve the standard of living of farmers and other stakeholders along the maize–legume and fodder value chains.

The effect of CASI practices, including labour saving, water use efficiency and soil bulk density, resulted in higher productivity and were environmentally friendly. This will enable Kenya to transition to climate-smart agricultural research for higher productivity and sustainability and support the Climate Smart Agriculture Strategy. On-station trials should continue for longer to accumulate adequate data to confidently define the effects of CASI.

8 During 2018, the results of a final adoption and benefits survey estimated substantially greater levels of adoption than in 2012 or 2016.

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16 Sustainable intensification of maize and legume farming systems in Tanzania

John Sariah, Frank Mmbando, Lameck Makoye & Bashir Makoko

Key points

- Scaling out SIMLESA technologies through innovation platforms increased the number of farmers using improved seeds of maize and legumes from 30–40% to 85%.
- Adoption of a conservation agriculture-based sustainable intensification (CASI) technology package increased yields for maize from 1.5 t/ha to 4.5 t/ha and legumes from 0.38 t/ha to 1.5 t/ha.
- Crop resilience to climate variability increased with CASI due to improvements in natural soil fertility (increased soil organic carbon from 2.55% to 3.23%) and structure (increased soil water holding capacity from 20.69% to 22.23%).
- The CASI technology package reduced labour time by 50% and increased profits by 33% compared to farmers' conventional practices.

Introduction

Tanzania has a total area of 94.5 Mha of land, of which 44 Mha is classified as suitable for agriculture. Of the available arable land, only 10.1 Mha (23%) is currently under cultivation. Agriculture in Tanzania is mainly rainfed and is dominated by smallholder farmers cultivating on small areas of land, averaging 2.5 ha. About 70% of Tanzania's crop area is cultivated by hand hoe, 20% by ox plough and 10% by tractor. Food crop production dominates the agriculture economy, with 85% of the annually cultivated land under food crops. Women represent the majority of the agricultural labour force.

The agriculture sector in Tanzania faces various challenges. Major concerns for agriculture in Tanzania are decreasing labour and land productivity. Major productivity constraints include limited access to agricultural technology, low soil fertility and climate change (Makuvaro et al. 2017). A 2011 SIMLESA baseline survey reported yields as low as 1–2 t/ha for maize and 0.5 t/ha for pigeonpea during the 2010 cropping season. Overcoming these challenges to reduce poverty has been declared a top government priority (Policy Forum 2016).

Efforts that support smallholder farmers have been viewed as an effective way to drive economic growth and combat poverty, based on the significant share that impoverished household production systems contribute to the national agriculture sector. Higher farm productivity and more diversified farm produce are expected to reduce the need to purchase supplementary foodstuffs and offer the possibility of selling surplus for cash. Conservation agriculture has the potential to achieve these benefits as it aims at minimising soil disturbance, soil water and nutrient losses, therefore preserving many of the ecological functions of natural ecosystems that support crop production (Giller et al. 2009). Benefits of conservation agriculture can multiply when combined with sustainable intensification practices like improved varieties and good agronomy. This production system is also known as conservation agriculture-based sustainable intensification (CASI).

CASI offers a number of potential benefits for farmers such as soil improvement through nitrogen fixation, increased organic matter through crop residue decomposition and reduced incidence and severity of disease, weed and insect population damage. It also improves micro and macro-organism activities and soil structure. These are all important factors for crop growth and establishment (Derpsch 2008). Empirical studies have shown that CASI has benefits across a wide range of agroecological conditions (Thierfelder & Wall 2011). Many studies have highlighted the potential of conservation agriculture, especially when complemented with sustainable intensification practices as CASI, in addressing livelihood security challenges while improving soil and water management (Kassam et al. 2009). CASI has been increasingly promoted in Tanzania by many international and national organisations as a means for smallholders in eastern and southern Africa to avoid soil degradation and enhance productivity (Mazvimavi & Twomlow 2009).

The SIMLESA program conducted several on-farm studies to identify major production constraints and management practices that enhance maize–legume cropping system performance in Tanzania. The studies covered five districts: Karatu, Mbulu, Mvomero, Kilosa and Gairo. The baseline survey conducted in 2010 revealed numerous production constraints. These included unimproved seeds, poor agronomic practices, crop diseases, insect infestations, low soil fertility, moisture stress, weeds like *Striga*, unreliable input and output markets, lack of credit facilities and poor infrastructure (SIMLESA 2016–18; Sariah et al. 2019).

SIMLESA started to promote CASI technologies in 2010, based on the constraints observed in the baseline survey. The CASI technologies that were promoted, in conjunction with improved varieties and proper crop management, included:

- zero tillage
- crop residue retention
- maize–legume intercropping
- use of herbicide for weed control.

On-farm and on-station agronomy intervention studies under SIMLESA identified specific sets of technologies and intensification practices that increased productivity by more than 50%. The use of improved crop varieties, proper agronomic practices and conservation agriculture improved the maize yields from 1.5 t/ha baseline levels to 4–6 t/ha and legume yields from 0.5 t/ha to 2 t/ha. Four improved maize and legume varieties, recently developed and released with support from SIMLESA, increased availability of better-performing crop varieties. These improved technologies reached farmers through innovation platforms, short message information, national agricultural shows (commonly known as NANE NANE), national agribusiness expos, and different media and scaling-out partners under the SIMLESA competitive grant scheme.

The adoption rate of these technologies were fairly consistent between male- and female-headed households, ranging from 42% in Mbulu district to 54% in Kilosa district. These efforts have potential long-term impact, given the enhanced capacity of National Agricultural Research System researcher and extension that resulted from SIMLESA training. In addition, this program supported one PhD and seven MSc students, and two research institutes were endowed with two vehicles and lab equipment to bolster research. Ninety-eight farmers (24 female and 74 male) also benefited directly, gaining knowledge of CASI management practices through short courses.

What did SIMLESA do?

To address production constraints, SIMLESA conducted on-farm and on-station studies. On-farm studies were conducted in five districts of Tanzania: Karatu, Mbulu, Mvomero, Kilosa and Gairo with 10 trial sites in each district. On-station studies were conducted at the Selian Agricultural Research Institute and the Ilonga Research Station. The on-farm studies were conducted in high- and low-production potential environments in the northern and eastern zones of Tanzania for more than four consecutive cropping seasons, beginning in 2010 (Sariah et al. 2019).

The technologies evaluated through on-farm exploratory and on-station trials were:

1. CASI: characterised by minimum soil disturbance, use of herbicide (mainly glyphosate), crop residue retention, use of fertilisers (basal and top dressing), use of improved crop varieties, intercropping of maize and legumes and proper crop husbandry.
2. Conventional practice: similar to conservation agriculture, except tillage is practised as maximum soil disturbance, without the use of herbicide or crop residue retention.
3. Farmers' practice: suboptimal or no use at all of fertilisers depending on the individual farmer's decision, poor plant population, poor weed and pest management, soil disturbance by oxen or hand hoe, no crop residue retention.

Program sites

Karatu

Karatu is one of the five districts in the Arusha region of Tanzania. Its geographical coordinates are 3°20'S, 35°40'E and the district measures about 3,300 km^2. Land use is classified into arable (102,573 ha), pasture (155,808 ha) and forest, bush and tree cover (61,218 ha). The population is estimated at 178,434 (92,895 men and 85,539 women) aggregated into 33,000 households. Based on relief, land physiography and drainage pattern, Karatu can be categorised into three zones—uplands, midlands and lowlands—with an altitude ranging from 1,000 m to 1,900 m above sea level. Rainfall in the district is bimodal. The short rain season lasts from October to December and the long rains occur from March to June. Rainfall may range from less than 400 mm in the Eyasi Basin to over 1,000 mm in the highlands, with rain zones classified as semi-arid (300–700 mm/year) and subhumid (700–1,200 mm/year). Rainfall intensity can be very high, causing erosion, particularly during the onset of the rainy season when soils are bare. Soil fertility is low to moderate. Agriculture in the highlands used to be very productive but in recent years crop yields have declined, mainly due to unreliable rainfall (erratic precipitation and lower annual totals) and poor soil fertility.

Mbulu

Mbulu is one of the five districts of the Manyara region of Tanzania. Mbulu is located in north-eastern Tanzania, 3°51'S, 35°32'E. The altitude ranges from 1,000 m to 2,400 m above sea level. The district contains semi-arid and subhumid climates that receive annual rainfall of <400 mm and >1,200 mm, respectively. The long rainy season extends from March to mid-May and the short rainy period extends from November to December. Relative humidity ranges from 55% to 75% and mean annual temperature ranges from 15 °C to 24 °C. Livelihoods in both Karatu and Mbulu districts depend on crop and livestock keeping. The farming system is maize–legume intercropping. The major cereal crops grown in these two districts (Karatu and Mbulu) are maize, wheat and barley. The major legume crops are pigeonpea, common bean, chickpea and green gram (Douwe & Kessler 1997).

Kilosa, Mvomero and Gairo are districts in the Morogoro region of eastern Tanzania. Rainfall has a bimodal pattern with a main season that begins in March and ends in June and short rains that occur from October to December. The average annual rainfall varies from year to year and between ecological zones. An average rainfall of 1,000–1,400 mm is common in the southern flood plains, while Gairo in the north averages 800–1,100 mm. The mountain forest areas can receive up to 1,600 mm annually. Throughout Kilosa, the dry period extends from June to October. The average annual temperature is 25 °C in Kilosa town with extremes in March (30 °C) and July (19 °C). Livelihoods in these districts depend mainly on maize, legumes, vegetables, sweetpotato, oil seed production and livestock keeping. The dominant cropping system is maize–legume intercropping (Paavola 2004).

Selian Agricultural Research Station

Selian Agricultural Research Station is located at 3°24'S, 36°47'E at an altitude of 1,250 m above sea level and the soil type molisol. Rainfall used to be bimodal but has recently been unimodal, with average annual rainfall reaching 1,500 mm. Selian Agricultural Research Station has minimum temperatures of about 20 °C and maximum temperatures of about 25 °C.

Ilonga Research Station

Ilonga Research Station is located at 6°47’S and 37°2’E at an altitude of 498 m above sea level, with minimum temperatures of about 25 °C and maximum temperatures of about 35 °C. The main soil type is eutopicfluvisols and the rainfall type used to be bimodal. However, the rainfall pattern is more recently unimodal, with average annual rainfall of 1,059 mm.

Program objectives

On-farm trials

1. Characterise maize–legume production, input and output value-chain systems, impact pathways and identify broad systemic constraints and options for field testing.
2. Test and develop productive, resilient and sustainable smallholder maize–legume cropping systems and innovation systems for local scaling out.
3. Increase the range of maize and legume varieties for smallholders through accelerated breeding, regional testing and release.

On-station trials

1. Determine the long-term influence of different tillage practices and different fertiliser levels on soil dynamics and maize and pigeonpea crop yields under intercropping systems.
2. Determine the long-term influence of different tillage practices on yields of different ratooning regimes of pigeonpea and maize.

Researcher and extension capacity building

The program facilitated capacity building for researchers and extension through long-term and short-term training, reaching a total of 148 trainees (Table 16.1).

Table 16.1 Course and number of trainees by gender

Training course	Participants
Gender mainstreaming	27 (17 male, 10 female)
Monitoring and evaluation training of trainers	3 (3 male, 0 female)
Principles of conservation agriculture	25 (17 male, 8 female)
Weed management	26 (21 male, 5 female)
Data management	29 (22 male, 7 female)
Innovative platforms	10 (7 male, 3 female)
Climate variability	5 (4 male, 1 female)
APSIM	3 (3 male, 0 female)
Statistical analysis	20 (12 male, 8 female)
Total	**148 (106 male, 42 female)**

What we found

Characterisation of maize–legume production and input and output value-chain systems and impact pathways

The average yields for various crops during 2010 were:

- dry maize: 1,198 kg/ha
- dry legumes:
  - common bean: 413 kg/ha
  - pigeonpea: 385 kg/ha
  - peanut: 389 kg/ha
  - cowpea: 148 kg/ha.

The average yield for maize varieties was relatively higher in Karatu and Mbulu districts compared to Mvomero and Kilosa.

Results further show that floods, poor agronomic practices, poor genotypes, drought and inaccessibility of agricultural inputs—both in terms of availability, costs involved and timing—were the most important limiting factors in crop production for maize–legume farming systems in Tanzania. The main means of transportation among households also indicated that households required considerable time to acquire goods and services. Average walking distance to the nearest village market was about 6.6 minutes. The main means of transport to these local markets was on foot (46%) and bicycle (11%).

Household characteristics

At the household level, the majority of surveyed households were male-headed (82%). Mbulu district reported the highest proportion of the male-headed households (Table 16.2). The average age of the household head was about 47 years, although Karatu farmers were older (51 years) than other districts. The average level of formal education for the household heads was about seven years, but households in Mbulu had slightly more years of education on average (7.4 years). The average size of the surveyed households was about five members. Mbulu had the smallest family size of four members, while Karatu had the largest family size of six members. The majority (about 80%) of the household heads were married, while about 5% were divorced or separated and 7% were widowers.

Land ownership

Land was the basic productive asset by smallholder farmers in the survey districts. Descriptive analysis of this important asset revealed that the average landholding among the surveyed households was about 2.7 ha (Table 16.3). An average of 2.1 ha was cultivated while 0.8 ha was left uncultivated. Kilosa had the largest average landholding (3.9 ha).

Table 16.2 Household demographics

Characteristic	District					Average (*n* = 410)
	Karatu (*n* = 114)	Mbulu (*n* = 96)	Kilosa (*n* = 105)	Mvomero (*n* = 49)	Gairo (*n* = 46)	
Male-headed households (%)	82.5	85.4	81.0	77.6	84.6	82.2
Age of household head (years)	50.9	47.3	47.0	46.2	44.5	47.2
Household size (number)	6.0	4.3	5.2	5.5	6.6	5.5
Education of household head (years)	6.8	7.4	6.7	7.1	6.0	7.3
Marital status						
Married (% households)	82.5	80.2	77.1	73.5	84.8	79.6
Divorced/separated (% households)	2.7	2.0	17.2	10.2	4.3	7.3
Widow/widower (% households)	3.8	4.1	3.8	10.2	4.3	5.2
Never married (% households)	13.2	15.6	1.9	6.1	6.5	8.7

Table 16.3 Land ownership at district level

Land category	District					Average (*n* = 410)
	Karatu (*n* = 114)	Mbulu (*n* = 96)	Kilosa (*n* = 105)	Mvomero (*n* = 49)	Gairo (*n* = 46)	
Total farm size (ha)	2.1 (3.3)	1.5 (2.2)	3.9 (3.0)	2.8 (3.3)	3.4 (4.7)	2.7 (3.8)
Cultivated (ha)	1.6 (2.7)	1.4 (1.3)	3.2 (2.3)	1.3 (2.4)	2.8 (4.7)	2.1 (2.2)
Uncultivated (ha)	0.6 (1.3)	0.4 (1.6)	0.7 (1.4)	1.1 (1.7)	1.3 (2.0)	0.8 (1.3)
Rented in (ha)	0.02 (1.7)	0.3 (0.3)	1.5 (2.4)	0.7 (1.2)	2.0 (2.8)	0.9 (2.1)
Rented out (ha)	0.01 (0.0)	0.0 (0.2)	0.2 (0.7)	0.5 (1.2)	0.2 (1.5)	0.2 (0.1)

Note: Numbers in parentheses are standard deviation.
Source: SIMLESA 2016–18

Technology adoption

The most widely adopted management practices were maize–legume intercropping (96%) followed by crop residue retention (52%), herbicide use (38%) and crop rotation (34%). Zero tillage was the least adopted CASI practice (adopted by about 25% of sampled households).

The proportion of farmers adopting these management practices varied by district. Adoption of maize–legume intercropping ranged from 94% in Karatu and Mbulu to 98% in Kilosa and Mvomero (Table 16.4). Adoption of crop residue retention was more variable across the research sites, ranging from 39% in Gairo to 76% in Mvomero. Herbicide use also varied across sites, as low as 12% in Mbulu and as high as 57% in Mvomero. Adoption of crop rotation was also relatively low (22%) in Mbulu and relatively high (47%) in Mvomero. Few (about 25%) of the sampled farmers had adopted zero tillage at the household level. This was variable across districts, with Karatu reporting the highest (about 47%) and Mvomero reporting the lowest (about 10%).

Table 16.4 Adoption of CASI practices at household level

CASI practice	District					Average (*n* = 410)
	Karatu (*n* = 114)	Mbulu (*n* = 96)	Kilosa (*n* = 105)	Mvomero (*n* = 49)	Gairo (*n* = 46)	
Zero tillage	46.5	25.0	17.1	10.2	26.1	25.0
Maize–legume intercropping	94.0	93.8	98.2	98.0	96.8	96.2
Crop rotation	33.5	22.0	33.3	46.9	32.6	33.7
Residue retention	39.6	47.4	59.0	75.5	39.1	52.1
Herbicide use in zero tillage	27.4	12.3	55.2	57.1	39.1	38.2

Note: CASI = conservation agriculture-based sustainable intensification
Source: SIMLESA 2016–18

About 48% of the sample households adopted at least one CASI practice (Table 16.5). The adoption rate ranged from 42% in Mbulu district to 54% in Kilosa district. Results show that female-headed households were slightly more likely to adopt than male-headed households.

Table 16.5 Adoption of at least one CASI practice, by gender

District	Male-headed household (*n* = 331)	Female-headed household (*n* = 79)	Average (*n* = 410)
Karatu	47.8	50.0	48.9
Mbulu	40.2	42.8	41.5
Kilosa	52.9	55.0	53.9
Mvomero	52.6	45.5	49.1
Gairo	38.4	57.1	47.8
Average	**46.4**	**50.1**	**48.2**

Note: CASI = conservation agriculture-based sustainable intensification
Source: SIMLESA 2016–18

Number of adopters

The estimated number of adopters of the CASI practices (maize–legume intercrop, zero tillage, crop rotation, residue retention and herbicide use) for the 2015–16 season is shown in Table 16.6. Results reveal that the estimated number of adopters for the five districts was about 12,046 farmers. Kilosa district had the highest number of adopters (about 3,579), followed by Gairo (about 2,844) and Karatu (about 2,844) districts. Mvomero and Mbulu districts had 1,829 and 1,049 adopters, respectively.

Table 16.6 Estimated number of adopters of CASI practices, 2015–16

District	Sample size			Number of respondents adopting at least one component of CASI			Adoption rates			Projected number of adopters		
	Male	Female	Total	Male	Female	Total	Male	Female	Total	Male	Female	Total
Karatu	94	20	114	45	10	55	47.8	50.0	48.9	2,245	500	2,745
Mbulu	82	14	96	33	6	39	40.2	42.8	41.5	887	162	1,049
Kilosa	85	20	105	45	11	56	52.9	55.0	53.9	2,112	1,467	3,579
Mvomero	38	11	49	20	5	25	52.6	45.5	49.1	1,044	785	1,829
Gairo	39	7	46	15	4	22	38.4	57.1	47.8	1,979	865	2,844
Total	**338**	**72**	**410**	**158**	**39**	**197**	**46.4**	**50.1**	**48.2**	**7,686**	**3,666**	**12,046**

Note: CASI = conservation agriculture-based sustainable intensification
Source: SIMLESA 2016–18

Farmers' sources of information

Farmers' main sources of information about CASI practices were SIMLESA demonstrations (34%), fellow/neighbouring farmers (25%) and extension services (11%) (Figure 16.1). Other sources such as radio/TV and innovation platforms also played a significant role in information transfer.

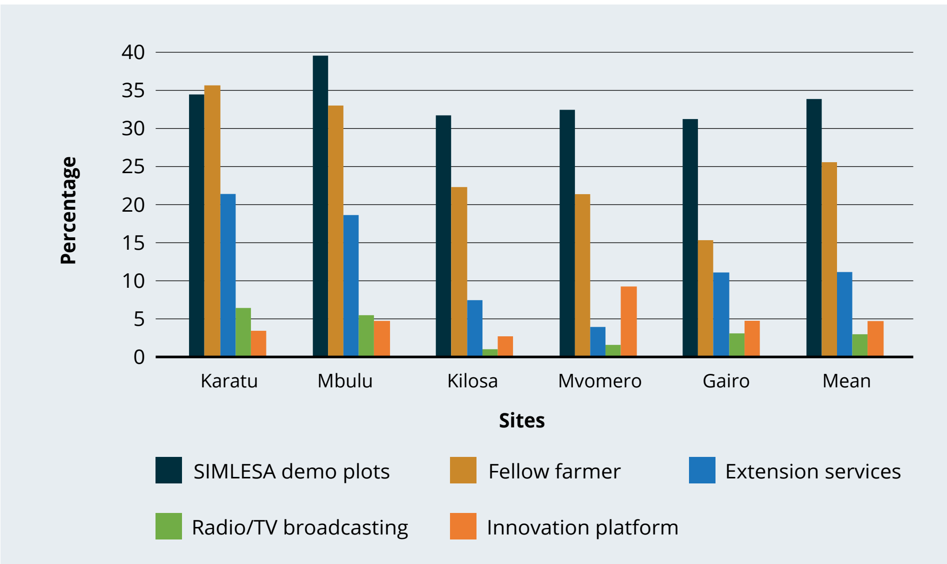

Figure 16.1 Farmers' sources of information about CASI practices

On-farm testing of sustainable and resilient climate-smart technologies

CASI and conventional practices increased yields from farmers' practice. Yields increased twofold for pigeonpea and threefold to fourfold for maize, compared to the baseline yield represented by the farmers' practice (Figures 16.2 and 16.3).

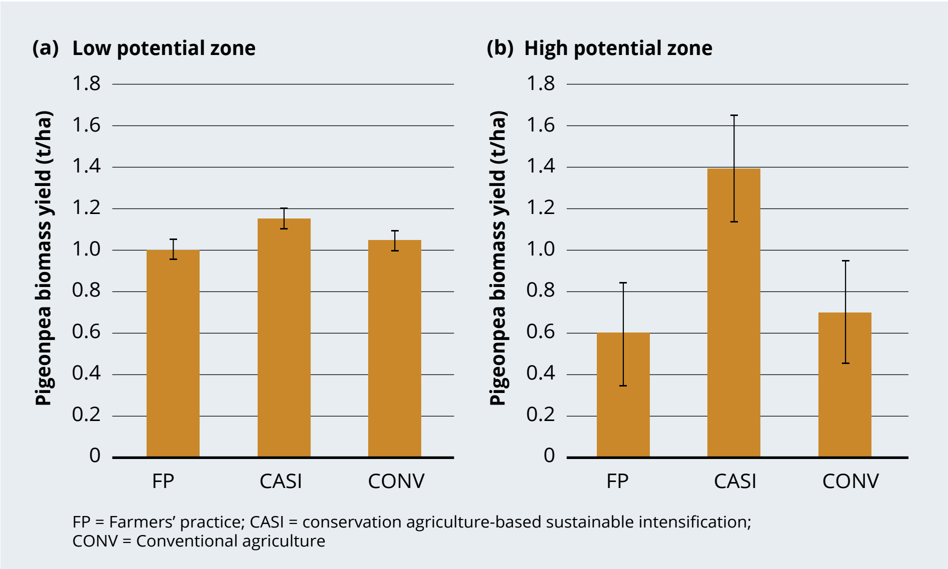

Figure 16.2 Average pigeonpea yield for four seasons for (a) low-potential and (b) high-potential environments in northern Tanzania

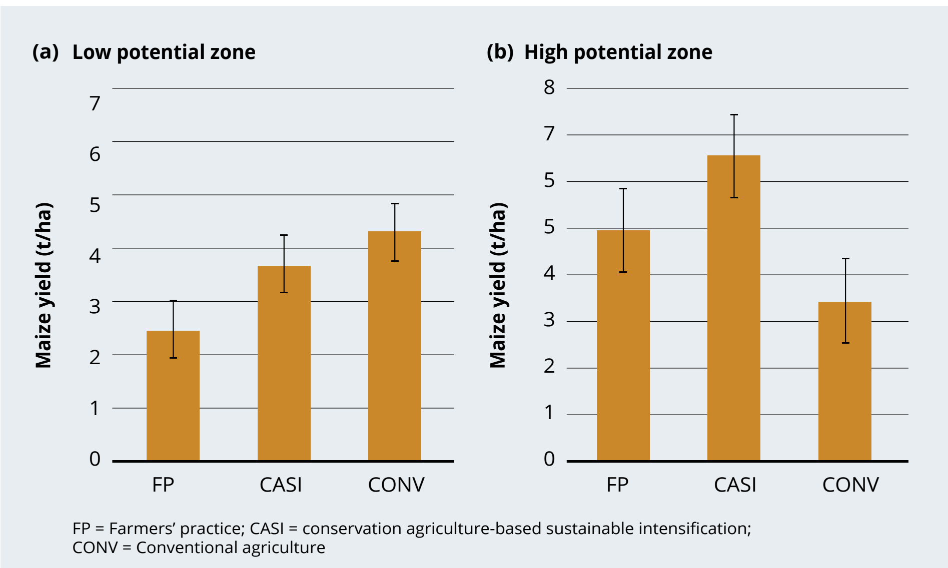

Figure 16.3 Average maize yield for four seasons for (a) low-potential and (b) high-potential environments in northern Tanzania

There were significant differences ($P < 0.05$) between the CASI system and conventional practice for both pigeonpea and maize yields in high-potential environments (Figures 16.2b and 16.3b). This was attributed mainly to relatively higher moisture at different times of crop development in CASI plots due to soil cover and rainfall. In low-potential environments, the pigeonpea yield was higher in the CASI system than conventional practice, although not significantly. In contrast, maize yields were higher in conventional agriculture than the CASI system in the low-potential environment. The reason for low maize yield under CASI in low-potential environment was due to high termite infestation caused by early onset of drought. Under dry conditions, termite activity typically becomes severe. Termites preferentially attacked dried maize crops over pigeonpea, because pigeonpea stayed green for a longer period of time beyond maize maturity (Figure 16.4).

Figure 16.4 Alternating rows of maize (matured and dried) and pigeonpea

The time spent on various operations in the CASI plots was almost 20% less compared to other practices (Table 16.7). CASI has been shown to be a timesaving technology. CASI showed sevenfold increase in net benefits over conventional practice (Table 16.8). The soil analysis results indicate slightly improved soil dynamics in terms of increased soil moisture retention, soil organic matter and total nitrogen in CASI compared to conventional practice (Table 16.9). This suggests that practising CASI over a longer period of time will change the soil conditions in favour of crop growth and development and increase resilience to climate change. In addition, CASI increased organic carbon and moisture retention compared to farmers' practice and conventional agriculture practices in the two contrasting environments (high-production potential environment represented by Rhotia and Bargish sites and low-production potential environment represented by Bashay and Masqaroda) (Table 16.9). This indicates the superiority of CASI practices over other practices, regardless of the environment.

Table 16.7 **Average time over four seasons spent in different activities for different practices**

Practice	Herbicide application (hour/ha)	Ploughing (hour/ha)	Weeding (hour/ha)	Total (hour/ha)
Farmers' practice	–	13.6	91.8	105.4
Conventional practice	–	13.3	100.2	113.5
CASI	9.9	–	74.9	84.7

Note: CASI = conservation agriculture-based sustainable intensification

Table 16.8 **Average farm partial budget for different practices for different communities in Tanzania**

Costs/revenue for inputs and outputs across different practices	Conventional practice	CASI	Farmers' practice
Cost of cultivation (US$/ha)	109.4	0	109.4
Cost of fertiliser basal (100 kg DAP/ha) + top dressing (100 kg N/ha)	168.8	168.8	0
Cost of fertiliser application (US$/ha)	28.1	28.1	0
Cost of herbicide (US$/ha)	0	18.8	0
Cost of herbicide application (US$/ha)	0	28.1	0
Cost of weeding (US$/ha)	234.4	78.1	234.4
Cost of maize stover (US$/ha)	0	31.3	0
Total variable costs (US$/ha)	**540.6**	**353.1**	**343.8**
Gross yield of maize (t/ha)	*4.5*	*5.0*	*2.0*
Gross revenue from maize (US$)	1,2	1,3	427.1
Gross revenue from stover (US$/ha)	31.2	62.5	20.5
Gross yield of pigeonpea (t/ha)	*1.6*	*1.8*	*0.8*
Gross revenue of pigeonpea (US$/ha)	842.1	947.4	28
Total revenue (US$)	**2,027.4**	**2,324.9**	**519.2**
Net benefit (US$)	**1,486.7**	**1,971.8**	**175.5**

Note: CASI = conservation agriculture-based sustainable intensification

Table 16.9 Soil dynamics analysis of four communities hosting exploratory trials for four seasons

Location	Practice	At sowing						
		MC (%)	pH	EC (mS/cm)	OC (%)	TN (%)	AP (mg/kg)	K (cmol(+)/kg)
Rhotia	farmers' practice	26.02	7.00	0.074	1.548	0.160	11.480	1.300
	conventional practice	26.10	6.98	0.070	1.574	0.172	13.034	1.360
	CASI	29.40	7.06	0.068	1.908	0.200	11.312	2.380
Bashay	farmers' practice	24.60	6.98	0.058	0.989	0.116	8.992	4.140
	conventional practice	23.96	7.02	0.070	0.936	0.106	10.088	1.520
	CASI	24.30	7.04	0.066	1.428	0.148	9.286	1.600
Masqaroda	farmers' practice	16.23	7.30	0.098	0.958	0.082	10.720	0.404
	conventional practice	16.60	7.40	0.106	0.930	0.088	11.280	0.484
	CASI	17.56	7.22	0.098	1.222	0.106	13.280	0.326
Bargish	farmers' practice	14.40	6.78	0.072	1.210	0.092	2.960	0.458
	conventional practice	18.91	7.16	0.152	1.562	0.110	6.280	0.804
	CASI	19.89	7.20	0.118	1.794	0.120	3.840	0.640

Notes: MC = moisture content; EC = exchangable cation; OC = organic carbon; TN = total nitrogen; AP = assimilated phosphorus; K = potassium; CASI = conservation agriculture-based sustainable intensification.

Adoption of CASI increases resilience to climate change

In a situation of climate variability, CASI technology performed better compared to conventional and farmers' practices. With alternating seasons of good and bad weather (Figure 16.5), CASI performed better in both, proving resilience to climate variability and changes.

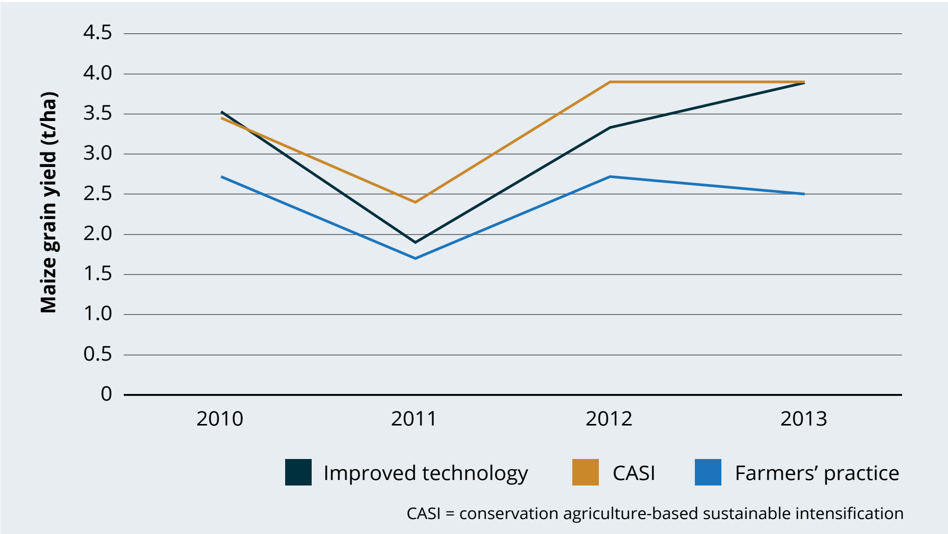

Figure 16.5 Response of different practices in varied seasons, 2010–13

Influence of tillage practices on different fertiliser rates and soil dynamics on yields of maize and pigeonpea

The influence of tillage practices on grain yields was clear between CASI and conventional practice. The Selian Agricultural Research Station site received rainfall for three months only (March–May) (Figure 16.7). All the fertiliser rates in the CASI system yielded significantly ($P < 0.05$) higher compared to the same rates in conventional practice (Table 16.10). One reason for the observed differences was relatively high conserved moisture in the CASI system (Figure 16.6), which was efficiently utilised by plants and reflected in grain yields (Table 16.10).

The highest maize grain yield was realised under CASI practices and differed significantly from conventional practice ($P < 0.05$) (Table 16.9). This suggests that fertiliser use efficiency was good under CASI due to relatively high soil moisture content at different stages of crop development and also high organic matter build-up due to decomposition of crop residues over time (Table 16.9).

There was a significant difference among the fertiliser level treatments under CASI. The highest (100 kg N/ha) level gave the highest yields. However, the 60 kg N/ha did not differ significantly from 40 kg N/ha ($P > 0.05$) (Table 16.8). This suggests that microdosing fertiliser application at a rate of 40 kg N/ha is more effective than 60 kg N/ha. The 40 kg N/ha rate produced significantly higher ($P < 0.05$) yields of 2.653 t/ha than 10 t farm yard manure per hectare, which yielded 2.083 t/ha. The way the manure was stored and applied should be considered, because some of nutrients might have been lost in the process.

Table 16.10 **Mean grain yield for maize in CASI and conventional practice for four seasons at Selian Agricultural Research Station**

CASI		Conventional practice	
Fertiliser levels	Grain yield (t/ha)	Fertiliser levels	Grain yield (t/ha)
100 kg N/ha	3.190[a]	100 kg N/ha	2.753[bc]
60 kg N/ha	2.820[b]	60 kg N/ha	2.440[c]
40 kg N/ha	2.653[bc]	40 kg N/ha	2.093[d]
10 t FYM/ha	2.083[d]	10 t FYM/ha	1.657[e]
0 kg N/ha	1.670[e]	0 kg N/ha	1.430[e]

Notes: CASI = conservation agriculture-based sustainable intensification; Mean = 2.279, LSD (0.05) = 0.342, CV (%) = 7.07. FYM = Farm yard manure from cattle; LSD = least squares difference; CV = coefficient of variation. Figures followed by different letters differ significantly.

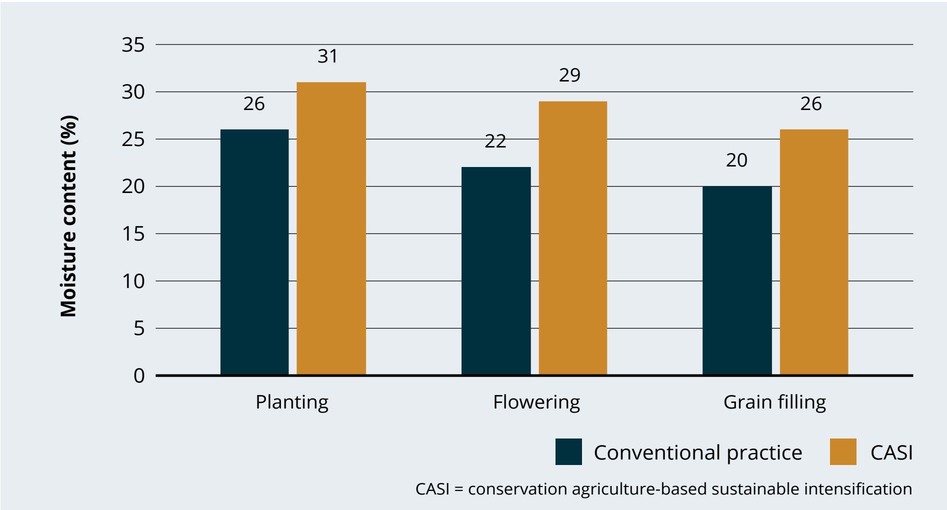

Figure 16.6 **Average soil moisture level at different stage of plant development at Selian Agricultural Research Station**

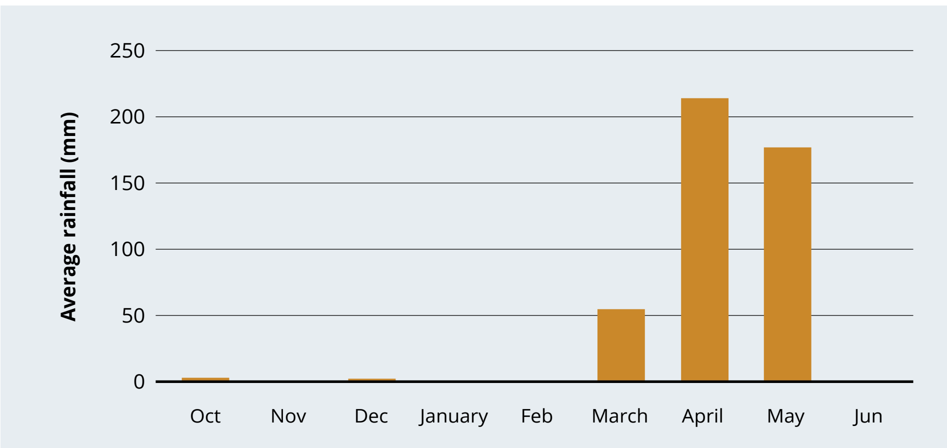

Figure 16.7 **Average monthly rainfall at Selian Agricultural Research Station**

Effect of tillage and cropping system on growth parameters in the intercropping system

The effect of tillage and cropping systems on growth parameters of maize for the 2016 season at Ilonga are as shown in Table 16.11. Results show that there was a slight variation in plant height and shoot weight under CASI compared to conventional practice, but they did not differ significantly. The reason might be that the serious crop residue damage from high infestation of termites towards the end of the wet season significantly reduced the moisture conservation that could otherwise be realised. Pigeonpea grain yield under CASI was significantly higher than yields under conventional practice.

Phenology varied across treatments. There was a significant difference ($P \leq 0.05$) between the two tillage systems in days to 50% emergence. Seeds under CASI emerged significantly earlier than those in conventional practice (Table 16.12). This might have been attributed to the high infiltration rate in CASI due to the presence of mulch, high porosity due to microbial activities, and high organic matter from previous organic matter accumulation from mulch decomposition (as opposed to run-off in conventional practice).

Table 16.11 **Effect of CASI and conventional practice tillage systems on growth parameters of maize, Llonga, 2016**

	Treatments	50% emergence	Plant height (cm)	Shoot weight (t/ha)
Tillage systems	CASI	5.75[b]	123.83	0.56
	conventional practices	6.58[a]	89.17	0.20
Standard error ±		0.0589	11.2696	0.09

Notes: CASI = conservation agriculture-based sustainable intensification; figures followed by different letters differ significantly.

Table 16.12 **Effect of CASI and conventional practice tillage systems on growth parameters of pigeonpea, Llonga, 2016**

	Treatments	50% emergence	50% flowering	Plant height (cm)	100 seed weight (g)	Grain yield (t/ha)
Tillage systems	CASI	8.58[a]	136.5[a]	215.0[a]	13.03[a]	1.57[a]
	conventional practices	9.08[a]	138.5[a]	186.75[a]	12.75[a]	1.41[b]
Standard error ±		0.27	0.81	7.0497	0.087	0.027

Notes: CASI = conservation agriculture-based sustainable intensification; figures followed by different letters differ significantly.

Yield across maize varieties

Varieties CKH10692 and Selian H308 performed relatively better across all testing sites in Mbulu, especially BargishUa. The yield performances ranged from 5.36 t/ha to 8.94 t/ha (Figure 16.8). These varieties (CKH10692 and Selian H308) were selected for Mbulu. In general, all varieties performed highest (>8.0 t/ha) in BargishUa over the local control, which produced a maximum of about 7 t/ha. In Karatu, the yields ranged from 4.0 t/ha to 6.0 t/ha (Figure 16.9).

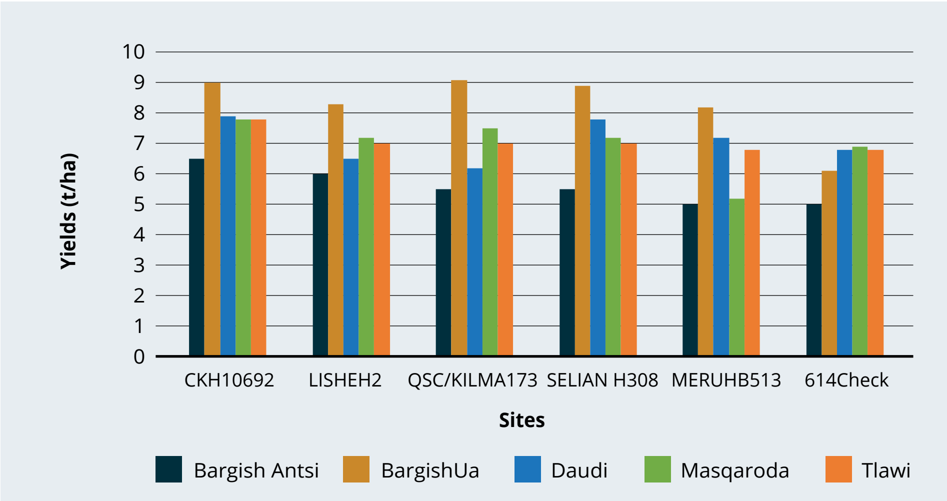

Figure 16.8 **Yield of maize varieties, Mbulu**

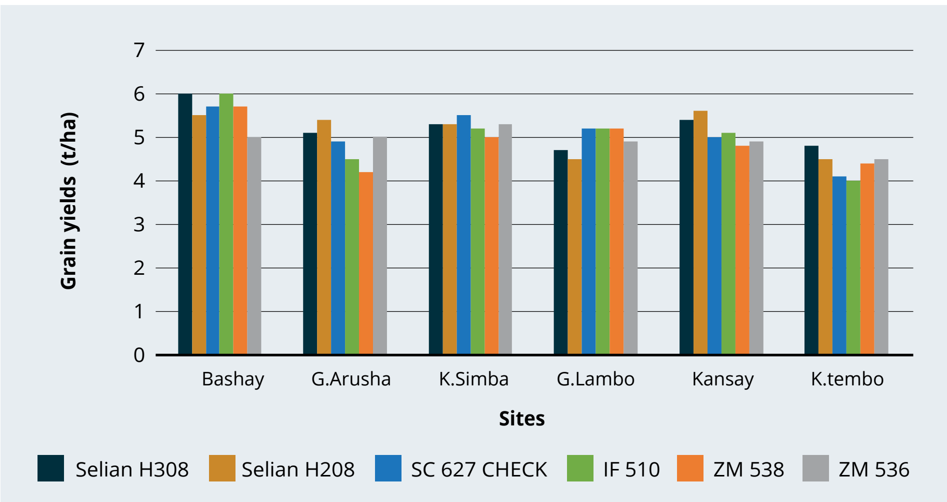

Figure 16.9 **Yield of maize varieties, Karatu**

In Kilosa, among 10 varieties that were evaluated, Selian H208, TAN250, TAN600 and ZM525 had the highest yields (Table 16.13). These were selected by farmers for wider scaling out in the eastern zone.

Table 16.13 Maize grain yield mean performance, Kilosa

Variety	Yield (t/ha)
LISHE H2	2.93
SELIAN H208	3.09
SITUKA M1	2.68
TAN254	2.66
TAN250	3.07
TANH600	3.77
TMV-1	2.86
ZM309	2.38
ZM523	2.73
ZM525	3.28
LSD (0.05)	**0.71**
CV (%)	**24**

Note: LSD = least squares difference; CV = coefficient of variation.

Production and maintenance of breeder seeds was undertaken to ensure sustainable availability of the selected maize varieties. The production and maintenance of breeders' seeds was done at Selian and Ilonga, while the certified seeds were produced by ASA, SATEC, MERU AGRO, Tanseed International and Krishna Seed (Tables 16.14 and 16.15).

Table 16.14 Production amount of pigeonpea breeders' seeds, 2011–14

Variety	Target production per year (kg)	Actual production per year (kg)			
		2011	2012	2013	2014
ICEAP 00557	100	300	45	600	200
ICEAP 00554	100	250	43	500	490
ICEAP 00932	100	270	41	550	0
ICEAP 00053	100	280	49	350	550
Mali	100	320	85	750	1,400
Tumia	100	250	80	1,150	1,150
Total	**600**	**1,770**	**343**	**3,900**	**3,790**

Table 16.15 Production of maize breeders' seeds and certified seeds for Selian H208

Grade	2011	2012	2013
Breeders' seed production (SARI)	Selian H208: • Parent 1 (70 kg) • Parent 2 (30 kg) • Parent 3 (120 kg)	Selian H208: • Parent 1 (70 kg) • Parent 2 (30 kg) • Parent 3 (120 kg)	
Foundation seed production (ASA)	Selian H208: • Parent 1 (400 kg) • Parent 2 (200 kg) • Parent 3 (1,200 kg)	Selian H208: • Parent 1 (6 t) • Parent 2 (3 t) • Parent 3 (3 t)	Selian H208: • Parent 1 (12 t) • Parent 2 (5 t) • Parent 3 (2 t)
Certified seed production	Selian H208: 20 t	Selian H208: 350 t	Selian H208: 750 t

What did we learn?

Obstacles, constraints and potentials exist within farming communities, including the need for improved technology. CASI was able to solve the challenges facing the farming communities. The extensive exposure of farmers to improved technologies through demonstration plots, field days, farmer exchange visits, extension materials, media (TV, radio), including the SMS platform, significantly contributed to increased adoption of the improved maize and legume production technologies in Tanzania.

Before the program, mean maize yield was about 1.5 t/ha. Under the CASI systems the yield increased to an average of 4–6 t/ha for the majority of adopting farmers where SIMLESA trials were conducted. This productivity was a result of farmers adopting improved seeds, proper agronomic practices and employing innovation systems under SIMLESA.

Capacity building of researchers and extension contributed to a significantly improved quality of the national staff and contributed to increased work efficiency.

During the four years of SIMLESA implementations, farmers learned and adopted improved technologies that were compatible with their farming systems. Adopted technologies saved time and labour. Farmers were willing to invest in agricultural technologies that addressed climatic challenges.

SIMLESA successes in Tanzania

- Of the farmers targeted under SIMLESA, 48% adopted at least one of the most preferred SIMLESA technologies (intercropping of improved maize and legume under proper management).
- The SIMLESA technologies introduced CASI, including the use of improved crop varieties, and proper agronomic practices. These technologies were proven to be practical and productive methods for increasing yields of maize from 2.5 t/ha to an average yield of 6 t/ha observed in SIMLESA interventions in various communities in high- and low-potential environments. Pigeonpea yield increased from 0.5 t/ha to 2 t/ha.
- SIMLESA technologies showed resilience to climate variability. The yields from the CASI intervention remained above other common practices, and demonstrated high profitability and timesaving compared to the other tested technologies.
- The downside risk of total crop loss dropped significantly with the introduction of drought-tolerant varieties coupled with proper agronomic practices and CASI practices.

Conclusions

Using adoption monitoring data collected from smallholder farmers in the northern and eastern zones of Tanzania, the study analysed the adoption of CASI practices. About 48% of the sample households adopted at least one CASI practice. Maize–legume intercropping was the most popular component of CASI to be adopted by farmers, followed by crop residue retention, zero tillage and crop rotation. Herbicide use in zero tillage as a component of CASI was adopted the least by the sampled households.

The estimated number of adopters of the CASI practices (maize–legume intercrop, zero tillage, crop rotation, residue retention and herbicide use) for the 2015–16 season was about 12,046 farmers. Some impediments to complete adoption of CASI practices included competition for crop residues between soil health and livestock (Rodriguez et al. 2017), and labour demands. Farmers' practice and conventional agriculture in Tanzania was labour-intensive, with the majority of farmers cultivating by hand hoe and only 10% using tractors. Although CASI decreased labour time, labour time still remained high. Labour savings may need to be more substantial for farmers to experiment with new technologies.

Adoption of CASI has been directly correlated with gender, farm size, age and exposure to the technology. Household typologies may provide a useful tool for identifying target communities for a given technology. On-farm experimentation and demonstrations of various technologies has also been effective at promoting adoption of new technologies. Effective means of promoting adoption of the improved technologies based on the adoption monitoring studies was the on-farm trials and demonstrations (participatory variety selection) established on farms. Farmers saw improved productivity, time savings, increased yield (twofold to fourfold) and financial gains (11-fold). Involving farmers and other key stakeholders in new improved agricultural technology dissemination was crucial for adoption and sustainability.

To cope with ever-changing agricultural environment and production technologies, capacity building for agricultural practitioners was a priority. The long- and short-term training capacity building done through the SIMLESA program contributed significantly to the success of the program.

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17 Identifying and out-scaling suitable CASI practices for cropping systems in Malawi

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Key points

- Through SIMLESA, Malawi identified and promoted suitable maize and legume varieties, and out-scaling options of conservation agriculture-based sustainable intensification (CASI) of cropping systems across different agroecological zones.
- The identified cropping systems were found to have the potential to hedge farmers well against climate and economic risks.
- CASI technologies provide an avenue through which Malawi can increase productivity and reduce food insecurity across different socioeconomic groups.
- Capacity building and knowledge management were central to sustaining program achievements beyond the implementation period.

Introduction

The frequent occurrence of drought and floods in the new millennium has greatly affected agricultural production and productivity in Malawi. In response, the government of Malawi intensified efforts focusing on sustainable agricultural production practices. One major policy action is the intensive promotion of conservation agriculture through different programs and projects. One such program is SIMLESA. This regional program was established in 2010 with the goal of reducing food insecurity through intensified sustainable agricultural production systems.

This chapter reviews the implementation and associated impacts of the SIMLESA program in Malawi. It further identifies out-scaling options that extend beyond the program period to sustain the identified conservation agriculture-based sustainable intensification (CASI) cropping systems of different agroecological zones. Empirical evidence indicates that SIMLESA identified and promoted CASI systems with the potential to hedge against climatic and economic risks, thereby sustaining maize production both at household and national levels. SIMLESA promotion efforts contributed to the adoption of CASI practices that improved maize productivity and, consequently, production at the household level. To achieve intensive and extensive out-scaling of the CASI systems, SIMLESA leveraged various strategies, strengthening existing innovation platforms and establishing new partnerships. To enhance adoption, the policy recommendation was to promote a community approach to field management and value-chain approach in input and output markets. Knowing that there is no silver bullet solution to all the complex problems in the agriculture sector, Malawi will continue to carry out systemic research in agriculture and capacity building at all levels of the value chain.

What was the situation before 2010?

Malawi is a landlocked country located in the south-eastern part of Africa along the Great East African Rift Valley. It shares its boundaries with Zambia to the north-west, Tanzania to the north-east and Mozambique to the south, south-west and south-east. The country covers a total area of 118,484 km^2 of which 94,276 km^2 is suitable for agriculture (Government of Malawi 2002). The weather conditions of the mainly subtropical country include a wet/rainy season between November and April, a dry and cold season between May and July and a dry hot season between August and October. As of 2017, the population estimate was 17.6 million with a population density of 186 people/km^2. Of the total population, 80% lived in rural areas and 50.7% of the country was impoverished (Government of Malawi 2018; World Bank 2016). This put Malawi among the least-developed countries in the world.

Agricultural production has represented a major industry in Malawi since independence in 1964, utilising the majority of land area and generating major returns for the national economy. In 2010, cultivated land accounted for 56% of total land area (Government of Malawi 2010). In 2016, agriculture contributed 28% of the country's gross domestic product (Government of Malawi 2016b; World Bank 2016). The sector has contributed directly to domestic levels of food availability and indirectly through export activities. The major food crops grown are maize, rice and cassava, while tobacco, tea, sugarcane and cotton are cash crops mainly for the export market (Government of Malawi 2016b, 2016c). Legume production also represents a substantial share of agricultural production activities and is the main source of food and income in the domestic market (Government of Malawi 2016a).

Production of these crops has involved both smallholder and estate farmers (Government of Malawi 2016b, 2016c). Except for tea and sugarcane, smallholder farmers have produced almost 90% of the crops under unimodal rainfed conditions (Government of Malawi 2016b). Notwithstanding this diversity of food crops, maize has been most dominant in Malawi production systems, grown nationally and treated as the nation's food security crop. Maize production has accounted for 90% of the land cultivated by smallholder farmers (Denning et al. 2009), where smallholder farmers hold almost 60% of the total cultivated land (Government of Malawi 2002). Malawi had a persistent national deficit in maize from the new millennium until 2004–05 (Figure 17.1). Low levels of maize production have been attributed to low soil nutrient levels and in-season drought among other factors.

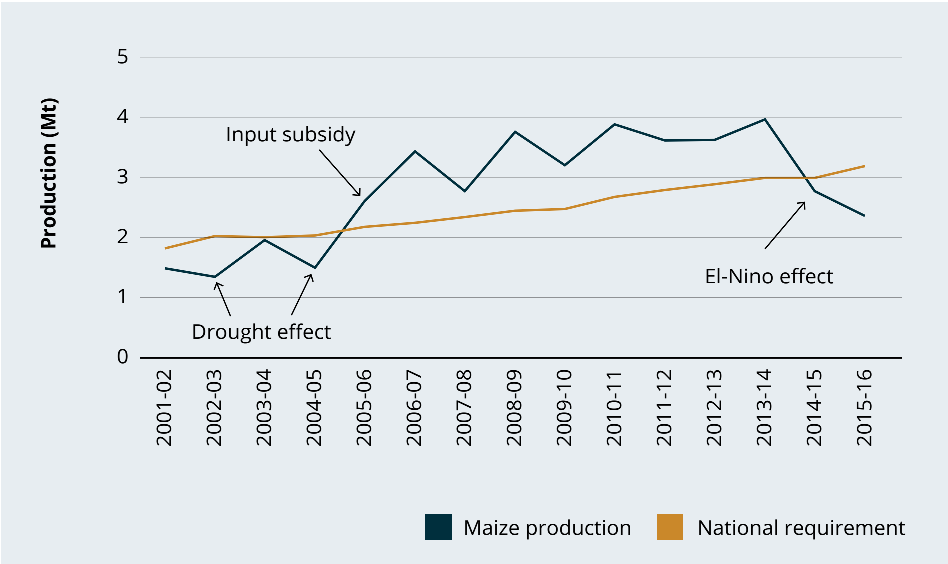

Figure 17.1 **Maize production and national food requirement**

Source: Government of Malawi 2016a

Climate risk

Large dependence on rainfed maize and tobacco production under unimodal rainfall conditions has made Malawi's economy especially vulnerable to climate shocks. Dilley (2005) reported that 5.5% of land and 12.9% of the population faced a persistent risk of two or more natural hazards. This analysis concurs with government records indicating that, in the past 100 years, Malawi recorded at least 20 incidences of drought as well as floods and storms. These records show the frequent occurrence of drought and floods in the new millennium, citing 1999–2000, 2002–03, 2004–05, 2007–08 and 2015–16 as production seasons affected by drought while 2014–15 was a season affected by floods (World Bank Group, United Nations & European Union 2016). Apart from these phenomena, the volatility of average rainfall and temperature across the years also affected overall agricultural planning and production (Figure 17.2). These occurrences, coupled with nutrient depletion and low nutrient soil input (Weber et al. 2012), have greatly affected maize production and food security agendas over the years.

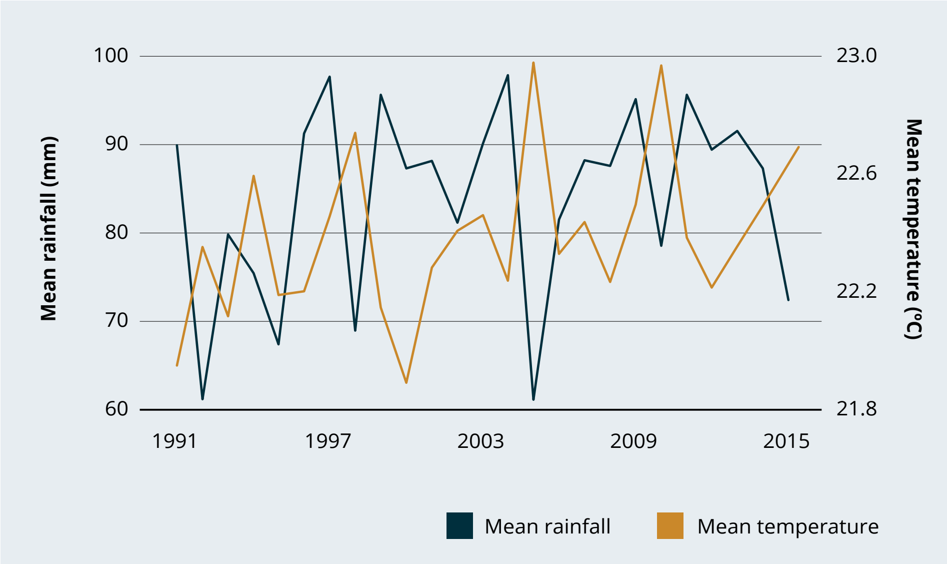

Figure 17.2 **Average rainfall and temperature, 1991-2015**

Source: World Bank Group 2017

Government subsidy program

In light of low maize production levels and soil nutrition constraints, the government of Malawi implemented the Farm Input Subsidy Program since 2004–05 to encourage investment in farm inputs. The program subsidised one 50 kg bag of basal and top-dressing fertiliser each and up to 10 kg of improved seed. The program targeted, at most, 45% of resource-poor farmers registered with the Ministry of Agriculture (Centre for Development Management 2017).

Coupled with good weather conditions and extension services, the improved soil nutrient levels through the Farm Input Subsidy Program led to improved maize production and the achievement of national food self-sufficiency (Denning et al. 2009; Dorward & Chirwa 2011). Despite improvements from the Farm Input Subsidy Program, maize production continued to show evidence of certain vulnerabilities (Figure 17.1). For instance, national production dropped considerably in 2014 and 2015. This has been attributed to floods and drought associated with El Niño (World Bank Group, United Nations & European Union 2016). This illustrates the limitations of subsidies in hedging against drought (Holden & Mangisoni 2013; Holden & O'Donnell 2015). Considering the importance of maize in the economy, the vulnerability of agriculture to climate shocks easily translates to national food and economic risks.

Various avenues have been explored to address these challenges, including agriculture sector development for technologies that can enhance crop productivity and yield stability through drought resilience, increased nutrient intake and nutrient maintenance. In 2010, the government of Malawi launched the Agriculture Sector Wide Approach as the sector investment plan for 2011–15. One of the key priority areas of the investment plan was sustainable agriculture and land and water management, with a focus on sustainable land and water utilisation. In alignment with this priority, Malawi participated in the SIMLESA program: Phase 1 in 2010–14 and Phase 2 in 2015–18.

Conservation agriculture

Before the Agriculture Sector Wide Approach, the government of Malawi had been promoting sustainable management of agricultural land and water since 2000, after the introduction of Sasakawa Global 2000 (Ngwira, Thierfelder & Lambert 2013). Under the Sasakawa initiative, the focus was on denser plant populations, specific herbicides used for controlling weeds and fertilisation guidelines (Ngwira, Thierfelder & Lambert 2013). This resulted in increased maize yield but limited soil nutrient management (Ito, Matsumoto & Quinones 2007). After 2007, there was more focus on conservation agriculture, which is based on three basic principles:

1. minimal mechanical soil disturbance
2. permanent soil cover by organic crop residues and/or cover crops
3. diversified crop rotations or associations with legumes (Food and Agriculture Organization 2015).

The idea was to promote a sustainable cropping system that may help reverse soil degradation, stabilise and increase yield and reduce labour time.

According to Ngwira, Thierfelder and Lambert (2013), conservation agriculture management practices also help to improve rainfall infiltration as a way of improving water use efficiency, reducing soil erosion, increasing soil biological activity and reducing labour hours per unit yield and hectare. Prior to 2010, the baseline report from sampled farm households in the six districts targeted to implement SIMLESA, compiled by Mulwa et al. (2010), showed that farmers did not value the use of crop residues in Malawi (Figure 17.3). The percentage of households reported to have been practising reduced or minimum tillage was almost zero in all districts, compared to other technologies. To increase production and improve soil nutrient management, SIMLESA in Malawi focused on CASI management practices in line with the three principles outlined above.

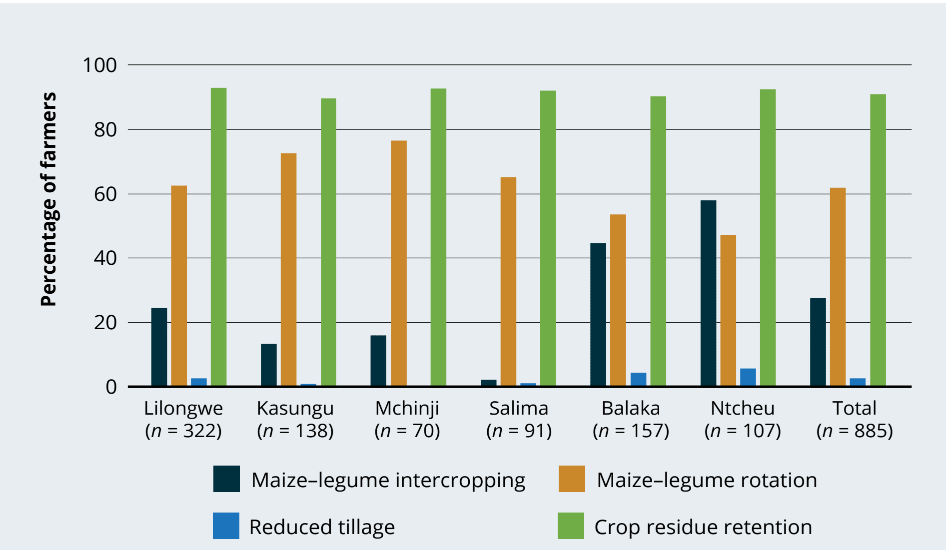

Figure 17.3 **Technology use in Malawi, 2010**

Source: Mulwa et al. 2010

The rest of this chapter is organised into four sections. First, we present the implementation of SIMLESA in Malawi in line with the overall objectives of the program. The next section highlights lessons learned from exploratory trials conducted in Malawi—both on-station and on-farm—and farmers' experiences. Next, we present the estimated impacts obtained from program monitoring reports and other empirical papers. The chapter concludes with options for out-scaling suitable conservation agriculture practices and discusses key priorities for sustaining agricultural productivity and production in Malawi.

What did SIMLESA do?

Local project partners

SIMLESA activities were designed and implemented within the framework of existing regional agricultural development efforts. The Department of Agricultural Research Services under the Ministry of Agriculture was the lead institution in Malawi, supported by the International Maize and Wheat Improvement Center (CIMMYT) and the Queensland Alliance for Agriculture and Food Innovation. The department collaborated with other institutions within the country, both through direct implementation of program activities and innovation platforms. The collaborating institutions included seed producers, agrodealers, associations of smallholder farmers like National Smallholder Farmers' Association of Malawi and non-government organisations that promoted conservation agriculture such as Total Land Care and the Catholic Development Commission in Malawi. The Lilongwe University of Agriculture and Natural Resources played a key role in adoption and monitoring studies through the Adoption Pathways sister project.

Project sites

In line with the research and farmer practice objectives of the programs, Malawi selected six districts in two agroecological zones: low and mid-altitude zones (Figure 17.4). The mid-altitude districts were Lilongwe, Mchinji and Kasungu. The low-altitude districts were Salima, Balaka and Ntcheu. The mid-altitude areas have favourable rainfall patterns and good soils for maize and legume production. The altitude is between 760 m and 1,300 m above sea level and the districts typically receive 600–1,000 mm of rainfall per annum with annual minimum and maximum temperatures of 16–18 °C and 26–28 °C (Kanyama-Phiri, Snapp & Wellard 2000). The low-altitude areas included the lakeshore and rain shadow areas that tend to receive low average rains for maize and legume production. This region spans altitudes of 200–760 m above sea level, tend to receive 500–600 mm of rainfall per annum with annual minimum and maximum temperatures of 18–20 °C and 28–30 °C (Kanyama-Phiri, Snapp & Wellard 2000)

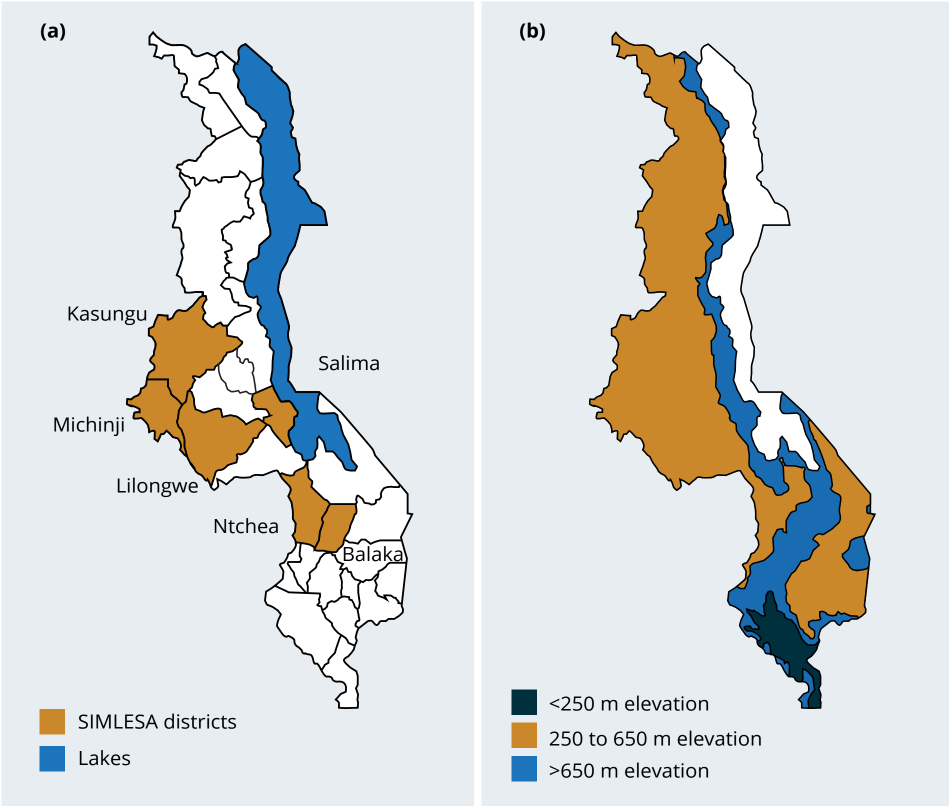

Figure 17.4 **(a) SIMLESA districts and (b) agroecological zones based on elevation**

Sources: (a) Land Resources Department—Mapping Unit 2012; (b) Land Resources Department—Mapping Unit 1998

In each of the targeted districts, the program also targeted one extension planning area and one section (administrative units in the district) to conduct the exploratory trials. Within each section, the program selected six farmers to host exploratory trials for demonstrations for a period of four years (2010–14). These farmers were referred to as 'host farmers'. The communities identified host farmers from six different villages through open forum discussions. The host farmers lived within a 1 km radius of each other for ease of data collection and monitoring. A host farmer was one who was believed to be receptive, innovative, representative, hardworking and accessible by follower farmers, project staff and researchers. Each farmer allocated up to 3,000 m^2 of their land for all the exploratory trials, which covered up to six plots each measuring 20 m × 25 m (500 m^2).

Adoption monitoring and identification of social constraints

To enhance the understanding of CASI options for maize–legume production systems, social scientists collected household-level data and conducted complementary value-chain studies. Specifically, household adoption monitoring surveys were conducted in 2013 and 2015. The interviews were with farmers within the proximity of host farmers to assess their knowledge and use of the CASI systems demonstrated by the host farmers. The adoption monitoring surveys used a snowballing method of sampling, starting with the host farmer, then farmers who learned from each host farmer, or follower farmers. These surveys gave an overview of farmer awareness and uptake of the technologies. Complementary studies included assessing the maize–legume input and output value chains, agrodealer surveys and impact pathways (using 2013 and 2015 survey data).

Long-term CASI trials

Long-term trials were introduced to understand crop responses beyond one seasonal trial and understand soil effects. The trials evaluated the major components of CASI:

1. minimal mechanical soil disturbance
2. permanent organic soil cover by crop residues and/or cover crops
3. diversified crop rotations or associations with legumes.

The treatments (Table 17.1) were implemented in both low- and mid-altitude agroecological zones. The on-station trials were conducted at the Chitala research station, located in the low-altitude district of Salima. In addition, 36 on-farm exploratory trials were conducted, six in each of the six SIMLESA districts. These trials were implemented in SIMLESA Phase 1 (2010–14) and modified in SIMLESA Phase 2 (2015–18). The modification was the inclusion of different maize and legume varieties based on the experiences of SIMLESA Phase 1.

Table 17.1 Treatments for on-farm trials in different agroecologies of Malawi

Low-altitude agroecology site treatments	Mid-altitude agroecology site treatments
Farmers check: soil tillage, crop residues burned or buried	Farmers check: soil tillage, crop residues burned or buried
Minimum tillage + basins (15 cm × 15 cm) + maize–pigeonpea intercropping	Minimum tillage + dibble sole maize, no herbicides
Minimum tillage + dibble maize–pigeonpea intercropping	Minimum tillage + dibble sole maize with herbicides
Minimum tillage + dibble sole maize	Minimum tillage + dibble maize–soybean rotation
Minimum tillage + dibble maize–peanut rotation	Minimum tillage + dibble soybean–maize rotation
Minimum tillage + dibble peanut–maize rotation	

SIMLESA provided the farmers with hybrid seed, fertiliser and herbicides for the trials. To ensure proper management of the trials, the program trained agriculture extension workers in the identified sections to monitor and advise the farmers. Each community established a research committee to ensure proper management of the trials. The committees also acted as community monitoring institutions by monitoring performance, recording trial observations at agreed upon time points, organising exchange visits during the season and communicating issues and concerns regarding trial management to extension workers or other project personnel.

To test the effect of CASI systems on reducing seasonal downside risks, researchers from Chitedze Research Station in collaboration with the Queensland Alliance for Agriculture and Food Innovation used the Agricultural Production Systems sIMulator (APSIM) model. Soil characteristics, including soil nutrient uptake, maintenance of nutrients, water infiltration and resilience to pest attack, were also evaluated to compare CASI and conventional farming (Table 17.2).

Table 17.2 Initial chemical soil characterisation of trial sites, 2010–11

Threshold values		pH	Organic carbon (%)	Organic matter (%)	Nitrogen (%)	Phosphorus (μg/g)
		Range for critical values				
District	**Extension planning area**	**5.5–7.5**	**0.88–2.35**	**1.50–4.0**	**0.09–0.15**	**19.0–25.00**
Ntcheu	Nsipe	6.57	0.47	0.81	0.04	69.89
Balaka	Rivirivi	6.33	0.85	1.46	0.07	74.04
Salima	Tembwe	5.84	0.98	1.69	0.08	166.40
Kasungu	Mtunthama	6.14	0.67	1.15	0.06	93.56
Mchinji	Kalulu	5.28	0.55	0.96	0.05	83.38
Lilongwe	Mitundu	5.39	1.04	1.79	0.09	41.05

Varietal trials

Breeders at the Department of Agricultural Research Services together with seed companies, the International Crops Research Institute for the Semi-Arid Tropics, the International Institute for Tropical Agriculture and non-government organisation partners did an inventory of potential drought-tolerant maize and legume varieties. The varieties identified for maize were Malawi Hybrid (MH) 26, MH 30, MH 31, MH 32 and MH 38. Under legumes, the identified varieties in Malawi were Nasoko, Tikolore and Makwacha for soybean; Mwaiwathu alimi, Chitedze pigeonpea 1 and Chitedze pigeonpea 2 for pigeonpea; Sudan 1 and IT82E-16 for cowpea; and CG 7, Chitala, Kakoma and Nsinjiro for peanut.

Breeders also developed and released peanut varieties of Virginia and Spanish genotypes. The evaluation of both genotypes indicated that they were high-yielding, resistant to rosette disease (a major challenge in legume production) and had medium seed size. The major difference was in the maturity period. The maturity period of the Virginia genotype was medium duration while that of the Spanish genotype was short duration.

Breeders further conducted on-station trials for the evaluated varieties under CASI systems to compare production results with conventional farming methods. These trials evaluated the level of tolerance to drought and maize nitrogen content. Based on the identified and released varieties, seed companies assisted in the multiplication of pre-basic and basic seed of both maize and legumes. The ultimate objective was to make the identified seed available to farmers.

Knowledge-sharing platforms

To create a knowledge-sharing platform, host farmers were encouraged to share their exploratory results with fellow farmers in their sections through field days and farmer-to-farmer exchange visits. To scale out technologies, SIMLESA also facilitated farmer exchange visits, demonstrations, farmer field schools, and farm business schools and capacity building for extension workers. In line with this, SIMLESA established six local innovation platforms, one for each of the selected districts. These platforms were developed to bring together farmers, seed producers, agrodealers, non-government organisations and extension workers. Mainly the platforms were formed to help mobilise resources and increase access to market information.

Capacity building

SIMLESA supported both long-term and short-term training, within and outside Malawi. The program contributed to the capacity building of scientists, extension agents and farmers in the use of CASI management options, extension methodologies, gender mainstreaming, use of modelling tools and scientific writing, with the attainment of certificates, masters and doctoral degrees.

What did we learn?

Yield gains

The exploratory trials from Phase 1 found that conservation agriculture produced higher average maize yield when compared to conventional farming in treatment one. Tables 17.3 and 17.4 indicate differences in maize yields across the mid-altitude and low-altitude districts. From this data, we observed that the average yields of the CASI system were higher than the conventional system.

Table 17.3 Average maize yields by cropping system in low-altitude districts, 2010–11 to 2013–14 cropping seasons

Cropping system	4-year mean yield (kg/ha)	Yield increase (%)
Conventional practice	2,397	0
CASI: basins, maize–pigeonpea intercrop	2,824	18
CASI: dibble stick, maize–pigeonpea intercrop	2,628	8
CASI: dibble stick, maize sole	2,718	12
CASI: dibble stick, maize–peanut rotation	3,286	33

Note: CASI = conservation agriculture-based sustainable intensification

Table 17.4 Average maize yields by cropping system in mid-altitude districts, 2010–11 to 2013–14 cropping seasons

Cropping system	4-year mean yield (kg/ha)	Yield increase (%)
Conventional practice	3,798[1] (2,943)[2]	0 (0)
CASI + sole maize + no herbicide	3,889	2 (32)
CASI + sole maize + herbicides	4,088	7 (39)
CASI + herbicides + maize–soybean rotation	4,434	17 (51)

Notes:

1. Conventional yield estimated in the trial plot.
2. Results in parenthesis are calculated maize yields from plots next to the exploratory trials under farmer management without the influence of researchers.

Percentage comparisons for conventional practice are in parenthesis; CASI = conservation agriculture-based sustainable intensification.

This concurs with Ngwira, Thierfelder and Lambert (2013), who reported that maize yield biomass in Malawi increased by 2.7 Mg/ha under CASI management of a monocrop and by 2.3 Mg/ha under CASI for a maize–legume intercrop when compared to conventional methods in the 2009–10 production season. Ngwira, Aune & Mkwinda's (2012) on-farm evaluations in Balaka and Ntcheu districts also indicated positive yield changes from CASI systems. Their study reported a positive effect on maize yield with an average yield of 4.4 Mg/ha observed in CASI systems compared to 3.3 Mg/ha with conventional practice during the dry production seasons of 2009–10 and 2010–11. Summary yield results from the first four years of SIMLESA in both agroecological zones have been reported elsewhere (Nyagumbo et al. 2016). Yield increases were highest in maize–peanut rotation systems (33%) in the lowlands while the maize + soybean rotation enabled a 17% increase in maize yields in the mid-altitudes.

Performance across agroecological zones

Despite positive average results under CASI, variable impacts have been reported across agroecological zones from prior studies. For example, Giller et al. (2009) informed an assessment of conditions under which CASI is best suited to SIMLESA households. The exploratory trials demonstrated high levels of yield variability for a given set of CASI management practices across sites. Differences in yields were attributed to the onset of planting rains, variety choice, rainfall distribution, soil quality and plot management.

The set of CASI management practices with the greatest yield benefit depended on the specific site attributes. In the lowland districts, CASI plus rotation and CASI plus basins yielded superior grain yields in years with mid-season dry spells (Tables 17.3 and 17.4). The basins had a water harvesting effect while rotation had a soil nitrogen-fixing effect. In contrast, basins performed poorly in seasons with above-normal average rainfall and good rainfall distribution. With basins, excess rain resulted in waterlogging that decreased maize yields (Nyagumbo et al. 2016). Similar observations have been highlighted by Nyamangara et al. (2014) in Zimbabwe. In Salima and Ntcheu, the general performance of CASI plus basin technology was poor because of waterlogging and infestation of wireworm across all seasons. However, CASI and rotation were highly effective in Salima because of weed management, considering that the soils in this area are poor and susceptible to witchweed (*Striga asiatica*) infestation (Berner, Kling & Singh 1995).

In mid-altitude areas, technologies that performed better were CASI plus herbicides and CASI plus rotation, because of their ability to suppress weeds. This is in line with the observations of Nichols et al. (2015). Apart from climatic conditions in this region, field observations showed that farmers' experiences in crop variety and planting time positively influenced differences in yields. Most farmers from the mid-altitude areas were more experienced in maize production under conventional farming than those from low-altitude areas.

Farmers' preference

Farmers' preferences were also evaluated across trial sites to identify practices for site-specific recommendations. Their preferences were evaluated based on labour, time and cost (saving potential) measures in line with literature that these factors can also significantly influence adoption decisions (Giller et al. 2009; Ngwira et al. 2014). Focus group discussions were conducted during field demonstrations, farmer field schools, field days or national and international exchange visits (farmers in Mozambique visited Malawian farmers in 2015) to solicit farmer preferences in the choice of technologies. Table 17.5 presents a summary of the preferred technologies from the focus group discussions.

Table 17.5 Technologies preferred by farmers in SIMLESA districts

District	CASI + legume–maize intercropping	CASI + legume–maize rotation	CASI + basin + herbicides + sole maize	CASI + sole maize minus herbicides	CASI + sole maize + herbicides
Balaka	√		√		
Ntcheu		√			√
Lilongwe	√		√		
Mchinji	√				√
Kasungu	√	√			
Salima		√			√

Note: CASI = conservation agriculture-based sustainable intensification

Farmers mostly preferred CASI practices that allowed for intercropping maize and legumes. Although rotation and use of herbicides gave higher yields and were preferred during trials, farmers reported limited access to land and capital as major challenges affecting uptake of these high-performing technologies.

Dissemination pathways

The evaluation of dissemination modalities suggests that partnership with non-government organisations and government programs and projects in mounting demonstrations and hosting field days assisted in achieving intensive and extensive dissemination of CASI technologies. At the same time, innovation platforms played a key role in technology adoption and use. Furthermore, the involvement of local leaders was instrumental in technology adoption through enforcement of by-laws that protect residue use in conservation agriculture against competing needs. Often farmers reported free-range grazing of livestock, wildfires and hunting of mice as reasons for not mulching their fields in time. Where local leaders enforced by-laws, the areas were successful in the management of CASI systems. This suggests that a community approach offers major advantages when out-scaling CASI systems through innovation platforms.

The value-chain review study for maize and legume production from 2013 found that collective purchasing and marketing was one of the key strategies that producers applied to enhance economies of scale. However, the agrodealers study in 2015 showed limited effort by agrodealers to take cost-effective opportunities that exist among smallholder farmers in acquiring inputs and selling outputs. Together, these results helped to identify promising management practices for scaling out (Table 17.6).

Table 17.6 Scalable technologies

Agroecology	Scalable technology	Crop varieties
Low altitude	• use of planting basins/minimum tillage • use of stress-tolerant crop varieties • maize–peanut rotation • maize–pigeonpea intercrop	Maize: MH 26 Peanut: Kakoma & Chitala Pigeonpea: Mwaiwathu alimi Cowpea: IT18E-16
Mid altitude	• maize–soybean rotation including inoculation • improved maize and legume varieties that withstand multiple stresses • flat planting	Maize: MH 26 & MH 27 Soybean: Nasoko

What was the impact?

SIMLESA activities increased adoption of CASI technologies and overall crop yield at the household level. Evidence presented here shows:

1. the program contributed to the development and adoption of user-preferred maize and legume conservation agriculture technologies
2. adoption increased in on-farm production.

We use findings from adoption monitoring surveys in 2013 and 2015 and studies from the Adoption Pathways project.

Adoption of CASI technologies

By 2013, all sampled farmers were aware of the CASI technologies demonstrated by SIMLESA and about 63% had tried them as either SIMLESA host farmers or follower farmers. Of those that tried, 78% had adopted these technologies. Minimum tillage (basins) was the most preferred and adopted technology. Minimum tillage practices became more common after the implementation of SIMLESA compared to reduced tillage in 2010. On average, 32% of farmers indicated they were practising minimum tillage in 2013 (Figure 17.5).

By 2015, 95% of the interviewed farmers had tried CASI technologies, an increase from 63% in 2013. The most widely adopted technologies were residue retention/mulching (24%); use of improved seed and herbicides (17%) and a combination of minimum tillage and rotation (13%) (Figure 17.6). Furthermore, 13% of interviewed farmers preferred and adopted crop rotation while 11% adopted zero/minimum tillage by 2015. Between 2013 and 2015, farmers continued to intensify use of minimum tillage or residue retention but with an emphasis on combining the technologies. Female-headed households were more likely to adopt a combination of minimum tillage and crop rotation than male-headed households. Alternatively, male-headed households were more likely to invest in herbicides and hybrid seeds (Figure 17.6).

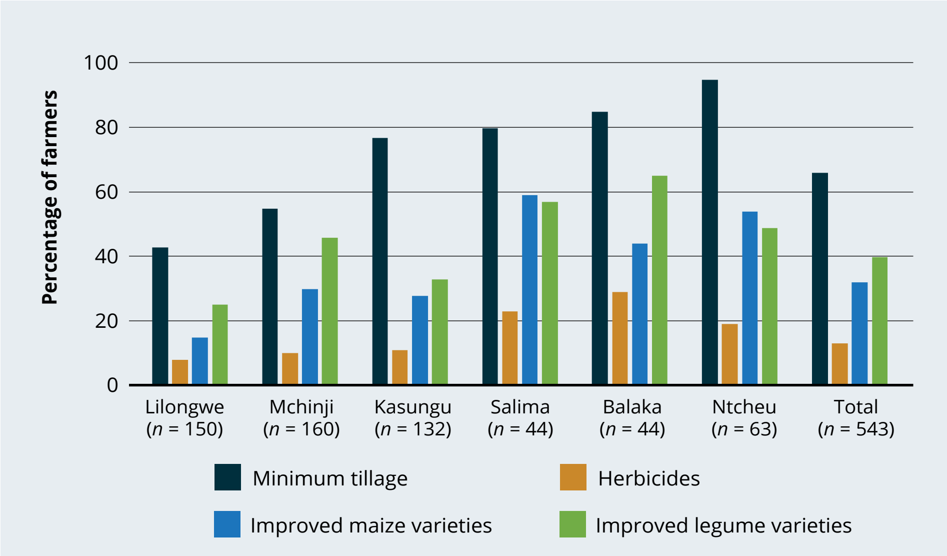

Figure 17.5 Technology adoption, 2013

Source: Government of Malawi 2013

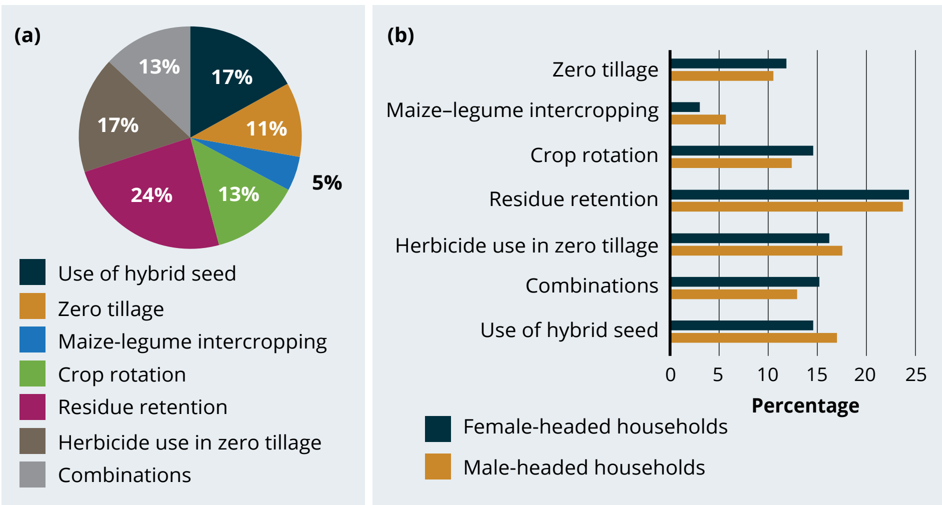

Figure 17.6 Technology adoption by (a) total sample and (b) gender of household head, 2015

Note: 'Combinations' means the farmers are practising minimum tillage with mulch and rotations.
Source: Government of Malawi 2015

Of the total sample in 2015, 52% of the households had stopped using at least one of the CASI management practices in the early stages of adoption. The most commonly reported reasons for disadoption in both 2013 and 2016 included lack of equipment/inputs and cash constraints (Figures 17.7 and 17.8). These reasons are consistent with observations by Giller et al. (2009).

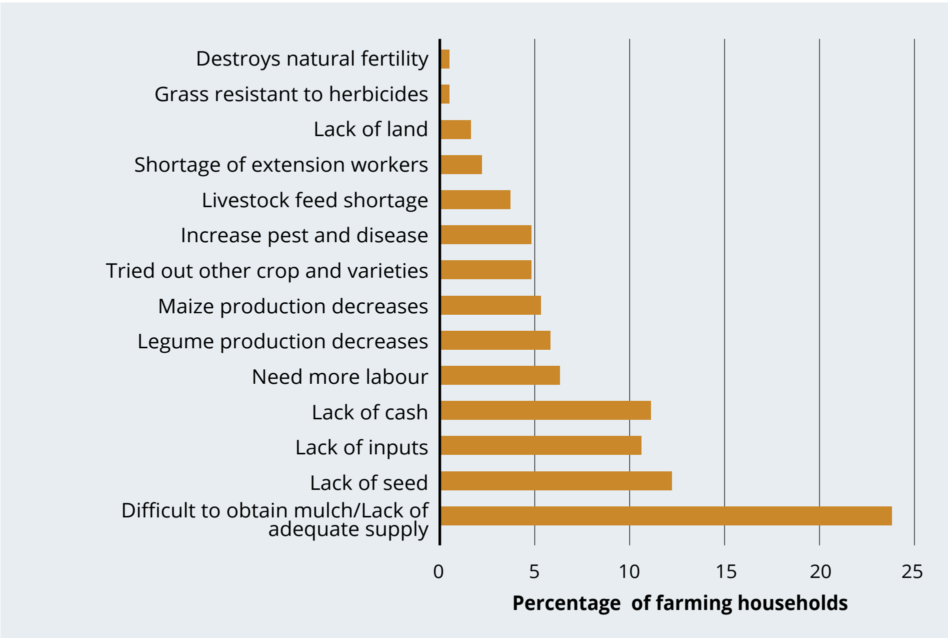

Figure 17.7 Reasons for disadoption of technologies, 2013

Source: Government of Malawi 2013

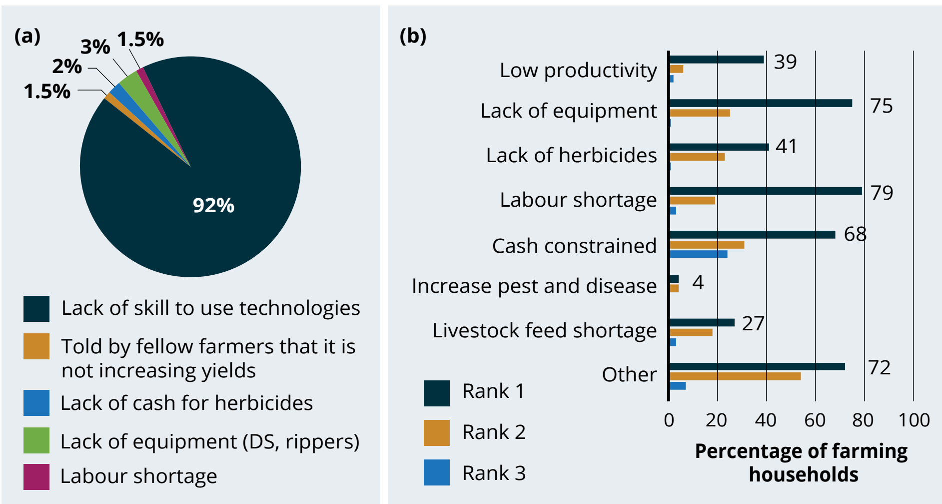

Figure 17.8 Disadoption of technologies by (a) overall main reason and (b) ranked reasons, 2015

Source: Government of Malawi 2015

Impact on yield and income

Maize productivity has increased since SIMLESA was implemented (Figure 17.9). Zero/minimum tillage increased yields by an average of 67% while adoption of improved maize and legume varieties increased yields by an average of 68% and 67% respectively in 2013. The story of the Mpomola family in case study at the end of chapter (page 328) is one of many cases of increased maize production when farmers practised conservation agriculture technologies.

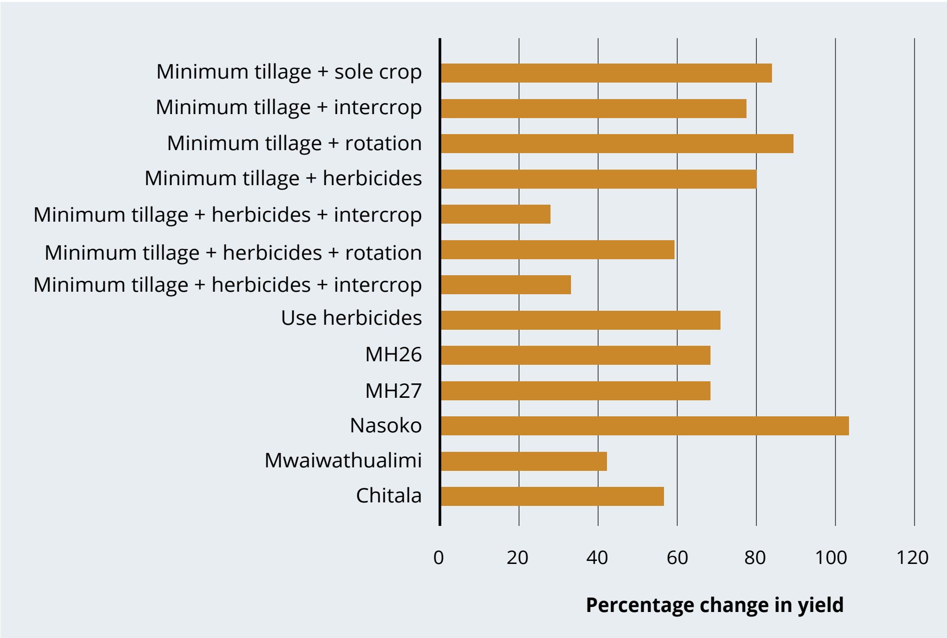

Figure 17.9 **Average change in maize yield (2010–13)**

Source: Government of Malawi 2013

Farmers suggested that yield changes were the result of improved soil nutrient and nutrient maintenance from using CASI systems. Farmers also indicated that amid changing rainfall patterns, CASI systems retained moisture to alleviate drought stress. Empirical research validated the farmers' perceptions of reduced risk. Based on APSIM results, adoption of a combination of different recommended conservation agriculture technologies decreased downside risks by 16%. Among the conservation agriculture management practices, crop residue retention contributed most to risk reduction by substantially reducing the amount of run-off that can contribute to land degradation or soil erosion (Figures 17.10 and 17.11). Crop residues also maintained biodiversity and helped to reduce the build-up of pests and diseases. Legume–maize rotation/intercropping improved soil nutrients by fixing nitrogen.

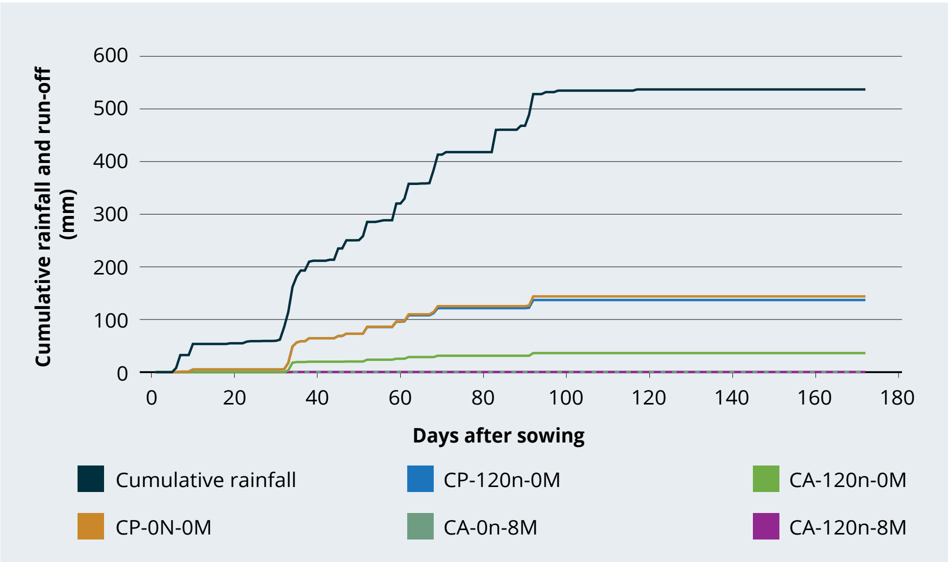

Figure 17.10 **Cumulative run-off at different rates of nitrogen and crop residues**

Source: SIMLESA farm trials

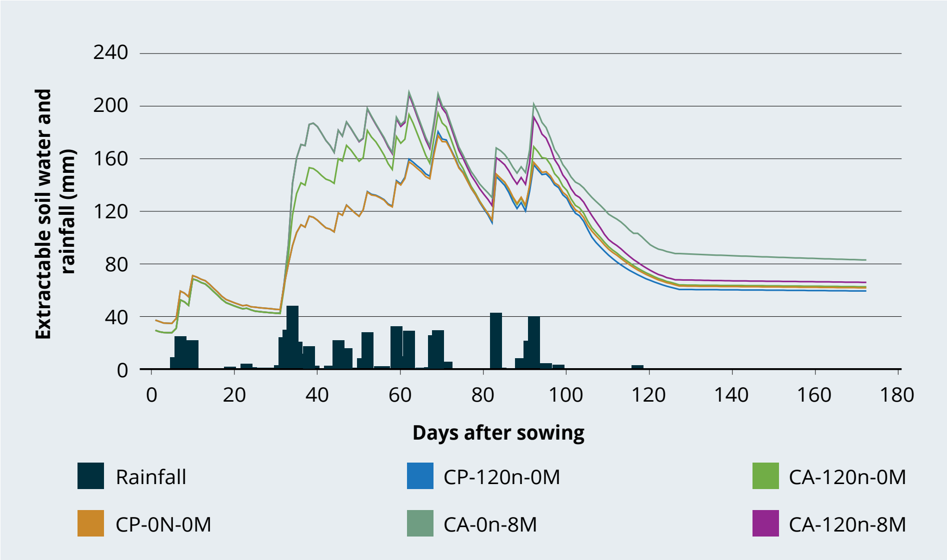

Figure 17.11 **Extractable soil water at different rates of nitrogen and crop residues**

Source: SIMLESA farm trials

These results concur with Kassie, Teklewold, Marenya et al. (2015), who reported positive impacts of adopting CASI practices such as maize–legume diversification and minimum tillage on increased food security and reduction in yield risk and cost of risk in Malawi. The estimated impact was highest with simultaneous adoption of the entire set of CASI practices. Specifically, they reported an increased maize yield of 850 kg/ha on plots with crop diversification and minimum tillage compared to those on conventional methods. The study further reported that adopting a combination of sustainable intensification practices together with complementary inputs such as improved seeds could raise maize net income in Malawi by 117%. Estimated results indicate that the income effect is not only from increased yield but also from reduced intensity of fertiliser and chemical pesticides. Kankwamba and Mangisoni (2015) also reported higher and consistent farm output and incomes in households who adopted CASI practices compared to non-adopting households.

Physical evidence of improved income from the field is provided by a case of one host farmer in Lilongwe (mid-altitude area) who attributed her family's new iron sheet house with proceeds from increased production after adopting a CASI system (Figure 17.12). Given that smallholder farmers in Malawi face recurrent low and unstable crop yield due to weather shocks and low nutrient intake (Weber et al. 2012), these findings suggest that joint adoption of crop diversification and minimum tillage can hedge against income and climatic risk exposure. See the case study below for more success stories on CASI systems and maize production in Malawi.

Case study: Through SIMLESA, CASI increases maize production in Malawi

Chrissy Samson Mpomola hails from Balaka district, which is located in the lowlands of Malawi. If Chrissy was to choose a method of farming for her whole farm, it would be the CASI system of land management, with no ridges, maize intercropped with pigeonpea and herbicide applied (only glyphosate) for weed control. Why? 'Because the work is not so difficult and thus labour saving. We leave the residue on the ground, and the crop that grows has a good stand and yields more,' she says. 'I think this is a profitable farming method, and my neighbours always admire my crop stand.'

Chrissy and Afiki Mpomola are a married couple with six children, three of whom are also married. Chrissy is a full-time farmer with about 30 years' farming experience. Her family owns a total of 4.2 acres (1.7 ha). The couple mainly produce maize for food self-sufficiency and peanut for food and income. They also grow cotton and pigeonpea as cash crops, which are suitable for this agroecological zone.

Before she joined SIMLESA, Chrissy's household was constantly challenged by climate shocks, including persistent dry spells, seasonal droughts and intense rainfall, which resulted in low productivity and left her household chronically food insecure. Thanks to SIMLESA, she started practising CASI management in her own field and now her chronic food shortage has turned into surplus to sell, even in poor rainfall seasons.

Chrissy says, 'Before the 2013–14 production season, using conventional farming practice, we used to get four to five bags of maize on our land but now we are getting about 20 bags.' The yield increase is fourfold to fivefold.

On the recommendation of extension workers and an open forum community vote, the Mpomola family hosted all six SIMLESA treatments. Because of this, Chrissy has follower farmers who imitate what she has done on her farm. Alice Mpochera, Chrissy's neighbour, says she admires Chrissy's CASI crop, and, although she does not know much about the technology, she can see that the crop stand on Chrissy's farm appears to have a higher yield than her field. Alice says she would be interested in learning more about the improved farming methods used by her neighbour.

What should we do next?

The sustainability of agricultural productivity and production in Malawi depends on intensive and extensive use of CASI practices such as the ones SIMLESA promoted. With increasing population density in Malawi, improving land productivity is the key to the twin problems of increasing production for food security and sustaining soil nutrition. In this section, we present the out-scaling options and key priorities for Malawi, based on the lessons learned from exploratory trials and farmers' evaluations of the technologies.

Existing innovation platforms and new partnerships can be both strengthened and established to provide the institutional capacity for scaling out technologies beyond SIMLESA. Specific areas for improvement and observed challenges encountered in the program include:

- inadequate published extension materials/guides distributed to extension workers, which limited the delivery of knowledge to the farmers
- inefficiency in marketing systems.

The results surrounding disadoption further suggest the need to establish and strengthen local institutions and provide farmers with credible and timely information on capital sources, credit facilities, business development and management skills. In general, this calls for a value-chain approach to the development of agriculture systems. With this approach, service providers can be equipped with better skills to supply farmers with quality and timely information while farmers respond with timely decisions.

Kassie, Teklewold, Jaleta et al. (2015) reported other key factors that created barriers to long-term adoption, including the existing capacity for institutional support in the form of extension services and skills of extension agents on the adoption of CASI practices in Malawi. Furthermore, Marenya et al. (2015) showed that input subsidies and strong extension services enhance the adoption of CASI practices. The results imply that keeping down the costs of complementary inputs, such as inorganic fertiliser, improved seed, herbicides and equipment, and enhancing extension services are key to increasing adoption of CASI practices. Given that the government of Malawi has been implementing the Farm Input Subsidy Program, integrating the SIMLESA practices with the Farm Input Subsidy Program has potential to drive the country's food security agenda beyond the areas initially targeted. Generally, these lessons indicate the complexity of problems in Malawi that require holistic solutions.

Innovation platforms might be a feasible and promising value-chain-based avenue for addressing these challenges. Innovation platforms can support partnerships among different players to holistically support farmers to access inputs, credit, transportation and extension support. Through these platforms, farmers can engage in forwarding contracts or structured markets and avoid spot markets. Innovation platforms can also present an opportunity to lobby the government to invest in marketing infrastructure and institute policies that promote farming as a business.

Future efforts can also work to ensure equitable benefits across demographic groups. Differences in the conservation agriculture technologies adopted by male-headed households and female-headed households might reflect gaps in access to resources and production capabilities between these households. Although enhancing equal access to resources would significantly contribute to increased production among gender groups, Gilbert et al. (2002) and Kassie, Stage et al. (2015a) reported that the food insecurity gap would remain without appropriate policies to address differences in returns to resources (e.g. improved labour-use efficiency). Thus, reducing gender gaps in adoption benefits from CASI practices would have a major impact on food security, especially among female-headed households (Kassie, Stage et al. 2015).

Key priorities

Key priorities in sustaining agricultural production through CASI cropping systems include:

- continually and systemic research. Knowing that there is no single solution to all the complex problems in agriculture, Malawi will continue conducting systemic research. This is because among the technologies or improved farming practices tried in SIMLESA, there is no silver bullet, only a shopping list with choices depending on, not only ecological factors, but also socioeconomic characteristics. That is, going beyond a disciplinary approach to an interdisciplinary approach in research.
- Embedding the innovation platforms into government agricultural policy to facilitate legal and social recognition. This is one way of ensuring that the innovation platforms efficiently assist in resource mobilisation and contract agreements. In Malawi, there is a need for innovative institutional arrangement and policy alignment to transform agriculture.
- Enhanced private–public partnerships as a way of facilitating scaling out and scaling up of CASI practices among farmers.
- Enhance knowledge management. Referring to the words of the philosopher George Berkeley, 'If a tree fell in the forest and no-one is there to hear it, did it make a sound?' There is a need to package information for various users if these findings are to be of impact.
- continually research on labour- and land-saving technologies in line with new challenges that might arise. Maize–legume intercropping is vital for a country like Malawi, due to increased land pressure from population growth.
- Facilitate short-term and long-term training. The need to continually train and build capacity at all levels remains vital amid new challenges and new methodologies for dealing with these challenges.

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18 The sustainable intensification of agriculture in Mozambique

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Key points

- The use of conservation agriculture-based sustainable intensification (CASI) technologies in Mozambique increased maize and legume yields by up to 37% compared to current farmer practices.
- The use of mechanised animal traction and winter preparation of fields was a potential strategy for labour reduction and improved timeliness of operations, particularly in female-headed and labour-constrained households.
- The application of maize residues had more positive effects in low rainfall conditions, and could depress yields in unfertilised high rainfall environments.
- Uptake of improved varieties and cropping systems continues to be negatively impacted by low input/output market incentives to farmers.
- Innovation platforms and other farmer-driven strategies created opportunities for the uptake of technologies. By 2018, more than 38,000 farming households were reached.
- Results from laboratory analysis of five years of continuous maize cropping systems under CASI practices in Sussundenga showed a 0.12% (+/- 0.10) gain in total carbon in the 0–5 cm soil layer. This equates to approximately 124,000 Mt C/year input across all SIMLESA farmers in Manica.
- To foster agriculture productivity through CASI, policymakers should:
  - include proven CASI strategies at all levels of policy conversations
  - invest in the incubation of new business opportunities, including demand creation
  - facilitate investment funds to support acquisition of machinery by agribusinesses
  - invest in training for large cohorts of technicians to mainstream smallholder mechanisation
  - invest in the establishment and maintenance of large networks of community-based demonstration plots and farms
  - initiate funds and seed capital to catalyse private investments in scaling CASI.

Introduction

The average maize yield in Mozambique is low at 0.85 t/ha and highly variable. Despite the ample availability of land, good soil fertility, research and extension capacity, the agriculture infrastructure is weak. Agriculture is characterised by frequent droughts and floods, poor access to seed of improved varieties, restricted access to fertilisers and use of unsustainable soil management practices coupled with dysfunctional agricultural markets and weak research and extension services.

To improve crop yields among smallholders, ACIAR and the International Maize and Wheat Improvement Center (CIMMYT), in partnership with the Instituto de Investigação Agrária de Moçambique (IIAM), implemented SIMLESA in 2010. Best-bet technologies were tested, including the use of conservation agriculture-based sustainable intensification (CASI) practices, which had a strong potential to enhance yields and sustain food security. CASI practices were applied and the best fit were selected by farmers and out-scaled by three major scaling partners and innovation platforms in central Mozambique. In the project, 34 varieties (11 maize, 4 bean, 5 pigeonpea, 6 cowpea and 8 soybean) were supplied to smallholder farmers through participatory variety selection trials for legumes and mother–baby trials for maize. Innovation platforms were established in each of the six SIMLESA communities, located in four districts and three provinces of Mozambique (Figure 18.1).

Figure 18.1 Location of SIMLESA communities in central Mozambique

Preliminary results showed that more than 38,000 farmers were directly engaged in ground activities through innovation platforms and reached out to some 100,000 farmers. CASI and other best-management practices increased maize yields by 37%, cowpea yields by 33% and soybean yields by 50% across farms in Sussundenga (Manica province) and maize yields by 46% in Angonia (Tete province). This was well above the target set by the Ministry of Agriculture of a 7% in yield increase above current base yields. Key lessons from monitoring and evaluation activities suggest that improved timeliness and management, including fertility management and weeding, were key productivity factors that need attention in future.

What was the situation in 2010?

Mozambique has a variety of regional cropping patterns driven by agroclimatic zones ranging from arid, semi-arid and subhumid (mostly in the central and the northern agroecological regions) to the humid highlands (mostly the central provinces). The most fertile areas are in the northern and central provinces, which have high agroecological potential and generally produce agricultural surpluses.

At least three agroecological zones (AEZ) can be identified in each of the four provinces in central Mozambique (Instituto Nacional de Investigação Agronómica 1997):

- Manica (AEZ R4, R6, R10)
- Sofala (AEZ R5, R4, R6)
- Tete (AEZ R6, R7, AEZ)
- Zambezia (AEZ R7, R5, R8, R10).[9]

With the large majority of agricultural production being rainfed, weather variability is a major factor in determining crop performance. The main growing season starts with the first rains in September in the south and December in the north. There is also a minor growing season, based on residual soil moisture, from March to July, accounting for approximately 10% of total cultivated area. There are about 36 Mha of arable land, suitable for agriculture. Maize is the most widely grown crop, occupying some 1.4 Mha and producing 1.2 Mt annually, but this is highly variable from year to year. Despite ample land, soil fertility is low, with southern provinces having poorer soils and more erratic rainfall, and being subject to recurrent droughts and floods.

Mozambique is one of the world's poorest countries, despite its great potential. Its agriculture is characterised by low soil fertility, frequent droughts and floods, use of unimproved varieties, poor access to good-quality seed of improved varieties, restricted access to fertilisers and use of unsustainable soil management practices coupled with dysfunctional agricultural markets and weak research and extension services. To improve crop yields among smallholders, CIMMYT in partnership with IIAM implemented SIMLESA in 2010, a research initiative from ACIAR aimed at promoting sustainable intensification of maize–legume cropping systems for food security in eastern and southern Africa. The use of CASI management and adoption of best practices was considered to have great potential to boost yields and sustain food security.

9 At least three agroecological zones can be identified in each one of the four provinces in central Mozambique: Manica (AEZ-R4, AEZ-R6 and AEZ-R10), Sofala (AEZ-R5, AEZ-R4 and AEZ-R6), Tete (AEZ-R6, AEZ-R7 and AEZ-R10) and Zambezia (AEZ-R7, AEZ-R5, AEZ-R8 and AEZ-R10).

What did SIMLESA do?

IIAM staff directly targeted 27,000 households in six communities with two contrasting agroecologies of the following provinces:

- Manica: Sussundenga-sede, Muoha (AEZ 4), Chinhandombwe and Rotanda (AEZ 10)
- Sofala: Canda-Sede in Gorongosa (AEZ R4)
- Tete: Chipole and Cabango in Angonia (AEZ R10).

Over the seven-year period (since 2010), 36 on-farm CASI exploratory trials covering more than 38,057 households were conducted (Table 18.1). Apart from the exploratory trials, 871 participatory variety selection and mother–baby trials were conducted across all SIMLESA target communities. After the review of SIMLESA-1, the IIAM concentrated its efforts on scaling out earlier successes by developing locally-relevant innovation platforms for CASI. The scaling out of CASI technologies in central Mozambique was mainly conducted during SIMLESA-2 through a competitive grant scheme with local partners and targeted Manica and Tete provinces.

Table 18.1 **Results from on-farm trials in Mozambique comparing yields in conservation agriculture to conventional maize production and the number of households impacted**

Location	Maize yields under conventional practices (kg/ha)	Maize yields under CASI (kg/ha)	Estimated number of households impacted	
			National teams	Scaling partners
Sussundenga, Manica, Rotanda (Manica)	1,497	2,063	27,000	50,000
Angonia (Tete)	3,600	4,200	11,057	50,000
Total			**38,057**	**100,000**

Note: CASI = conservation agriculture-based sustainable intensification

Evaluating the benefits of local CASI packages

Exploratory trials during SIMLESA Phase 1 compared locally adapted CASI systems (no-till, fertiliser application, legume rotation, new maize and legume varieties) with conventional systems (continuous maize, deep tillage). On average, CASI increased maize yields by 37%, cowpea yields by 33% and soybean yields by 50% across farms in Sussundenga and Gorongosa (Table 18.2) (Nyagumbo et al. 2016). This was well above the 7% yield increase target set by the Ministry of Agriculture.

Table 18.2 **Sussundenga and Gorongosa (low-potential area) yield increase in six years of CASI practices**

Cropping systems	Maize grain yield (kg/ha)	% increase
Conventional practice	1,497[a]	0.0
CASI + jab planter	1,784[b]	19.2
CASI + basins	1,789[b]	19.5
CASI + basins maize–cowpea intercrop	1,802[b]	20.4
CASI + basins maize–cowpea rotation	2,063[c]	37.8

Notes: CASI = conservation agriculture-based sustainable intensification; figures followed by different letters differs significantly.

When on-farm impact of various conservation agriculture packages were compared with conventional systems, all with same level of fertiliser in north-west Mozambique, only one site observed significant increases in yield from CASI using the dibble-stick method. In this region, yields increased from 3,066 kg/ha (conventional production) to 3,145 kg/ha (dibble stick, sole maize), representing only a 2.5% yield increase (Table 18.3) (Nyagumbo et al. 2016).

Table 18.3 Maize yields across CASI practices for two communities in Angonia, Mozambique

Cropping system	Maize grain yield (kg/ha)		
	Kabango	Chiphole	Overall mean
Farmers' check (i.e. flat hoe prepared seedbed)	3,712	2,579	3,066
CASI + basins + sole maize	3,622	2,510	3,145
CASI + dibble stick + maize sole	4,182	3,091	3,636
CASI + dibble stick + maize–bean rotation	4,043		
CASI + dibble stick + maize–bean intercrop	3,881		
CASI + basins + maize rotation		2,549	
CASI + basins + maize–bean intercrop		2,424	
	$LSD_{(0.05)}$ = 574 *df* = 20 CV = 37.7% *N* = 120	$LSD_{(0.05)}$ = 282 *df* = 20 CV = 39.5% *N* = 120	$LSD_{(0.05)}$ = 316 *df* = 20 CV = 39.7% *N* = 144

Notes: CASI = conservation agriculture-based sustainable intensification; LSD = least squares difference; *df* = degrees of freedom; CV = coefficient of variation.

Due to the detrimental effect of termites on residue retention and maize lodging, the project evaluated various methods of termite control suitable for the conditions of the sites in Mozambique. Field studies in 2011–12 and 2012–13 found that termite activity could be reduced through application of fipronil (1.5 g a.i./ha) but that termite control did not increase maize yields in the short term (Nyagumbo et al. 2015). The presence of surface residues decreased the incidence of maize lodging from termite activity.

The project found that by reducing the constraint of labour availability, mechanised CASI practices improved timeliness of planting, which led to reductions in maize yield variability (Nyagumbo et al. 2017). Finally, two on-station intensification trials were tested during SIMLESA Phase 2 and, while these data are available, more seasons are needed to produce recommendations.

A survey of farmers in Macate district conducted by the Queensland Alliance for Agriculture and Food Innovation (QAAFI) found wide variability in on-farm implementation of promoted CASI systems in 2013 (Roxburgh 2017). Sowing densities were found to vary widely on farms and most households were not using fertiliser in their CASI systems. Modelling analysis found that there were potential yield gains (120%) simply by focusing on best agronomic practices such as weeding and population densities when implementing CASI systems. Work done in Rotanda and Macate (Manica) by QAAFI also recommended a stepwise intensification approach, with good agronomic management as the first step.

Selecting improved maize and legume seed varieties

The SIMLESA program activities identified 22 legume and 12 maize varieties from IIAM, Drought Tolerance Maize for Africa–CIMMYT and Tropical Legumes II projects. The improved seed was made available to households. From 2012 to 2014, 64 mother and 228 baby variety demonstrations were evaluated. Demonstration plots, host farmers and extension officers all increased technology awareness. An estimated 7,436 and 5,295 households were using improved maize and legume varieties, respectively, by 2016. Householders estimated that technologies promoted by SIMLESA increased their yield by an average of 19% (male-headed households) and 20% (female-headed households).

Approximately 360 maize genotypes were evaluated through 15 regional trials across representative environments. The best entries were selected for evaluation in advanced trials to fast-track improved variety release. A total of 183 maize mother and baby trials (Table 18.4) and legume participatory variety selection trials (Table 18.5) were evaluated in three years across 24 sites involving 183 farmers. Six maize varieties were released with the support of the SIMLESA program in 2011 (one hybrid and three open-pollinated varieties) and in 2013 (one hybrid and one open-pollinated variety). From the participatory variety selection trials, a total of 24 legume varieties were released (eight common bean, three cowpea, four pigeonpea and nine soybean). All were released in 2011. The seed of released varieties were multiplied by seed companies and sold in communities, as well distributed for scaling-up variety and CASI demonstration plots.

Table 18.4 Number of trials conducted under the mother–baby trial design, 2012–14

Type of trial	2012	2013	2014	Total
Mother	16	24	24	64
Baby	54	72	102	228
Demonstration	0	24	24	48
Farmer fields	62	108	138	308

Table 18.5 Number of participatory selection trials conducted for legume varieties, 2012–14

Legume type	Number of trials and host farmers	Number of harvested trials	Number of varieties	Number of sites
Soya bean	219	202	32	22
Cowpea	208	198	16	24
Pigeonpea	136	126	8	14
Total	**563**	**526**	**56**	**60**

Preliminary scaling-out activities and results

Through the competitive grant scheme aimed at scaling out SIMLESA-1 CASI technologies in Manica and Tete, implemented by partners Instituto Superior Politécnico de Manica (ISPM), AGRIMERC and Manica Farmers Union (UCAMA), SIMLESA-2 reached a further 100,000 households. Results from the first year of the competitive grant scheme activities, i.e. the 2016–17 cropping season (Table 18.1), show that targeted households were provided with specialised assistance in implementing CASI systems. This was achieved through a network of on-farm demonstration plots, field days, business development support and input loans, SMS piloting systems with tailored CASI technological information packages, and awareness creation campaigns conducted through the radio. This intervention led to an average estimated maize yield increase of 19% and 21% in participating households in Tete and Manica province.

Assessing downside risk from CASI adoption

A team of researchers at IIAM, in collaboration with QAAFI and CIMMYT researchers, also used experimental results from additional on-farm trials conducted in Sussundenga and Angonia to assess the impact of various conservation agriculture components on maize yields and yield stability. Full adoption of minimum tillage, residue retention and crop rotation decreased the frequency of maize yields below the 25th percentile for improved practice by 37% for Manica and 9% for Tete, compared to the conventional control with the same level of inputs (i.e. improved seed and fertiliser) (Figure 18.2).

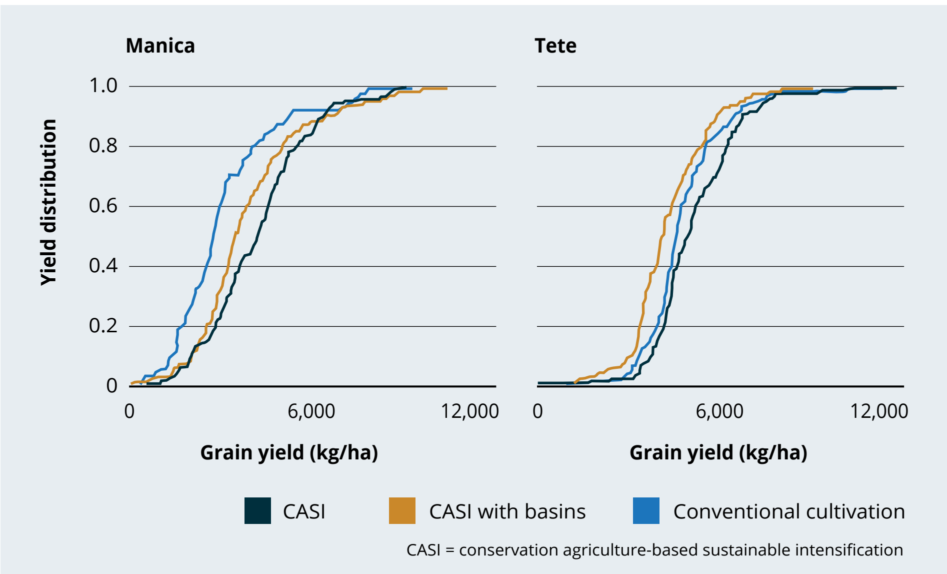

Figure 18.2 **On-farm maize yield distributions in Tete and Manica provinces for full adoption of CASI with and without planting basins vs conventional tillage with local fertiliser recommendations and improved seed**

Results of modelling residue management interaction with soil type

Modelling analyses (64 years) were conducted to simulate the effect of carbon-rich residues on nitrogen-deprived soils in central Mozambique. The Vanduzi district, in agroecological zone 4 (AEZ 4) with average annual rainfall of 834 mm (1951–2015) was the simulation site. Maize–legume systems managed under CASI at different levels of nitrogen supply were simulated for three soils of contrasting water holding capacity:

- sandy clay loam textured red ferralsol (cSaCL)
- lowland sandy loam textured Gleysol (SaL)
- drier fine sandy textured arenosols (fSa).

Results from the modelling exercises indicate that residues were only beneficial to maize yields on the low water holding capacity fine sandy soils (fSa), although legume yields increased on all soil types.

Simulations also showed that in unfertilised (0 kg N/ha) and limited nitrogen-application (23 kg N/ha) systems, the application and retention of carbon-rich residues reduced maize yields by 42.4% in 80–85% of the seasons in the cSaCL. The yield reduction was mostly driven by losses in both nutrient use efficiency and water use efficiency, which ranged between 6–20% and 33% respectively. Benefits from water use efficiency due to residue application were only observed in the driest 20% of the simulated seasons for the two nitrogen-application levels. The same results were also observed on the sandy loam textured soils (SaL), common in the lowland spaces of the catena.

Positive yield responses (40.5–55.9%) from mulched soils were simulated in less than 20% of the seasons in unfertilised and low nitrogen-applied cSaCL and SaL maize systems. At high nitrogen-application levels (92 kg N/ha), simulations indicated maize yield benefits of almost 50% from application of carbon-rich residues in 20% of seasons on high water holding capacity soils. These benefits were only attained during the driest years. In contrast, cowpea yield was improved 29%, 72% and 99% by residue application in unfertilised plots of fSa, SaL and cSaCL respectively. Nevertheless, benefits from residue application decreased with increased nitrogen application above 23 kg N/ha in all soils. In the drier and low water holding capacity fine sandy soil (fSa), positive responses to residue application were simulated in 85–90% of the seasons for both maize and cowpea.

In terms of resource productivity, maize was more responsive to nitrogen application, especially on the wet and high water holding capacity sandy loam soil. Here, maize response to nitrogen application was attributed to better nitrogen uptake and translocation efficiency due to high in-crop moisture regimes. In the drier fSa, poor soil water availability led to poor nitrogen uptake and consequently lower maize nutrient use efficiency and yields.

Model-assisted field trials also showed that, in the rainfed nitrogen-deprived systems of central Mozambique, the overall performance of maize–legume cropping systems managed under CASI is governed by two critical interactions:

1. crop type and soil water holding capacity induced residue response
2. residue modified, nitrogen-driven water use efficiency and nutrient use efficiency trade-off.

Therefore, understanding these two responses is the key to validating locally feasible resource management strategies that are crucial to effectively tailor CASI systems for smallholder households in central Mozambique. To fine-tune residue and fertiliser allocation at the field level, a set of rules based on existing soil water holding capacity gradients in the region are proposed:

- In high water holding capacity soils and AEZ R4, R5, R7 and R10, where incrop soil moisture is not a limiting factor, high carbon:nitrogen ratio residues should be used to improve the performance of the sole legume crop during the legume phase of the rotation rather than applied into an unfertilised cereal crop where the soil moisture advantages provided by residues (water use efficiency increments) do not compensate for the yield losses due to N-immobilisation in most of the seasons except in the driest years.
- High carbon:nitrogen ratio residues only offer a significant yield advantage to maize in drier environments (AEZ R6 and R8) and across low water holding capacity soils. In these soils, poor soil moisture delays residue decomposition and significantly improves in-crop rainfall capture, generating moisture benefits that surpass the negative impacts from nitrogen immobilisation on maize yield.
- Best responses from inorganic nitrogen fertiliser are likely to be attained in wet and high water holding capacity environments where there is enough moisture for the crop to efficiently use the supplied inorganic nitrogen fertiliser. This is because, in dry and low water holding capacity soils, poor soil moisture regimes reduce crop N uptake leading to poor responses to inorganic nitrogen application.
- For wet and high water holding capacity soils, the beneficial effects of applying crop residues on the legume crop are likely to be observed on the subsequent years of cereal crop.

Residual effects from carbon-rich residue application on maize and cowpea

Low C:N residue application and retention in continuous maize showed overall maize yield penalties ranging between 0% and 40% in continuous maize cropping systems. However, the penalties differed across residue levels and were largely overcome by increasing N-application levels. Nevertheless, gains from high carbon:nitrogen ratio residue application in continuous maize sequences were simulated in the lowest rainfall seasons for the high water holding capacity cSaCL soil. These benefits were only attained in less than 25% of the seasons for 0 kg N/ha and 23 kg N/ha and less than 35% with 92 kg N/ha. On the other hand, penalties from residue application and retention in continuous maize systems were simulated in almost 75% of the seasons, for 0 kg N/ha and 23 kg N/ha fertilisation levels. This indicates that the use of residues might be more beneficial during the legume phase of the legume–maize sequence, rather than applying the crop residues on the maize crop.

What did we learn?

Evidence for increased environmental sustainability

Crop residue retention (a key component of CASI in Mozambique) has been widely adopted by smallholder households. Previously, burning of crop residues before planting was common practice (Woldemariam 2012), leading to carbon emissions and loss of soil surface cover.

Households are now aware of the importance of residue retention, soil cover, no burning and zero tillage among other CASI practices. Results from surveys showed that about 25% of interviewed households are using residue retention and 7% are using herbicides. Results from more localised QAAFI surveys indicate average surface cover at sowing is now 61% in the Macate district of Manica province. However, benefits from residue retention in the system proved to be crop- and soil-dependent across sites.

A recent review concluded that CASI prevents the loss of soil organic carbon through erosion but soil organic carbon increases are inconsistent across experiments in Africa (Thierfelder et al. 2017). Results from laboratory analysis of SIMLESA continuous maize cropping systems trials in Chimoio identified a 0.12% (+/- 0.10) gain in total carbon in the 0–5 cm soil depth layer after five years (Table 18.6). This equates to approximately 124,000 Mt C/year input across all SIMLESA farmers in Manica.

Table 18.6 Soil carbon and nitrogen changes, Chimoio, Mozambique

Treatment	Soil depth (cm)	Total carbon (%) mean (s.e.)	Total nitrogen (%) mean (s.e.)
Continuous maize + minimum tillage + residue retention	0–5	1.06 (0.05)	0.08 (0.00)
	5–15	1.08 (0.06)	0.08 (0.01)
	15–30	0.95 (0.04)	0.07 (0.00)
Continuous maize + conventional tillage + residue removal	0–5	0.94 (0.01)	0.08 (0.00)
	5–15	0.92 (0.01)	0.07 (0.00)
	15–30	0.91 (0.03)	0.08 (0.00)

Note: s.e. = standard error

Improvements to gender equality

Raising awareness of gender equality was critical to adoption of technologies under SIMLESA. Due to the initial lack of capacity to mainstream gender, 28 stakeholders were trained at regional, national and local levels to reach a common understanding of gender mainstreaming and implement it correctly in the country. These trainings contributed to increased awareness among researchers, extension officers, participating households and other partners of gender integration in agricultural programs.

Improvements made in gender equality included:

- equal opportunities for men, women and youth in terms of access to information, markets, participation in demonstrations, trials and field days
- provision of leadership training in local agricultural innovation platforms and other scaling frameworks
- improved access to inputs, credit and markets
- better income through innovation platforms.

All key activities were gender mainstreamed by taking into account gender and using gender-sensitive indicators. For instance, the SIMLESA project developed strategies that allowed for the participation of both men and women in all activities (e.g. demonstrations and field days), the evaluation of the technology was made in recognition of preferences of men and women, and equal opportunities for men and women were made available in terms of access to inputs and markets.

These improvements in gender equality are documented in various SIMLESA reports (Manjichi & Dias 2015; Dias, Nyagumbo & Nhantumbo 2011; Quinhentos & Mulima 2016). For instance, a study conducted with a member of Sussundenga innovation platform showed that women who were engaged in a farmers' association were empowered and had increased production and income, as well as improved household nutrition. Yields, nutrition, income and social harmony also increased for men and women involved in SIMLESA, because women had the opportunity to increase their income. Additionally, women reported improvements in production due to participation in demonstration plots and field days and increased access to new information and knowledge over the project's lifetime.

Another improvement in gender mainstreaming was recognising that women, men and youth have different access to value chain nodes. There is therefore a need to collect data disaggregated by gender along the value chain and conduct risk analysis studies in order to increase the adoption of technologies. The concerns, needs and challenges of men, women and youth were collected, documented and incorporated in policy recommendations. In these exercises, legumes preferred by women were scaled up in recognition of the identified need to improve household food security, nutrition and overall wellbeing. Gender-disaggregated data also allowed the project to foster women's leadership positions at local and regional agricultural innovation levels.

SIMLESA Phase 1 ended in 2014 and, based on the experiences of this phase, a gender strategy was developed for SIMLESA Phase 2. This strategy included efforts to increase the capacity to integrate men and women's needs, preferences and aspirations when setting priorities, offering the potential to improve the lives and livelihoods of men and women in Mozambique.

SIMLESA greatly contributed to the concept of gender in Mozambique's agricultural research programming, which spilled over to other programs.

Improvements and knowledge acquired for the private sector

The private sector is an important actor in the maize–legume value chain. Different private sector partners were members of the SIMLESA innovation platform. Some were engaged in production, some in processing and others in marketing inputs and outputs. Some examples of partners include seed companies that multiply and sell seed produced under the contribution of SIMLESA, and private companies that scaled out demonstrations to reach more farmers.

The approach of working with private companies was innovative in the sense that they were not only engaged in the discussions at the local level, but also at the regional level. Private partners could attend regional meetings where they were able to meet multidisciplinary teams and visit farms. In addition to these meetings, they could also attend exchange visits where they had the opportunity to understand more about seed businesses in other countries. Thus, they could not only increase their business connections with other countries but also understand more about the challenges and opportunities of the agriculture sector in eastern and southern Africa.

Another benefit to the private sector was training on how to define and use the seed road map. Under SIMLESA, the private sector could plan their production and sales for the next season. They were asked to estimate the amount of seed they were willing to receive from SIMLESA that would be multiplied and sold in the next season. This was new for many of the partners, so they had the opportunity to learn a lot from engaging with SIMLESA scientists. This increased their business skills and may have benefited their performance.

The private sector was also trained in the importance of recordkeeping, because SIMLESA needed records of what was being done by the partners in terms of quantities sold by variety. In the beginning, most of the information the private sector provided was incomplete. When they started to understand the importance of this data, the quality of the data improved.

Despite all these improvements, SIMLESA Mozambique recognises that attracting the private sector to the SIMLESA innovation platforms was a challenge (Manjichi & Dias 2015) and efforts should be made to have more private companies working with SIMLESA.

Key messages

Throughout the last nine years of research trials, innovation platforms and scaling out with competitive grant scheme partners, the IIAM team identified clear messages for households, extension officers, policy workers and agribusiness.

Households

Improved maize and legume varieties and CASI practices have a positive effect on yield. Encouraging households to adopt and use improved maize varieties that are tolerant to extreme weather conditions, such as drought, but also give good yields in other years under optimal conditions were the key messages delivered to households. Households were also able to select varieties and CASI practices that they preferred and that are suitable to their local conditions in order to improve yield, soil fertility and reduce erosion. Model simulation results suggest that residues are most beneficial to legume yields but may negatively impact maize yields on sandier soils.

Extension officers

Extension officers were advised to work more closely with households and aid both men and women. They were also advised to support linkages to input supply and markets, and improve the connection between the innovation platforms and extension agents to improve delivery of information.

Labour constraints proved to be a significant barrier to adoption of CASI practices, particularly the application of residues. There is a need to educate households on how to prepare fields and sow using CASI practices. The merits of improved planting techniques (in line with SIMLESA CASI packages) need to be reiterated. Residues were most beneficial to legume yields but may negatively impact maize yields on sandy soils without sufficient fertiliser in the short term.

Fertiliser and seed suppliers must be connected with households adopting CASI practices so that timely purchase of inputs can occur. This requires strategic sharing of market information with households during the growing season at times when fertiliser applications would be most rewarding.

Policy

A SIMLESA program forum, National Policy Forum on Sustainable Intensification Based on Conservation Agriculture SIMLESA-OYE, was held on 8 March 2019 at IIAM headquarters in Maputo. The theme was 'Policy forum on intensification based on conservation agriculture'. The event was officially opened by Her Excellency Deputy Minister of Agriculture and Food Security, Dr Luisa Meque, assisted by IIAM's general director, Dr Olga Fafetine. The event was also attended by the first regional SIMLESA coordinator and CIMMYT representative, Dr Muluguetta Mekuria, as well as the national coordinator in Mozambique, Domingos Dias. The forum was also attended by IIAM technicians, Minister of Agriculture and Food Security technical directorates, directors of regional zonal centres, SIMLESA program collaborators, cooperation partners, competitive grant recipients and academic institutions. The event was attended by 60 guests. The objective of the policy forum was to find mechanisms to increase capacity to respond to the needs of farmers and the country with agricultural technologies appropriate for the various agroecological zones with a view to increase production, productivity and income generation. The specific objectives were to share the overall results of SIMLESA research over the last 10 years with policymakers and other actors and stakeholders in the agriculture sector, and also to share the information and policy documents relevant for the development of the agricultural research in the SIMLESA context with decision-makers.

Policy recommendations included:

- increase the number of extension officers or their capacity to reach more farmers
- bring extension services closer to households and aid both male- and female-headed households (the lack of cash and access to credit services, access to input and output markets are a constraint to adoption of technologies, and markets are distant from the villages)
- improve the linkage between producers and suppliers in the value-chain process:
  - intensify the dissemination of information on the proposed law of agriculture in general and particularly CASI
  - reactivate the courses on agricultural mechanisation in universities, higher education and technical-professional institutions
  - improve communication with farmers
  - reach more families during technology transfer
  - enable greater diffusion of information generated by the SIMLESA program
  - create mechanisms to facilitate the availability of information from the SIMLESA program
  - adopt SIMLESA as a development focus in districts
  - involve the government in the implementation of private sector projects
  - reduce farmers' expectations of the existence of resources outside their communities and enhance stability through local sustainability and resiliency
  - generate new technologies to cope with the effects of climate change
  - encourage farmers to use and purchase good-quality seed
  - provide smart incentives to support farmers
  - study the possibility of maintaining CASI on farms after the SIMLESA program ends
  - provide the Ministry of Agriculture with relevant information on the CASI system

- raise awareness among farmers about the value of purchasing improved seed
- identify regions to invest in improved seed production
- scale in and out production methods to youth with some level of education to allow them to share their knowledge with others
- invite politicians to participate in agricultural and scientific forums to help them understand farmers' concerns
- intensify the use of smart incentives to remove market barriers
- create a credit system to manage the seed production sector
- address seed problems across communities like access, quantity and quality as well as high prices
- improve cereal and legume silos.

Input markets (e.g. fertiliser, seeds, herbicides) must function effectively. Poor road infrastructure in rural areas continues to be a significant problem, affecting many aspects of agricultural development. Illiteracy in rural areas continues to be a barrier to extension efforts, particularly in knowledge-sharing through information and communication technology. Ensuring radio communications and telecommunication network coverage in rural areas will be essential to connecting households to markets and information to help them better manage their crops.

Agribusiness

Households are increasingly interested in and demanding herbicides. There are opportunities in herbicide marketing using a village-based adviser approach to expand herbicide businesses at local and village levels.

What was the impact?

In collaboration with local competitive grant schemes, we scaled out maize–legume technologies to reach a further 100,000 farmers. Results from the first year of the competitive grant scheme activities (season 2016–17) showed that 38,057 farmers were helped to adopt CASI systems (in the form of demonstrations, field days, business development and loans, SMS piloting systems with technological packages, training and other activities and awareness creation).

The grantees worked to increase quantities of seed at village level. In 2017, they produced 12 t of soybean seed (*Glycine max*), 12 t of cowpea seed (*Vigna unguiculata*) and 15 t of common bean seed (*Phaseolus vulgaris*). The degree of community participation was satisfactory in all partners, which contributed to the achievement of planned objectives. However, there must be a strong link with other local actors to accelerate scaling-out technologies and increase synergies that could be created by input suppliers, markets and technical assistance in knowledge dissemination. The participation of youth is a dimension that deserves emphasis, as they are the future farmers. According to local information, youth work on their parents' fields on holidays, weekends or in the afternoons after school. This situation is positive, as it shows that parents have opportunities to educate their children.

Immediate impacts include:

- increased productivity through improved input use in soil management practices (currently, yields average 800 kg/ha and this could increase to 1,600 kg/ha through adoption of improved inputs)
- less time and labour spent on control of weeds due to herbicide efficiency
- reduced distances travelled looking for inputs and output markets
- farmers accessed better prices for their produce through price negotiations, and storing produce in silos and warehouses to allow it to be sold during periods of scarcity
- farmers' cooperatives became seed producers with non-government agriculture and market support (e.g. AGRIMERC)
- improved farmers' technical assistance through village-based agents and agrodealers who become public extension support promoters
- 1,563 new entries in the SMS database, taking the total to almost 1,800 farmers
- a signed contract with the Youth Employment Program to reach 5,000 youth in Manica, Sofala and Zambezia through SIMLESA's SMS program.

What should we do next?

There are still a number of challenges and opportunities within the maize and legume value chain in Mozambique which, if carefully handled, can improve the functionality of the chain.

Recent value-chain studies (Cachomba et al. 2013) show that, on the input side, gaps include:

- a shortage of improved seed of legumes in the market
- high transport costs of seeds and fertilisers
- lack of incentives for seed production
- lack of microcredit in communities
- lack of information about and market access to fertiliser, pesticides and herbicides.

On the output side, gaps include:

- a lack of quality grading system (mainly for legumes)
- poor organisations of farmers
- poor risk-mitigation mechanisms
- poor storage infrastructure
- seasonality of grain supply for processing
- poor processing activities
- poor road network
- poor information flow
- highly seasonal prices within and across the years
- lack of value-added products, particularly in the legume sector
- low quality of products available in the market
- poor storage facilities.

There are huge opportunities for the maize and legume value chain (Cachomba et al. 2013). On the input side, opportunities include:

- good environment for seed production (policy, land and labour)
- existence of ports for importing fertilisers
- awareness of improved seed by farmers.

On the output side, opportunities include:

- favourable weather to produce a range of crops
- donors and government interested in investing in this subsector
- many farmers engaged in maize and legume production
- national and international markets for legumes
- a market information system for maize and legumes
- beans being the main (vegetable) source of proteins and vitamins for humans in the country
- high demand for maize processing
- use of legumes in the poultry industry.

Some companies, such as Vanduzi and Danmoz (both in Manica, close to Beira port), demonstrated the potential to take advantage of Mozambique's favourable climate to produce higher-value products and export them overseas.

Another opportunity is that Manica province's agroecology is favourable for production of a number of crops. This can be confirmed by the fact that many smallholder maize households in Manica province practise some form of horticultural production. Additionally, climate analyses indicate that avocados and macadamias could be widely grown and have the potential to be harvested earlier than key competitive markets overseas. If output markets were properly fostered (initially in key domestic markets such as Vilanculos, while simultaneously providing adequate assistance for households in seeds and pest and disease control), the potential to increase commercial agricultural production and improve livelihoods could be substantial.

Maize milling companies also procured maize OPV ZM523, released with the assistance of SIMLESA, as a primary raw material. In Angonia, the presence of the nearby Malawian maize and soybean market offers commercial opportunities, as prices are very attractive. Also, Abilio Antunes, a successful poultry producer, is able to buy more than 5,000 t soybean/year in Angonia, where the crop is successfully grown. The presence of a new large maize buyer, big warehouse companies and grain buyers (Export Trading Group), is a promising means of boosting adoption of new CASI technologies.

Other examples of the opportunities available are processing companies like DECA in Chimoio and Escola do Povo in Ulóngue (Angonia) that buy maize from households, process it into flour and sell it at urban and export markets. The existence of poultry industries in Manica and Tete provinces and a soybean processing company in Chimoio are other example of opportunities to increase soybean production.

Traders and buyers of legumes indicate that the production of pigeonpea in Macate district is relatively low compared to their demand. The existence of traders and buyers of pigeonpea in these areas present an opportunity for households to increase pigeonpea production as a cash crop. Additionally, companies such as LUTEARI that provide maize and pigeonpea seed in credit to households and then buy the production provides a great opportunity to develop this value chain.

From 2017, SIMLESA scaling-out partners worked in maize and legume seed production and, in partnership with agrodealers, sold the seed to households. This increased the availability of seed and provides an opportunity to increase production and productivity in years to come.

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19 Promoting conservation farming for the sustainable intensification of maize–legume cropping systems in Uganda

Drake N. Mubiru, Jalia Namakula, James Lwasa, William N. Nanyeenya, Ramsey Magambo, Godfrey A. Otim, Joselyn Kashagama & Milly Nakafeero

Key points

- Overgrazing and soil erosion has led to compacted soil layers and often bare ground, in extreme cases.
- Compacted soil layers have affected agricultural land by inhibiting root growth and water movement, limiting water infiltration and retention. This has facilitated run-off and made ploughing difficult. Agricultural productivity has been directly affected, resulting in yield gaps.
- The SIMLESA Uganda program found that compatible maize–bean intercropping patterns increased labour and land use efficiency and reduced soil degradation due to reduced soil nutrient mining and soil erosion.
- Maize–bean intercropping systems improved the food, nutrition and income security of smallholder farming households in Uganda.
- A combination of permanent planting basins and rip-line tillage, together with improved seed and fertiliser, brought maize and bean grain yields within the expected productivity targets for SIMLESA households.

Introduction

The Uganda SIMLESA program initiated a project to improve maize–legume farming systems by addressing downside production risks associated with climate variability and commodity value-chain constraints. The overall objective of the project was to improve livelihoods of maize–legume producers by addressing pre-production, production and post-harvest challenges. Key activities of the project entailed evaluating conservation agriculture-based sustainable intensification practices (CASI) through on-farm trials with farmer groups, and demonstrating and promoting those proven to be effective under specific conditions. With the aim of promoting performance through synergies, crop–livestock–household–soil–weather relationships were evaluated for specific CASI practices: minimum soil tillage, soil moisture retention and soil fertility enhancement. The project, coordinated by the National Agricultural Research Organization (NARO) in 2012, was implemented in two rural districts: Nakasongola and Lira.

Through a diagnostic study, producers' challenges, constraints and operating circumstances were analysed, setting the stage for technology exposure and skills improvement. The main challenges were failure to open land on time, unreliable rainfall and declining soil fertility. Rip lines and permanent planting basins, introduced by the SIMLESA program, in combination with improved seeds and fertilisers, contributed to enhanced bean grain yields of up to 1,000 kg/ha, a drastic improvement from baselines as low as 300 kg/ha. Maize grain yields under these conditions doubled from an average baseline of 3,000 kg/ha to 6,000 kg/ha. These interventions, coupled with private sector and policymaker engagements, effectively reduced downside production risks, and enhanced food and income security and smallholder livelihoods.

There is potential for long-term impact. Technology exposure and skills development through the Uganda SIMLESA program led to enterprise, household, community and value-chain level adjustments. These include shifts in enterprise management and performance, cost reduction, labour savings, demand for relevant agricultural inputs and services, and general livelihood enhancement.

What was the situation in 2010?

Uganda lies across the equator and extends from latitude 10°29'S to 40°12'N and longitude 290°34'E and 350°0'W. It is located in eastern Africa and has a total surface area of 241,551 km^2, with a land surface of 199,807 km^2. The remaining 41,743 km^2 are swamps and open water, including part of Lake Victoria, the third-largest lake in the world. It is also the source of the world's longest river—the Nile. By 2015, Uganda had a population of 34.9 million people, with an annual population growth rate of 3.03% and an average population density of 174 people/km^2 (UBOS 2015).

Uganda's geography influences its climate. The mean annual rainfall spatially varies from 510 mm to 2,160 mm (Komutunga & Musiitwa 2001). There is a defined bimodal rainfall pattern in the south and a unimodal pattern in the north, above latitude 30°N. The temperature across the country is highly influenced by altitudinal variations, which range from 610 m above sea level in the Rift Valley to 4,324 m above sea level on Mt Elgon (Wortmann & Eledu 1999). However, seasonal variation in mean monthly maximum temperatures has historically remained at or below 6 °C (Komutunga & Musiitwa 2001). The country has a diverse agricultural production system with 10 agricultural production zones (Government of Uganda 2004).

The zones are determined by soil type, climate, topography and socioeconomic and cultural factors, and contribute to the diversity of farming systems across the country (Mubiru et al. 2017). Due to the different zonal characteristics, the agricultural production zones experience varying levels of land degradation and vulnerability to climate-related hazards, which have included drought, floods, storms, pests and disease (Government of Uganda 2007).

Due to diverse agricultural production systems, the country has varied crop enterprises, including banana, root crops, cereals and legumes, among others. Among the cereals and legumes, maize and beans are major staple foods for much of the population, and are a major source of food security. They have played an important role in human and animal nutrition and constituted a major share of market economies (Goettsch et al. 2016; Namugwanya et al. 2014; Sibiko et al. 2013; Pachico 1993). At the household level, household-sourced maize and beans have served as a staple food supplying proteins, carbohydrates, minerals and vitamins to resource-constrained rural and urban households with rampant shortages of these dietary elements. The annual per capita maize consumption has been estimated to be 28 kg, and bean consumption 58 kg (Soniia & Sperling 1999). Reportedly, the dietary intake for the most resource-constrained households in Uganda comprises 70% carbohydrates. This is mainly from maize, supplying 451 kcal/person/day and 11 g protein/person/day. Beans provide about 25% of the total calories and 45% of the protein intake in the diets of many Ugandans (NARO 2000).

Despite the importance of maize and beans in Uganda, available data from the Food and Agriculture Organization Statistical Database (FAOSTAT) indicate that the yield of maize is currently stagnant at 2.5 t/ha compared to a potential yield of 4–8 t/ha (Otunge et al. 2010; Semaana 2010; Regional Agricultural Expansion Support 2003), with the open-pollinated varieties being on the lower end compared to hybrid varieties. The actual mean bean grain yield in Uganda is 500 kg/ha compared to potential yield of 1.5–3 t/ha (Namugwanya et al. 2014).

Land degradation

In Uganda, land degradation has had significant impacts on smallholder agroecosystems, including direct damage and loss of critical ecosystem services such as agricultural land/soil and biodiversity (Mubiru et al. 2017). Poor land management, including overgrazing and soil erosion, has produced compacted soil layers and bare ground in extreme cases (Figure 19.1) (Mubiru et al. 2017). Mubiru et al. (2017) further identified hand hoeing (Figure 19.2), the main tillage practice applied on most farmlands in Uganda, as a major contributing factor to soil compaction. Hand hoeing only disturbs the first 15–20 cm—or sometimes as little as 5 cm—of the top soil and, if done consistently and regularly, can potentially produce restrictive layers below 0–20 cm of the top soil. Soil compaction has affected agricultural land in several ways, by inhibiting root and water movement (Coyne & Thompson 2006; Brady & Weil 1996, p. 224), limiting water infiltration and retention facilitating run-off, resulting in moisture stress and making ploughing difficult (Coyne & Thompson 2006).

Moisture stress arising from poor land management has been compounded by climate change and variability. Recently, erratic weather patterns that impact negatively on soil moisture content have led to either reduced crop yields or total crop failure (Mubiru et al. 2012; Mubiru, Agona & Komutunga 2009). On the socioeconomic side, limited use of good-quality agro-inputs such as improved seed and fertiliser, and rudimentary means of production, are widely regarded as a major impediments to increased output and productivity (Ministry of Agriculture, Animal Industry and Fisheries 2010). The combined effect of these factors has directly affected agricultural productivity and contributed to the yield gap between potential output and farmer outputs.

Figure 19.1 **Bare land patches interspersed with shrubs in Nakasongola district**

Photo: James Lwasa, 2013

Figure 19.2 **Hand hoeing in Uganda**

Photo: Drake N. Mubiru, 2014

Productive and sustainable practices, tactics and strategies

CASI offers land management technology packages with the potential to help farmers produce competitively and profitably and meet market expectations. The technology packages present an opportunity to disturb the soil as little as possible, keep the soil covered as much as possible and permit mixing and rotation of crops. These practices are expected to support soil moisture conservation and minimise soil erosion from wind and water while the leguminous cover crops in conservation farming systems fix nitrogen, thereby improving the fertility status of the soil and promoting economy with nitrogenous fertilisers (Calegari 2001; Calegari & Alexander 1998). These technology packages have addressed the soil and water management constraints faced by smallholder farmers (Mupangwa, Twomlow & Walker 2007). In maize–legume cropping systems, CASI farming can make an enormous contribution towards sustainable food production at a relatively low cost to the farmers, while conserving soil and water.

CASI strategies for sustainable production and adaptation to climate change include utilisation of optimum seeding rates and intercropping. When the quality of seed, plant nutrients and soil moisture are ensured, the other highly important factor is the amount of radiant energy reaching the plant canopy. According to Johnson (1980), the factor that sets the upper limit on potential yield is the quantity of energy that crop tissues capture from the sun. It has therefore been important to determine the optimum seeding rate for a plant population with a closed canopy early in the growth period.

In order to increase land productivity and enhance sustainable crop production, farmers have taken diverse cropping system approaches (Hauggaard-Nieson, Ambus & Jensen 2001). The cropping systems have typically been shaped by soil types, climate, topography, and socioeconomic and cultural factors. One common cropping system among smallholders is intercropping. Intercropping is defined as a type of mixed cropping where two or more crops are grown in the same space at the same time (Andrew & Kassam 1976). Smallholder farmers practise intercropping for various reasons, including diversification and reducing production risks to avert total crop failure in the event of unsuitable climatic conditions. This practice also has the advantage of catering for the starch and protein needs of households, especially among resource-poor farmers. Judicious intercropping, which entails growing suitable and compatible crops together, increases productivity through maximum utilisation of land, labour and crop growth resources (Craufard 2000; Marshal & Willy 1983; Quayyum, Ahmed & Chowdhury 1999). It has also been observed that yields from intercropping are often higher than in sole cropping systems (Lithourgidis et al. 2006) due to efficient utilisation of resources such as water, light and plant nutrients (Li et al. 2006).

Smallholder farmers have the potential to improve rural food security, livelihoods and adaptation to climate change through adoption of appropriate CASI practices. Barriers to adoption can, however, be substantial and limit uptake of practices that offer maximum economic returns (Parvan 2011; Wreford, Ignaciuk & Gruere 2017). SIMLESA Uganda addressed the need to identify appropriate CASI practices and support uptake and adoption.

What did SIMLESA do?

To address production constraints, the Uganda SIMLESA program first identified CASI practices that increased yields and reduced downside production risks. The program carried out demonstrations and promoted CASI practices and other climate change adaptation technologies. Relationships between crop, livestock, household, soil and weather were exploited through minimum soil tillage by use of herbicides, and soil moisture retention by covering soil with crop residues. Soil fertility was improved through judicious use of chemical and organic fertilisers and crop rotations. To address market-related limitations on uptake and adoption, the second aim of the Uganda SIMLESA project was to identify commodity value-chain constraints.

Project objectives

The project goal was to unlock the potential of the maize–legume production system as a strategy for addressing food and nutrition security, incomes and long-term environmental management through improved productivity. The overall objective of the project was to improve livelihoods of maize and legume producers by addressing pre-production, production and post-harvest challenges of the commodity value chains.

The specific objectives were to:

- evaluate production constraints and opportunities to increase production through CASI practices
- evaluate and overcome value-chain constraints.

Project sites

The project, which commenced in 2012, was implemented in two rural districts: Nakasongola in central Uganda and Lira in the north (Figure 19.3). The two districts were comprised primarily of smallholder farmers with a combined population of 623,100 in 2016 (Uganda Bureau of Statistics 2015). Nakasongola district, in an agropastoral setting, is located in what is known as the cattle corridor of Uganda. The corridor cuts across the country, from south-western Uganda, through the centre, to north-eastern Uganda. Agriculture (crops, livestock and fisheries) has been by far the most important activity in the district, employing about 90% of the people (Magunda & Mubiru 2016; Nanyeenya et al. 2013). Although the majority of production activities have been for subsistence, Lira is largely crop-oriented and is located in a higher potential production zone in northern Uganda (Nanyeenya et al. 2013). Lira is characterised by a continental climate modified by the large swamp areas surrounding the southern part of the district. The major economic activity in Lira is agriculture (crops, livestock and fisheries).

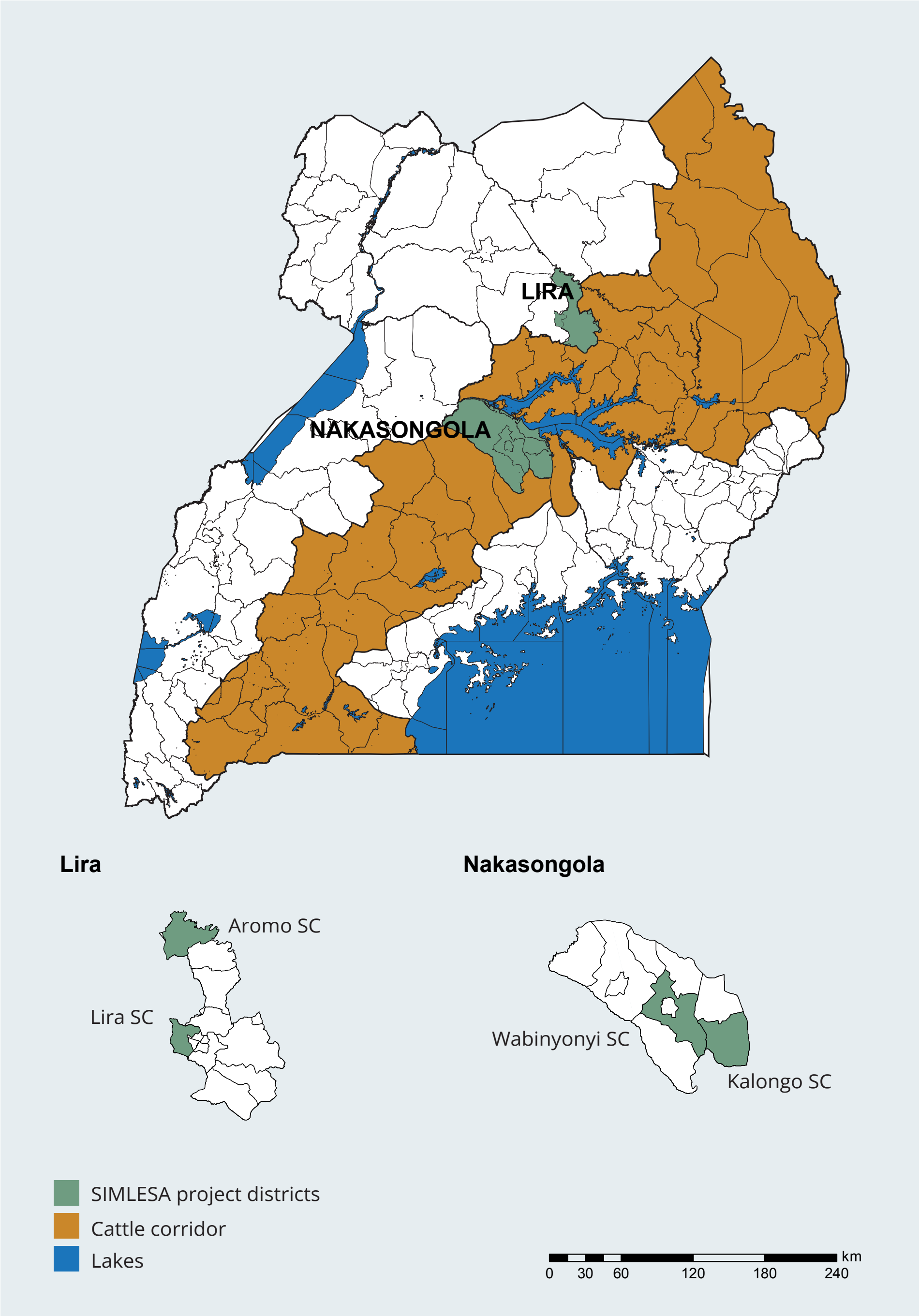

Figure 19.3 **Uganda SIMLESA program sites: Lira and Nakasongola districts and the cattle corridor**

Source: Geographic Information Systems, National Agricultural Research Laboratories, Kawanda

Site selection

Diagnostic surveys were conducted in the implementing districts to understand the producers' challenges, constraints and operating circumstances in order to set the stage for technology exposure and skills improvement. In the sampling procedures, each district was divided into two broad zones depending on agricultural potential based on soil, climate and major community livelihood sources. From these, two subcounties were selected to represent high- and low-potential production areas. In Lira, Aromo and Lira subcounties were sampled as high- and low-potential areas, respectively. In Nakasongola, Kalongo and Wabinyonyi subcounties were sampled as high-potential and low-potential areas, respectively.

Assessing the biophysical state of soils

Bare ground coverage data was included in the project site evaluations as a proxy for extreme land degradation. Supported by the SIMLESA program, NARO scientists evaluated the extent of bare ground in Nakasongola, one of the project sites. Data were collected by an initial physical survey using GPS to estimate the spatial extent of a few bare grounds. These data were then used to locate the same features on a satellite image of all the research sites from a fairly dry month. These points were used to develop digital signatures for searching similar features in the rest of the image and generating coverage statistics using geographic information system tools (Mubiru et al. 2017).

Intensification of sustainable production

Covering the soil with live or dead vegetal materials is one of three principles of CASI production systems. Cover crops are plants grown to improve the quality and productivity of the soil by enhancing organic matter build-up and soil moisture conservation, which all improve the soil biology and its health. With support from SIMLESA, five pigeonpea (*Cajanus cajan*) elite lines (ICEAP 00850, ICEAP 00540, ICEAP 00557, KAT 60/8 and ICEAP 00554) were acquired from the International Crops Research Institute for the Semi-Arid Tropics and planted at the National Agricultural Research Laboratories (NARL)—Kawanda in 2015. These were evaluated for performance and the seed was multiplied for upscaling. At the flowering stage, a 0.25 m^2 quadrant placed at four random positions within each plot was used to determine the accumulated above-ground dry matter.

Pigeonpea used as cover crops provided multipurpose benefits such as improving the quality and productivity of the soil, suppressing weeds and providing nutrient-rich pigeonpea grain, which directly benefited the farmers (Odeny 2007; Upadhyaya et al. 2006; Valenzuela & Smith 2002).

Maize–bean intercropping patterns

Three seasons of maize–bean intercropping trials were conducted with farmer groups to determine the optimum maize–bean intercropping patterns (Figure 19.4). The maize and bean seeds were drilled using conventional methods.

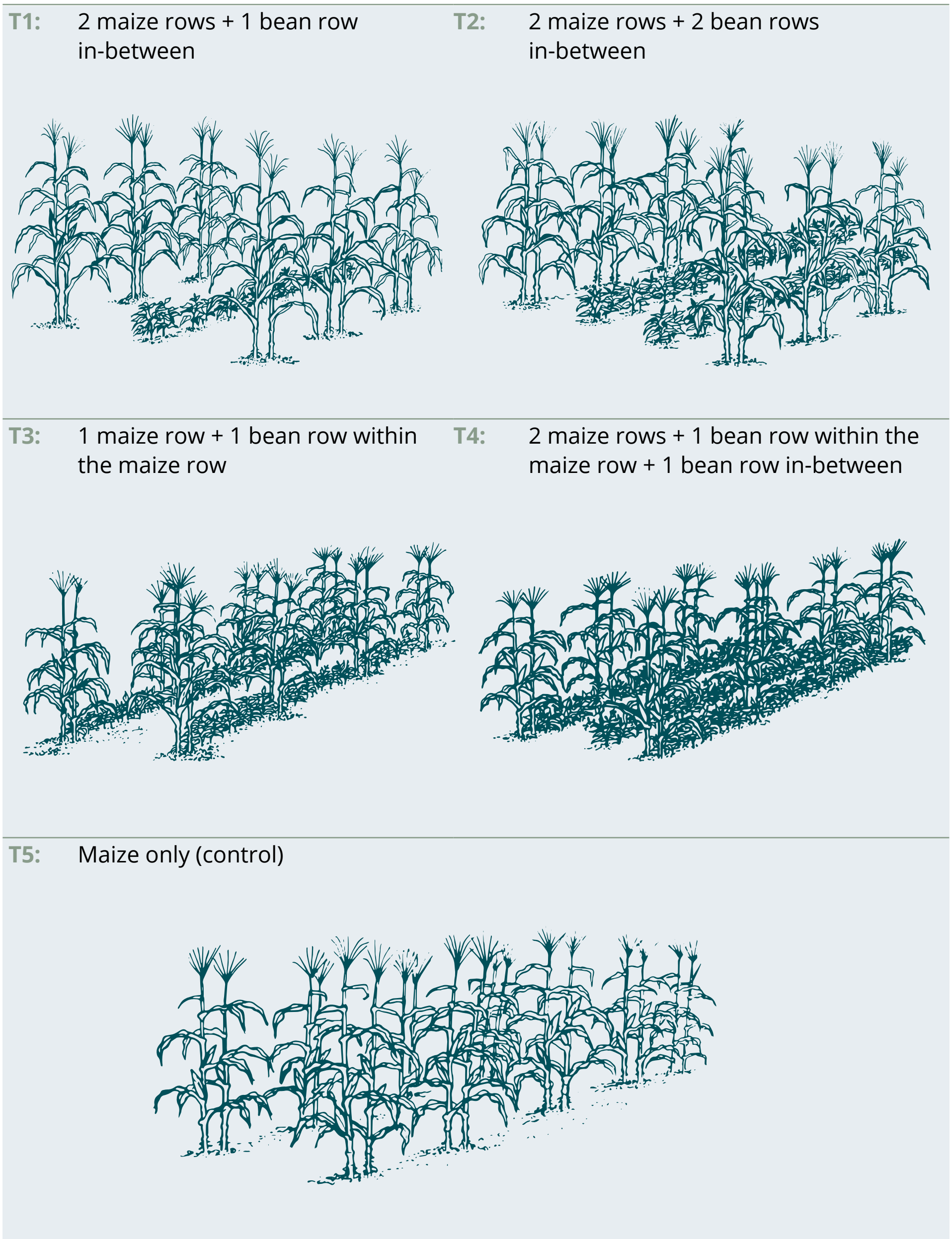

Figure 19.4 **Maize–bean intercropping patterns**

Maize and bean seeding rates

Permanent planting basins and rip lines, widely used in southern Africa (Zambia and Zimbabwe), were recently introduced in Uganda as new tillage methods under the umbrella of CASI. The two tillage practices can enhance the capture and storage of rainwater and allow precision application and management of limited nutrient resources, reducing the risk of crop failure due to erratic rainfall.

Trials to determine optimum maize and bean seeding rates using permanent planting basins were conducted for two seasons (2013A and 2013B) at NARL–Kawanda in central Uganda and Ngetta Zonal Agricultural Research and Development Institute (Ngetta ZARDI) in northern Uganda. The seeding rate trials under rip lines were also conducted for two seasons (2013A and 2013B) at Ngetta ZARDI. In Uganda, rip lines were made using oxen. Due to the heavy clay soils in the central region, animal draught power was rarely used (eds Omoding & Odogola 2005).

Basins, dug before the onset of rains, were designated using planting lines and digging planting basins. The basins were 35 cm long × 15 cm wide × 15 cm deep, with a spacing of 75 cm between rows and 70 cm within rows from centre-to-centre of the permanent planting basin. Available crop residues were laid between rows to create a mulch cover. The maize seeding rates were 3 seeds/basin (57,144 plants/ha), 4 seeds/basin (76,192 plants/ha), and 5 seeds/basin (95,240 plants/ha). The seeding rates for beans were 6 seeds/basin (114,286 plants/ha), 8 seeds/basin (152,381 plants/ha) and 10 seeds/basin (190,476 plants/ha). The control treatments were 3 seeds/basin for maize and 6 seeds/basin for beans.

Rip lines were also prepared before the onset of rains by an ox ripper set at a depth of 15 cm. Maize was seeded at three spacings with 1 seed/hill: 60 cm × 25 cm (66,667 plants/ha), 65 cm × 25 cm (61,538 plants/ha) and 75 cm × 25 cm, (53,333 plants/ha). Beans were also seeded (with 2 seeds/hill) at three spacings: 60 cm × 10 cm (333,333 plants/ha); 65 cm × 10 cm (307,692 plants/ha) and 75 cm × 10 cm (266,667 plants/ha). An open-pollinated Long 5 maize variety and a NABE 15 bean variety were used. The maize and bean grain yields were determined by harvesting the whole plot.

Comparison of tillage methods

Three tillage methods were compared: conventional farmer practice, permanent planting basins and rip lines.

Under conventional farmer practice, planting holes for maize were designated by planting lines and digging with a hand hoe at a spacing of 75 cm between rows and 60 cm within rows. The rows were seeded with 2 seeds/hole (44,444 plants/ha). In the case of beans, spacing was 50 cm × 10 cm, seeded with 1 seed/hole (200,000 plants/ha).

The permanent planting basins were designated as mentioned earlier. The basins were seeded with 3 maize seeds/basin (57,143 plants/ha) and 6 bean seeds/basin (114,286 plants/ha).

The rip lines were designated as mentioned earlier. Maize was seeded with 1 seed/hill at a spacing of 75 cm × 25 cm (53,333 plants/ha). Beans were seeded with 2 seeds/hill at a spacing of 75 cm × 10 cm (266,667 plants/ha).

Business model analysis

The business model analysis, funded by ACIAR under the Small Research and Development Activity project, was conducted in Nakasongola in 2015. The study focused on the role of small rural enterprises in contributing to the adoption and scaling up of a range of technologies developed by the Uganda SIMLESA program to support adoption of CASI practices. The project involved disseminating proven agricultural technologies that ranged from complex and knowledge-intensive to simple rule-of-thumb approaches. These technologies included minimum tillage, integrated soil fertility management, use of improved seed and water harvesting.

Impact assessment

The impact assessment was carried out to examine transformations to society as a result of project interventions. Specifically, the study:

- assessed the enterprise performance (yield) response due to the interventions
- determined household and societal livelihood transformations
- examined project spillover effects.

What did we learn?

Improved understanding of socioeconomic conditions

The diagnostic surveys helped to understand producers' challenges, constraints and operating circumstances. Farmers' challenges in the maize–legume value chains were grouped into three categories: pre-production, production and post-harvest. Table 19.1 shows the main challenges/constraints in the three categories, in descending order of importance.

Table 19.1 Challenges faced by farmers along the maize–legume commodity value chains, Nakasongola and Lira

Maize	Legume
Pre-production constraints (descending order of importance)	
failure to open land on time shifts in seasons/ prolonged drought	
shifts in seasons/prolonged drought	lack of good-quality seed
poor-quality seed	failure to open land on time
lack of agro-input supplies	lack of reliable agro-input supplies
Production constraints (descending order of importance)	
weed infestation	weed infestation
crop damage by pests	crop damage by pests
declining soil fertility	declining soil fertility
crop damage by diseases	crop damage by diseases
Post-harvest constraints (descending order of importance)	
poor storage	poor storage
exploitative markets	exploitative markets

The main challenge in the pre-production phase for maize was failure to open land on time. This was followed in importance by shifts in seasons and/or prolonged droughts. The quality of maize seed and poor access to agro-inputs were also issues of concern.

In the production phase, the main challenge was weed infestation followed, in declining order of importance, by crop damage by pests, declining soil fertility and crop damage by diseases. After harvest, farmers reported that they faced challenges in storage and finding good markets for their maize produce.

In the case of legumes, the main challenge during the pre-production phase was reported as shift in seasons and/or prolonged droughts. This was followed, in declining order of importance, by lack of good-quality seed, failure to open land on time, and poor access to agro-inputs. In the production and post-harvest phases, the issues as well as their level of importance were the same as reported for maize.

The differences in the importance of challenges experienced during the pre-production phase between maize and legumes (for example, failure to open land on time) can be attributed to the acreage used for both crops. In legume production, less acreage is used among smallholders. For maize, a larger acreage is required. The underlying input and constraint to opening land on time is the labour requirements for land preparation. This greatly limits the acreage, as most farmers use a hand hoe for opening land as opposed to mechanised services (eds Omoding & Odogola 2005). The most important challenge in the pre-production phase for legumes was shifts in seasons and/or prolonged drought. This was only of moderate importance in maize. It could be argued that, since maize takes longer in the field than legumes, it has a chance to recover from erratic rainfall once the rains stabilise. This may not be the case for legumes, which take a shorter period to mature. However, in case of a shortened rainy period, which is uncommon these days, the legume would survive, unlike maize, which takes longer to mature.

Lack of good-quality seed was the second most limiting factor for legume production after shifts in seasons/prolonged droughts. Most farmers reported that high-yielding and drought-, disease- and pest-tolerant bean varieties were rare in their production systems. Unlike legumes, poor-quality seed was the issue in maize. Where it is easy to identify seeds of different legume varieties, especially beans and peanut, this is not the case for maize. Therefore, in an unregulated market, such as that prevailing in Uganda, farmers often ended up buying maize seed of inferior varieties disguised as superior varieties. The viability of maize seed generally can also be easily compromised by unsuitable environmental conditions compared to legume seed. According to documented evidence, maize seed generally stays good for only one year whereas bush bean seed lasts for two years (Savonen 2003). The issue of lack of reliable agro-input supplies was of equal importance for both maize and legumes. Things like fertilisers, pesticides and chemicals to control diseases are often unavailable or inaccessible and when available the prices are prohibitive (Okoboi, Muwanga & Mwebaze 2012).

In regard to markets, when farmers do not have proper grain storage, they are forced to sell their produce when supply is still very high and can be exploited by shrewd traders. Several workers (Salami, Kamara & Brixiova 2010; World Bank 2008) have stated that low productivity among smallholder farmers stems from lack of access to markets.

The biophysical state of soils

Bare ground coverage in Nakasongola, due to extreme cases of soil compaction, was 187 km² (11%) of the 1,741 km² of arable land (Table 19.2 and Figure 19.5) (Mubiru et al. 2017).

Table 19.2 Spatial distribution of different land cover classes in Nakasongola

Class	Area (km)	Cover (%)
Open water	233	7.9
Vegetated	1,527	51.7
Bare ground	187	6.3
Seasonal wetland	915	31.0
Cloud cover	48	1.6
Permanent wetland	46	1.6
Total	**2,956**	**100**

Source: Mubiru et al. 2017

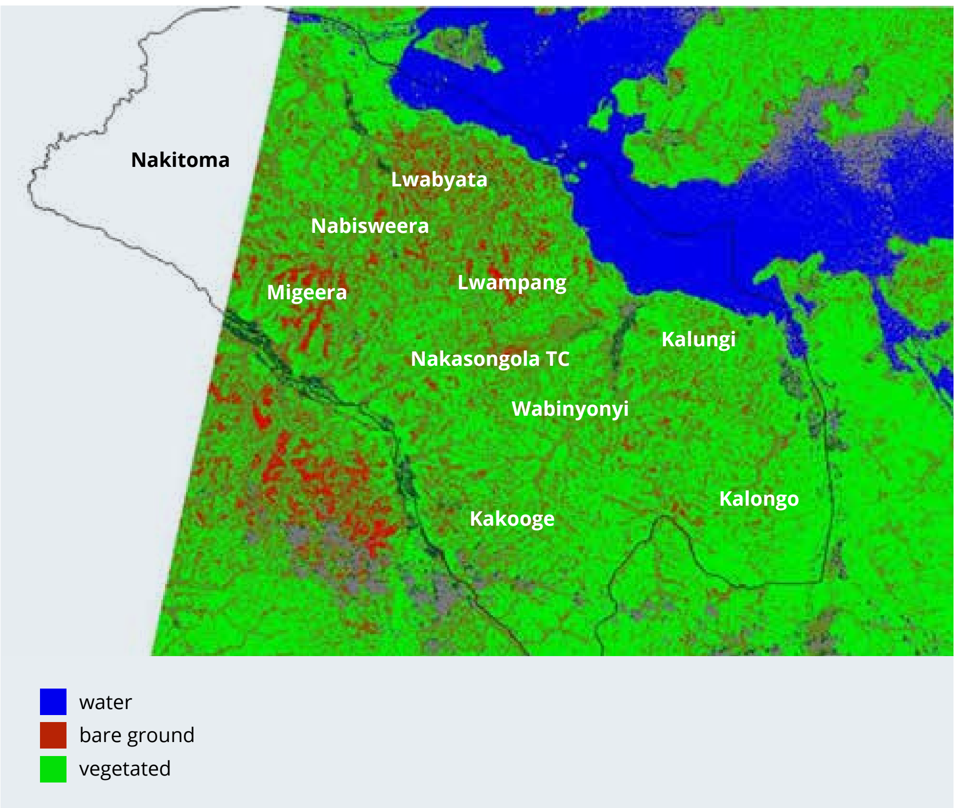

Figure 19.5 Spatial distribution of bare grounds in Nakasongola and surrounding areas

Source: Mubiru et al. 2017

Intensification of sustainable agricultural production

Generally, all pigeonpea elite varieties yielded significantly ($P < 0.05$) more above-ground dry matter than the natural fallow (Figure 19.6). This can potentially enhance organic matter build-up and soil moisture conservation. In that regard, the introduced pigeonpea elite varieties were promoted for multipurpose improved fallows.

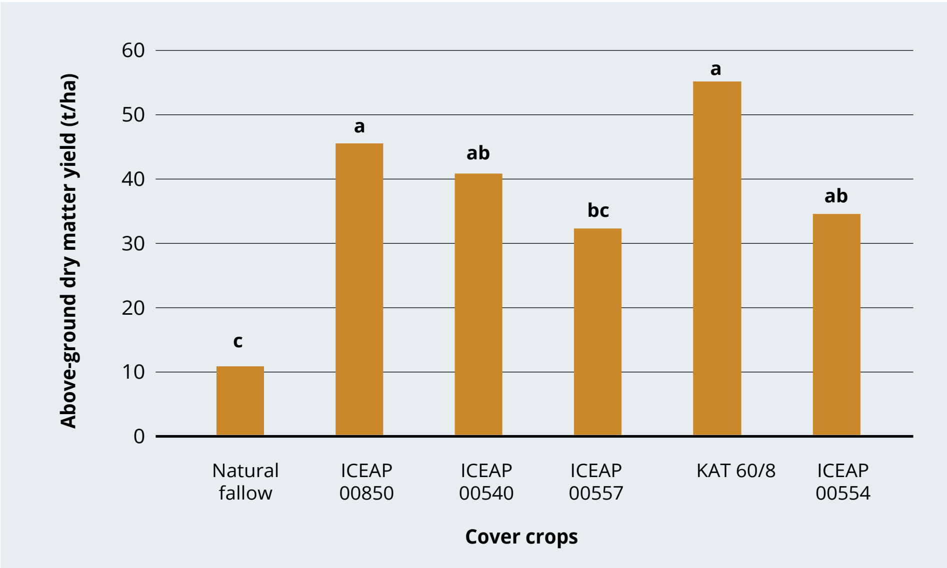

Figure 19.6 **Above-ground dry matter yield of pigeonpea elite varieties compared to natural fallow**

Note: Means are different according to the LSD method ($P < 0.05$) if different letters appear above the bars.

Intercropping

As a means of intensifying maize–bean production, the Uganda SIMLESA program evaluated maize–bean intercropping patterns to establish the optimum patterns. The optimum intercropping patterns were then promoted, targeting mainly rural households with small landholdings. In all treatments, intercropping did not affect maize yield. There were no significant yield differences between maize planted as a sole crop compared to maize yield in all maize–bean intercropping patterns. However, there were significant differences in bean grain yield among the different intercropping patterns, leading to significant differences in the combined revenue from maize and beans. From an economic point of view, the optimum maize–bean intercropping patterns were T1 (two maize rows with one bean row in-between) and T3 (one maize row with one bean row within the maize row). These two provided ample spacing for the beans, probably leading to better performance. Maize planted as a sole crop offered the least economic returns, indicating that for smallholders it is not profitable to grow maize as a sole crop (Table 19.3).

In technology verification meetings, farmers overwhelmingly confirmed the increased economic returns from intercropping maize and beans as opposed to monocropping (SIMLESA 2014). Daniel Kato, the chairperson of Wantabya East Farmers' Group, Wabinyonyi subcounty, Nakasongola, explicitly stated, 'Intercropping maize with beans has increased farm outputs as we are able to harvest both maize and beans from one field and in one season, moreover using the same labour'. Other workers (Ahmad & Rao 1982; Grimes et al. 1983; Kalra & Gangwar 1980; Seran & Brintha 2009) also underscored the economic benefits of intercropping compatible crops.

Table 19.3 Maize–bean intercropping patterns, their attributes, grain yield and accruing revenue

Maize–bean intercropping pattern	Attributes	Maize grain yield (kg/ha)	Bean grain yield (kg/ha)	Combined revenue from maize and beans (US$/ha)	Comments
T1: 2 maize rows + 1 bean row in-between	easy to establish	5,942[a]	257[a]	1,700[a]	The spacing from one bean row to another is 75 cm. This ample spacing could have helped the bean crop to perform well.
T2: 2 maize rows + 2 bean rows in-between	easy to establish	5,703[a]	151[b]	1,552[b]	The spacing from one bean row to another is 25 cm. This limited spacing could have led to the poor performance of the bean crop.
T3: 1 maize row + 1 bean row within the maize row	easy to establish	5,601[a]	277[a]	1,631[ab]	This pattern with 75 cm inter-row spacing also provides ample spacing leading to good performance of the bean crop.
T4: 2 maize rows + 1 bean row within the maize row + 1 bean row in-between	not easy to establish (need more labour)	5,486[a]	125[b]	1,476[bc]	This pattern leads to overcrowding, which could have affected the performance of the bean crop.
T5: Maize only (control)	easy to establish	5,702[a]	–	1,426[c]	This cropping system offers the least economic returns.

Notes: Different letters within each column indicate statistical differences among treatments, using the LSD method. Commodity prices (2017): US$0.25/kg maize; US$0.83/kg bean.

Optimum seeding rates

At both NARL–Kawanda and Ngetta ZARDI, there were no season × seeding rate interactions, indicating that effects of seeding rates on yield were independent of seasons. In that regard, yield for each seeding rate was averaged across seasons.

However, at NARL–Kawanda in central Uganda, there were significant yield differences ($P < 0.05$) from the different maize seeding rates. Permanent planting basins planted with 3 seeds/basin (57,144 plants/ha) had significantly lower grain yield than basins planted with 4 seeds/basin (76,192 plants/ha) and 5 seeds/basin (95,240 plants/ha). However, the grain yields realised from basins planted with 4 seeds/basin and 5 seeds/basin were not significantly different. There was a 27% increase in grain yield from the 3 seeds/basin to the 4 seeds/basin. The different maize seeding rates performed similarly at Ngetta ZARDI in northern Uganda, for two seasons in 2013 (Table 19.4).

Table 19.4 **Maize seeding rates and grain yield, Ngetta ZARDI and NARL–Kawanda, average of two seasons (2013A and 2013B)**

Station	Seeds/basin	Yield (t/ha)
NARL–Kawanda	3	4.43[b]
	4	5.64[a]
	5	6.39[a]
Ngetta ZARDI	3	2.40[a]
	4	2.67[a]
	5	2.89[a]

Note: Different letters on yield data for each station indicate statistical differences among treatments, using the LSD method.

The NARL–Kawanda site, with heavy textured soils and medium organic matter within a bimodal rainfall regime, is representative of areas below latitude 30°N. The Ngetta ZARDI site, with light textured soils and low organic matter within a unimodal rainfall regime, is representative of areas above latitude 30°N. It can therefore be tentatively concluded that, in Uganda, for areas below latitude 30°N, a seed rate of 4 maize seeds/basin (76,192 plants/ha) is optimal while in areas above latitude 30°N a seed rate of 3 maize seeds/basin (57,144 plants/ha) is optimal. The difference in the best-performing seeding rates between the two agroecologies (Kawanda vs Ngetta) could be attributed to the differences in soil moisture regimes, soil types and fertility. While the soils at Kawanda are heavy in texture and have a higher organic matter content, the soils at Ngetta ZARDI are light and have a lower organic matter content (Government of Uganda 1960).

Bean plant population in permanent planting basins

At both experimental sites, NARL–Kawanda and Ngetta ZARDI, there were no significant yield differences among the different seeding rates (Table 19.5). As the seeding rate increased from 6 to 10 seeds/basin, it is likely that competition among the plants for numerous resources, especially light, also increased. Several workers (Ghaffarzadeh, Garcia & Cruse 1994, 1997) have observed that the potential for stress could be increased when crops compete among themselves. They further argued that competition for resources might develop as a result of root growth patterns and/or different resource demands. Although they only mention the root growth patterns, observations from our study indicate that the above-ground plant architectural arrangement also confers serious competition among the plants, limiting their production potential.

Table 19.5 **Bean seeding rates and grain yield, NARL–Kawanda and Ngetta ZARDI, average of two seasons (2013A and 2013B)**

Station	Seeds/basin	Yield (t/ha)
NARL–Kawanda	6	0.556[a]
	8	0.681[a]
	10	0.664[a]
Ngetta ZARDI	6	2.58[a]
	8	2.43[a]
	10	2.75[a]

Note: Different letters on yield data for each station indicate statistical differences among treatments, using the LSD method.

Maize and bean seeding rate in rip lines

Rip lines did not have any observable impact on yield, regardless of seeding rates, crop (maize and beans) and season (Table 19.6). Since there was little difference in yields, the costs of inputs (seed and fertiliser) played a more direct role in determining the preferable management strategy. The lowest plant population (widest inter-row spacing) required the least amount of inputs and therefore would be considered optimal. In that regard, the 75 cm inter-row spacing of rip lines for both maize and beans with intra-row spacing of 25 and 10 cm, respectively, were promoted.

Table 19.6 **Effect of varying maize and bean seeding rates using rip lines on maize and bean grain yield at Ngetta ZARDI, average of two seasons (2013A and 2013B)**

Inter-row spacing (cm)	Maize yield (t/ha)	Bean yield (t/ha)
60	3.14[a]	1.63[a]
65	2.45[a]	1.58[a]
75	2.99[a]	1.57[a]

Note: Different letters on yield data for each station indicate statistical differences among treatments, using the LSD method.

Comparison of tillage methods

Bean grain yields increased from as low as 300 kg/ha to 834 kg/ha with CASI technologies (rip lines and permanent planting basins) introduced by the SIMLESA program, in combination with improved seeds and fertilisers and/or manure and optimum seeding rates (Table 19.7). However, these yields were still well below the yield potential of beans in Uganda of 2,000 kg/ha (Sebuwufu et al. 2012).

Maize grain yield increased from an average of 3,000 kg/ha to 4,442 kg/ha (Table 19.7). This was also well below the yield potential for hybrid maize ranges of 5,000–8,000 kg/ha (Semaana 2010).

A combination of permanent planting basin and rip-line tillage together with improved seed and fertiliser brought maize and bean grain yields within the expected productivity range for both crops in Uganda.

Table 19.7 **Average bean and maize grain yields as a response to different tillage practices**

Tillage practice	Bean yield		Maize yield	
	(kg/ha)	SE	(kg/ha)	SE
Conventional	359[c]	±138	1,536[b]	+879
Conventional + fertiliser	560[abc]	±138	2,481[ab]	+879
Permanent planting basin	512[abc]	±138	3,328[ab]	+918
Permanent planting basin + fertiliser	784[ab]	±138	4963[a]	+918
Rip line	438[bc]	±148	2,086[b]	+963
Rip line + fertiliser	884[a]	±148	3,921[ab]	+963

Notes: Yield means for a particular crop followed by the same letter are not significantly different according to LSD at $P = 0.05$. SE = standard error.
Source: Mubiru et al. 2017

Business models

Through business modelling, it was observed that private entrepreneurship had potential to contribute significantly to the adoption and scaling of research technologies. However, uptake was seen to be limited by the capacity of the private sector to expand its business at the local level. Adoption and scaling could be enhanced by the bundling of goods and services, accessing finance, offering information on markets and input sources, enhancing entrepreneurship skills, promoting collective action and providing effective support services within an environment that is conducive to the development of small rural enterprises. Public–private collaboration at the subcounty level was believed most likely to be augmented through establishing multistakeholder innovation platforms as a mechanism for information sharing, providing local support services and linking to upstream value-chain stakeholders, among others.

What was the impact?

During the survey period, Uganda had an estimated 7.2 Mha of arable land under crop production, which is less than 50% of the arable land, estimated at 16.8 Mha (National Environment Management Authority 2007). Pessimistic forecasts indicate that the available arable land for agriculture will run out in most parts of the country by around 2022. With such grim statistics, the country cannot afford to lose any arable land. It is therefore imperative that Uganda embraces sustainable land management to reverse this trend of land degradation.

Technology exposure and skills development through the Uganda SIMLESA program led to enterprise, household, community and value-chain level adjustments. These include shifts in enterprise management and performance, cost reduction, labour savings, demand for relevant agro-inputs and services, and livelihood enhancement in general. Specifically, 60% of farmers exhibited knowledge of CASI farming and its principles. Of the technologies being promoted by the Uganda SIMLESA program, crop rotation, use of herbicides and pesticides, and intercropping were highly recognised as having the largest impact. Aspects of food security and the need to increase farmers' yields were driven by these technologies, while the ability of farmers to use small pieces of land with higher returns was a proxy indicator of impact.

Mechanisation services markedly contributed to the adoption of promoted CASI technologies and facilitated the need for farm inputs such as improved seeds and chemicals (e.g. herbicides and pesticides). Other benefits ranging from biological responses in the form of yields and food diversity due to weed suppression, fertility enhancement and moisture retention were attained. For instance, maize grain yields rose from an average of 2,000 kg/ha to 5,000 kg/ha and peanut from an average of 250 kg/ha to 875 kg/ha per season. This in turn had a positive financial impact. For instance, in 2016 the selling price for maize was US$0.22/kg and the increase in gross margin was noted at US$650/ha. For peanut, the increase in gross margin was noted at around US$928/ha. The increased aggregate maize production volume attracted new produce dealers in the area. The increased need for quick shelling and increased storage made some farmers acquire motorised maize shellers and do shelling as a business. All things considered, it is important to note that, although productivity increases were significant, the actual yields remain below the potential.

Table 19.8 shows the benefits along the commodity value chains. The livelihood benefits to direct and auxiliary beneficiaries include higher incomes, better household nutrition and higher capacity to address household welfare, education and health concerns, and socio-networks.

Table 19.8 Benefits from the Uganda SIMLESA program interventions along the commodity value chains

Pre-production	Production	Post-harvest	Auxiliary
• reduction in cost of opening land • expansion in size of enterprise • timely planting after onset of rains • use of improved crop varieties • productive assets (e.g. land, oxen, ploughs) • investment in farm power systems (e.g. oxen, ploughs, spray pumps)	• yield enhancements • profitability (gross margins/acre) • diversification into varied crop production (e.g. intercropping) • crop–livestock integration • diversification into livestock production • labour-use efficiency • cropping systems (intercropping vs monocropping)	• expansion of produce buyers • investment and expansion of processing capacity (e.g. maize shellers) • produce handling capacity (e.g. cribs, collective marketing) • storage price advantage	• human capital development • household subsistence and school feeding programs • domestic wellbeing (e.g. house construction, solar power, school fees) • transport assets • socio capital

What should we do next?

Research

Although research has developed and evaluated technology packages for intercropping, seeding rates and tillage methods, there is need for systematic quantification, contextualisation and documentation of costs and benefits or trade-offs at the household level, in order to better identify opportunities and constraints to adoption. Value-chain studies that extend beyond the household can also shed valuable insight into constraints that operate at a systemic level, shaping household opportunities and risks.

Undoubtedly, the Uganda SIMLESA program interventions increased agricultural productivity among supported farmers; however, adoption and scaling up is still low. This is attributable to inadequate extension services and substandard infrastructure. Generally, there is poor access by smallholder farmers to information, advisory services and modern agricultural inputs. To circumvent this, the project introduced technical service units and agricultural innovation platforms and produced communication materials such as brochures and a CASI implementation guide. Moving forward, there is a need to grow the agricultural innovation platforms and technical service units through technical and financial backstopping and also effectively disseminate the CASI farming information generated.

Through the agricultural innovation platforms, we expect to:

- introduce input credit systems from big agro-input companies to local dealers
- create linkages of potential agro-input dealers to financial institutions that offer long-term and friendly agricultural loans
- create linkages and networking between individual farmers, farmer groups and cooperatives/associations as major producers of raw materials
- strengthen farmer, agro-input dealer, trader and agro-processor linkages to engender better market opportunities
- introduce two-wheel tractors for farm operations along the commodity value chain, for example pedestal sprayers, direct seeders, small-scale irrigation, shelling and milling
- facilitate skills development, especially targeting women (although women are not the final decision-makers, the technologies and practices promoted have considerable impact on their wellbeing)
- promote utilisation of information communication technologies, especially among the youth
- encourage vertical diversification into livestock to exploit the crop–livestock–household–soil–weather interactions
- promote sustainable land management interventions at catchment level, including soil and water conservation measures, agroforestry and woodlots for climate change mitigation.

Case study: Heeding the call to transform from subsistence to commercial agriculture

Before 2012, Mr Mugisha, a member of the Biyinzika Farmer Group in Kalongo subcounty, Nakasongola district, was struggling to produce maize on a 7-acre piece of land. He used to get 2–3 t/ha by rudimentary means, such as a hand hoe and using locally saved seed without application of fertilisers. Being an astute businessman, he supplemented his meagre farm outputs by purchasing maize grain from his neighbours. This he bulked and sold, but his business was still struggling.

Mr Mugisha says that when the SIMLESA program was introduced in his village, it was a godsend. His group received demonstrations on CASI farming practices. The SIMLESA team that ran the demonstrations also introduced improved and drought-tolerant seed varieties, for example water-efficient maize (UH5053, PH5052) and NABE 15 bean varieties. They also encouraged group members to use fertilisers.

Most of the practices under the CASI framework (e.g. killing weeds using herbicides, preparation of planting basin during the dry season, planting more than two seeds in the basins, and application of fertiliser on beans) were alien and, at times, seemed bizarre. For someone used to planting in a weed and trash-free garden, planting in a freshly sprayed garden with weeds still standing was more than crazy. And to watch the seeds germinating while the weeds were dying off, and the crop growing luxuriously to physiological maturity, was not only peculiar but bordered on wizardly.

Mr Mugisha has abandoned his old ways of growing maize and beans, and now exclusively employs herbicides to burn down the weeds. This has not only helped him increase his acreage but has freed up more time to build his produce trade business.

Seeing the transformation in production and productivity, Mr Mugisha, with support from SIMLESA, constructed a 10-tonne maize storage crib. During the first season of 2017, using the CASI methods of preparing basins during the dry season, he planted his maize early and was among the first to harvest. Given that Uganda was hit by a severe drought in 2016 and millions of acres of maize were decimated by the fall armyworm (*Spodoptera frugiperda*), the demand for maize grain was very high. He was able to sell at a premium price. He bulked 13 tonnes of maize grain and sold each tonne at US$389, giving him a total of US$5,056. This was not a small achievement, especially in a country where the per capita income is US$419 and 28% of the population lives below the poverty line (Uganda Bureau of Statistics 2015).

This field was sprayed with herbicides immediately after planting. Bean seeds are germinating while the weeds are dying off.

A field of field beans planted in permanent planting basins nearing physiological maturity.

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20 CASI: a vital component of integrated soil fertility management in Rwanda

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Key points

- Conservation agriculture plus crop intensification leads to agriculture productivity for the current generation and soil health for future generations.
- The yield difference between tillage agriculture and conservation agriculture-based sustainable intensification (CASI) was insignificant in the initial cropping seasons.
- Yield levels showed varying responses to production inputs for tillage agriculture and CASI across agroecological zones.
- The environmental benefits of CASI can be achieved without yield penalties.
- Integrating agroforestry in the CASI package to control erosion and boost availability of biomass for mulch and animal feed is key for adoption of CASI practices.
- The large-scale adoption of CASI requires much on-farm demonstration effort to create a positive perception among policymakers, scientists, technicians and farmers.

Introduction

In the highlands of Rwanda, agricultural production is undermined by soil water erosion, mainly in the north and west. In the east, it is constrained by high risk of crop failure due to scarce rainfall. Erosion and dry spells are aggravated by tillage agriculture on steep slopes and the low organic matter content of soils.

To produce sustainably, Rwanda's soils need an increased organic carbon stock. Many of Rwanda's soils also need efficient use of fertilisers and at least 50% need the application of lime. So far, erosion control and organic matter supply remain the principal constraints on production in Rwanda (Ministry of Finance and Economic Planning 2017). Erosion control measures, such as bench terraces, are quite expensive (800–1,200 labour days/ha) and do not resolve the need for organic matter (Roose & Ndayizigiye 1997).

Conservation agriculture-based sustainable intensification (CASI) practices employ minimum tillage, mulching, crop rotation and fertiliser use (Vanlauwe et al. 2014). These practices have advantages for cost-effective erosion control, soil organic carbon stock (Rodriguez et al. 2017) and improvement of soil health and pest and disease control (Midega et al. 2018). In Rwanda, before SIMLESA, no study was undertaken to test the technical feasibility and adoption of CASI practices by farmers. This publication presents SIMLESA's achievements in establishing the value of CASI technologies in Rwanda.

The study addresses the following specific objectives:

- to demonstrate the effect of CASI practices compared to tillage agriculture on maize and bean yields in rotation
- to compare the effects of different soil fertility input treatments on maize and bean yields
- to identify CASI adoption drivers in three agroecological zones.

Methodology

Project sites

In Rwanda, SIMLESA activities were implemented in three sites located in three agroecological zones. The characteristics of these agroecological zones are summarised in Table 20.1.

Table 20.1 Characteristics of SIMLESA intervention sites

Site	Agroecological zone	District	Altitude (m)	Rainfall (mm/year)	Site topography	Soil fertility
Gashora	semi-arid lands of Bugesera	Bugesera	1,000–1,400	900	flat	very good
Runda	Central Plateau	Kamonyi	1,400–1,800	1,200	hilly	good
Cyuve	volcanic lands of Birunga	Musanze	>2,000	>2,000	flat	excellent

Experiment treatments

A split-plot experimental design was used in field experiments. It consisted of comparing CASI and tillage agriculture blocks side-by-side (Table 20.2) and randomised treatments in the blocks. The main factors were CASI and tillage agriculture farming practices. Each farming practice was subdivided into three treatments:

- T1: manure
- T2: manure plus fertiliser
- T3: manure plus fertiliser plus biofertiliser.

The trial plot was 5 m × 5 m = 25 m^2. At block level, treatments were randomised but the same treatment was always side-by-side (split-plot) to ease overtime growth comparison by technicians and farmers themselves.

Table 20.2 Split-plot experimental design

Tillage agriculture block	CASI block
T2	T2
T1	T1
T3	T3

Note: CASI = conservation agriculture-based sustainable intensification

Results and discussion

Figure 20.1 presents maize yields (cobs) under CASI and tillage agriculture for two consecutive growing seasons (2017A and 2017B) at Runda. In season 2017A, tillage agriculture was statistically higher than CASI across all treatments. However, there was no observable difference between CASI and tillage agriculture in the following season.

The superiority of tillage agriculture over CASI in the first season could be a result of inefficient implementation of CASI technologies or the fact that the soil was still poor in soil organic matter and nitrogen.

During the second growing season, the difference between tillage agriculture and CASI was reduced. More appropriate application of the techniques by farmers and subsequent improvement of soil properties under CASI could explain the reduced performance margin for the previous season. During the second season, the difference between treatments were not significant where manure had the same effect irrespective of the additional amendments (manure combined with fertilisers and manure combined with fertilisers and biofertilisers). An apparent significant difference is also observed in T3 of 2017B where yields under tillage agriculture were significantly higher than those under CASI. However, in all treatments T3 outperformed T2, and T2 outperformed T1.

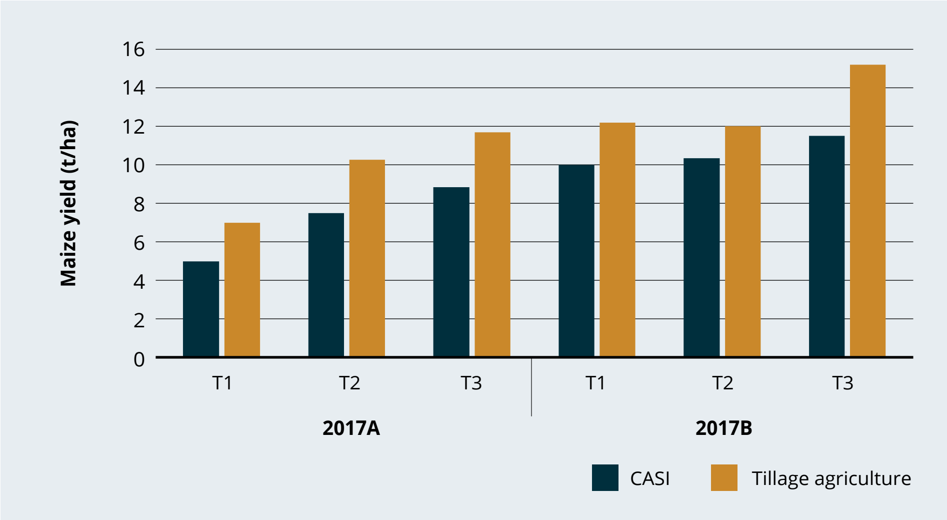

Figure 20.1 **Maize yield (cobs) in Kamonyi, Runda, 2017A and 2017B**

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

Figure 20.2 presents bean yields under CASI and tillage agriculture for two consecutive growing seasons (2017A and 201B) at Runda. In general, there was no significant difference between CASI and tillage agriculture. A significant difference was observed between seasons and treatments. The benefit of CASI over tillage agriculture became apparent in the second growing season. This was due to the residual effect of the mulching of the last season and because the farmer was more familiar with the CASI techniques (e.g. mulching and timely weed control) and applied it with more rigour than in the first growing season.

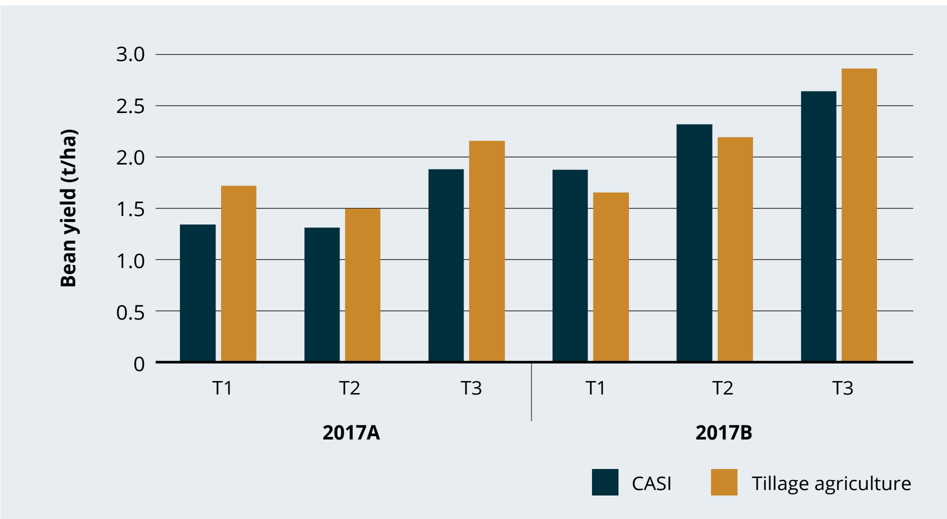

Figure 20.2 **Bean yield in Kamonyi, Runda, 2017A and 2017B**

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

Figure 20.3 presents maize yields under CASI and tillage agriculture for one growing season (2017B) in Bugesera. The figure shows that there was no significant difference between CASI and tillage agriculture. A significant difference was observed between T1 and the rest of treatments (T2 and T3). This supported the idea of including fertiliser use as a fourth principle of CASI (Vanlauwe et al. 2014). The significant improvement of yields with fertiliser application was explained by the depleted soils in the Bugesera site, which required amendments for maize production. However, the effect of biofertiliser was not statically significant. Bugesera production in 2017A was a total failure in both CASI and tillage agriculture due to drought.

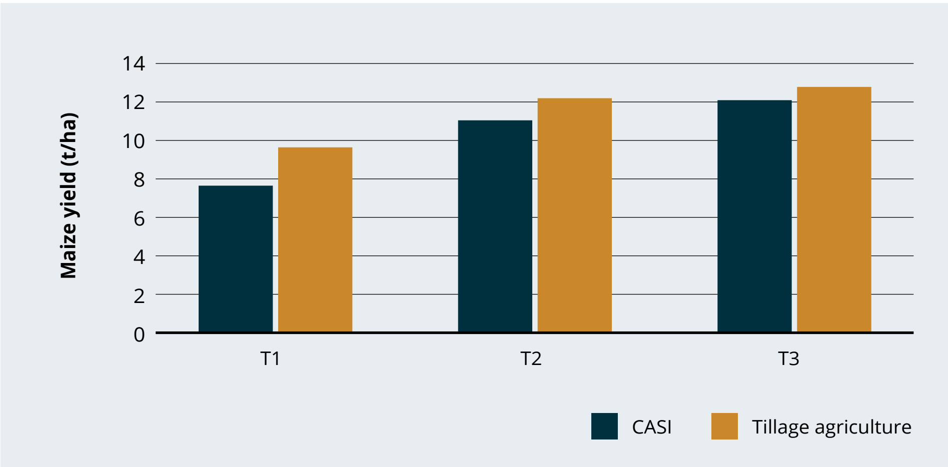

Figure 20.3 **Maize yield (cobs) in Bugesera, Gashora, 2017B**

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

Figure 20.4 presents bean yields under CASI and tillage agriculture for two growing seasons (2016B and 2017B) in Bugesera. The figure shows that there was no significant difference between CASI and tillage agriculture, or between treatments. Bean production might have been less sensitive to inputs than maize because the crop was less nutrient-demanding (Roose & Ndayizigiye 1997) and the soils of Bugesera were more fertile compared to soils of Runda (Birasa et al. 1990).

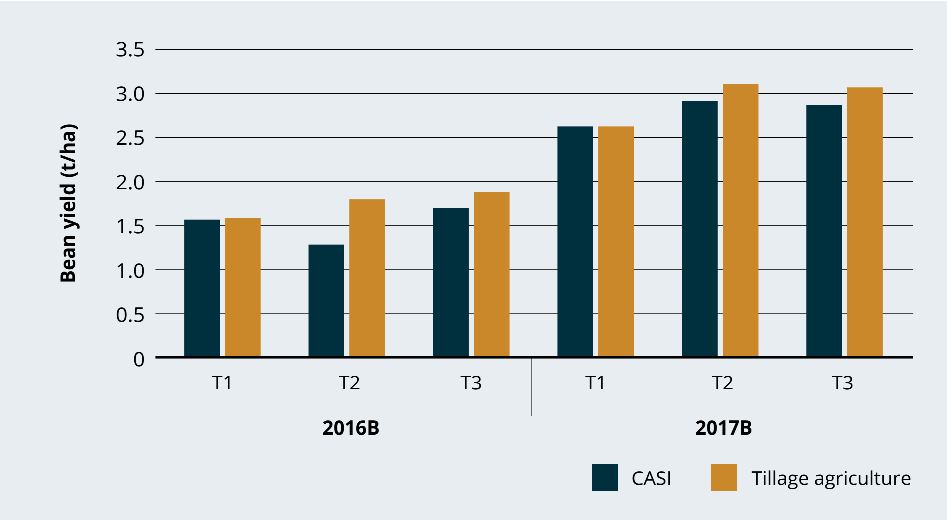

Figure 20.4 Bean yield in Bugesera, Gashora, 2016B and 2017B

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

Figure 20.5 presents maize yields under CASI and tillage agriculture at Cyuve for one growing season (2017B). CASI with manure was the best option in Cyuve. There was no significant difference between CASI and tillage agriculture, or between treatments. The rich volcanic soils may have provided adequate nutrients to support maize production.

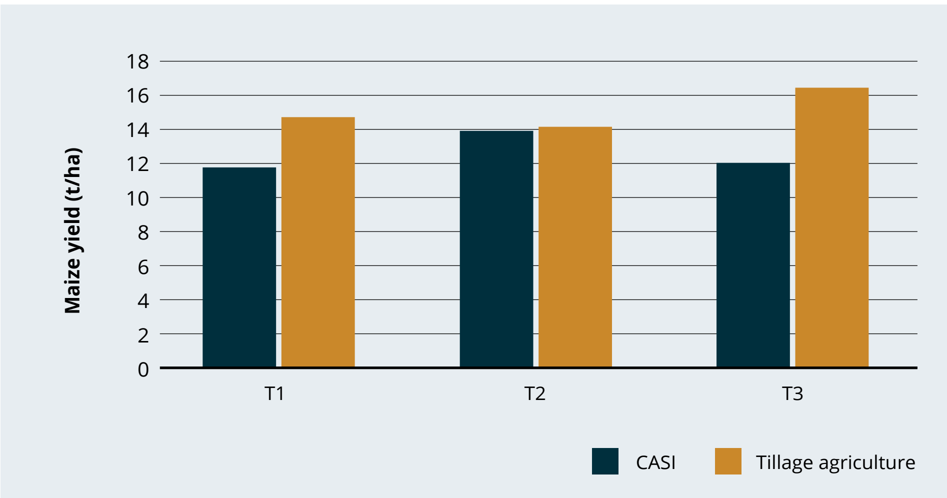

Figure 20.5 Maize yield (cobs) in Musanze, Cyuve, 2017B

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

Figure 20.6 presents maize yields under CASI and tillage agriculture for two growing seasons (2016B and 2017B) at Cyuve. In 2016B, there was a significant difference between CASI and tillage agriculture. Maize yields were higher under tillage agriculture compared to CASI. One possible explanation is that farmers were not yet used to CASI techniques (mainly mulching and weeding). There was no significant difference between treatments. This is normal, as the soil of the region was rich enough to provide adequate nutrients to the crop. This is consistent with Rushemuka et al. (2014), who found that fertile soils in Rwanda (pH >6.0) can produce good yield with manure and without any fertiliser. The best option for this season was tillage agriculture with manure only.

Interestingly, the outcomes were reversed in 2017B, when the best option was CASI with manure only. Yields were consistently higher under CASI compared to tillage agriculture across all treatments, and the difference was significant in the manure treatment. This is consistent with previous studies that found that CASI benefits improve over time as soil properties improve (Rodriguez et al. 2017). In tillage agriculture, on the other hand, yields declined over time as the soil was exposed to a degrading tillage. However, field trials show that the benefits of manure could be minor when CASI is practised and soil organic carbon content is good to secure optimum crop production. This is consistent with Rushemuka, Bock & Mowo (2014), who indicated that in Rwanda 2% of soil organic carbon is enough for optimum crop production, when other factors are provided.

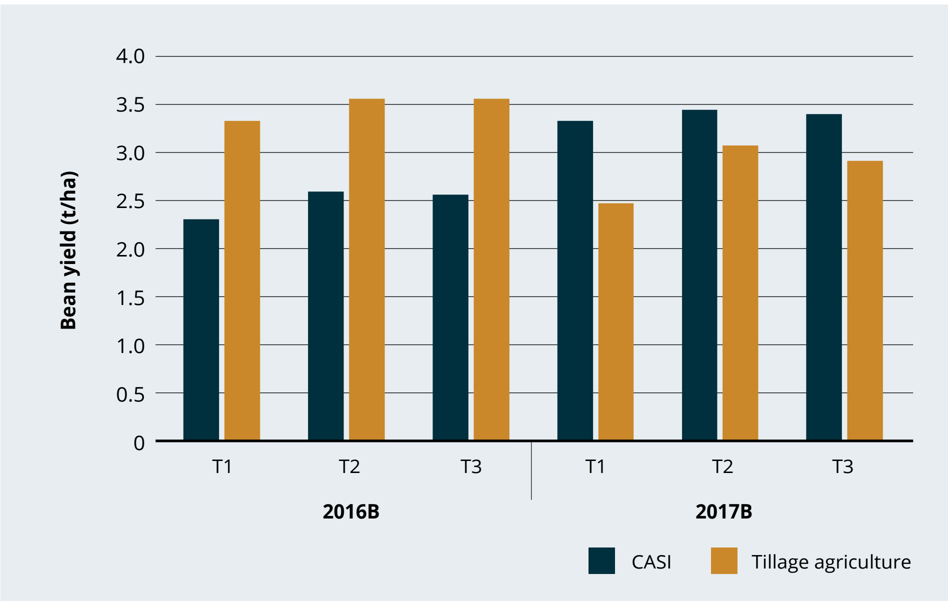

Figure 20.6 Bean yield in Musanze, Cyuve, 2016B and 2017B

Notes: T1 = manure; T2 = manure and fertilisers; T3 = manure and fertilisers and biofertilisers; CASI = conservation agriculture-based sustainable intensification.

What was the impact?

Identified and addressed knowledge gaps

The practice of CASI techniques in Rwanda was only introduced at research stations (Kabirigi et al. 2017). The SIMLESA on-farm experiments reported in this publication are among the few known examples of engagement with smallholder producers. Evidence from this short-term study show that CASI and tillage agriculture tend to perform similarly. The fact that CASI requires less labour, at least in the long run, suggests that CASI could be more advantageous for farmers. Under fertile soil conditions, yields were higher under tillage agriculture compared to CASI in the first season; however, the situation reversed the second season. This suggests that the benefits of CASI occur faster in fertile soils than in infertile soils: Cyuve was more fertile than Bugesera and Bugesera was more fertile than Runda (Birasa et al. 1990).

The benefits of CASI also depend on the management of the field by the farmer. The more engaged and informed the farmer, the better the results. In general, without the use of herbicides, the benefits of CASI became apparent in the third growing season. At this stage, the farmers were proficient in CASI techniques, the effect of mulch on soil properties was significant, weed control was manageable and the benefits of tillage completely disappeared (Figure 20.7). Beans were planted in 2017B, after maize harvest in 2017A. This field was prepared to receive seeds without tillage, but water and additional mulch were needed.

Figure 20.7 **A field under CASI after bean harvest at Cyuve**

These encouraging results can support scaling up the adoption of CASI production systems. However, additional efforts are required to promote adoption. Outreach and extension can help inform farmers on CASI principles. Farmers had many questions and concerns when they were first introduced to CASI, including:

- Is it possible to grow crops without cultivation?
- How are we going to manage the weeds?
- Where are we going to find mulch?

It was not only farmers who were anxious, but also extension agents, policymakers and scientists. In general, there was widespread scepticism around CASI in the absence of empirical support, training and implementation/demonstrations.

The two first principles of CASI were most challenging: no-tillage/minimum soil disturbance and permanent soil cover. The uncertainty over minimum soil disturbance was fundamental in degraded lands, where farmers historically practised deep tillage (30–50 cm deep) to uproot all the roots of *Digitaria abyssinica* (Hochst. ex A.Rich) Stapf (Urwiri in the local language), a widespread weed in the many degraded soils of Rwanda. In Rwanda, most weeding is either by hoe or hand, so weed management requires careful consideration of labour availability, especially as the scale of production increases.

The question about mulching also needs to be considered in the context of the socioeconomic conditions of Rwanda. In small landholdings, even crop residues are utilised for other competitive uses like fodder and fuel. The problem of using mulch for other competitive purposes is common in the highly populated regions of Africa (Rodriguez et al. 2017).

Community networks that support adoption of CASI

SIMLESA Rwanda was able to create three community networks from which large-scale extension can start. The networks were made by farmers who collaborated with SIMLESA during fields trials and converted their lands for large-scale practices of CASI. They were enthusiastic and actively encouraged their neighbours to also adopt CASI. Neighbour involvement was facilitated by exposure, as they were able to watch CASI practices along the growing seasons in the fields of their neighbours. They were surprised to see vigorous crops under conservation agriculture (Figures 20.8 and 20.9) and concluded that they were expending unnecessary energy by practising tillage agriculture.

It is in this framework that SIMLESA generated interest in CASI and demand for CASI inputs in Runda, Bugesera and Cyuve. Also, because SIMLESA technicians have experienced the benefits of conservation agriculture, they agreed to experiment with its adoption in Gatsibo (eastern Rwanda), Huye, Nyanza, Nyaruguru and Nyamagabe districts (southern Rwanda).

Figure 20.8 A field of climbing beans grown under CASI (left) and tillage agriculture (right) plots, Cyuve, 2017B

Figure 20.9 A field of bush bean grown under CASI after a season of maize, Runda, 2017A

What should we do next?

For the large-scale promotion of CASI in Rwanda, the next priorities can be:

1. mainstream CASI in the long and midterm strategic planning documents under Vision 2050
2. develop and disseminate a user manual for CASI, adapted for Rwanda
3. develop and implement a capacity-building program
4. promote CASI, with integration of agroforestry as a principle component
5. promote appropriate use of other inputs
6. etablish a research program or integrated research that seeks to understand and provide quantitative data on the effect of CASI on soil nutrient dynamics, pest management and crop yields.

Mainstreaming CASI in Vision 2050

In Rwanda, the agriculture development of the next 30 years, after the 20 years of the Millennium Development Goals, will be governed by Vision 2050. For any program to stand a chance of benefiting from the political and financial support of the government of Rwanda, it will need to be incorporated as an important program into this strategic document. Vision 2050 will be aligned to the global policy framework of the Sustainable Development Goals.

Development of a detailed user manual for CASI, adapted for Rwanda

As with any change, the move from tillage agriculture to CASI cannot to be taken for granted. It needs theories and practice. This means that it needs to be supported by a theory of change (Thornton et al. 2017). This would imply that any successful introduction of CASI should be circumscribed in a theory of integrated soil fertility management and be accompanied by a detailed user guide manual about CASI principles and practices, adapted to Rwandan agroecological zones, soils and socioeconomic context. An example is *Farming for the future: a guide to conservation agriculture in Zimbabwe* (eds Harford, Le Breton and Oldrieve 2009).

Development of an important and intensive capacity-building program

For many decades and during many generations, Rwanda's scholars and farmers have been exposed to tillage agriculture discourse and tillage practice. They have learned this at school through mainstreamed curriculum, in practice, through the media and in professional courses. The entrenched nature of these practices can pose challenges to the adoption of new technologies. There is a need to change this mindset at policy, academic, professional and farmer levels. At the policy level, the priority can be to run awareness-raising conferences advocating for the CASI model. At the academic level, the priority can be to mainstream CASI into academic curriculums. At the professional level, there is a need for professional training. At the farmer level, there is a need for field demonstrations.

Promotion of CASI through its integration with agroforestry

The main justification for cultivation/tillage practices is the control and management of weeds. One entry point for CASI adoption is as an innovative solution for weed control. The use of herbicides appears to be a solution, at least at the beginning, to fulfil the principle of minimum soil disturbance. It is expected that, with time and improvement of soil properties, fields will move from the hard weeds, characteristic of degraded lands, to softer and fewer weeds, characteristic of fertile soils and easily uprooted by hand. In the long run, the trend will be for less or no use of pesticides and less need of tillage mechanisation.

Another entry point is the availability of a cost-effective and permanent source of mulch for permanent soil cover. The use of crop residues as mulching materials in conservation agriculture-based farms faces strong competition, as they are also used as fodder by cattle keepers (Rodriguez et al. 2017). In this context, the integration of CASI with agroforestry appears to be a priority (Figure 20.10). The synergism between agroforestry (e.g. a permanent source of mulch) and CASI (e.g. mulch and minimum soil disturbance) is expected to continually enrich the soil organic matter and improve physical, chemical and biological soil properties. The improvement of soil properties contributes efficiently to environmentally friendly soil erosion control and reduces the need for tillage. The enrichment of soils in organic matter increases the water use efficiency by crops and, in the long run, increases soil resilience to drought. This reduces the effect of drought on crops during dry spells (Rockström 2003). Soil organic matter also increases the soil cation exchange capacity and supplies additional nutrients, improving crop nutrient use efficiency and, in the long run, reducing the need for mineral fertilisers (Gill & Meelu 1982). By improving biological soil properties, agroforestry and CASI empower crop health, reducing the need for pesticides. For instance, it was recently shown that ecological practices such as intercropping and CASI significantly reduced the population of the fall armyworm (*Spodoptera frugiperda* (J.E. Smith)) (Midega et al. 2018).

Figure 20.10 **Agroforestry is potentially a permanent source of mulch for CASI systems**

Correct use of other inputs (varieties, fertilisers, lime and pesticide)

In addition to the conditions described above, fertilisers and high-yielding crop varieties may constitute important inputs for sustainable and productive agrosystems. However, they need to be introduced with a clear understanding of the specific biophysical environment and socioeconomic context (Rushemuka et al. 2014). In the context of Rwanda, the majority of potential adopters will also practise agroforestry on nutrient-poor and acidic soils that benefit from lime and manure amendments (Rushemuka & Bock 2016). While the country has sufficient mines for limestone, the large-scale utilisation of lime is limited by the fact that the mines are located a long way from where the lime is needed. More investment in transportation is needed. It is expected that the need to supply manure will be overcome with the CASI system.

Ongoing research programs

The majority of existing agronomic research results that have been widely disseminated were obtained under tillage agriculture practices. Conservation agriculture-related experimental results are insufficient. For instance, the United Nations' Food and Agriculture Organization recognises that there is a lack of information on the impact of the introduction of CASI on nutrient and water use efficiency, soil organic matter dynamics, control of weeds and crop disease and the interactions between them. Research is needed to develop optimal CASI management practices that are adapted to local needs and conditions. Isotopic techniques (Nitrogen-15 and Carbon-13) and other soil sensors can be effectively used to track carbon, water and nutrient movement and their dynamics under CASI in diverse agroecosystems. Likewise, CASI in Rwanda has produced many benefits in different fields of science that could constitute interesting fields of research.

In flat areas of volcanic regions, there is normally a problem of water lodging, which negatively affects crop growth. Usually, farmers manage this problem by constructing soil ridges. CASI has had positive effects on soil drainage/infiltration (Figure 20.11). These effects on erosion control and water use efficiency need to be quantified and documented.

Figure 20.11 Tillage agriculture and water lodging affected crop health (left); soil ridges for drainage (middle); CASI had a positive effect on soil drainage, water infiltration and plant vigour (right)

During SIMLESA field trials, chickens were observed in CASI plots (Figure 20.12) but were not observed in tillage agriculture plots. This is not to suggest that chickens should be integrated into CASI systems, but it is indicative that CASI induces positive development of soil insects, earthworms and micro-organisms (bacteria, fungi, protozoa). This soil biota and its effects on vigour of crops should also be documented.

Figure 20.12 **Chickens in maize plots are indicators of a good soil microbial activity under a soil conservation system at Runda (left) and Cyuve (right)**

Under CASI, crops (especially maize) showed excellent vigour at the earlier stage but, as they grew, they showed symptoms of nitrogen and phosphorus (Figure 20.13) deficiency that did not appear in similar plots under tillage agriculture. This suggests the need for a careful study to understand the dynamics of soil nutrients under CASI.

Figure 20.13 **Maize growth under CASI at Runda: very good maize growth at the beginning (left); nitrogen deficiency appearance at flowering (middle); phosphorus deficiency symptoms at maturity (right)**

Another important observation of sustainability is the fact that while maize crops in tillage agriculture were severely attacked by fall armyworm, the incidence was minimal under CASI plots in the same fields (Figure 20.14). The positive effects of CASI were probably due to the push–pull effect of mulch and its interaction with soil micro-organisms (Midega et al. 2018). This implies that there is room for testing CASI as an integrated pest management practice.

Figure 20.14 **Fall armyworms severely damaged maize under conventional agriculture (left); less damage from fall armyworm to maize under CASI (right)**

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21 Lessons learned from country innovations

Eric Craswell

Key points

- The SIMLESA project engaged key policymakers through a program steering committee that supported the country coordinators and provided policy advice.
- Conservation agriculture-based sustainable intensification was nurtured under an enabling policy environment, particularly in regard to the price of inputs.
- Interdisciplinary system approaches to research provided the most effective approach.
- Component technologies, such as the use of herbicides to reduce tillage, fed into innovation platforms that provided a foundation for large-scale transformation of agriculture.
- One of the keys to success was private sector linkages through value chains, marketing of produce and the supply of improved seeds.
- SIMLESA also provided valuable insights into the sustainable intensification of agriculture in northern Australia based on diversified farming systems and sources of income in a changing climate.

Introduction

Five countries in eastern and southern Africa, with the cooperation of Australia and several spillover African countries, collaborated in the SIMLESA project (Table 21.1). Led by the International Maize and Wheat Improvement Center (CIMMYT) and supported by ACIAR, organisations in eight countries of eastern and southern Africa, and Australia, collaborated for eight years in research to design, test and scale out technologies for the sustainable intensification of agriculture. SIMLESA activities occurred in two phases: 2010–13 and 2014–18.

Table 21.1 Participating countries and institutions

Country	Lead institution	SIMLESA country coordinator
Ethiopia	Ethiopian Institute of Agricultural Research	Dr Bedru Abdi
Kenya	Kenya Agricultural and Livestock Research Organization	Charles Nkonge
Tanzania	Department of Research and Development	Dr John Sariah
Malawi	Department of Agricultural Research Services	Grace Timanyechi Munthali
Mozambique	Instituto de Investigação Agrária de Moçambique	Dias Domingos
Rwanda*	Rwanda Agriculture Board	Dr Pascal Rushemuka
Uganda*	National Agricultural Research Organization	Dr Drake N Mubiru
Botswana*	Department of Agricultural Research	Mrs MG Ramokapane
Australia	Queensland Alliance for Agriculture and Food Innovation	Dr D Rodriguez

*Spillover countries

The principles of conservation agriculture-based sustainable intensification (CASI)—retain crop residues, minimise tillage and rotate crops—underpinned the research and development approaches of all the organisations. The stepwise or transformational nature of sustainable intensification technology adoption was a central topic across all the countries in the SIMLESA program (Dimes, Rodriguez & Potgieter 2015). The CASI principles provided the framework for the stepwise project activities (Figure 21.1).

This chapter draws from the rich tapestry of SIMLESA experiences in the partner countries that has been captured in the previous chapters in this book. It will highlight the main lessons learned from the project. Additional source material for this chapter includes the material presented by country representatives in the final review meeting and outcomes of annual deliberations of the program steering committee, which engaged research leaders from the participating countries, regional organisations as well as CIMMYT and ACIAR staff.

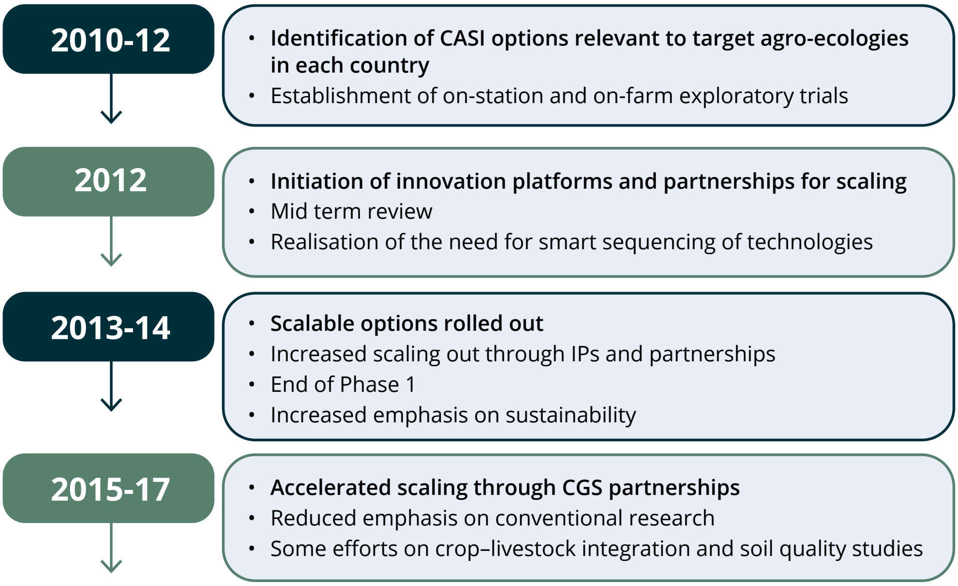

Figure 21.1 **Stepwise SIMLESA activities to promote CASI technologies**

Notes: CASI = conservation agriculture-based sustainable intensification; IP = Innovation platforms; CGS = Competitive Grants Scheme

What did we learn?

The majority of the lessons learned, as discussed below, derive from the experience of the African countries involved in SIMLESA. However, the Australian experience is also noted based on the importance of returns on investment from international agricultural development initiatives, for example, the Doing Well by Doing Good approach advocated by ACIAR (Blight, Craswell & Mullen 2014).

Project design

The project design treated the program steering committee as a distinct entity with unique functions. Major project achievements emerged out of operations by the program steering committee. The committee members attending the annual meetings showed their ownership of the project throughout committee deliberations where they provided strategic and technical advice and recommendations to ACIAR. This high-level support from within the countries provided SIMLESA country coordinators with backing for their activities as well as a direct pipeline to policymakers. A program management committee effectively handled the more routine management issues.

Research paradigm

Researchers from across all the SIMLESA countries identified the following common lessons:

- The questions of interest to SIMLESA required systemic research based on an understanding of multiple disciplines and how they relate.
- The key determinant of the performance and successful adoption of conservation agriculture-based sustainable intensification (CASI) was the suitability of the technology for the biophysical environment (soils and climate).
- SIMLESA participants found that the most effective approach to sustainable intensification was to delineate the agroecologies that would benefit from CASI and identify the practices that would best benefit smallholders in the countries.
- The key entry point for CASI under SIMLESA was the improvement of soil organic carbon and its effects on soil physical and biological properties.
- The approach of promoting many technologies allowed farmers to adopt a basket of technologies that was most suitable to their unique environment, risk levels and goals.
- Ongoing research and data analysis is necessary for identifying emerging issues and promotion of the most promising CASI technologies.

Component technologies

Exploratory on-station and on-farm trials provided the following lessons that fed into the deliberations of innovation platforms:

- Herbicide application obviated the use of tractor or draught animals for weed control, which minimised greenhouse gas emissions.
- Residue retention increased soil carbon.
- Soil bulk density decreased with CASI.
- Soil organic carbon marginally increased with CASI in the short time frame of the SIMLESA program at a rate of increase that was likely to produce significant change over a longer time frame.

Inputs

Sustainable intensification required external inputs to account for the increased harvests:

- Investments in inputs, including seeds and agrochemicals, was often prohibitively costly and unprofitable for the large proportion of farmers with very low levels of expendable income who sold produce at low prices (extremely low maize prices = $US0.083/kg).
- Increased demand for improved seeds was associated with frequent shortages of desired varieties (e.g. Embean 14).
- Use of fertiliser was a key element in CASI to redress soil fertility decline.
- The greatest benefits of CASI occurred when farmers applied several inputs (lime, fertilisers and good-quality seeds) in combination.
- Open grazing reduced the benefits of residue retention for soil quality outcomes.

Input and product markets

- Farmers did not have reliable markets to sell the production gains from intensification.
- Spatial and temporal variability in sales and ad hoc negotiations reduced the certainly of returns from production while marketing models that integrated farmers in value chains increased certainly of returns from production.
- Unreliable markets for inputs like new seed varieties and basic CASI equipment and herbicides prompted some SIMLESA farmers to become agrodealers.
- Thin markets and low prices were most likely at harvest time.

Innovation platforms

Contact with stakeholders can be effectively established through innovation platforms (Table 21.2):

- Agricultural innovation platforms could be supported through exchange visits with other successful platforms.
- Agricultural innovation platforms provided a link for farmers to financial institutions.
- Technical service unit models facilitated innovation in agricultural innovation platforms.
- There was a need for innovative institutional arrangement and policy alignment to transform agriculture.
- Agricultural innovation platforms were a good framework to tackle the problems of the agriculture sector and for large-scale transformation of agriculture.
- Mechanisation service providers (spraying, ripping and shelling) worked effectively through innovation platforms.

Table 21.2 Agricultural innovation platforms established under SIMLESA

Country	No. of sites	No. of agricultural innovation platforms	Levels of agricultural innovation platforms
Ethiopia	7	19	Woreda (District)/Community
Kenya	5	13	District/Community
Tanzania	5	10	District/Community
Malawi	6	6	District/Community
Mozambique	4	4	District/Community
Rwanda	4	4	Sector
Uganda	2	2	District
Total	**33**	**58**	

Public–private partnerships

Both the public and the private sector enabled adoption of CASI technologies:

- Public–private partnerships facilitated adoption of CASI technologies.
- Business model analysis revealed that private entrepreneurship had potential to contribute significantly to the adoption and scaling of research technologies.

Labour inputs

Intensification involved enhanced labour productivity:

- Initiatives, such as those of the Agricultural Productivity Program for Southern Africa-Mechanization (APPSA-MEC), worked in parallel with SIMLESA to reduce labour-related challenges.
- Resource conservation increased as labour costs declined.

Constraints to production

Production was limited by a wide range of factors:

- Uncertain dry spells, flood events, diseases and pest outbreaks increased production risks.
- Maize diseases were widespread (e.g. maize lethal necrosis disease).
- Fall armyworm was a major pest.
- *Striga* weed presented a major challenge to many farmers.
- Competing uses of crop residue (e.g. firewood for energy and feed for livestock) across farming activities limited adoption of the CASI practice of protecting the soil surface with crop residues.
- Although a yield gap was apparent for many farmers, constraints to bean production were not identified.

Extension/communications

Multiple forms of media were used to achieve widespread communication of CASI benefits:

- The dissemination materials that were produced included journals, proceedings and extension materials.
- The project introduced technical service units and agricultural innovation platforms to engage directly with end users.
- Identifying and implementing a knowledge management system that suited all users was an ongoing challenge.

Policy engagement

An enabling policy environment at the national and regional levels was needed to support CASI:

- Policy reforms were required to underpin and enhance all aspects of CASI.
- Communicating research results to policymakers involved recasting findings in a political context that was initially unfamiliar to some researchers.
- Policy recommendations that enhance input access were made to promote CASI.
- Price relief through lifting of some taxes in agricultural inputs was shown to increase the affordability of CASI technologies.
- The arrival of government-subsidised fertilisers too late in the planting season was a frequent problem in some areas.
- Regional policies for the bulk purchase of fertiliser reduced the price of fertiliser by almost 40%.

Mechanisation

Mechanisation was needed to overcome the shortage of power as agriculture intensified:

- Zero or furrow tillage resulted in higher soil moisture for crops, which was especially beneficial in low rainfall areas.
- No single form of mechanisation was identified (animal traction, two- and four-wheel tractors) that would suit all of the diverse production settings and farmer conditions.
- Technologies promoted by SIMLESA were incorporated into agricultural development frameworks and mainstreamed into national agendas (e.g. Mtandao wa Vikundi vya Wakulima Tanzania, the national farmers organisation of Tanzania).

Competitive grants scheme

A program of competitive grants schemes (Table 21.3) enhanced the scaling out of CASI technologies:

- Without scaling-out partners SIMLESA took four seasons to reach 78 communities but under the competitive grants scheme it took three partners one season to reach almost the same number of communities (64).
- Constant engagement, hands-on training, exposure to technologies, and tools and implements along the commodity value chains strengthened and made farmer groups more coherent.
- Backstopping scaling-out partners was a key to success.

Post-harvest

The sale of marketable surpluses relied on post-harvest transport and storage operations:

- Limited access to suitable implements often delayed peanut shelling.
- Maize storage cribs reduced post-harvest losses and provided farmers with a wider selling window for higher sales prices.

Capacity building

Capacity building occurred across all countries at all levels of the SIMLESA program:

- At the farmer level, SIMLESA targeted men, women and youth.
- At the field extension worker level, SIMLESA targeted both men and women.
- At the scientist staff level, SIMLESA targeted young scientists.

Australian lessons learned

- Sustainable intensification of agriculture showed great potential for production in the semi-arid tropics of Queensland.
- Sustainable intensification of agriculture was able to bridge yield gaps and increase production efficiencies in dryland cropping systems.
- Investment in transformative changes to the agriculture sector (e.g. infrastructure) showed great potential to generate opportunities to diversify farmers' income under the climate change scenarios predicted for Australia.

Table 21.3 Selected partners in each country

Country	Farmer association	Information and communications technology	Non-government organisation	Media	Seed	University	Church organisation	Level
Kenya	Secondary partners esp. AIP	Secondary partners: QAAFI, Mediae Ltd		Mediae Ltd	Freshco Seed Co.	Egerton	NCCK	County
Malawi	NASFAM	Secondary partners: QAAFI, FRT		Farm Radio Trust				National
Mozambique	UCAMA	ISPM, QAAFI	AgriMerc ODS	ISPM	Secondary partners	ISPM		National
Tanzania	MVIWATA	Secondary partners: QAAFI, CABI	RECODA	Secondary partner	SATEC	Secondary partner: Sokoine University		National
Ethiopia	Seven scaling-out partners (East Shewa, East Wollega, Hadiya, Sidama, West Arsi, West Gojjam and West Shewa) were commissioned because of their strengths in extension work.							

Notes: FRT=Farm Radio Trust; ISPM - Instituto Superior Politécnico de Manica ; NCCK= National Council of Churches Kenya; ODS = Sustainable development goals; RECODA = Research, Community and Organisational Development Organisation; QAAFI = Queensland Alliance for Agriculture and Food Innovation; SATEC = Suba Agro Trading and Engineering Co.Ltd.

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