SECTION 2

REGIONAL FRAMEWORK AND HIGHLIGHTS

6 Conservation agriculture as a determinant of sustainable intensification

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Key points

- Retention of crop residues improved water infiltration and reduced water run-off and water erosion soil losses.
- Maize yields improved under conservation agriculture-based sustainable intensification (CASI) across eastern and southern Africa, averaging 11%, while yield variability was reduced by about 4%.
- Maize–legume rotations accounted for 20–50% of yield increases under CASI (depending on the legume under rotation), increased macrofauna diversity, increased nitrogen fixation and lowered the incidence of crop diseases.
- Intercropping reduced maize yields but resulted in higher net benefits to farmers by providing two crops from the same piece of land. Intercrops were a preferred option for land-constrained farmers.
- Yield benefits from CASI, particularly CASI basins, were lower for poorly drained or waterlogged sites. CASI basins should be restricted to well-drained sites with a high probability of erratic rainfall seasons, such as the semi-arid regions.
- Herbicide use was common and preferred because it reduced labour requirements.
- In Malawi and Mozambique, improving agronomic practices like planting density, planting configurations, inorganic fertiliser, improved seeds and timely weed management increased yields by more than 60%.
- Challenges in implementing CASI included the need to adapt and apply the three principles effectively across diverse settings. Initial weed management and a scarcity of crop residues for soil cover also limit adoption.
- Further research is needed to address the competition for crop residue use, between feeding livestock and soil cover, in mixed crop–livestock systems.

Introduction

Challenges around the intensification of maize–legume cropping systems in eastern and southern Africa (ESA) have been explained by high levels of soil degradation and poor soil fertility and nutrient mining (Dixo, Gulliver & Gibbon 2001; Wagstaff & Harty 2010; Vanlauwe & Zingore 2011; Jama et al. 2017; Kihara et al. 2016). Soil health has been widely recognised as an important contributor to the sustainability of agroecosystems. Persistent promotion of conservation agriculture-based sustainable intensification (CASI) has occurred in Sub-Saharan Africa (SSA), although the life in the soil has not been fully understood. CASI, by definition, refers to practices that reduce soil disturbance, provide permanent soil cover and use crop rotations or associations (Kassam et al. 2009). CASI has demonstrated the potential to curb further erosion from degraded soil resources (Enfors et al. 2011; Huang et al. 2012; Kassam et al. 2009). CASI has increased soil moisture conservation and mitigates yield losses from in-season dry spells (Nyagumbo & Rurinda 2012). The crop rotation component of CASI consistently reduced pests and diseases (Govaerts et al. 2006) and improved soil fertility (Maltas et al. 2009). Rotations and intercropping have also diversified farmers' incomes and spread the risk of complete crop failure (Wang et al. 2003), and increased N soil fertility for resource-constrained farmers (Peoples et al. 2009). While the yield, soil health and water conservation benefits of CASI are well established, other effects of CASI (e.g. soil faunal biodiversity) remain poorly understood. SIMLESA tested CASI technologies using improved maize and legume varieties in on-farm and on-station experiments over three to eight seasons. This chapter highlights the agronomic findings from these studies, with particular attention to yield and environmental outcomes.

Assessment of CASI systems

CASI systems that were best suited to two contrasting agroecologies for each country were selected based on local farm power sources, farmer preferences for legume crops and technical feasibility in that environment (Table 6.1; Figure 6.1). Where mechanisation was scarce, planting basins allowed for land preparation to commence during the dry season and alleviated labour bottlenecks at the onset of the cropping season (Nyagumbo et al. 2017). Direct seeding using dibble sticks or jab planters were used as the crop establishment techniques in Malawi, Mozambique, Kenya and Ethiopia. These are common techniques in the region (Thierfelder et al. 2014) but had not been compared with CASI basins. Ox-drawn rippers and direct seeding with the Fitarelli seeder were also used in animal traction–based systems of Manica district in Mozambique.

Table 6.1 **Major agroecologies and a summary of conservation agriculture-based sustainable intensification (CASI) systems tested in each of the five SIMLESA countries**

Country	Agroecology	CASI systems tested
Ethiopia	mid-altitude, subhumid, high-potential	maize–bean intercrops and rotations
		animal traction ripper (minimum tillage), crop residue retention
		improved drought-tolerant maize and legume varieties
	mid-altitude, dryland	maize–haricot beans
		maize–bean intercrops and rotations
		crop residue retention
Kenya	humid to semi-arid	zero tillage
		control of weeds with appropriate herbicides
		crop residues retained on the soil surface after every harvest
		maize–bean intercrops vs sole maize and beans
	high-altitude, humid	zero tillage + *Desmodium*: no-till
		maize intercropped with *Desmodium*
		herbicides weed control and crop residue retention
		crops are maize–bean intercrops
Tanzania	high-potential zone	maize–pigeonpea intercrops
		agronomic efficiency
	low-potential zone	maize–pigeonpea intercrops
		agronomic efficiency
Malawi	mid-altitude	maize–soya rotations
		with or without herbicides
		maize variety compatibility with conservation agriculture
	lowlands	maize–peanut rotations
		maize–pigeonpea intercrops vs sole maize
		crop establishment using conservation agriculture dibble stick vs basins
Mozambique	subhumid	maize–common beans rotations and intercrops
		maize–soybean rotations and intercrops
		animal traction ripping vs direct seeding
		basins vs direct seeding
		animal traction ripping vs direct seeding
	semi-arid	maize–cowpea intercrops vs rotations

Note: CASI = conservation agriculture-based sustainable intensification

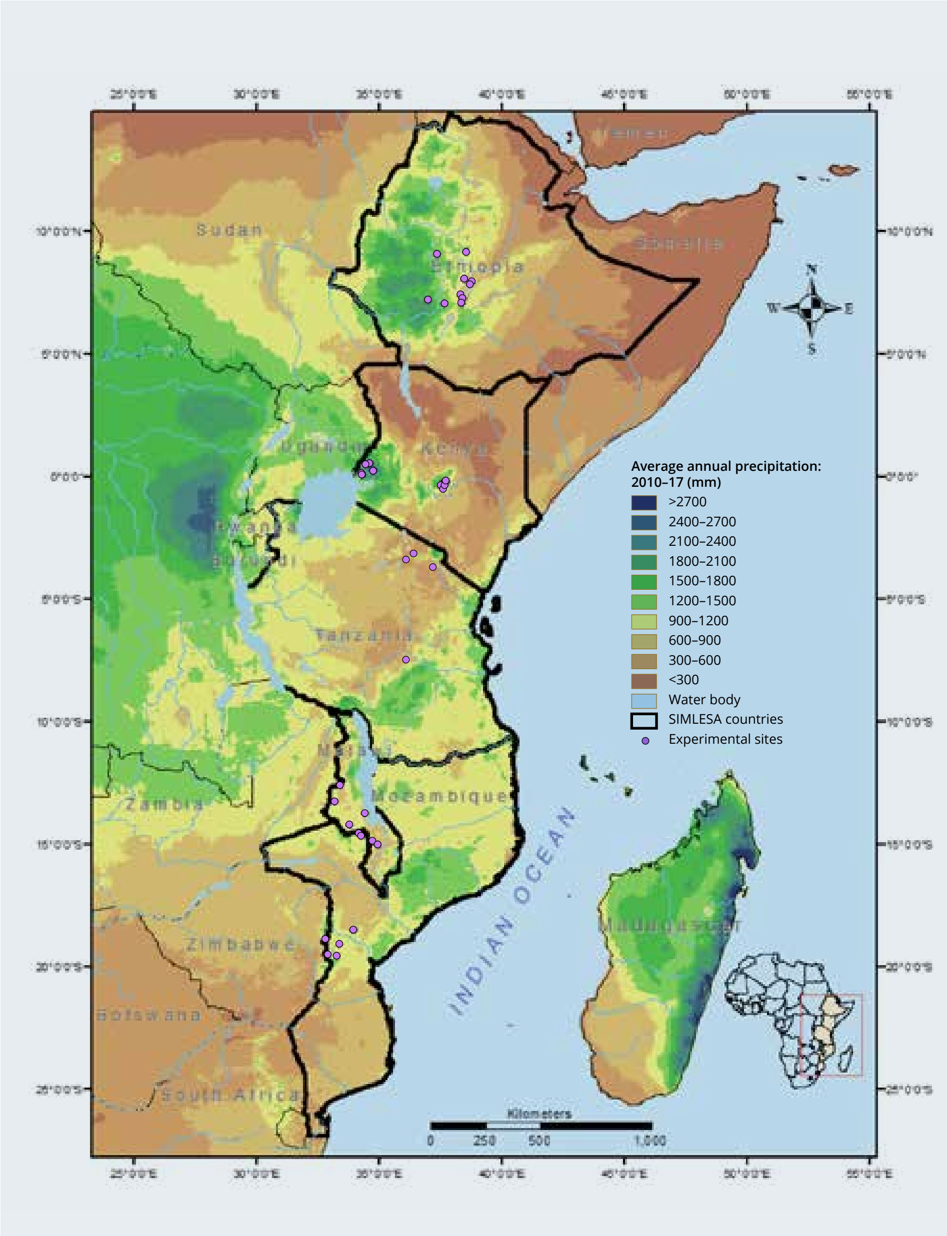

Figure 6.1 Five SIMLESA countries, location of experimental sites and average annual precipitation (2010–17)

Regional comparisons across countries

Soil carbon content

Given the short duration of the long-term trials (three years), significant changes in soil carbon were not expected. Compared to the initial assessments of soil carbon in Malawi in 2013, after three years of CASI, no differences between cropping systems were observed. In Kenya, soil carbon within the top 20 cm of the soil did not indicate differences between cropping systems (Micheni et al. 2015). In Melkassa, Ethiopia, soil carbon under CASI increased slightly (Figure 6.4).

CASI practices had significant effects on soil properties after five or more years. Differences between cropping systems were apparent in Malawi in 2016, after six seasons of CASI implementation (Figures 6.2 and 6.3). These results align well with findings obtained elsewhere (Steward et al. 2018).

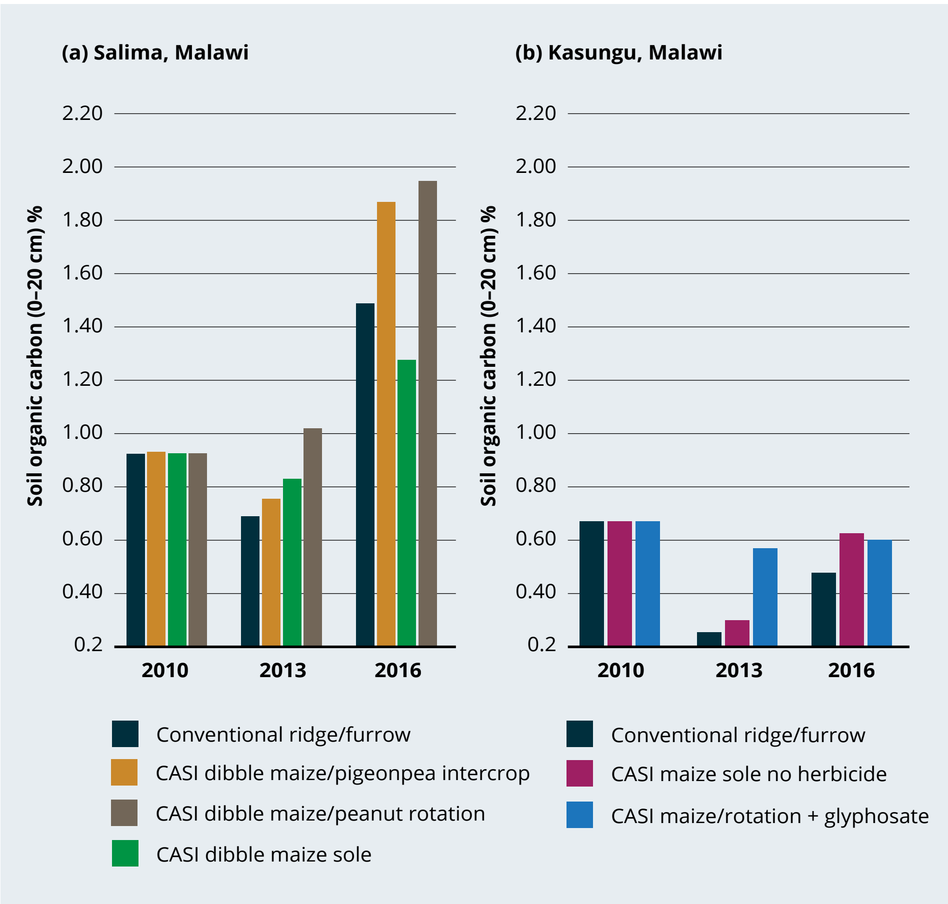

Figure 6.2 **Soil organic carbon under CASI across cropping systems over time in (a) the lowland district of Salima, Malawi and (b) the mid-altitude district of Kasungu, Malawi**

CASI = conservation agriculture-based sustainable intensification

Water

Unlike maize yield benefits, soil moisture content improved across districts, increasing rainfall use efficiency (e.g. Teklewold, Hassie & Shiferaw 2013 in Ethiopia). This is in contrast to conventional ridge/furrow systems that had poor water infiltration and surface ponding resulting in high run-off, soil loss and degradation in Malawi. These results were also confirmed by higher time to pond in CASI systems compared with conventional ridge and furrow systems in 2013 (Figure 6.3).

Soil moisture increases from CASI systems were also observed in Mozambique's Angonia district, where CASI systems had a significant effect on soil moisture in the top 20 cm of the soil. However, in Angonia, the use of CASI basins contributed to excessive waterlogging and led to yield decreases of at least 2.5% over the first four years of SIMLESA (Nyagumbo et al. 2016). CASI practices resulted in less run-off and soil loss from erosion than conventional ploughing practices at Bako Agricultural Research Center, Ethiopia (Table 6.2). These results agree with experiments in Zimbabwe (Nyagumbo 2008; Vogel, Nyagumbo & Olsen 1994).

CASI practices in Ethiopia also improved rainwater infiltration and conserved more soil moisture than conventional practices (Figure 6.4). Rainwater productivity in a maize–bean intercrop under CASI was 10 kg/mm/ha compared to 7.4 kg/mm under conventional practice (Merga & Kim 2014). Overall, CASI systems had higher soil water content than conventional practices. This has been attributed to improved soil properties such as bulk density and organic carbon (Liben et al. 2018). CASI systems, especially residue retention, reduced run-off and soil loss from erosion. Improved soil cover helped control rainfall erosivity, while reduced soil disturbance improved soil aggregate stability and reduced the erodibility of the soil.

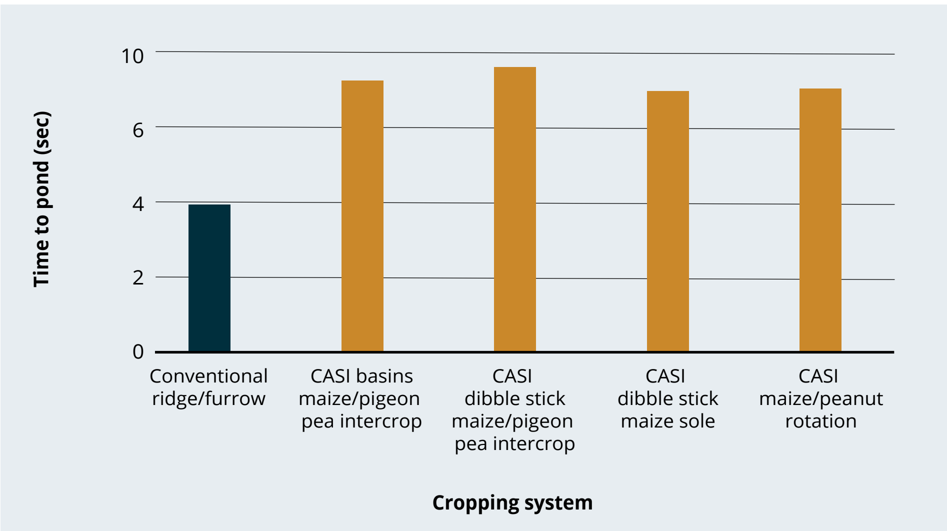

Figure 6.3 **Mean time to pond water infiltration assessments in the lowland communities of Balaka, Ntcheu and Salima (Malawi) in 2013, for conventional agriculture and CASI basins, dibble stick, dibble stick intercropping with cowpea and peanuts**

CASI = conservation agriculture-based sustainable intensification

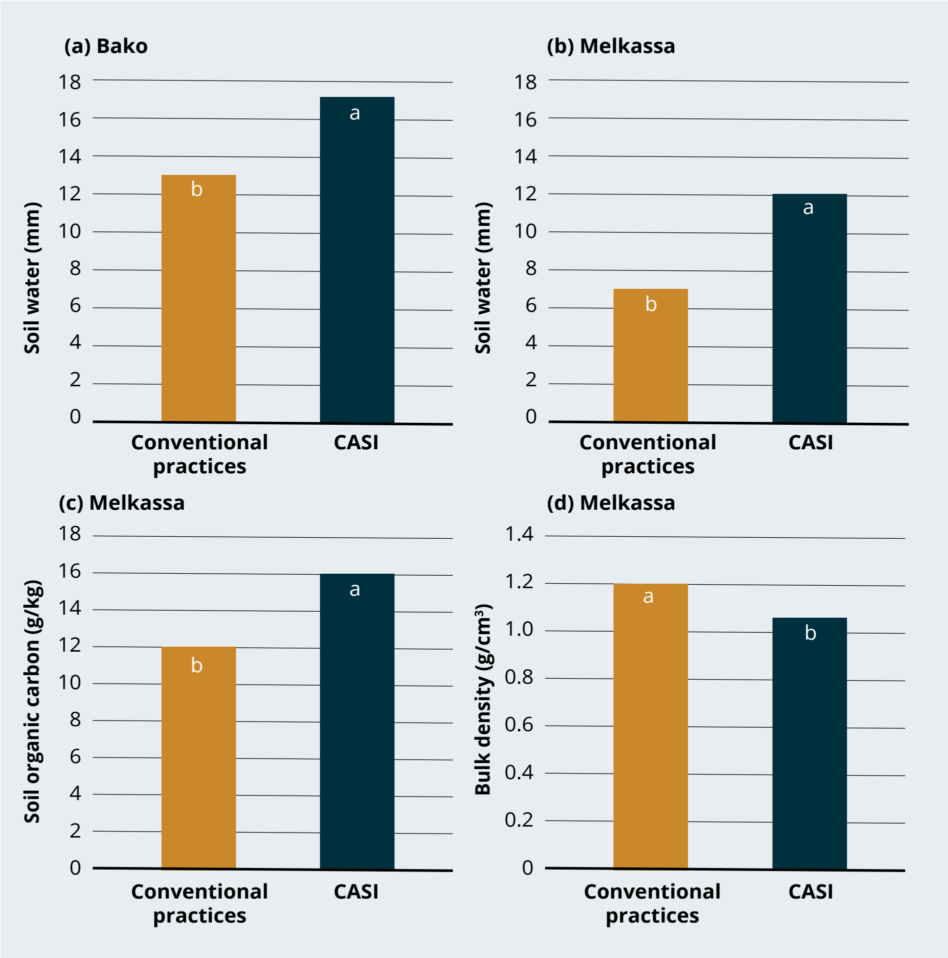

Figure 6.4 **Soil water content, soil organic carbon and soil bulk density with conventional practices and CASI practices at Bako (humid) and Melkassa (semi-arid) in Ethiopia**

Notes: CASI = conservation agriculture-based sustainable intensification. In this graph, a and b indicate that the two bars reflect values that are significantly different; a is significantly larger than b.

Table 6.2 **Effects of CASI systems on soil erosion at Bako Agricultural Research Center**

Practice	Soil loss (t/ha/yr)	Per cent
Sole maize using conventional tillage	5.21	100
Maize–common bean intercropping and farmer practice	3.44	66
Maize–common bean intercropping and conventional tillage	2.71	52
Sole maize, mulch and minimum tillage	1.95	37
Maize–common bean intercropping under CASI	1.8	35

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

Soil biology (fauna and bacteria)

In Kenya, macrofauna and mesofauna richness was not affected by management practices, except for macrofauna in Nyabeda (Table 6.3). Topsoil macrofauna richness was significantly lower for the farmer practice than the other treatments, while residue incorporation in conventional tillage increased macrofauna in the subsoil. On the other hand, the abundance of macrofauna and mesofauna were not affected by treatments at both 0–15 cm and 15–30 cm soil depths, except for mesofauna in Kakamega (Table 6.4). Here, the topsoil mesofauna abundance was higher ($p < 0.05$) in zero tillage compared with conventional and farmer practice treatments. Across management practices, soil fauna richness declined with depth, reaching nearly ≤50% of top soil levels at 15–30 cm. The decrease in faunal richness with depth could be associated with the reductions in organic matter levels (Ayuke et al. 2003; Ayuke, Brussaard et al. 2011; Ayuke, Pulleman et al. 2011; Fonte et al. 2009).

Microbial richness was lowest across almost all microbial species under zero tillage without residue application. Residue removal significantly reduced the diversity of several soil microbial phyla (Table 6.5) involved in atmospheric nitrogen fixation, phosphorus solubilisation and carbon and nitrogen turnover. Richness for most species was highest with residue application under a 13-year trial, zero tillage system. Glomeromycota, the phylum for arbuscular mycorrhizae, was significantly higher under zero tillage than in conventional tillage. Increased microbial diversity under zero tillage with surface residues was previously observed at the same site (Kihara et al. 2012).

Table 6.3 **Macrofauna and mesofauna diversity (richness) across long-term and short-term trials in Nyabeda and Kakamega, Kenya**

	Macrofauna		Mesofauna	
Treatment	**0–15 cm**	**15–30 cm**	**0–15 cm**	**15–30 cm**
Nyabeda				
farmer practice	2^{b}	3.7^{ab}	4.3	3.0
CTMSr + CR	8^{a}	5.3^{a}	5.3	5.7
ZTMSr + CR	7^{a}	2.7^{b}	4.3	2.3
ZTMSi + CR	5^{ab}	2.7^{b}	4.7	3.3
p-value	0.038*	0.050*	0.429	0.125
Kakamega				
farmer practice	5.7	5.0	2.0	2.0
CTMBi + CR	6.7	5.3	3.7	3.7
ZTMBi + CR	11.3	7.0	5.7	2.3
p-value	0.384	0.417	0.058	0.502

Notes: CT = conventional tillage, ZT = zero tillage, MSr = maize–soybean rotation, MSi = maize–soybean intercropping, MBi = maize–bean intercropping, CR = crop residue. The a and b suffixes indicate differences across countries within a treatment where yield values with a b suffix are significantly lower than yield values with an a suffix. Asterisks indicates a significant difference between conservation agriculture-based sustainable intensification practices and conventional yields while n.s. indicates 'no significance'. *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$.

Table 6.4 **Macrofauna and mesofauna abundance across long-term and short-term trials in Nyabeda and Kakamega, Kenya**

Treatment	Macrofauna		Mesofauna	
	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Nyabeda				
farmer practice	107	203	1,814	970
CTMSr + CR	672	133	4,219	3,080
ZTMSi + CR	395	107	4,684	1,224
ZTMSr + CR	496	149	2,954	759
p-value	0.203	0.927	0.321	0.318
Kakamega				
farmer practice	219	171	633[b]	338
CTMBi + CR	336	192	844[b]	1,224
ZTMBi + CR	1,163	272	4,937[a]	1,097
p-value	0.089	0.546	0.030*	0.372

Notes: CT = conventional tillage, ZT = zero tillage, MSr = maize–soybean rotation, MSi = maize–soybean intercropping, MBi = maize–bean intercropping, CR = crop residue. The a and b suffixes indicate differences across countries within a treatment where yield values with a b suffix are significantly lower than yield values with an a suffix. Asterisks indicates a significant difference between conservation agriculture-based sustainable intensification practices and conventional yields while n.s. indicates 'no significance'. *** = $p < 0.01$, ** = $p < 0.05$, * = $p < 0.1$.

Studies on macrofauna abundance in Zimbabwe in both arid and semi-arid conditions also confirmed the findings in Kenya that the application of residues increased macrofauna activity and improved soil health (Mutema et al. 2013; Mutsamba, Mafongoya & Nyagumbo 2016). Under crop residue-covered fields, termites were more abundant, particularly in the sandy soils. Tillage and removal of residues disturbed their habitats and limited their energy sources, while different mulches (maize or grass residues), which contain cellulose and crude protein, attracted them. Increases in termite numbers have a clear effect on increased biological activity. This did not necessarily translate into entirely positive effects (i.e. increased nutrient mobilisation through residue decomposition) as crops (especially cereals) could be attacked by termites, especially towards harvest when residue cover has diminished (Giller et al. 2009). The SIMLESA studies in Mozambique also showed increased termite activity with crop residue retention (Nyagumbo et al. 2015).

Table 6.5 **Effects of treatments on different phyla at the SIMLESA trials (CT1 and KALRO Kakamega) in western Kenya**

Treatments	Microbial richness (Chao 1)	Microbial diversity (Shannon-Wiener)	Cyanobacteria	Actinobacteria
CT + CR (CT1)	1,249	4.4	18.4[a]	228[ab]
RT + CR (CT1)	1,280	4.4	18.6[a]	270[a]
RT – CR (CT1)	877	4.2	3.9[b]	115[b]
CT + CR (KALRO)	1,271	4.6	14.6[ab]	173[ab]
RT + CR (KALRO)	1,222	4.5	14.9[ab]	169[ab]

Notes: CT + CR = Conventional tillage + crop residues; RT + CR = Reduced tillage + crop residues; RT – CR = Reduced tillage without crop residues; CT1 = SIMLESA trials; KALRO = Kenya Agricultural and Livestock Research Organization. The a and b suffixes indicate differences across countries within a treatment where yield values with a b suffix are significantly lower than yield values with an a suffix.

CASI practices had higher potential of promoting ecosystem health and productivity through increasing soil faunal biodiversity than conventional tillage, and should be promoted. The enhancement of faunal abundance under reduced tillage systems can be attributed to the presence of organic residues, reduced soil disturbance and enabling conditions that favour faunal colonisation and establishment (Aislabie, Deslippe & Dymond 2013). Crop residues provided sources of food substrates for microbial species and their removal can deprive microbes of inputs necessary for their growth, development and survival (Aislabie, Deslippe & Dymond 2013). Zero tillage without residue application was less desirable because it tended to reduce soil faunal abundance, and thus undermined the benefits (e.g. soil aggregation, organic matter decomposition, nutrient transformations and cycling) of other conservation agriculture practices.

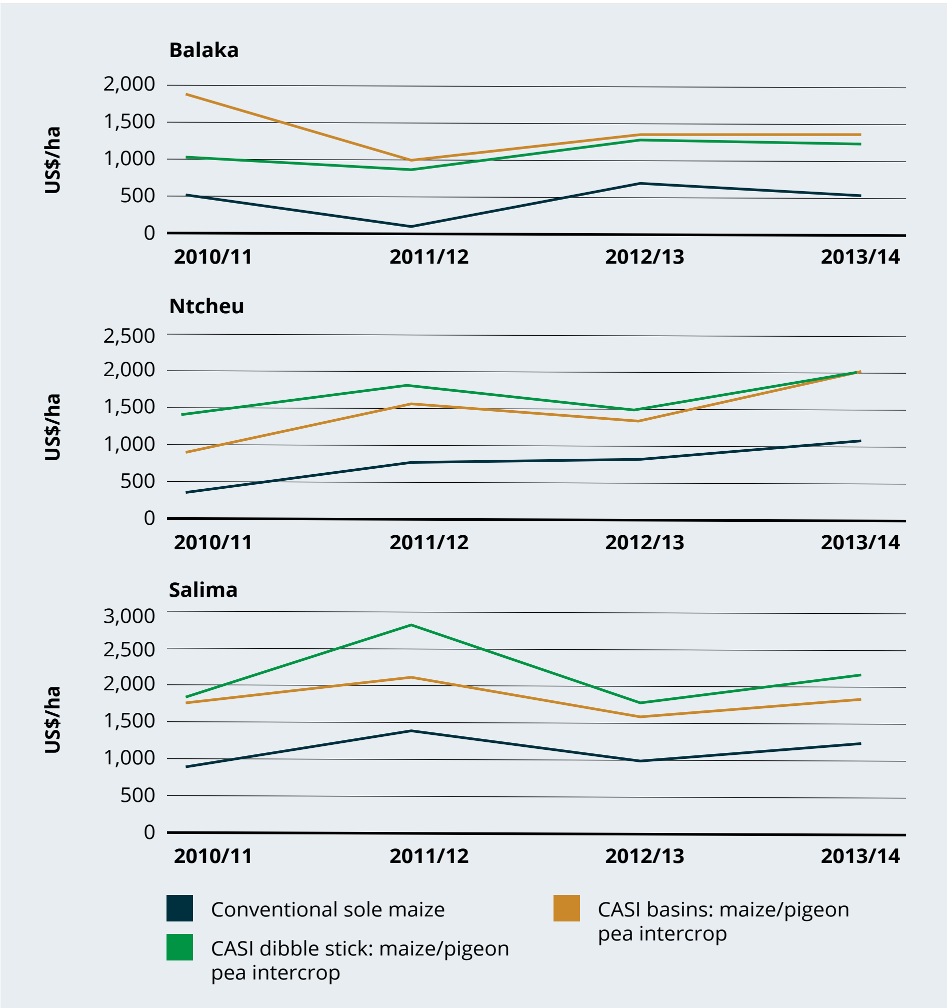

Figure 6.5 **Gross margin analysis of CASI practices in Malawi for conventional sole maize cropping, conservation agriculture in basins and with dibble stick**

CASI = conservation agriculture-based sustainable intensification

Gross margins

Maize–pigeonpea intercropping under CASI and basins under CASI maize sole systems, on average, produced higher gross profit margins over a period of four seasons in Malawi than the conventional sole systems (Figure 6.5). Similar findings emerged from Tanzania and Ethiopia, where higher net benefits were realised from CASI systems than from improved conventional practice. Results from Kenya also suggest that labour savings from the use of herbicides increased profits. There are therefore clear benefits of CASI practices in terms of labour savings, increased maize yield and better economic returns on investment. However, these benefits are generally context-specific as they varied across experimental sites and associated market conditions.

Over the entire period of SIMLESA experimentation, CASI yields were 11% higher than those of conventional cropping systems (Nyagumbo et al. 2018). The highest increase in yield was observed under rotation under CASI, while intercropping under CASI showed a slight decrease in maize grain yield. Yields remained stagnant in the first three years for most countries. At that stage, yields began to progressively increase at rates that depended on the agroecology of the site. Yield depressions from CASI mostly occurred in Ethiopia and Mozambique in agroecologies experiencing excessive waterlogging. Results also suggest that CASI tended to depress yields when rainfall was above normal. Increased yields in seasons with low rainfall have been reported in Zimbabwe (Michler 2015). Yield variability from CASI was reduced by a modest 4% across ESA (Table 6.6).

Table 6.6 Comparison of CASI and conventional maize grain yields across ESA

Countries	CASI		Conventional practices		*t*-probability	Relative difference (%)	Coefficients of variation	
	Maize yield (kg/ha)	Nitrogen (kg/ha)	Maize yield (kg/ha)	Nitrogen (kg/ha)			Conservation agriculture	Conventional practices
Ethiopia	3,568[a]	466	3,590[a]	156	0.903[n.s]	−1	53	57
Kenya	2,762[a]	499	2,397[b]	528	0.004**	15	77	78
Malawi	3,678[a]	678	3,433[a]	227	0.109[n.s]	7	55	55
Mozambique	2,766[a]	1,225	2,494[b]	314	0.007**	11	58	63
Tanzania	1,533[a]	151	1,258[b]	294	0.006**	22	71	76
Overall	**3,032**[a]	**3,019**	**2,474**[b]	**1,519**	**<0.001**	**11**	**63**	**66**

Notes: CASI = conservation agriculture-based sustainable intensification. The a and b suffixes indicate differences across countries within a treatment where yield values with a b suffix are significantly lower than yield values with an a suffix. Asterisks indicates a significant difference between conservation and conventional yields while n.s. indicates 'not significant'.
** = $p < 0.05$.

Beyond CASI: improved agronomy

While the results presented so far indicate benefits from using CASI practices, in this section we use results from Kasungu district, Malawi, to illustrate the contribution of improved agronomy. Improved agronomy in this case comprised improved maize variety, use of recommended fertiliser and better planting configurations. In Figure 6.6, the yield under a range of CASI treatments is compared with the farmer practice treatment (farmers check) in the experiment, and yield measured in the surrounding field (true farm practice). Maize yields from farmer practices were often much lower than those from improved management regimes and improved agronomy. For Kasungu, mean yields computed over six years show that the relative yield increases of CASI practices compared with the farmers' own true farm practice was 71%. Of this increase, 73% was due to improved agronomy and 27% was due to conservation agriculture practices.

Similarly, for Mozambique, more than half the yield gains could be attributed to better agronomy (Nyagumbo et al. 2018), while in Tanzania, CASI (Rusinamhodzi et al. 2017; Sariah et al. 2018) did not do better than conventional tillage with the same level of inputs. This implies that investments in good agronomic practices potentially offer farmers the largest return to investments in the short term, although adoption of CASI practices can give them an extra increase and sustainability in the long run. The use of good agronomic practices by farmers therefore could be the 'lowest hanging fruit' that policymakers can promote to close the maize yield gap in SSA (Van Ittersum et al. 2013).

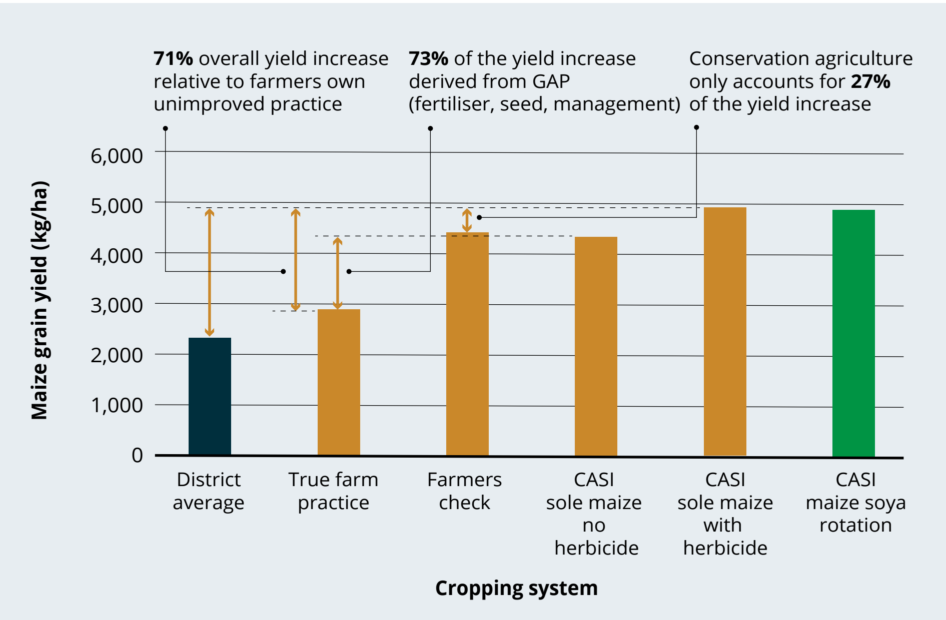

Figure 6.6 **Mean maize yields from Kasungu district, Malawi, over six seasons (2010–11 to 2015–16) relative to local averages and true farmer practices and CASI**

CASI = conservation agriculture-based sustainable intensification

Conclusions

Across the five countries, CASI increased yields by 11% above the conventional practice. Yield responses were influenced by amount of seasonal rainfall and soil-related factors such as drainage and fertility status. High rainfall or high-potential agroecologies benefited less from CASI than low-potential or drier agroecologies, as found in Ethiopia, Mozambique and Malawi (Nyagumbo et al. 2016). CASI systems generally had a modestly lower yield variability (63% compared to 67% with conventional practices), suggesting CASI could contribute marginally to more stable yields and be a climate-smart technology. Results clearly showed that the application of crop residues immediately improved hydraulic properties of the soil with increased water infiltration and rainwater use efficiency and reduced run-off and soil loss (Degefa, Quraishi & Abegaz 2016). CASI technologies could therefore contribute to improved resilience and climate change adaptation when water is limiting for crop production.

Many field trials were established for more than five years, providing an opportunity to assess changes in soil properties over time. Soil organic carbon (0–20 cm) did not change much in the first three years. However, after five years, soil carbon had increased at some sites in Malawi and Ethiopia, but not in Kenya or Tanzania. There were also changes in soil pH and bulk density at some sites. In terms of soil health, the studies clearly show that macrofauna abundance and diversity increased when CASI systems with residue cover applications were employed. This was found in Kenya and Mozambique (Nyagumbo et al. 2015) and previous studies prior to SIMLESA in Zimbabwe. Many factors that affect soil properties can explain variability across sites, such as agroecology, soil type, biomass production or mulching rates and crop management.

Improved agronomic practices, including planting density, planting configurations, inorganic fertiliser, improved varieties and timely weed management, offered farmers the opportunity for the largest yield gain. In Malawi and Mozambique, good agronomic practices accounted for more than 60% of the yield increases over conventional farmer practices. Low plant population densities were a particular challenge in Mozambique. Investments in spreading knowledge of good practice could provide the fastest pay-off in terms of productivity increases on farmers' fields.

Herbicides were a popular technology investment towards weed control under CASI systems due to labour reductions, especially for youth and women (Micheni et al. 2015). Yield was not affected by weeding methods (manual, mechanical-controlled and herbicide-assisted systems) as long as weed control was carried out well and was timely (Nyagumbo et al. 2016). This shows both the value of good agronomy as well as the fact that herbicides are not a prerequisite for successfully implementing CASI.

Many farmers across the SIMLESA countries have embraced crop rotation and intercropping. Crop rotations and intercrops improved soil cover and can restore soil fertility through nitrogen fixation from the legumes. Across ESA, results clearly demonstrate maize yield benefits from rotations under CASI systems, with maize yield increases of up to 50%. In most cases these yield advantages of CASI increased progressively over time and were more apparent after the third cropping season. Rotation benefits, however, tended to depend on the legume crop employed and its capacity to fix nitrogen that would benefit the subsequent maize crop. Peanuts and soybeans were the most effective at increasing subsequent maize yields. Although intercrops reduced maize yields compared with rotations, most land-constrained farmers preferred intercrops due to the dual benefits—food security and profitability—of two crops from the same piece of land (e.g. maize–pigeonpea intercrops in Tanzania and maize–cowpea intercrops in Mozambique).

In some cases, yields were reduced on poorly drained or waterlogged sites due to excessive moisture under CASI, particularly with the CASI basins, for example in Mozambique, and the lowlands of Malawi in the Ntcheu and Salima districts (Nyagumbo et al. 2016). Yet the same CASI basins had beneficial water conservation effects that translated to higher yields in Balaka (Malawi) and the Chimoio and Gorongosa districts of Mozambique, where rainfall was more erratic and soils were well drained (Nyagumbo et al. 2016). This suggests the use of CASI basins should be restricted to well-drained sites with a high probability of erratic rainfall seasons, which is characteristic of semi-arid regions.

Despite some successes, key challenges to the adoption of CASI technologies remain. Aside from the knowledge-intensive nature of CASI, early stage weed control required more labour than farmers had available, and shortages of crop residues for soil cover limited the uptake of CASI technologies (Valbuena et al. 2012). An improved understanding of the interactions between residue application rates, nitrogen, rainfall and soil type is necessary to address the trade-offs that occur when crop residue retention limits availability of livestock feed. The competition for crop residues for soil cover and livestock feed requires new system-level innovations. Identifying alternative sources of soil cover and livestock feed in crop–livestock environments can be a first step.

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7 Knowledge generation and communication for climate-informed management practice

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Key points

- Proactive, climate-informed sustainable intensification practices can add value to farming systems.
- Adoption and benefits of sustainable intensification practices in eastern and southern Africa rely on our capacity to identify optimum management practices under variable climates.
- Climate data can be interfaced with dynamic crop models to identify management practices likely to provide the greatest benefit under prevailing and expected conditions.
- Persistent gaps in knowledge and practice can be strengthened in the following areas:
  - climate data: install, maintain and monitor more reliable and evenly distributed observation networks to validate satellite data and train prediction models
  - climate forecasts: establish skilful prediction products for targeted farming systems to increase the resolution of predictions for diverse production regions
  - decision-support tools: refine dynamic whole-farm models with farming system data of target production systems to provide more relevant, production-level outcomes
  - information transfer: design communication strategies and simple decision-support tools that have been tested by end users to minimise interpretive uncertainty.

Introduction

Farmers usually base their management decisions on uncertain knowledge surrounding future production conditions. Research and development efforts have worked to minimise this uncertainty, increasing opportunities for proactive climate-informed management practice. This chapter reviews research and development efforts for climate-informed management practice in eastern and southern Africa (ESA).

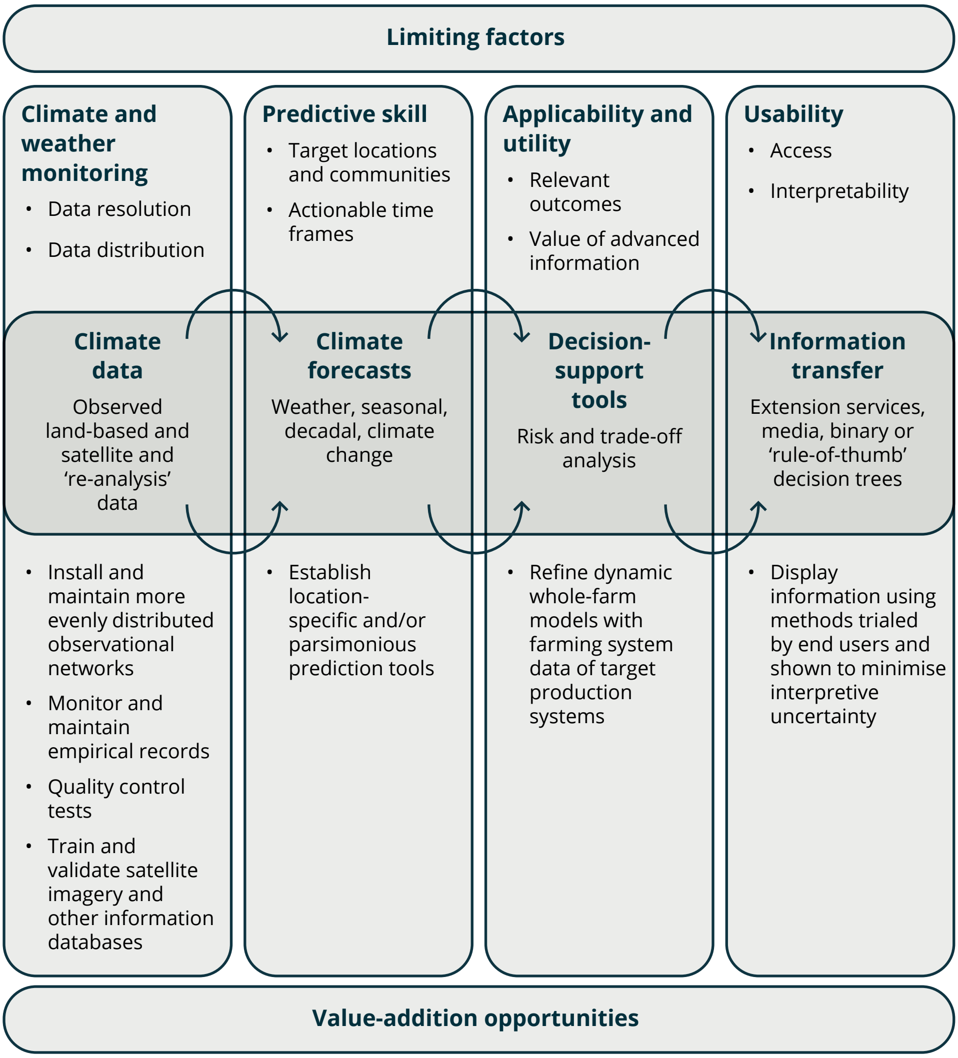

Figure 7.1 **Research and development pipeline for climate-informed decision-making in agriculture**

Figure 7.1 shows limiting factors and opportunities for value addition along a four-stage process that supports adoption of climate-informed management practice. The main research areas along the pipeline are:

1. climate data
2. climate forecasts
3. decision-support tools
4. information transfer.

The pipeline is linear, to reflect the dependence of each step on the preceding steps. The limiting factors at each stage compound along this pipeline to produce climate information with high, irreducible uncertainty. Each stage has research and development opportunities to enhance the value of proactive, climate-informed on-farm management.

Capacity for climate-informed management in ESA has recently improved with the development of complex analytical tools that collect and interpret global land, ocean and atmospheric data. Dynamic whole-farm models that integrate biophysical and socioeconomic processes have also assisted efforts to evaluate benefits and trade-offs of management decisions under prevailing and anticipated climate scenarios. Research on sources of 'interpretive uncertainty' and the needs and interest of end users has also assisted efforts to leverage research activities and products for actionable recommendations and adoption of climate-informed management practice.

Various aspects of the most recent state of research and development for climate-informed management have presented important challenges in skilfully predicting future climate conditions and communicating climate information to decision-makers. These challenges include unreliable and scarce climate and weather monitoring tools, the low predictive skill of climate forecasts, the mismatch between information provided by forecasts and the outcomes of interest to end users. Innovations at multiple stages of a research and development pipeline have potential to add value to farming systems under variable climates. These stages include climate data collection, climate forecast and decision-support tool development, and information transfer.

Climate data

Climate data (both observed and simulated) has been fundamental in predicting future production conditions and identifying climate-informed management options. Patterns in atmosphere, ocean, land and cryosphere data have revealed processes and dynamics underlying climate variability that have been used to develop prediction tools (Singh et al. 2017). Data used to develop forecast algorithms and prediction models for ESA include the Southern Oscillation Index, the Tropical Atlantic 200 hPa winds and convection near the equatorial African coast (Jury & Pathack 1993; Mason & Jury 1997; Walker 1990). Equatorial Indian Ocean wind direction (Greischar & Hastenrath 1997) and sea surface temperature (SST) data for the south-west Atlantic Ocean (Jury & Pathack 1993; Mason & Jury 1997) have been especially strong and valuable predictors of rainfall patterns in ESA.

Data from instrumental land-based tools and remote sensing satellites have provided the empirical measures to generate prediction algorithms and 'reanalysis', reference datasets that have served as common yardsticks for refining prediction tools and evaluating forecast skill (Batté & Déqué 2011; Lynch 2007). Reference datasets have included the Comprehensive Ocean-Atmosphere Data Set (now International COADS or ICOADS) (Freeman et al. 2017; Slutz et al. 1985), the Global Sea-Ice and Sea Surface Temperature dataset (now the Hadley Centre Sea-Ice and Sea Surface Temperature or HadISST) (Rayner et al. 2003) and the National Oceanic and Atmospheric Administration Climate Prediction Center data (Xie, Chen & Shi 2010). Other 'reanalysis' datasets have included products of the Global Precipitation Climatology Project, Climate Prediction Center Merged Analysis of Precipitation, and National Oceanic and Atmospheric Administration Precipitation Reconstruction over Land (Chen et al. 2002). The Global Precipitation Climatology Centre under the World Meteorological Organization produced a global simulated monthly precipitation dataset dating back to 1901, based on gridded rain-gauge data from up to 45,000 land stations around the world (Batté & Déqué 2011; Schneider et al. 2008). The particularly extensive scope and quality of the Global Precipitation Climatology Centre data provided the information used to develop atmosphere–ocean general circulation models and algorithms that have been applied for seasonal and decadal forecasts in ESA (Jury 1996).

Advances in satellite-based technologies allowed direct rainfall measurements to support algorithms and refine forecasting tools for ESA. Notable advances in satellite technologies began with efforts to support seasonal forecasting schemes in the 1990s. The Advanced Microwave Sounding Unit and Special Sensor Microwave Imager satellites developed out of these efforts and provided precipitation estimates up to four times per day and Global Precipitation Index cloud-top infra-red temperature and precipitation estimates on a half-hourly basis (Jury 1996). By 1996, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) and the African Centre for Meteorological Applications for Development (ACMAD) established an agenda for the use of the Meteosat satellite data. Ongoing development of the Meteosat Second Generation (MSG–1, renamed Meteosat-8) of satellites was a major catalyst for the Preparation for the Use of MSG in Africa (PUMA) project (World Meteorological Organization 2003). Implemented in 2003 and declared operational in 2004 by the European Commission and EUMETSAT, PUMA provided the national meteorological and hydrological services of 53 African countries with MSG receiving stations, training and support required for receiving the latest spaced-based meteorological and environmental data and images and products from EUMETSAT via the EUMETCast broadcast system (EUMETSAT 2020). In addition, ACMAD was responsible for providing technical assistance for the validation of the PUMA receiving stations. In 2010, Météo-France, in cooperation with EUMETSAT, gradually updated the RETIM2000 stations that entered service in 2002 (Meteosat-1 to -7) with the Meteosat-8 satellites (EUMETSAT 2010). The continued investment allowed EUMETCast to continue disseminating Reseau de Transmission d'Information Météorologique (RETIM) data on a fully operational basis through the transition. The African Monitoring of the Environment for Sustainable Development (AMESD), launched in 2007 with support from the European Commission, installed over 100 receiving stations across 48 countries in Africa. Under AMESD, Regional Implementation Centers developed products and services based on Earth observation data, which were disseminated through regional networks. The Global Monitoring for Environment and Security (GMES) initiative was also launched in 2007. Building on the results obtained in PUMA and AMESD to maintain satellite data processing, ocean and Earth observation data usage and interpretation, the Monitoring of Environment and Security in Africa program, launched in 2014, was the first contribution to the Global Monitoring for Environment and Security (GMES) Africa initiative of the EU and European Space Agency-Africa Joint Strategy.

Climate prediction algorithms have improved with the growing body of climatological data. Algorithms that have been applied for forecasts in ESA include the Tropical Rainfall Measuring Mission Microsatellite Precipitation Analysis 3B42, version 6 (3B42v6) under the Tropical Rainfall Measuring Mission (Huffman et al. 2010); the Merged Analysis of Precipitation, known as the Climate Prediction Center morphing technique (Xie & Arkin 1997); and the Climate Prediction Center [African] Rainfall Estimator (RFE) (Herman et al. 1997) developed by the Global Precipitation Climatology Centre (Huffman et al. 1997). The African Rainfall Estimation Algorithm Version 1 (RFE 1.0) provided a unique product relative to other satellite-based rainfall estimators because of its high 0.1-gridded spatial resolution and its combined use of gauge and satellite information. In 2001, the Climate Prediction Center implemented the African Rainfall Estimation Algorithm Version 2 (RFE 2.0), which showed reduced bias and improved estimation accuracy and computational efficiency relative to Version 1. In 2012, the National Oceanic and Atmospheric Administration Climate Prediction Center brought RFE 2.0 to operational status. The newly improved and released RFE 2.0 algorithm served as the main source of rainfall estimates for the United States Agency for International Development/Famine Early Warning Systems Network operations, providing datasets of 10-day, monthly, and seasonal rainfall totals (Novella & Thiaw 2012). However, the brevity of the dataset record (2001–present) did not allow for meaningful analysis of rainfall anomalies (Novella & Thiaw 2012). To address biases and other shortfalls of RFE 2.0, the African Rainfall Climatology (ARC) was developed. The second and improved iteration of this algorithm, ARC2, was developed through the acquisition, recalibration and incorporation of all Meteosat First Generation infra-red data (1983–2005) and daily summary gauge data (Love et al. 2004). ARC2 generated more stable output than ARC and, most notably, had the capacity to monitor and predict extreme events, wet and dry spells, the number of rain days and the onset of rainfall seasons, in addition to precipitation patterns associated with synoptic and mesoscale disturbances (Novella & Thiaw 2012).

Efforts to understand climatological phenomenon over longer time frames (e.g. climate change) prompted the development of a common experimental framework for data consolidation and sharing, specifically towards integrating general circulation models (GCMs) with sea surface temperature (SST) data (Hastenrath, Nicklis & Greischar 1993; Overpeck, Meehl et al. 2011; Singh, Daron et al. 2017; Washington and Downing 1999). The Coupled Model Intercomparison Projects (CMIP, CMIP2 and CMIP2+), led by the World Climate Research Program, were instrumental in incorporating GCMs into prediction tools to simulate 20th and 21st century climates (Overpeck, Meehl et al. 2011). Bringing together 16 international modelling groups from 11 countries and 23 models, the CMIPs archived 36 terabytes of model data providing open-access climate-model outputs. In 2003, the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) applied the CMIP multimodel datasets to run early climate change scenario experiments and the results were made public as open-source data (Meehl, Covey et al. 2007).

Despite these developments, scholars have noted major information gaps and the need for capacity building to support ongoing data collection. Most critically, real-time weather data from rain-gauge stations have been unavailable for large areas of the continent, as these areas have gone unmonitored. Although satellite-based datasets have provided spatially complete coverage and have been particularly useful in rainfall monitoring, ground-based data have been necessary for calibrating and validating satellite imagery and training forecasting models. By 2001, approximately 1,000 daily Global Telecommunications Stations spanned the entire African continent to collect rain-gauge data. However, less than 500 stations typically provided data for any given day, due to issues related to station maintenance and erroneous data (Climate Predication Center 2014). By 2003, climate monitoring and evaluation resources had declined and the national meteorological services in ESA had the lowest reporting rate of any region of the world (Washington et al. 2006). The network of 1,152 World Meteorological Organization and World Weather Watch stations in Africa in 2003 were distributed at an average density of one station per 26,000 km^2 (Washington et al. 2004). By 2004, when 7,500 gauges existed globally, the African continent contained roughly 1,300 stations, of which 800–1,200 reported each day (Love et al. 2004). This made the density of rain gauges that provided easily accessible, daily, near real-time observations for Africa approximately 1 per 23,300 km^2—eight times lower than the minimum recommended level set by the World Meteorological Organization (Washington et al. 2006). Reports from 2014 show increased coverage for countries like Ethiopia (Dinku et al. 2014). Although coverage in Ethiopia was high relative to other countries in ESA, it was still below World Meteorological Organization standards.

The uneven distribution of stations has limited analytical capacity to capture microscale processes across the diverse terrain of ESA and maintain skill in certain regions (Washington et al. 2004). The MarkSim stochastic weather-generating platform provided a tool to fill this knowledge gap. MarkSim contains a calibration dataset of about 10,000 stations worldwide, most of which have 15–20 years of historical daily data. Widely supported and used by the CGIAR Research Program on Climate Change, Agriculture and Food Security, the online tool generates simulated daily weather rainfall data and has supported the development of climate-forecast models. This analytical package was able to provide a first approximation of climatological data (Jones & Thornton 2000). However, ground-based data have increased confidence in MarkSim output and, as a simplified model, MarkSim produces inevitable errors that land-based stations could rectify.

Climate forecasts

Climate forecasts broadly refer to predictions of climatological phenomenon, which can be deterministic or probabilistic in nature, depending on the type of climate forecast. Predictions of certain climatological phenomena in ESA have shown persistent biases including unrealistic rain day frequency and rainfall intensity (Haensler, Haegemann & Daniela 2011; Tadross, Jack & Hewitson 2005) and early onset of the rainy season (Nikulin et al. 2012). These biases reflect reduced skill under certain prediction settings. Forecast skill, or the accuracy of a prediction to an observation or reference forecast, theoretically enhances the capacity of decision-support tools to identify optimal management practices for the future, affording greater utility to end users (Figure 7.1). Climate-forecast skill for the temporal and spatial scales that end users use to make management decisions has been a priority for developing actionable management recommendations.

Timeliness of forecast products

Adoption of a new management practice can require preparation time, investments and a period of learning. The timeliness of a forecast can impact the feasibility of uptake and application of climate-informed management practices. Farmers' decision-making cycles can determine the minimum time required for producers to adjust their practices (Lobo, Chattopadhyay & Rao 2017). The forecast skill horizon, or the lead time when forecasts cease to be more skilful than the climatological distribution, has depended on the type of information that is conveyed and the location and scale of the prediction.

Weather, seasonal forecasts and decadal projections have had different skill horizons that reflect differences in the type of climatological phenomenon reported and the research capacity behind these efforts. Weather forecasts in ESA have been able to provide deterministic predictions of specific weather events with a skill horizon of up to five days (Hansen et al. 2011; Washington & Downing 1999). With this relatively short skill horizon, most weather services in ESA have not been issued beyond a 24-hour lead time, providing little time for adaptive management.

With greater lead times than weather forecasts, seasonal forecasts for ESA have allowed months between the issuance of a probabilistic forecast and the occurrence of the phenomena. Hansen et al. (2009) developed seasonal forecast outputs that could be made routinely available by early September. This was believed to provide sufficient lead time for farmers and local agricultural input suppliers to respond prior to planting. Southern African Regional Climate Outlook Forum forecasts have typically been released in August or September and extended to the following March, with potential for monthly updates or correction following mid-season meetings in December. Similarly, the International Research Institute for Climate and Society (IRI) has increased the skill of seasonal forecasts with regular updates, beginning months prior to the occurrence of the predicted phenomena.

Anomaly-focused products that predict phenomena like El Niño and La Niña have had especially long skill horizons (Singh et al. 2017). Seasonal forecasts in eastern Africa, especially Kenya, eastern Uganda and northern Tanzania, have also tended to have greater skill horizons for the characteristically more volatile 'short rains' than the 'long rains' (Mason 2008). GCMs have produced skilful seasonal forecasts with lead times of more than a month before the conventional start of October–December 'short rains' in eastern Africa and the boreal spring 'long rains' in southern Africa (Ndiaye, Ward & Thiaw 2011). Sea surface temperature, represented as the large-scale fluctuation in the regional circulation system over the tropical Atlantic[1], contributed substantially to the skill horizon of 'short rain' forecasts for eastern Africa (Greischar & Hastenrath 1997). Seasonal predictions for regions with unique cropping seasons have been issued with arguably enough lead time for adaptive management. Since 1987, the national meteorological service of Ethiopia started to issue seasonal forecasts targeting seasons that did not coincide with the crop calendar established by the Greater Horn of Africa Climate Outlook Forum but were more relevant to the crop cycle in Ethiopia. Uganda also independently produced forecasts that fell outside the forum's calendar but were more synchronised with crop cycles in the northern part of the country (Hansen et al. 2011).

1 The leading empirical orthogonal function, or EOF1 analysis, is performed on monthly sea surface temperature data, which have been spatially coherent and shown widespread correlations with 'short rain' season events.

With skill horizons in the 10-year time frame, decadal projections filled a longstanding gap in predicting climatological phenomenon beyond the time frame when traditional seasonal forecast skill tended to diminish and before the point when the climate change signal has been difficult to detect against natural variability (Meehl, Goddard et al. 2014). The skill horizon of decadal projections has, however, been limited by a sensitivity to factors like the initial state of the model, especially, within the first five years (e.g. CMIP5) and external forcing beyond 10 years (Taylor, Stouffer & Meehl 2012). Addressing these limiting factors can help ensure that decadal projections can inform strategic transformation decisions so end users can more effectively address longer-term processes with consequences for food security and soil quality outcomes.

Spatial resolution of forecast products

The majority of seasonal forecasts that are skilful at the aggregate scale have lost skill when downscaled to the spatial scales that concern most producers in their decision-making (Gong, Barnston & Ward 2003). Small-scale climatic processes have been prominent across ESA, given the diverse and extremely contrasting terrain of the region, the existence of large inland lakes and the proximity of the Indian Ocean (Singh et al. 2017; Sun et al. 1999a). These features have contributed to the complexity of climate patterns over ESA and the need to capture mesoscale nonlinear effects for prediction accuracy across locations. With limited skill at finer scales, seasonal forecasts have typically displayed the probability of rainfall levels as very coarse-scale maps (Hansen et al. 2011). Encouragingly, research in Kenya demonstrated that seasonal rainfall forecasts could be downscaled to the local scale for farm management (Hansen & Indeje 2004; Hansen et al. 2009).

Statistical downscaling techniques, where higher resolution regional climate models are driven by the output of relatively low-resolution GCMs, have been able to derive regional- to local-scale forecasts for ESA (Kalognomou, Lennard et al. 2013). Multiple regional climate models (e.g. ARPEGE5.1, HIRHAM5, RegCM3, CCLM4.8, RACM02.2b, MPI-REMO, RCA3.5, PRECIS, WRF3.1.1, CRCM5) have increased the resolution of general circulation model forecasts of basic and higher-order weather statistics (e.g. wet and dry spell distributions (Sun et al. 1999a) and interannual variability (Sun et al. 1999b)). For example, the Intergovernmental Authority on Development Climate Prediction and Application Center and the South Africa Weather Service have used regional climate models to downscale IRI global forecasts over the Greater Horn of Africa since 2004 and southern Africa since 2006. These methods produced skilful rainfall phenomena predictions (e.g. realistic extreme events, short rain, wet and dry spells, the number of rain days and the onset of the rainfall seasons) that could not be captured by coarser climate datasets for many locations across ESA. The ARC2 model has predicted rainfall at a spatial resolution of 0.1° (~10 km). The local-scale resolution of the ARC2 model was arguably instrumental to the USAID/Famine Early Warning Systems Network program, allowing for studies on the impact of rainfall on agriculture and water resource management outcomes (Novella & Thiaw 2012). Global Precipitation Climatology Project, Climate Prediction Center Merged Analysis of Precipitation and National Oceanic and Atmospheric Administration Precipitation Reconstruction over Land products further outperformed ARC2 based on agreement with independent gauge data (Novella & Thiaw 2012). However, forecasts in ESA have been coarser than other regions of the world. Downscaling in ESA has been limited by the sparse and patchy quality of long-term observational data at point and regional scales. Historically necessary to calibrate and validate satellite-based observations, land-based data have been critical for fine-scale forecasts.

Spatial breadth of forecast products

The skill level of projection products has varied across ESA. The Coordinated Regional Downscaling Experiment (CORDEX) regional climate models have shown systematic biases for different regions in Africa (Kim et al. 2014). All CORDEX models performed better for western Africa and the tropics than eastern Africa and the northern Sahara in predicting interannual rainfall. CORDEX models also had greater skill for the western Sahel than for the Ethiopian highlands in simulating variation in the wet season. Predicting rainfall in Ethiopia has been a persistent challenge. For instance, the skill of the ARC2 prediction algorithm for predicting rainfall was especially low in Ethiopia. Although ARC2 showed some sensitivity to complex topography and supported fine resolution predictions, the correlation between ARC2 predictions and daily gauge data observed in Ethiopia from 2003 to 2007 was especially low (Novella & Thiaw 2012). Improving predictions for regions like Ethiopia, where the skill of prediction tools has tended to be lowest, requires a better understanding of the processes that drive the unique climatological patterns observed in those locations.

Decision-support tools

Research and development of climate-informed decision-support tools have focused on enhancing the applicability and utility of management recommendations. Here, applicability refers to the how closely aligned the outcomes of climate analyses are to the information that end users directly apply to decision-making. The utility of decision-support tools has been evaluated based on a standard economic definition of the value of advance information: the expected improvement in outcome (Hansen et al. 2009).

Applicability

Dynamic whole-farm models have played a major role in translating climate information to outcomes that more directly inform decision-making. Used to compare outcomes under various climate and management scenarios, they have skilfully estimated benefits, trade-offs and risks of management strategies that a producer might adopt in preparation for expected climate conditions (Hansen & Indeje 2004). The first step in developing dynamic whole-farm models has typically been linking crop models with climate-forecast products to create dynamic crop models. Multiple approaches have been used to link crop models with climate forecasts, including classification and selection of historic analogues, stochastic disaggregation, direct statistical prediction, probability-weighted historic analogues and the use of climate-model output data (Hansen & Indeje 2004). The Agricultural Production Systems sIMulator (APSIM), a dynamic crop model that has been applied for a wide range of crops in ESA, incorporates a climate model, soil and crop models, each of which are configured by specifying input parameter values (Holzworth et al. 2014; Holzworth et al. 2015). Dynamic crop models like APSIM have then been linked to livestock and socioeconomic models for analyses that reveal dynamics underlying farming-system level outcomes (e.g. trade-offs) (Rodriguez et al. 2017).

Dynamic whole-farm models have mainly been utilised to inform on-farm management practice. Although most dynamic whole-farm models were initially developed for locations outside of Africa, they have been adapted and performed with high skill in ESA. These models have identified optimal management practices for expected climate conditions with the highest skill level (based on the Brier skill score) under production that is most sensitive to in-crop rainfall (Rodriguez et al. 2018). This skill has made dynamic whole-farm models well-suited for application in ESA, where the majority of production systems are rainfed and highly susceptible and sensitive to rainfall. For instance, Castelán-Ortega et al. (2003) first linked two biological models, one socioeconomic model and a survey database to create a decision-support system, known as the CERES-Maize model, for maize and cattle production in Central Mexico. The CERES-Maize model identified the optimum allocation of resources for maximising farm income. Hansen and Indeje (2004) were then able to apply the CERES-Maize model to simulate field-scale maize yields in two semi-arid locations in southern Kenya under rainfall conditions derived from the general circulation model, ECHAM. ECHAM is an atmospheric general circulation model, developed at the Max Planck Institute for Meteorology to support its contribution to the fifth and sixth phase of the coupled model intercomparison project (CMIP).

Three specific models have most typically been linked to evaluate mixed crop–livestock farming systems in ESA:

- a farming systems model (APSFarm) (Rodriguez & Sadras 2011), which is an extended configuration of the dynamic APSIM crop model
- the livestock production model (LivSim) (Rufino et al. 2009)
- the Integrated Assessment Tool household model (Rigolot et al. 2017).

The inputs for the LivSim model are principally livestock herd structure and management practices. The Integrated Assessment Tool model uses both APSIM and LivSim outputs with costs and sales information to calculate outcomes like farm income and food security.

Climate prediction models have been applied to decision-making at broader, landscape and regional levels. In a comprehensive review, van Wijk et al. (2014) evaluated the predictive ability of 126 farm household models to describe short-term (3–10 years) food security of smallholder households under climate variability and various climate scenarios. The evaluation found that modelling tools reached a sufficient level of detail to analyse the combined effects of climate on food production and economic performance (van Wijk et al. 2014). These have allowed researchers and practitioners to consider land-use change options and plan for major losses from climate-related events like floods, climate-induced poverty and agri-market volatility, among others (Hertel, Burke & Lobell 2010).

Utility

Bio-economic and dynamic whole-farm modelling studies have shown that climate forecasts and climate-informed management generally tend to benefit farming systems, increasing upside risks and providing modest and sometimes substantial increases in expected farm profits (Meza, Hansen & Osgood 2008). The benefits of climate-informed management have varied across ESA (Hansen et al. 2009). A simple illustration using a cost-loss model showed that the potential economic value of the ENSEMBLE multimodel, which is based on seasonal-to-annual predictions from the five best-performing European global coupled climate models, can reach over 10%, depending on the region of ESA (Batté & Déqué 2011). A comparison between historical yields and 2003–04 yields of farmers in Zimbabwe found that changes in production practices based on forecast information increased yields by 19% (Patt, Suarez & Gwata 2005). Hansen et al. (2009) estimated that perfect foreknowledge of daily weather, when combined with adaptive risk management, had major benefits for maize producers in two semi-arid locations in southern Kenya, worth 15–30% of the average gross value of production and 24–69% of average gross margin. Other studies have, however, found that downside risks can still be significant with climate-informed decision-making. For instance, Hansen et al. (2009) estimated downside risk of forecast-based management strategies at 25% in Katumani and 34% in Makindu, Kenya.

The benefits of climate-forecast information have also been evaluated at the community level. Osgood et al. (2008) estimated potential benefits of a climate-based crop insurance scheme in Malawi. The insurance scheme combined climatic, management and financial models to adjust the amount of high-yield agriculture inputs given to farmers based on the favourability of predicted rainfall conditions. The approach substantially increased production in La Niña years (when droughts were unlikely), reduced losses in El Niño years (when drought and insufficient rainfall would often damage crops) and doubled cumulative gross revenues from existing schemes (Osgood et al. 2008). This study demonstrates that climate information can be used to inform both on-farm management and risk-sharing financial instruments to increase production and minimise risk for farmers.

Information transfer

Efforts to communicate skilful, applicable and valuable climate information to end users have had limited impact across ESA. For instance, adoption of climate information and climate-informed management practice by producers from Tanzania and Zimbabwe was low in 2017 (Nyamwanza et al. 2017). Local knowledge was considered the most reliable source of information by far, especially at the seasonal timescale, because producers claimed it was more specific and easier to incorporate local knowledge indicators into their planning and decision-making processes than the climate-forecast products released through the media (Nyamwanza et al. 2017). The producers indicated that they prioritised local knowledge over output from the extensive research efforts because local knowledge was more consistent with the conceptual and language systems of household production. Two common criteria for assessing information transfer are the reach (or access for target users) and the accuracy of interpretations by the population with access to climate information.

Reaching out

The national meteorological services, often in partnership with regional agricultural extension, agribusiness and local translators, have disseminated information via a broad array of media (radio, television and newspaper), paper and electronic bulletins, websites and workshops for farmers and other end users. The reach and impact of these various communication strategies have varied greatly by region and country, although radio and internet services have consistently been recognised as the major means of delivering climate information to rural farmers across ESA.

In extreme cases, like the 1997–98 El Niño event (Ziervogel & Downing 2004), journalists organised around regional climate outlook forums in ESA with the goal of improving media coverage of climate-related information and usability. In 1997, the African Centre of Meteorological Application for Development (ACMAD) developed the Radio and Internet for the Communication of Hydro-Meteorological and Climate Related Information (RANET) as an international, collaborative project designed to deliver weather and climate information via a satellite-simulated internet. Since its inception, RANET has worked to improve limitations of disseminating climate-related information via radio. By combining low-cost, community-owned radio stations and wind-up radio receivers, they provided digital audio broadcasting technology and disseminated climate information to remote communities in ESA (World Meteorological Organization 2003). The digital radio technology provided the capacity to send radio and one-way internet anywhere within Africa to users with a low-cost WorldSpace receiver, adapter card and Windows-based computer. In addition to the national meteorological services, the Network of Climate Journalists of the Greater Horn of Africa was established in 2002 (Hansen, Mason et al. 2011). The network developed a regional resource centre for eastern Africa that has supported media-based communication activities.

Interpretability

Efforts to enhance the interpretability of climate information for end users have focused on bolstering and making use of decision-making theory. Publishing trends suggest that research focused on decision-making theory, and interpretation of climate data more specifically, has gained traction over time. In a recent literature review, van Wijk et al. (2014) found substantial increases from 1980 to 2010 in the number of publications that related farm household-level models to climate variability. Among these, publications that presented new models increased at a slower rate than those concerned with the application of existing models. This research trend may reflect an increased effort towards understanding factors that determine and can improve adoption. These efforts to understand the challenges of interpreting and applying climate data helped refine communication methods and reduce 'interpretive uncertainty' of climate data (i.e. differences in how end users understand. A survey targeting the user community of the Climate Information Platform found that interpretive uncertainly was higher for information displayed as percentiles than information displayed as ranges (Daron, Lorenz et al. 2015). Case studies with large-scale commercial farmers in Malawi found that climate information lacked detail and did not include the type of precipitation data that the producers used in decision-making (Nyamwanza et al. 2017). They noted, for example, that the rainfall forecasts they had access to, which reported rainfall as either 'above average, below average or average rain', were too vague for decision-making.

Communication strategies changed in response to evidence from studies that identified sources of interpretive uncertainty and user confidence. One example of a simplification in communicating complex climate data was to communicate drought predictions as binary outcomes (i.e. drought/no drought). The use of binary outcomes for reporting drought led to other simplifications. One project based in Zimbabwe was able to build on this binary reporting method to provide simple rule-of-thumb management recommendations (Unganai et al. 2013) that are depicted in a decision-tree format (Figure 7.2). Some binary decision trees have incorporated more technical information, including Brier skill scores to indicate confidence of each rule-of-thumb management recommendation (Rodriguez et al. 2018). Embedded within a simple heuristic device, this format still provides users with access to information on the uncertainty of the statistics behind the weather and climate forecasts and expected outcomes.

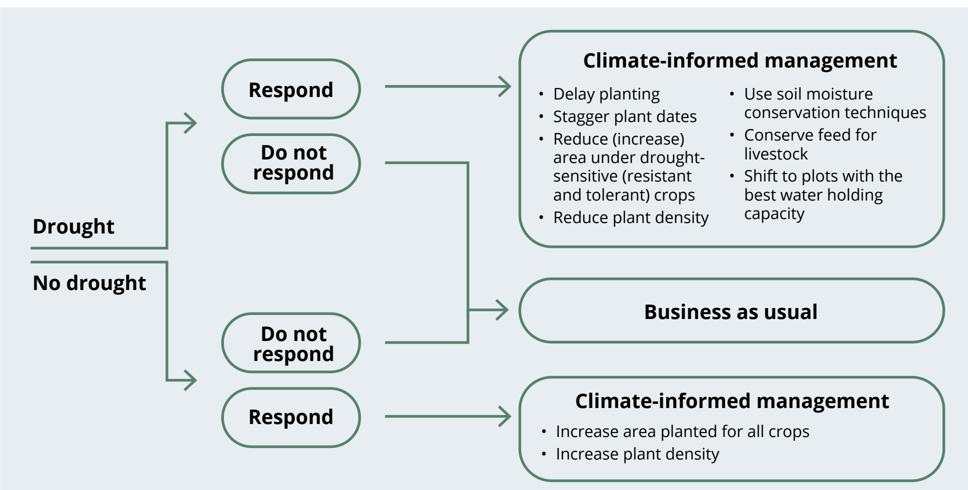

Figure 7.2 Farmers' decision-making process using a binary seasonal forecast

Source: Adapted from Unganai et al. 2013

Challenges

The research and development pipeline reviewed in this chapter includes a wide range of data types, data collection methods and resources that span research disciplines and scales. Collecting and aligning the spatial and temporal scales of previously disparate climate and farming system models and their components have been principal challenges to predicting optimal management for future climatic conditions. Part of a systematic effort to ease integration was the establishment of common standards for a minimum dataset and the American Standard Code for Information Interchange (ASCII) format (Jones & Thornton 2000). These standards precluded the need for third-party data manipulation software, greatly assisting transport of data between models. The Decision Support System for Agrotechnology Transfer – International Consortium for Agricultural Systems Applications (DSSAT-ICASA) developed one such standard for agronomic experiments to facilitate data and model exchange between crop modelling groups in the US, Canada, Europe and Australia (van Kraalingen & Hunt 1997). Data and model exchange remain a challenge for ESA that, if overcome, can greatly enhance the value of existing data and modelling tools.

The nonlinear nature of analytical approaches for identifying climate-informed sustainable intensification practices has contributed to high and irreducible uncertainty. Even analyses that utilise skilled forecasting tools and crop simulation models predict outcomes of alternative crop designs with high levels of uncertainty. The complexity and diversity of farming systems and interactions across farming system components has also produced nonlinear effects and analytical challenges that contribute to the uncertainty of predictions. This has posed a technically complex challenge for the climate science community in developing resources that quantify changes in outcomes (e.g. profits and risks) from climate-based sustainable intensification practices and inform management of intensified farming systems under variable climates.

Climate information products have also been developed for regions spanning farming systems with diverse goals, production conditions (e.g. incidence of pests and disease), market and institutional settings and human or personal operations (injuries). This diversity has presented a challenge to developing parsimonious models that maintain skill at the scale of most decision-making.

Understanding climate risk relative to other multiple sources of risk in farming systems has also been a challenging aspect of quantifying benefits of climate-informed management. In the multirisk scenario that most end users face, managing for climate variability can limit management for other risk factors and ultimately reduce farming system performance. Decision-making tools that evaluate trade-offs of climate-informed management can help identify opportunities where climate-informed management has the greatest potential (Meinke & Stone 2005). To achieve this, analyses have to account for variation in household vulnerability levels across risk factors, objectives and development pathways of farmers (Rijke et al. 2012; Ziervogel & Zermoglio 2009).

Next steps

Resources to support climate data collection and the development and dissemination of climate-informed management recommendations have, to a certain extent, been able to contribute to farming system performance in ESA. With some exceptions, the quality of these products has generally been less accurate and effective in ESA than those developed and applied in other parts of the world. Much of this variability is explained by systemic bias that requires broad-scale efforts.

Four investments with great potential to address quality concerns are:

1. install, maintain and monitor more reliable and evenly distributed observation networks to validate satellite data and train prediction models
2. establish skilful prediction products for targeted farming systems to increase the resolution of predictions otherwise applied to diverse production regions
3. refine dynamic whole-farm models with farming system data of target production systems to provide more relevant production-level outcomes
4. design communication strategies and simple decision-support tools that have been trialled by end users to minimise interpretive uncertainty.

Scholars and development practitioners have also argued against a myopic approach to climate research and development that focuses on technological skill and capacity. Given the limited skill of models, the irreducibility of uncertainties and poor accessibility of model output, Daron, Sutherland et al. (2015) suggest that a persistent focus on increasing precision and skill in regional climate projections is misguided and does not adequately address the needs of society. Rather, strategic partnerships can ensure that existing climate forecasts benefit producers. Partnerships with local agronomists can support pilot demonstration projects that apply climate-informed management decisions. Further training for national meteorological service forecasters in their interpretation and use can further generate the human capacity to support uptake of complex decision-making processes and promote adoption of climate-informed management practices (Washington et al. 2004).

Climate forecasts can also be applied to decision-making beyond the household and generate substantial benefits for rural communities when used to coordinate input, trade and credit supply markets, food crisis management and agricultural insurance products (Hansen et al. 2011). This requires ongoing and additional support from actors at the regional and country levels. Existing and emerging actors and collaborations are well positioned to seize this opportunity. National-level initiatives have demonstrated that they can effectively leverage climate forecast information to enhance cross-scale system interdependencies and support systemic changes (Daron, Sutherland et al. 2015). Climate initiatives have linked major actors like ACMAD, the Intergovernmental Authority on Development Climate Prediction and Application Center, and the Climate Systems Analysis Group (Ziervogel & Zermoglio 2009). Other actors like the IRI, together with the Global Climate Observing System, have bridged gaps in availability, access and use of national climate data through ongoing programs and initiatives (e.g. ENACTS). Climate-related research and development and adoption of climate-informed decision-making have faced considerable challenges. The successes and resources that have developed can play a powerful role in effectively utilising climate-informed management practices to enhance farming system performance.

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8 Adoption and benefits of sustainable intensification technologies across household gender roles and generations

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Key points

- Gender inequalities and lack of attention to gender in agricultural development have contributed to lower productivity, higher levels of poverty and under-nutrition.
- There is a need to support women's and youth's access to and control over land.
- There is a need to improve women's access to hired labour, especially for female-headed households, enhance women's use of tools and equipment, which reduce the amount of labour they require on farmland, and, if possible, provide community-based childcare centres.
- Very low levels of women's participation in agricultural extension services is widespread and must be addressed.
- In terms of access to markets, there is a need to create a platform in which women and youth can effectively participate in markets.
- Women must be empowered through education and training to increase agricultural production levels and sustainable intensification technology adoption.
- It is clear that the future of agriculture in Africa is in the hands of the youth.

Introduction

Gender inequalities and lack of attention to gender in agricultural development have contributed to lower productivity, higher levels of poverty and under-nutrition (Food and Agriculture Organization [FAO] 2011). The 2012 World Development Report, *Gender Equality and Development*, warns that the failure to recognise the roles of men and women, and the differences and inequalities between them, poses a serious threat to the effectiveness of agricultural development strategies (World Bank 2012). One of the key challenges is the unequal access to, and use of, new technologies by male and female farmers in the field. Addressing the gender differences between female and male farmers in Africa and other developing regions represents a significant development priority in the fight against poverty and hunger.

It cannot be ignored that gender issues in Africa and the developing world have generated significant interest among researchers and policy makers. A major reason for this is that African women play an engine role in farm work: they are responsible for ensuring household food security and taking care of other household reproductive matters (Meinzen-Dick et al. 2010). Although women play a crucial role in improving food and nutritional security in Africa, their contribution to agricultural production and the specific gender division of labour in household, farm and nonfarm activities is not uniform across countries and cultures (Doss 2001). Given women's crucial role in agriculture and family wellbeing, it is pertinent to understand the barriers women face in raising productivity to increase food security at the household and national levels. These constraints include limited access to land, livestock and other assets; limited access to education, health care, markets and extension services; and other subtle forms of social and cultural inequality[2] (Doss & Morris 2001; Quisumbing 1995; World Bank 2001). Furthermore, women face challenges related to weaker land tenure security, poorer land quality, little access to credit and reduced opportunities to participate in agricultural training and extension opportunities due to other household demands (Doss 2001; Doss & Morris 2001).

The global population is projected to increase to 9 billion by 2050. The number of young people aged 15–24 years is also expected to increase to 1.3 billion by 2050, which will account for almost 14% of the projected global population (FAO, Technical Centre for Agricultural and Rural Cooperation [CTA] & International Fund for Agricultural Development [IFAD] 2014). Most of this growth will take place in developing countries in Africa and Asia, where more than half of the population still reside in rural areas (United Nations Department of Economic and Social Affairs 2011). Furthermore, the profile of youth in development policy has increased considerably in recent years (Department for International Development 2016; FAO, CTA & IFAD 2014; MasterCard Foundation 2015; World Bank 2006; United States Agency for International Development 2012). Agriculture is widely seen as having an important role in the provision of productive employment for youth in Africa (Alliance for a Green Revolution in Africa 2015; Filmer et al. 2014; Losch 2016), which has had disproportionately high levels of youth unemployment, underemployment and poverty (FAO, CTA & IFAD 2014). The agriculture sector is of vital importance to rural economies in developing countries, and it also possesses significant untapped development and employment creation potential. Thus, it is relevant to consider the role that is played and will be played by youth in the agriculture sector. According to Ripoll et al. (2017), if agriculture is to be the hot spot for youth employment, then it must be more attractive, more productive and more profitable. In particular, it must modernise and be less laborious. Accelerating sustainable intensification technology adoption is a fundamental prerequisite to increasing agricultural productivity for food security, inclusive growth and poverty reduction (Ndiritu, Shiferaw & Kassie 2014).

2 Social and cultural inequality is linked to social perceptions about the proper roles of women and their perceived lack of suitability as farmers.

This chapter looks at how the benefits of intensification technologies and constraints to adoption compare across these gender and age demographics, offering new insights into lessons on gender as it relates to adoption of sustainable intensification in eastern and southern Africa (ESA). It uses findings derived from the analysis of datasets from SIMLESA 2010–11 and Adoption Pathways 2013 datasets, SIMLESA project country reports, SIMLESA policy briefs, as well as studies done in 2016–17 on:

- the benefits of sustainable intensification generated by innovation platforms and gender-equity initiatives
- gendered aspects of maize and legume farming
- youth's perception and participation in agriculture.

This chapter lays out the benefits and constraints for adoption of sustainable intensification to men, women and youth in Ethiopia, Kenya, Mozambique and Tanzania.

The findings show that even though some women farmers have made strides in terms of adopting sustainable intensification technologies, they still lag behind men in adoption numbers and obtaining sustainable intensification benefits. Youth are interested in agriculture, but they face barriers in adopting sustainable intensification technologies. In addition, the chapter shows how the deliberate targeting of men, women and youth in the agriculture sector facilitates scaling efforts and the realisation of social development goals. Several policy options are offered to bridge the gender gap in adoption of sustainable intensification. These focus on the key drivers of change: land, labour, fertiliser and herbicide use, improved seeds, extension services, access to markets, use of information and communications technology, and human capital.

Methods

We review past studies from the SIMLESA project to provide a complete picture of the situation on the ground. The reviewed study findings come from published analysis of data from the SIMLESA 2010–11 baseline survey (Marenya, Kassie, Jaleta et al. 2015; Mutenje et al. 2016; Ndiritu et al. 2014; Kassie, Ndiritu & Jesper 2014), the 2013 Adoption Pathway datasets (Marenya, Kassie & Tostao 2015) and policy brief (Odendo et al. 2014).

Key messages are also drawn from:

- the International Livestock and Research Institute's SIMLESA II annual report for 2015 (Wolde-Meskel, Adie & Derseh 2017)
- assessments of the benefits of innovation platforms for men and women from Adam et al. 2017a (Kenya); Quinhentos & Adam 2017b (Mozambique); Misiko 2016 (Rwanda); Ubwe & Adam 2017 (Tanzania)
- gender and value chains analysis for maize and legumes from Bedru, Mussema & Mekuriaw 2017a (Ethiopia); Adam et al. 2017b (Kenya); Quinhentos & Adam 2017a (Mozambique); Mmbando et al. 2017 (Tanzania)
- studies on youth's perception and participation in agriculture from Bedru, Mussema & Mekuriaw 2017b (Ethiopia); Adam et al. 2017c (Kenya); Quinhentos & Adam 2017c (Mozambique); Ubwe et al. 2017 (Tanzania).

Below we provide a brief description of the methods used for gender and value chain analysis for maize and legumes, and assessments of innovation platforms and gender-equity benefit sharing and youth's perception and participation in agriculture.

All three studies were conducted in SIMLESA research sites. Case studies and focus group discussions identified underlying factors that predicted successes and failures. The benefits examined in the study were:

- crop diversification and productivity
- business
- social
- environment
- infrastructure.

We used the participatory audit tool (P-Audit) to evaluate the benefits of innovation platform members. The benefits were rated on a scale of 0–3.

- 0 = no benefits
- 1 = weak
- 2 = average
- 3 = strong
- X = unknown benefits.

Key informants' interviews were conducted. Key informants included members in leadership positions who possessed information and records about innovation platforms, traders, agrodealers and any knowledge providers within the innovation platforms.

The gender and value chains analysis for maize and legumes study used a rapid assessment approach and the Integrating Gender into Agricultural Value Chains analytical framework developed by Rubin, Manfre and Nichols Barrett (2009). We used data from focus group discussions held in 2016–17 with men and women farmers, key informant interviews with producer associations, retailers and processors, local buyers and traders, export market buyers, National Agricultural Research System maize and legume breeders and other seed actors from Ethiopia, Kenya, Mozambique and Tanzania.

To understand young people's interest and perception as they relate to the agriculture sector, we examined young women and men's perceptions of several themes including:

- sustainability of farming
- existing opportunities for young people in the agriculture sector
- access to land, other farm inputs and output markets for their farm produce
- access to knowledge, skills and information.

Focus group discussions were conducted for male and female youth. Under the African Youth Charter, a youth is a person aged 15–35, which is the age range adopted in the study. However, youth in Ethiopia are defined as young men and women aged 15–29 years. In Kenya, the age range is 15–30 years. In Mozambique and Tanzania, the age range is 15–35 years.

Technology adoption

Evidence of adoption[3] under the SIMLESA program supports existing theories and expectations surrounding adoption processes. The adoption monitoring survey revealed that 91% (57% males and 34% females) of the targeted 258,493 farmers had adopted[4] at least one sustainable intensification practice[5] promoted by the project by December 2016[6] (Table 8.1). The commonly adopted sustainable intensification practices in all five SIMLESA countries were drought-tolerant maize varieties, maize–legume rotation, maize–legume intercrop and timely planting. The least adopted sustainable intensification technologies were crop residue retention, particularly in the crop–livestock mixed farms of eastern Africa, and improved legume varieties in Mozambique, due to market constraints. The project used a combination of scaling-out strategies to support adoption, including multistakeholder platforms, media (mainly radio programs), private–public partnerships, lead farmer approaches, farmer field days, exchange visits and demonstrations.

In eastern Africa, the sites covered in Ethiopia included the Central Rift Valley, the southern region and Pawe, for a total of 614 households. The adoption rate results for 2012–13 showed that 3,800 farmers adopted conservation agriculture-based sustainable intensification (CASI) technologies, with a gender distribution of 3,192 males (84%) and 608 females (16%)[7] (Figure 8.1). The adoption rate results for 2016–17 showed that 47,437 farmers adopted CASI technologies, with a gender distribution of 39,843 males (84%) and 7,594 females (16%) (Figure 8.2).

In Kenya, the sites covered were the Bungoma and Siaya districts from the western region, and the Embu, Meru South and Imenti South districts from the eastern region. The adoption rate results for 2012–13 showed that 3,467 farmers adopted CASI technologies, with a gender distribution of 1,401 males (40%) and 2,066 females (60%). The adoption rate results for 2016–17 showed that 63,870 farmers adopted CASI technologies, with a gender distribution of 34,641 males (54%) and 29,229 females (46%).

In Tanzania, the sites covered were the Arusha (Karatu district) and Manyara (Mbulu district) regions in the northern zone, and the Mvomero and Kilosa districts of the Morogoro region in the Eastern zone. The adoption rate results for 2012–13 showed that 3,287 farmers adopted CASI technologies, with a gender distribution of 2,088 males (64%) and 1,199 females (36%). The adoption rate results for 2016–17 showed that 34,960 farmers adopted CASI technologies, with a gender distribution of 24,290 males (69%) and 10,670 females (31%).

In southern Africa, the sites in Malawi spanned five districts in the central region (Lilongwe, Kasungu, Mchinji, Salima and Ntcheu) and one district in the southern region (Balaka). The adoption rate results for 2012–13 showed that 2,226 farmers adopted CASI technologies, with a gender distribution of 1,137 male (51%) and 1,089 females (49%). The adoption rate results for 2016–17 showed that 51,097 farmers adopted CASI technologies, with a gender distribution of 28,421 males (56%) and 22,676 females (44%).

3 Based on a loose definition of adoption, with criteria of time retaining at least one new technology varying across SIMLESA sites from 1 to 2 years.
4 An adopter is a farmer who has used a technology for more than one year in at least 25% of their cultivated land.
5 The major SAI practices considered were crop diversification (intercropping and crop rotation), conservation tillage (conservation/minimum tillage with residue retention) and use of improved seed varieties.
6 While this chapter is based on 2016 adoption data, later chapters report that by 2018 more than 480,000 farmers had adopted SIMLESA technologies (Adoption and Benefits Survey report; SIMLESA Program Final Report).
7 The gender-disaggregated data represent male-headed households and female-headed households because adoption of SAI practices was measured at household level.

In Mozambique, the sites covered were the Sussundenga and Manica districts of the Manica province, the Gorongosa district in Sofola province and the Angonia district in Tete province. The adoption rate results for 2012–13 showed that 2,226 farmers adopted CASI technologies, with a gender distribution of 1,137 male (51%) and 1,089 females (49%). The adoption rate results for 2016–17 showed that 51,097 farmers adopted CASI technologies, with a gender distribution of 28,421 males (56%) and 22,676 females (44%).

Table 8.1 Gender-disaggregated data of SIMLESA technology adopters by country (farm households)

Season	Country	Target	Male	Female	Total
2012–13	Ethiopia	3,800	3,192	608	3,800
	Kenya	3,240	1,401	2,066	3,467
	Tanzania	3,240	2,088	1,199	3,287
	Malawi	2,916	1,137	1,089	2,226
	Mozambique	2,916	3,763	2,026	5,789
	Total	**16,112**	**11,581**	**6,988**	**18,569**
2013–14	Ethiopia	10,454	8,781	1,673	10,454
	Kenya	8,913	8,236	5,364	13,600
	Tanzania	8,913	6,715	3,128	9,843
	Malawi	8,022	2,177	2,263	4,440
	Mozambique	8,022	6,222	2,419	8,641
	Total	**44,324**	**32,131**	**14,847**	**46,978**
2014–15	Ethiopia	18,817	15,823	3,015	18,837
	Kenya	16,043	14,841	9,665	24,506
	Tanzania	16,043	12,100	5,636	17,736
	Malawi	14,439	3,923	4,078	8,000
	Mozambique	14,439	11,211	4,359	15,570
	Total	**79,782**	**57,898**	**26,752**	**84,650**
2015–16	Ethiopia	33,870	28,449	5,421	33,871
	Kenya	28, 878	26,684	17,379	44,063
	Tanzania	28, 878	21,756	10,135	31,891
	Malawi	25, 991	19,185	18,454	37,639
	Mozambique	25,991	18,770	7,299	26,069
	Total	**143, 607**	**114,844**	**58,688**	**173,533**
2016–17	Ethiopia	61,005	39,843	7,594	47,437
	Kenya	51,957	34,641	29,229	63,870
	Tanzania	51,957	24,290	10,670	34,960
	Malawi	46,787	28,421	22,676	51,097
	Mozambique	46,787	27,156	10,901	38,057
	Total	**258,493**	**148,208**	**87,213**	**235,421**

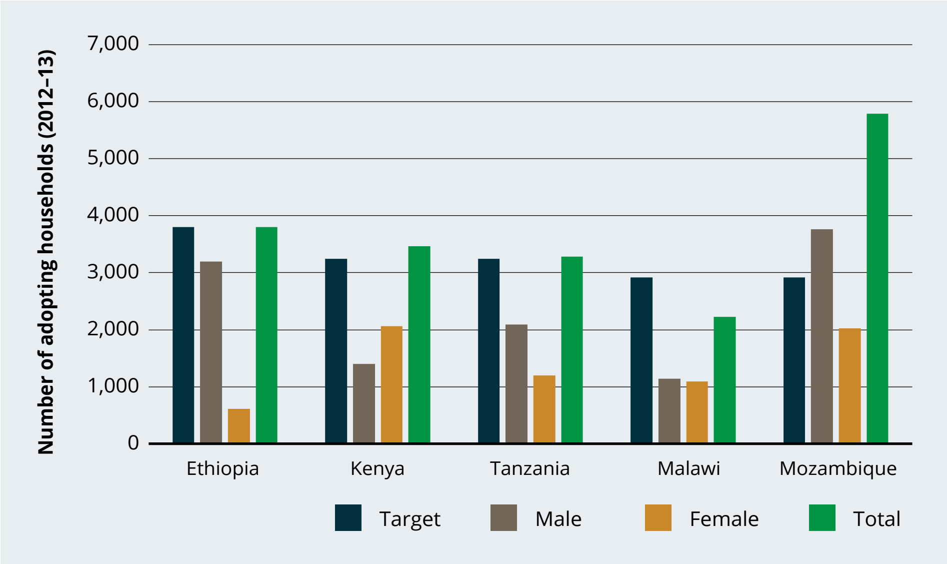

Figure 8.1 **Gender-disaggregated data of SIMLESA technology adopters in 2012–13 by country (estimated number of farming households) compared to the target population of 16,112 farmers**

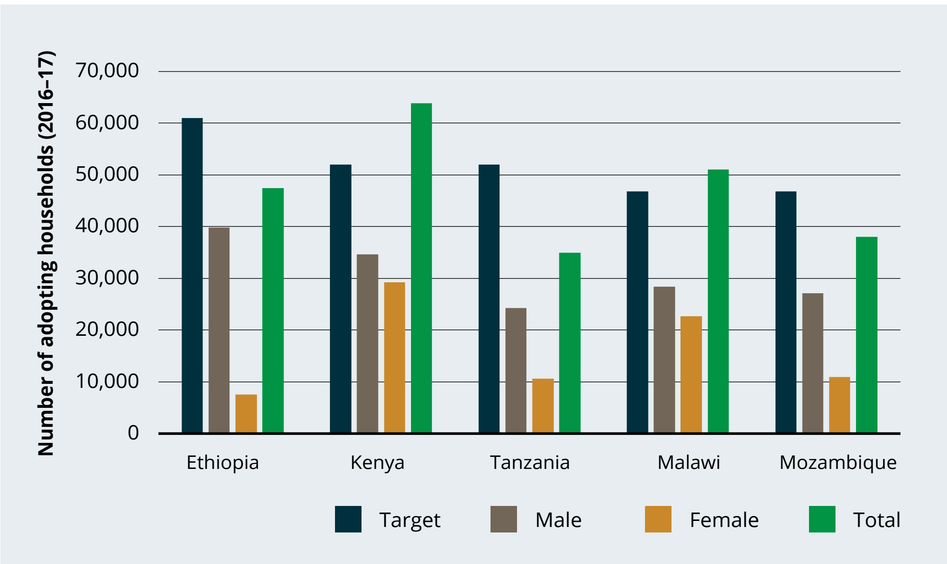

Figure 8.2 **Gender-disaggregated data of SIMLESA technology adopters in 2016–17 by country (estimated number of farming households) compared to the target population of 258,493 farmers**

Differences were observed across countries, sites and time points. The estimated number of farming households to adopt was especially high in Mozambique in 2012–13 and the total adopting households significantly exceeded the target. By 2016–17, adoption numbers were especially high in Kenya and the total adopting households exceeded the target.

The results from the ESA countries indicate that there is still a strong need to advocate for and promote women's participation in adopting SIMLESA technologies. The only observed case where the number of female-headed adopting households exceeded those of male-headed adopting households was in Kenya in 2012–13. Several studies on the gendered adoption of sustainable intensification provide important insights into the observed gender differences in CASI technology adoption. In 2011, female plot managers in western and eastern Kenya were less likely to adopt minimum tillage and manure for soil fertility management than male plot managers, but more likely to practise maize–legume intercropping, maize–legume rotations and take soil and water conservation measures (Table 8.2).

Table 8.2 Gender-disaggregated plot level technology adoption

Variable (1 = yes, 0 = no)	Full sample (*n* = 2,687)		Male plot manager (*n* = 843)		Female plot manager (*n* = 782)		Joint managers (*n* = 1,062)		Difference between male- and female-managed plots
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	B-C
Maize–legume intercropping	0.351	0.477	0.316	0.465	0.422	0.494	0.328	0.470	–0.106***
Maize–legume rotations	0.400	0.490	0.375	0.484	0.462	0.499	0.375	0.484	–0.087***
Improved seeds (maize and legume)	0.669	0.471	0.667	0.472	0.657	0.475	0.679	0.467	0.009
Chemical fertiliser	0.510	0.500	0.543	0.498	0.457	0.498	0.523	0.500	0.024
Soil and water conservation measures	0.667	0.472	0.620	0.479	0.645	0.479	0.718	0.450	–0.047**
Minimum tillage	0.045	0.207	0.070	0.150	0.023	0.150	0.041	0.199	0.087***
Manure use	0.461	0.499	0.501	0.477	0.396	0.489	0.477	0.500	0.104***

Note: SD = standard deviation; B = male-managed plot; C = female-managed plot; *** = $p < 0.01$; **= $p < 0.0$;. *= $p < 0.1$.
Source: Ndiritu, Shiferaw & Kassie 2014

The major reason for this difference, according to Ndiritu, Shiferaw & Kassie (2014), is that these practices required more labour, knowledge and resources such as livestock and credit, and female farmers had more limited access to these than their male counterparts. In addition, minimum tillage requires the application of herbicides, which are more likely to be prohibitively expensive for female than male farmers. Given that minimum tillage is also a new practice in Kenya, more time is needed for farmers to adopt the process (Ndiritu, Shiferaw & Kassie 2014). The researchers also found that livestock ownership increased the likelihood of farmers applying animal manure, and since female plot managers own less livestock, they may have less manure available for soil fertility management. Interestingly, jointly managed plots (by husband and wife) are more likely than male-managed plots to adopt maize–legume intercropping, maize–legume rotations and improved seeds. This shows the value of joint decision-making, which allows for pooling of resources and family effort to improve sustainable intensification and productivity growth for improving food security. The study also showed how access to institutional services (e.g. credit and extension), social capital and government support, and household resources increase the likelihood of adopting SIPs.

A study carried out in Mozambique by Marenya, Kassie & Tostao (2015) found that joint management of agricultural plots was associated with higher fertiliser application rates on maize plots for which proceeds were shared by the household, but with lower fertiliser application on non-food cash plots for which proceeds went mainly to the male head of household. Therefore, in the absence of equitable sharing of proceeds from jointly managed plots, efforts to increase access to inputs by women may need to target plots already managed by women themselves. And in land-scarce environments where women often lack land to cultivate independently, one way to improve gender equity in agriculture is by enhancing women's bargaining power through joint management of agricultural activities and land.

A study in Malawi by Mutenje et al. (2016) showed that education, marital status, religion and informal networks are important factors in shaping women's participation in agricultural technology. For example, the probability that women would actively participate in agricultural resource allocation and technology choice decisions decreased by 6.9% and 7.2% when they identified as Muslim or as a member of a traditional religion. The results also showed that informal networks greatly influence the attitudes, perceptions, preferences and use of technologies, and therefore choices.

Endowment differences from various forms of market participation across genders also support increased investment in new technologies by male-headed households while creating challenges for women. Another study, by Marenya et al. (2015) in Ethiopia, found that female-headed households were more than twice as likely as male-headed households to be net buyers of maize. Moreover, the probability of male-headed households acting as net sellers was 16.5% greater than that of female-headed households. Net buyer positions were significantly associated with having a larger family and lacking access to credit. Among female-headed households, ownership of livestock was associated with being in a net seller position. The gap between female- and male-headed households regarding quantities of maize sold was largely explained by endowment effects. The findings suggest that closing the observed market participation gaps requires designing and implementing policies that support the ability of women in both female- and male-headed households to make agricultural production decisions and participate in maize markets, and ensure equal access for male- and female-headed households to resources and other supportive social networks.

Lastly, a 2013 study by Rodriguez et al. (2013) on piloting a mobile phone system for delivering information to farmers and agribusiness to support sustainable intensification in Mozambique showed there was no gender difference in mobile phone ownership. Ownership was instead related to age: older farmers were more likely to own a mobile phone. However, it was reported that a majority of the farmers used their mobile phones to contact family and friends instead of for farming-related activities. The study showed the great potential for increasing female CASI technology adoption by using information and communication technology to reach out to women unable to access extension services or agricultural training.

Gender- and age-disaggregated benefits

In Kenya, the experience of the Liganwa farmers' group helps to explain the benefits women received from conservation agriculture practices (Odendo et al. 2014). The Liganwa farmers group located in Liganwa village, Kakumu Kombewa sublocation of central Alego in Boro Division, Siaya County of Nyanza Province, was formed in 2007. In 2007, an all-women group was formed with the purpose of helping widows in the community acquire capital to engage in microbusinesses. Members belonged to a rotating credit and savings association (referred to as 'merry-go-rounds' in Kenya). The group was initially not very successful in its efforts to raise capital for the rounds because some members were unable to pay their contribution. In March 2010, an opportunity came for the group to join SIMLESA as members of an innovation platform. The group learned about the SIMLESA project through a son of one member who informed them that researchers from Kenya Agricultural and Livestock Research Organization were looking for a group in Siaya County to participate in a new farming project. The group later met with Kenya Agricultural and Livestock Research Organization researchers, and after SIMLESA was explained to them, they agreed to experiment with suggested CASI practices. According to their chairperson, adoption of CASI practices allowed members to sell surplus maize and earn money, part of which was put back into circulation within the group. The amount of money that group members could borrow increased significantly from the initial 1,000 Kenyan shillings (KSh) (US$10) to KSh3,000–5,000 (US$30–50), with 100% repayment rates.

In Ethiopia, female-headed households in the southern region reported that engagement in forage cultivation and improved utilisation technologies reduced labour time (Wolde-Meskel, Adie & Derseh 2017). Moreover, households who adopted cultivation of different forage species on larger plots also reported an improvement in dairy production. In some sites, such as the Abchikly district of Amhara region, active dairy cooperatives with members owning an average of two crossbred cows were run by groups of both women and men. The members collected and sold milk and processed it into butter and cheese. These cooperatives benefited from planting Rhodes grass, Napier grass and Sesbania. In addition to dairy products, there was a very good market for veal in big hotels. For instance, a 2-year-old calf could be sold for between 25,000 Ethiopian Birr (Br) (US$918) and Br30,000 (US$1,102) in Bahirdar. It was common for women to manage the income from the sale of milk and dairy products, even in male-headed households. The increase in dairy production may be a result of the fodder interventions and improvements in women's access to and control over resources, which may improve child nutrition.

Despite these potential benefits, unequal benefits of SIPs across genders may underlie and reinforce differences in adoption levels and opportunities across household roles. Kassie, Ndiritu & Jesper (2014) found that female-headed households that invested in the same SIPs as their male counterparts (the same social capital network, household characteristics and plot characteristics) were still less food secure, due to unobserved characteristics. The study also argued that even though some policy interventions aid in ameliorating the gender gap in food security, they are not a panacea. It is very important to address gender-specific social norms and differences in the way female farmers are treated by others in certain countries.

In Ethiopia, youth unemployment has been on the national agenda. One of the potential employment opportunities identified has been involvement in small-scale animal production activities. Budget has been allocated from the central and regional governments to provide credit services for youth groups that have a business plan. It is reasonable to assume that fodder intervention, which has been promoted across the SIMLESA sites, can create opportunities for youth to access forage planting materials, cultivate homegrown forages and generate income, either by selling the forage biomass or by feeding it to fattening or dairy animals, which are sold as excess meat.

Benefits derived by farmers from innovation platforms

Innovation platforms combine the principles of cooperatives (commercial goals), community-based organisation's (community or collective approach), higher-level partnerships (value chains) and social welfare. They are effective mechanisms to channel policy solutions that target gender and youth. Strategic gender interests rely heavily on gender planning and policy development tools, such as the Moser Framework (March, Smyth & Mukhopadhy 1999). These help determine how women, youth and men generate and share sustainable intensification benefits. Below we concentrate on the benefits related to farm yield and diversification, and business-related outcomes.

Farm yield and diversification-related benefits include increased yields of crops and dairy products. For instance, in Mozambique, in the Zano Ra Mambo farmers' association Macate district, under the auspices of the Agência de Desenvolvimento Económico de Manica innovation platform, both male and female farmers within the association experienced an increase in access to improved varieties (drought-tolerant maize varieties, including PAN53 and ZM309) and legumes. Farmers also reported that training in conservation agriculture technologies has helped increase maize yields (Quinhentos & Adam 2017b). The approaches used by SIMLESA and innovation platforms increased knowledge and skills in the use of improved varieties of maize and legumes for all farmers. Women indicated that they gained access to improved agricultural inputs at good prices, unlike the past, when they only used local crop varieties. Results indicate that women grew more diversified legumes, including soybean, which is considered a cash crop and was dominated by men before the innovation platforms.

In Rwanda, innovation platforms contributed to more than a 100% average increase in three years in cassava for the KIAI innovation platform (formerly known as Cassava Innovation Platform of Eastern Province).[8] The potato yield increased from 10 t/ha in 2008 to 25 t/ha in 2016. The milk yield from the local cow breed increased from 1 litre/cow in 2008 to 7 litres/cow in 2016 for Muguka Mudende[9]. These yield increases were experienced by both male and female farmers.

The yield benefits described above influenced sustainable intensification and business outcomes, as income from these activities resulted in more input use in maize and pulse production. In Tanzania, the eight innovation platforms studied in depth in Arusha and Morogoro experienced an increase in maize and pigeonpea yields (Ubwe et al. 2017). In Kenya, the Kieni innovation platform farmers also reported an increase in bean yields (Adam et al. 2017a). The innovation platforms have managed to be successful and stay relevant because of higher income earnings, particularly profits and some dividends (KIAI and Mudende in Rwanda and Kieni in Kenya). For instance, replacing the maize local variety with Duma 43 increased maize yields, and made maize an important enterprise for group members in Kenya's Kieni innovation platform (Adam et al. 2017a). In Mozambique, membership in farmers associations provided access to reliable traders with predictable and profitable buying prices. This link to the market increased incomes from the sale of maize, cowpea and soybean for women and men farmers (Quinhentos & Adam 2017b). In Mozambique, women indicated that, in the past, mostly men would travel to more profitable distant markets to sell their products. Working with the innovation platform changed this trend. Women participated more in crop sales and were allowed by their husbands to sell crops in distant markets and to traders in the villages.

8 The information was obtained from the documented records of the KIAI AIP members.
9 The information was obtained from the documented records of the Muguka Mudende AIP members.

In Mozambique, Rwanda and Kenya, association members also had increased access to credit to purchase inputs and were consequently able to open bank accounts. For the Kieni innovation platform in Kenya, the Women Enterprise Fund, a government body that provides credit, assisted women in getting financial support for farming their individual farms and running innovation platform activities. At the innovation platform in Boro, western Kenya, agrodealers provided credits on inputs to frequent buyers and those buying in bulk, especially to innovation platform farmers buying feed and fungicides. In Tanzania, some innovation platforms, particularly the Bashay, accessed credit through village community banks (Ubwe et al. 2017).

Table 8.3 Membership composition of successful innovation platforms in SIMLESA countries

Innovation platform (country)	Women		Men		Total membership
	No.	%	No.	%	
Kieni (Kenya)	10	71	4	29	14
Mariani (Kenya)	18	72	7	28	25
Zano Ra Mambo (Mozambique)	15	24	48	76	63
Luta contra pobreza (Mozambique)	8	32	17	68	25
Mudende (Rwanda)	226	37	384	63	610
KIAI (Rwanda)	74	58	54	42	128
Mshikamano (Tanzania)	10	50	10	50	20
Rhotia Kati (Tanzania)	12	30	28	70	40

Innovation platforms have been effective vehicles for increasing gender and youth participation (Table 8.3). Successful innovation platforms in Rwanda and Kenya had a ratio of women to men leaders of 39:61. Personal characteristics and agendas of innovation platform leaders influenced the generation and sharing of SIPs benefits in Mozambique, Kenya, Rwanda and Tanzania. The age range for innovation platform membership was wide, ranging from 20 years to over 60 years. Leadership distribution was influenced by public policy, culture and founding principles of the innovation platforms.

However, in Mozambique, the level of female leadership was especially low. According to members of the farmer associations, the major reason was women's illiteracy. As women members of the farmers' association in Macate cannot read and write Portuguese or the local language, they were unable to represent the associations in partner or donor meetings. In addition, due to household and childcare responsibilities, women did not have the same ability as men to quickly travel and participate in exchange visits and field days outside their villages. The lack of women in leadership positions within the innovation platforms in Mozambique means that some of the women-specific issues are neglected topics at the table during innovation platforms meetings.

SIMLESA's 58 innovation platforms have not had adequate evolutionary cycles to reach maturity. However, the Kieni (Kenya), KIAI and Huguka Mudende (Rwanda) and Rhotia (Tanzania) innovation platforms showed features of maturing innovation platforms. Common challenges and deficiencies include:

- The innovation platforms had poor leadership. Leadership is key to the success of all innovation platforms. The skills and attitudes of leaders are important factors to strengthening group processes and the overall functioning of innovation platforms.
- Gender was not incorporated into the core business models and activities. The sociocultural characteristic of the site influenced the process of establishing the innovation platform.

- Innovation platforms were wholly dependent on SIMLESA to understand the innovation platform concept and access necessary resources. For example, literacy was necessary for innovation platform members to take on leadership roles because they needed to represent the innovation platform in partner and donor meetings. Women might not have been disadvantaged in this way if innovation platforms were independent of partners and donors.
- Facilitation was not consistent, and there was an absence of catalytic roles from initiators. Leaders needed to better engage members and keep them committed to the innovation platform and give ownership to the primary actors in the chain.
- Members did not define a clear business niche.
- Innovation platform characteristics maintained low levels of motivation, such as inconsistent and low attendance in innovation platform meetings, misunderstandings between members, self-defeatist logics, dishonesty, disrespect of meeting times and resistance to change.
- Financial and management errors occurred, including mismanagement of innovation platform funds among some of the innovation platforms.
- Limitations of innovation platforms were also rooted in factors beyond the innovation platforms' control, including late delivery of seeds, lack of short trainings, lack of field visits and extension, as well as natural causes such as drought.

One of the key lessons learned from the innovation platforms is that certain factors determine the equitable generation and sharing of farm yield, diversification-related, business-related and other social and economic benefits. These key determinants include:

- donor investment decisions and contributions towards research and skills are empirically-based and informed
- smart business niche is identified
- national officers are trained and mentored with support from consistent capacity-building programs
- trusting partnerships are well established
- appropriate business niche attracts private partner investment support and appropriate value-chain partnerships.

Gender and value chains analysis

Analyses of gendered production and marketing constraints and opportunities inform strategies for scaling maize–legumes systems and establish the potential medium-term impacts across food systems in Ethiopia (Bedru, Mussema & Mekuriaw 2017a), Kenya (Adam et al. 2017a), Mozambique (Quinhentos & Adam 2017b) and Tanzania (Mmbando et al. 2017). The analyses conducted under the SIMLESA program identified the following challenges faced by women farmers in producing and selling maize and legumes, and the challenges faced by retailers, buyers, traders and processors in dealing with maize and legumes.

Numerous production challenges disproportionally constrained women. Productive resources were unevenly distributed across genders. Access and control over land and labour were especially limited for women. Women had less money, which made purchase of improved, certified seeds and fertiliser prohibitively expensive. Women also had less knowledge of good crop varieties and field management practices; patriarchal power dynamics enabled disrespect of women; and school systems and family and social dynamics contributed to a higher illiteracy rate among women, which acted as a barrier to market participation. Together, these challenges significantly hindered technology adoption and placed upward limits on production and efficiency for women. The production challenges for men included high seed prices, the inability to identify different legume varieties, and lack of funds to hire extra labour and purchase inputs such as fertiliser. Men, however, had greater access to extension services, training and market information than women.

The major crop varieties under production had lower yield potential than improved varieties. More than half of the farmers who participated in the study were not able to afford improved seeds. They used local varieties for cultivation, leading to lower yields. Low adoption of improved seed varieties has been explained by high costs observed in the imperfect seed market. Marketing constraints for maize seed systems include:

- different prices for the same maize varieties by different companies
- high prices
- weak inspection system for seeds that are sold (e.g. grain sold as seed)
- middle men's late availability of inputs, especially from the national and county governments in Kenya.

Moreover, the 'claimed improved varieties of seeds' in the agrodealer shops are not always the real or genuine forms of improved seeds. Farmers in the study countries claimed that some of the agrodealers were known to sell seeds with low germination rates. This discouraged some farmers from investing in improved varieties, which perpetuated the cycle of low yields. However, women in Kenya tended to use more improved varieties of maize than their male counterparts.

Women in male-headed households were more likely to benefit from improved varieties of maize seeds than women in female-headed households. Gender-related challenges specific to maize marketing for women include the inability to:

- make decisions on sales
- anticipate pricing decisions
- access quality seeds.

Descriptions of the dominant culture in Manica district, Mozambique, suggest that it is patriarchal and maintains cultural norms that restrict women's mobility, reducing their access to distant and more profitable markets: For instance, women were responsible for housekeeping and bearing children, which restricted movement and opportunities. Specifically, women often sold their products in small amounts at farm gate and local markets when they needed money. Unlike men, who transported larger loads to the market on bicycles or oxen carts, women usually carried their loads on their heads or paid for transportation.

There were three general constraints for legume marketing. The first constraint was the high price of improved legume varieties, which cut into profits and discouraged investment in high-yielding varieties. The second constraint was the existing capacity of the few seed companies to produce certified legume seeds, which limited the supply of seeds to agrodealers who rarely met demand. The third constraint was low output prices and limited access to output price information. The low price of seed discouraged farmers from investing in improved seed production technologies.

Gendered marketing challenges for women in legume markets include:

- women's low literacy, which puts them at a disadvantage for market participation
- cultural norms that inhibited women's travel to markets
- lack of access to bicycles and oxen carts, which limited their access to markets with larger loads.

Cultural norms also gave men control and decision-making power over household income, as noted in Mozambique, Kenya and some parts of Tanzania and Ethiopia. Women sometimes did not have the right to sell what they planted. However, in some places in Kenya and Tanzania, men did not take much interest in common beans, as it had low value compared to maize, and labelled the common beans a 'mama's crop'.

Legume production decisions were also gendered in many ways. Men tended to own or claim joint ownership of crops that brought in the most cash, such as pigeonpea. This demonstrates gender differences in the type of legumes grown. In Mozambique, women mostly decided about growing peanut and cowpea, two crops mainly produced for home consumption, because they are responsible for cooking and providing food for their households. The decision about growing other legumes was made jointly because the crops were for both home consumption and for sale.

In Ethiopia, Kenya and Tanzania, there has been some improvement in gender equality in terms of control of income from maize and legume sales. For instance, in Ethiopia, 20 of 54 (37%) couples in male-headed households made decisions jointly about how to spend the money from crop sales. The respondents in Ethiopia reported increased decision-making for women in this regard. In Kenya, most of the women who participated in the focus group discussions reported that women no longer let men take control of income from crop sales. Although the time frame was unclear and may vary at fine scales across communities, husbands and wives in Kenya were generally treating participating in crop sales and financial decisions as a joint venture. In Tanzania, differences in income control among couples was observed between the northern (Arusha) and the Eastern (Morogoro) region. The data shows that, in the northern region, women tended to be concentrated at points along the value-chain characterised as having minimal resources, while men are more often at the end of the value chain. In contrast, women in the Eastern region were involved in every aspect of the value chain, even in the control and decision-making of money from crop sales. Further study is necessary to understand the different experiences of women in these two regions. We suspect that it has to do with the differences in cultural norms and customs, with the northern region being more conventionally patriarchal and the Eastern region more progressive.

The major challenge facing maize and legume retailers, buyers, traders and processors was inadequate capital, especially among women in these positions. With little access to credit, retailers and processors typically rely on personal savings and small loans to start their businesses. Monthly fees and costs to maintain the business were high, which limited the size, performance and profitability of their businesses. For buyers and traders, lack of reliable price information was a major challenge as it forced them to sell with incomplete information, which reduced their profits.

In terms of gender differences, Kenya was the only country where women were found participating in the retail, trading and processing of maize and legume business. This was in stark contrast to the other three countries, where more than 90% of maize and legume traders, retailers and processors were men. This has again been explained by cultural norms that associate business with men, and inadequate financial capital among women to start businesses. Women face further challenges that are reinforced by social norms that discourage women from joining in debate, including lack of marketing skills and low negotiation power, both of which put them at a risk of selling crops at lower prices. For women, the challenges reduce the overall profitability of their businesses.

Youth perception and interest in agriculture

The future of agriculture and sustainable intensification practices relies on youth and new and emerging gendered dynamics among this population. This study was done to gauge youth interest in agriculture. It sheds important light on the challenges and opportunities that exist for youth in the agriculture sector. The study shows that both female and male youth in Ethiopia (Bedru, Mussema & Mekuriaw 2017b), Kenya (Adam et al. 2017c), Mozambique (Quinhentos & Adam 2017c) and Tanzania (Ubwe et al. 2017) were interested in agriculture. In both eastern and western Kenya, all active youth farmers wanted to continue farming. Both female and male youth in Mozambique viewed themselves as career farmers and explained that farming was good for food production and income generation and was a source of survival for rural households. For youth in Mozambique, farming was seen as a default option because there was a lack of other economic activities and available jobs in the villages. As described by a male youth respondent, 'We prefer to dedicate our time to agriculture because there are more opportunities instead of looking for jobs, as jobs are very difficult to find.' In Tanzania, both female and male youth perceived agriculture as important for food security and income earning both in the present and the future. They inherited farming from their parents and were committed to continue the farming business. Farming was their priority activity and a source of income through sale of crops. The same was true in Kenya, where most of the female and male youth interviewed are participating in agriculture and considered farming as a primary activity. In contrast, Ethiopian youth indicated that they preferred to work in the agribusiness department of agriculture rather than in traditional farming.

Youth faced many challenges in farming that hindered them from moving from subsistence to more profitable agriculture. However, as noted by Ripoll et al. (2017), a number of these challenges were not specific to youth, but rather a general structural character and should be addressed accordingly. Some of the challenges that were noted by young women and men in this study include:

- lack of access to financial services to invest in improved inputs, labour and machinery
- problems obtaining good returns from trading crops due to price fluctuations and lack of reliable markets
- lack of access to knowledge, skills and information about farming
- gender-related barriers for young women (e.g. voicing their concerns and participation in meetings).

Conclusions

The findings reveal that the expansion of maize and legume production in the SIMLESA countries required increased access to improved varieties of seeds, subsidised fertiliser and herbicides, and training in better farming practices, for example crop rotation, intercropping and other CASI technologies. In addition, there was a need to improve market access for both maize and legumes to ensure that farmers were compensated fairly for their labour. The frequent price information asymmetries meant that innovations to improve the efficiency and wellbeing of value-chain actors needed to support reliable access to price information. There was a serious need to narrow the gender gap in adoption of sustainable intensification between men and women for all countries in the studies. This could be achieved through proper setting of policy priorities and implementation of those policies by governments and other supporting entities. Furthermore, as agricultural land sizes in the countries in the study (except Mozambique and Tanzania) decrease and the population of young people who are interested in agriculture increase, it became more pertinent for the youth to have knowledge of sustainable intensification practices and use the knowledge to enhance their agricultural vocation and better their lives as a whole.

To provide solid recommendations that will aid in bridging the gender gap in sustainable intensification adoption, we borrow some of the ideas for policies from O'Sullivan et al. (2014), adding our own arguments in order to strengthen the case. The first theme to tackle is land. There is a need to support women's and youth's access to and control over land. In particular, women need better access to land, as well as security that their land investments will benefit themselves and their families. The policy priority is to strengthen women's and youth's land rights. Policy options include:

- formalising land rights through registration to increase women's tenure security (as was done in Rwanda)
- expanding co-titling and individual titling for women
- reforming family and inheritance land to protect women's rights.

For the land registration (co-titling) to be effective, the interaction between formal and customary laws must be considered. Women's understanding of their own rights, the effective enforcement of these rights and village-level legal aid or paralegals that provide assistance can help enforce these co-titling reforms.

With regards to farm inputs, it is necessary to improve women's access to hired labour (especially for female-headed households), enhance women's use of tools and equipment (which reduces the amount of labour they require on farmland) and, if possible, provide community-based childcare centres. The policy can be executed through provision of vouchers, cash transfers or credit to women farmers that are specific to hiring labour. The value of providing women with these financing mechanisms is that many agricultural tasks are done within specific time periods, and labour shortages often occur during these periods. The financing instrument can aid female farmers in achieving the needed tasks. With hired labourers doing the work, women can continue to undertake other household responsibilities, such as child-rearing. Other farm inputs, such as fertiliser, improved seeds and herbicides, also need to be taken into consideration for advancing adoption of CASI technologies for women and youth. In terms of policy priorities, there is a need to encourage women and youth farmers to apply fertiliser and adopt improved seeds and herbicides. For adoption and expansion of maize and legumes to take place, seed system operations need to be improved.

Support for local private sector involvement in seed production is needed so that maize and legume seeds are high yielding and marketable. In addition, there is a need to stimulate farmers' demand for certified seeds, and support the delivery of these seeds to farmers, especially women. This can be achieved by providing women and young farmers with financing tools or price discounts for fertiliser, seeds and herbicide purchase, and helping women better identify and obtain good-quality seeds.

In addition, low levels of women's participation in agricultural extension services need to be addressed. In terms of policy priorities, extension services should be tailored to women's needs, and the use of social networks to spread agricultural knowledge should be expanded. In terms of policy options, there is a need to bring agricultural training and advice to women's doorsteps through farmer field schools and mobile phone applications, and identify volunteer female farm advisers to spread information within women's social networks.

In terms of access to markets, there is a need to create a platform in which women and youth can effectively participate in markets. This can be implemented by channelling existing women's and youth social groups to access market opportunities, and providing market services through information and communication technology. In addition, strong gender training and policies that target male farmers need to be crafted and executed so that male farmers are better educated about the importance of women having an equal say in the revenue collected from agricultural sales. This will mean that women are not left behind in terms of income or financial access and can reap the rewards of their hard labour. Village leaders also need to be involved in campaigns to ensure that women are more involved at the end of the value chain.

Furthermore, women need to be empowered through education and training to increase agricultural production levels and adopt CASI technologies. To raise education levels for adult female farmers and youth in general, governments will need to allocate funds to ensure that enrolment and retention of girls in school is increased, and to set up adult education institutions in rural areas that target older women who missed out on school when they were young.

Moreover, innovation platforms seem to be giving a glimmer of hope in terms of bridging the gender gap in adoption of CASI technologies for women and youth. It would be good to put more financial and human capital into making sure that the innovation platforms are functioning and that marginalised farmers, especially women and youth, reap the benefits.

The characterisation of gendered agricultural practices and social norms in the SIMLESA countries suggests that these policy recommendations can be instituted in a form that remains consistent with many social aspects of these communities. As well as creating new social dynamics and opportunities to decrease poverty, hunger will be mitigated (through increased food security), employment and income levels will increase, social and gender inequalities will be reduced, and health and wellbeing outcomes will improve. In sum, a majority of the sustainable development goals will be achieved.

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9 Maize and legume seed system improvement

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Key points

- Participatory variety selection accelerated the release, popularisation and commercialisation of farmer-preferred, productivity-enhancing, stress-tolerant and cropping system compatible maize and legume varieties.
- Stakeholders such as seed producers and delivery agents have linked formal breeding efforts to farmer-led varietal trials and distribution to better deliver the most favoured varieties to each target environment.
- Coordinated public and private sector participation in the formal seed sector has provided the most effective support network for delivering and promoting maize and legumes varieties in eastern and southern Africa.
- Seed system structures and the recycling potential of hybrid and open-pollinated varieties have created opportunities for maize and legume production but also obstacles that explain low adoption rates across SIMLESA countries.
- A seed road map supported production and delivery of targeted quantities of different maize and legume seed classes and varieties under SIMLESA.
- The SIMLESA program used formal, intermediate and informal seed systems to reach farmers with improved seeds. Quality-assured seeds of farmer-preferred maize varieties were distributed through the formal and intermediate seed systems, while all three types of seed systems contributed to legume seed distribution.

Introduction

Maize and grain legumes are important food crops in eastern and southern Africa (ESA), grown mostly by resource-poor farmers in maize–legume cropping systems under challenging environments and soil conditions. As the main and preferred staple crop, maize is cultivated by more than 85% of the smallholder farmers as a primary crop under rainfed systems (Food and Agriculture Organization Statistical Database [FAOSTAT] 2015). Legumes have historically provided the main source of dietary protein within the maize-based systems, especially among smallholder farmers who may not have access to animal protein (Smale 1995). In addition, legumes provide minerals (calcium, zinc and iron), and vitamins (folic acid and vitamin B) to humans and livestock. They have been widely used in intercropping and crop rotations to supply nutrients to the soil, reduce dependence on fertilisers and reverse soil degradation (Manner & Morrison 1991; Ngwira, Sleutel & De Neve 2012). Cereal crop residues, supplemented with forage legumes, can also significantly increase overall animal productivity. For example, a review of various legume-based feed alternatives found that poultry egg production increased when pulse grains were included in their feed (Robinson & Singh 2001). Adding legume crop residue to livestock forage can increase the digestibility and overall quality of cereal crop residues. For example, maize residues tend to be high in carbohydrates but low in protein, so adding leguminous plants generally enhances livestock nutrition. Stabilising and increasing productivity of maize and legumes in the face of recurring drought and poor soils has been a major priority in efforts to improve food security.

The maize–legume cropping systems in ESA are far from reaching their production potential. One contributing factor to low yields under smallholder farmers has been the slow replacement of recycled maize and legume varieties that are not adapted to climate variability or new diseases and pests, such as maize lethal necrosis and fall army worm (Atlin, Cairns & Bas 2017; Mahuku et al. 2015). Improved genetics in the seed can result in increased resistance to biotic and abiotic stresses (Bänziger et al. 2006). Breeder-improved maize and legume varieties that are most successful in growth and development and are high yielding may be adopted by farmers in hopes of increasing agricultural productivity (Langyintuo et al. 2008; Smale 1995; Smale et al. 1991).

However, efforts to enhance production have tended to promote management practices that are incompatible with aspects of existing cropping system operations. Synchronising promoted management practices with baseline farming systems could create the necessary conditions for increased production. Crop genetics, in particular, is a key driver of sustainable intensification. Together with the environment, seed genetics determine the upper limit of crop performance (Almekinders, Louwaars & De Bruijn 1994; Cromwell 1990). In addition to crop yield, crop genetics is a strong determinant of nitrogen uptake, crop nutrition, crop resilience to pests and diseases and water use efficiency. These traits are expected to become more crucial under projected climates. The genetic composition of farmers' seed is therefore critical to farming system performance. Adoption of maize varieties with best-bet traits and rotations or intercropping with legumes, when matched with compatible conservation agriculture-based sustainable intensification (CASI) practices, have considerable potential for boosting productivity and helping to reverse the decline in soil fertility, which is the fundamental cause of poor yields under smallholder conditions (Aagaard 2011; Thierfelder, Bunderson & Mupangwa 2015; Thierfelder, Cheesman & Rusinamhodzi 2013).

Notwithstanding benefits of new and high-yielding varieties, seed recycling and partial replacement of poorly performing varieties with breeder-improved material has been widely documented (Wilkus 2016). Varietal substitution and complete adoption among household farmers in ESA remains very low. In other parts of the world, progress in plant breeding and frequent release of improved varieties to the market have resulted in rapid variety replacement and large productivity gains (Boyer et al. 2013; Roth, Ciampitti & Vyn 2013; Shiferaw et al. 2011). In the US, the average life cycle of a maize hybrid on the seed market is only five years (Magnier, Kalaitzandonakes & Miller 2010) while in ESA the average life cycle of modern maize varieties grown by farmers is 23 years, thereby delaying—or forgoing—benefits of improved germplasm (Atlin, Cairns & Bas 2017; Hassan, Onyango & Rutto 1998). Recent evaluations of in situ maize–legume varieties in ESA found a predominance of traditional, lower-yielding varieties compared to modern maize and legume varieties with multiple stress-tolerant traits (Atlin, Cairns & Bas 2017).

The International Maize and Wheat Improvement Center (CIMMYT) initiated SIMLESA in 2009. This collaborative project investigated methods of incorporating best-bet varieties into farming systems to increase yields in low-input and/or drought-prone environments in ESA. A range of maize and legume varieties were first tested in regional multilocation trials and selected varieties were further tested with farmers and seed companies on farms practising sustainable intensification methods. Seed road maps were developed with seed companies to enhance the seed availability of the most favoured, best-bet maize and legume varieties. In collaboration with 42 seed companies, 51 drought-tolerant maize varieties with adaptive traits and 61 legume varieties of various maturity groups compatible for intercropping were identified for use in CASI systems. To date, more than 7,000 t of maize certified seed and 4,000 t of legume seed have been marketed and promoted annually by partner seed companies.

This chapter summarises the seed systems work under the SIMLESA program by reviewing efforts to identify and select maize and legume germplasm for various agroecologies in ESA. Seed system structures and operations involved in maize and legume seed production and distribution are then discussed. With a focus on seed access, we highlight seed flow between the formal and informal seed systems (Sperling & McGuire 2010; Sperling, Scheidegger & Buruchara 1996; Wilkus 2016) and differences between open-pollinated versus hybrid seed recycling potential. Finally, we present strategies for scaling development and dissemination of improved maize and legume germplasm.

Maize and legume crop production

Maize is one of the most important crops grown in ESA (Table 9.1), representing 85–90% of total cultivated land area (FAOSTAT 2015).

Table 9.1 **Area and production of maize and legumes in SIMLESA countries, 2012–14**

Country	Maize			Legumes		
	Area (Mha)	Yield (kg/ha)	Production (Mt)	Area (Mha)	Yield (kg/ha)	Production (Mt)
Ethiopia	2.115	3,421	7.235	1.532	1,706	2.613
Kenya	2.116	1,660	3.513	1.719	612	1.052
Malawi	1.676	1,656	2.776	0.66	1,008	0.666
Mozambique	1.704	797	1.357	1.175	428	0.503
Tanzania	4.146	1,625	6.737	2.068	931	1.924

Source: FAOSTAT 2015

Maize and legume variety selection and seed production in ESA is for crop production under rainfed conditions by smallholder farmers (Kassie et al. 2012; Smale 1995). Production across ESA spans highly variable environments and socioeconomic conditions. In general, conditions include low soil fertility, frequent drought and low, irregular use of inorganic fertiliser (Abakumov 2008). Most resource-poor farmers cultivate about 1–3 ha of land, the smallest hectarage being in Malawi and the largest being in Mozambique (Ray et al. 2012; Shiferaw et al. 2011). Maize and legume grain yields in 2015 were lowest in Mozambique and highest in Ethiopia, with maize yields of 707 kg/ha in Mozambique and 3,421 kg/ha in Ethiopia and pulse grain yields of 428 kg/ha in Mozambique and 1,706 kg/ha in Ethiopia (Table 9.1). One-third of maize in Kenya, Mozambique and Tanzania is grown in areas with a 40–60% frequency of a failed season due to drought, and the yield loss is estimated to be between 15% and 90% depending on the stage when drought occurs (Bänziger & Araus 2007; Kostandini, La Rovere & Abdoulaye 2013).

Yields are predicted to decrease with climate change and increased climate variability, due to increases in maximum temperatures and a reduced duration of the rainfall season (Cairns et al. 2012, 2103). These conditions affect varietal performance and farmer preferences. Maize and legume germplasm that is better suited to these conditions can support multiple performance outcomes with potential to slow down or reverse declining soil fertility and organic matter content (Thierfelder et al. 2013, 2015; Thierfelder, Cheesman & Rusinamhodzi 2012), while enhancing farmers' yields. The development and deployment of maize varieties that perform well under these conditions is an important intervention for ensuring a stable and secure agriculture sector into the future.

Maize and legume variety selection

Recognising the potential gains from genetic improvement, the CIMMYT maize program spent the last 30 years investing in the development of improved maize varieties for ESA. CIMMYT initiated a collaborative drought and low N maize breeding program in 1997 to increase yields in low-input and/or drought-prone environments (Bänziger et al. 2006). The new maize varieties with multistress-tolerant characteristics showed potential to increase farmers' yields by 20% to 50% under stress conditions (Setimela et al. 2017). The International Centre for Research into Semi Arid Tropics, under the Tropical Legume Project, also developed and released various legume varieties with potential to improve grain yield and maintain soil fertility, especially with improved rhizobia. The SIMLESA program selected the improved varieties obtained by breeding projects, tested them with farmers, promoted them and tried several scaling methods to disseminate them. Most of the legume varieties identified for scaling up in SIMLESA were derived from the Tropical Legume Project.

Hybrid breeding has consistently been the major focus of the CIMMYT breeding pipeline. However, open-pollinated varieties have also been generated within the hybrid pipeline (Masuka et al. 2017). Hybrids are the first-generation product of a cross between two or more genotypes under controlled pollination. Hybrids are more uniform and higher yielding than open-pollinated varieties, but the seed cannot be recycled as it results in high yield penalty in subsequent filial generations. Open-pollinated varieties, on the other hand, can be produced by allowing pollinations among plants so that individual plants share a common gene pool. Due to mixtures in genotypes, open-pollinated varieties are more variable than any type of hybrid. In contrast to hybrid seed, open-pollinated seeds can be recycled with lower or no yield loss penalty. Masuka et al. (2017) evaluated genetic gain of CIMMYT-developed open-pollinated varieties and found that both yield potential and stress tolerance consistently increased over time. The breeding strategy has been described by Bänziger et al. (2006) and can be summarised as follows:

1. parent lines are crossed and progenies advanced to the F3 stage
2. families are testcrossed to a single cross or to a broad base population tester
3. hybrids are evaluated under optimal conditions, managed drought stress and low N stress
4. selected materials are further evaluated in disease hotspots for key maize diseases
5. top performing hybrids are evaluated in regional trials across ESA.

These trials are designed to simulate smallholder fields with various biotic and abiotic stresses (Bänziger & Diallo 2001). Only those genotypes that perform well under managed stress and optimum conditions are considered ideal for production by smallholder farmers.

The selected maize hybrids and open-pollinated varieties are further tested on-farm using the participatory evaluation scheme known as the 'mother–baby' trials (Bänziger & de Meyer 2002). Mother trials are researcher-managed trials grown in the centre of farming communities with a complete set of varieties being evaluated under both recommended and farmer-representative agronomic practices. Baby trials are farmer-managed trials grown around the mother trials, with only a subset of the varieties in the mother trials, using farmer-representative agronomic practices. Under this evaluation methodology, farmers rank varieties based on the characteristics they prioritise when deciding on the relative merit of each maize variety. They indicate the importance of specific traits as 'very important', 'regular' or 'not important'. Varieties are scored and ranked. The score of a variety is the average, weighted by the level of importance of the specified traits. A value of 1 is allocated to 'very important', a value of 0.5 is allocated to 'regular' and a value of –1 is allocated to 'not important'. Criteria importance was the average score given to a characteristic (Table 9.2).

Table 9.2 **Farmers' selection criteria for various crops on-farm**

Rank of importance	Maize	Soybean	Common bean	Forage
1	drought-tolerant	seed colour	seed colour	shade-tolerant
2	stay green	maturity	maturity	biomass
3	yield	market ability	market ability	plant height
4	disease-resistant	seed size	seed size	maturity
5	husk cover	pest-resistant	pest-resistant	adaptability
6	cob size			dual-purpose
7				groundcover

The maize varieties that were identified and released through this process under SIMLESA ranged in maturity and ecology across sites (Table 9.3). This suggests that farmers select traits to suit a variety of growing conditions. Yield potential among selected materials tended to be high, but selections also included some medium-potential material and resistance to leaf rust, leaf blight, grey leaf spot and striga. Similar methods were applied for breeding and selecting legumes, with the participation of farmers.

Table 9.3 Identified and released maize varieties under the SIMLESA program for the various agroecologies

Country	Variety	Vigour	Maturity	Ecology	Yield potential	Special traits
Ethiopia	MH140	hybrid	medium	subhumid mid-altitude	high	
	MH130	hybrid	medium	subhumid mid-altitude	high	
	MH138Q	hybrid	medium	subhumid mid-altitude	high	QPM
	BH547	hybrid	medium	subhumid mid-altitude	high	leaf rust, leaf blight, GLS
	BH546	hybrid	medium	subhumid mid-altitude	high	leaf rust, leaf blight, GLS
	BH661	hybrid	medium	subhumid mid-altitude, transitional mid to highland area	high	leaf rust, leaf blight, GLS
	Gibe2	OPV	medium	subhumid mid-altitude, transitional mid to highland area	medium	leaf rust, leaf blight, GLS
	Melkassa2	OPV	medium	subhumid mid-altitude, transitional mid to highland area	medium	leaf rust, leaf blight, GLS
	BHQPY545	hybrid	medium	subhumid mid-altitude, transitional mid to highland area	high	QPM
	Shalla	OPV	medium	subhumid mid-altitude, transitional mid to highland area	medium	leaf rust, leaf blight, GLS
Kenya	KH500–39E	hybrid	medium	upper midland	high	
	KH500–38E	hybrid	medium	upper midland	high	
	KH533A	hybrid	early	upper midland	high	
	Emb 226	OPV	medium	upper midland	high	
	Emb 225	OPV	medium	upper midland	high	
	KH 633A	hybrid	medium	upper midland	high	
	KH631Q	hybrid	medium	upper midland	high	QPM, stay green
	KSTP 94	OPV	medium	low–medium midland	high	striga tolerant
	KDV1	OPV	medium	upper midland	high	
	KDV6	OPV	medium	upper midland	high	
	H520	hybrid	medium	upper midland	high	
Tanzania	TAN H600	hybrid	medium	mid-altitude	high	drought-tolerant, resistant to MSV, GLS and tursicum blight
	Selian H208	hybrid	medium	mid-altitude	high	drought-tolerant, resistant to MSV, GLS and tursicum blight
	Selian H308	hybrid	medium	mid-altitude	high	drought-tolerant, resistant to MSV, GLS and tursicum blight
	TZH538	hybrid	medium	mid-altitude	high	drought-tolerant, resistant to MSV, GLS and tursicum blight

Table 9.3 **Identified and released maize varieties under the SIMLESA program for the various agroecologies (continued)**

Country	Variety	Vigour	Maturity	Ecology	Yield potential	Special traits
Malawi	ZM309	OPV	very early	dry mid-altitude	low–medium	flinty, MSV resistant
	ZM523	OPV	medium	dry mid-altitude	medium	MSV resistant
	ZM623	OPV	late	dry mid-altitude	medium	MSV resistant
	ZM721	OPV	late	dry mid-altitude	medium–high	MSV resistant
	MH26	hybrid	medium	dry mid-altitude	high	MSV resistant
	MH27	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH31	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH32	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH33	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH34	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH35	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH36	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH37	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
	MH38	hybrid	medium	dry mid-altitude	high	drought-tolerant, MSV and GLS resistant
Mozambique	SP–1	hybrid	medium	mid-altitude	high	MSV and GLS resistant
	Molocue	hybrid	medium	mid-altitude	high	MSV and GLS resistant
	PAN 53	hybrid	medium	mid-altitude	high	MSV and GLS resistant
	Pristine 601	hybrid	medium	mid-altitude	high	MSV and GLS resistant
	ZM309	OPV	early	dry mid-altitude	low–medium	MSV and GLS resistant
	ZM523	OPV	medium	mid-altitude	medium	MSV and GLS resistant
	Tsangano	OPV	medium	mid-altitude	medium	MSV and GLS resistant
	Dimpa	OPV	early	low altitude	early	downy mildew resistant, MSV resistant
	Gema	OPV	early	low altitude	medium	orange, flint, downy mildew resistant

Notes: GLS = grey leaf spot; MSV = maize streak virus; OPV = open-pollinated varieties; QPM = quality protein maize

In ESA, where maize is most often intercropped with common bean, maize and common bean variety development has occurred in concert. Under SIMLESA, three participatory variety selection trials were conducted in Ethiopia to evaluate eight common bean varieties (Awash–1, Awash Melka, Nasir, Dinkinesh, Deme, GLP-2, ECAB-0081 and ECAB-0056). The trials were conducted across three locations in the Central Rift Valley. The results showed that farmers preferred small red bean (Nasir, Dinkinesh and Deme) at Shalla, and small white bean varieties (Awash–1 and Awash Melka) at Bulbula and Bofa. Unlike maize, farmers selected bean varieties based on colour and cooking qualities (Table 9.4).

Table 9.4 Legumes varieties demonstrated and promoted under SIMLESA

Country	Crop	Varieties
Ethiopia	Beans	Nasir, Awash 1, Hawassa, Deme, Dinkinesh, SER–125, SER–176, SER–119
	Soybean	Hawassa-04, Korme, AGS-7–1, Nyala, Gozilla, Nova, Belessa-95
	Peanut	Fetene
	Cowpea	Bole
	Mungbean	Boreda, N 26
	Cowpea	Acc. 17216, Acc.12688, Black eye pea, Kenkety
	Lupine	Bora, Vibrator, Sanabor
	Lablab	Acc. 1169
Kenya	Beans	KK 8, KK 15, B 9, Embean 118, K 071, Embean 14, KAT x69
	Pigeonpea	ICEAP 00554, ICEAP 00040, ICEAP 00850, ICPL 87091
	Soybean	SB 19, SB 3
	Peanut	ICGV 90701, ICGV 99568, ICGV 12991
Malawi	Peanut	Chitala, Kakoma, Chalimbana 2005, CG 7, Nsinjiro, ICGV SM 01711, ICGV 01514, ICGV 99551, ICGV 99556, ICGV 01708, ICGV 01728
	Pigeonpea	Mwaiwathu Alimi, Chitedze pigeonpea 1, Chitedze pigeonpea 2
	Soybean	Makwacha, Tikolere, Nasoko
Mozambique	Pigeonpea	ICEAP 00040
	Cowpea	IT 16, IT 18, INIA 36
	Soybean	TGx 17 40–2F, H7, H17, H 19
	Beans	Diacol Calima, Manteiga
Tanzania	Pigeonpea	Mali, Kiboko, Karatu 1, Ilonga 14-M1, Ilonga 14-M2, Tumia
	Peanut	ICGV 12991, ICGV 99568

In another experiment, beans were intercropped with maize 30–35 days after planting. The results show a 5% yield increase from sole cropping when Melkassa 2 maize was intercropped with Deme, Dinkinesh and GLP-2. Multiple maize and legume varieties were identified by farmers and registered for production in Kenya, Tanzania, Malawi and Mozambique in addition to Ethiopia. In Mozambique, two medium-duration (ICEAPs 00554 & 00557) and two long-duration pigeonpea varieties (ICEAPs 00020 & 00040) with yield advantage of 30–56% over local varieties were registered for production and promoted by SIMLESA.

Seed access

On-farm adoption of farmer-preferred, best-bet varieties realises the benefits of selection and breeding activities. These benefits can be substantial. For instance, yield gains and increased yield stability from adoption of drought-tolerant maize significantly reduced poverty with a 2.96% decline in Malawi, 0.58% in Mozambique, 1.39% in Zambia and 6.74% in Zimbabwe (Kostandini, La Rovere & Abdoulaye 2013; La Rovere et al. 2010). While these changes to the poverty level may seem minor, they show that benefits from genetic-based improvements can have downstream consequences to support positive social change. Multiple studies find evidence of breeder-improved seed in farmers' seed stocks, suggesting that farmers in ESA are interested in adopting breeder-improved varieties. For instance, farmers in Ethiopia reported the need for new varieties of seed as the most important reason for acquiring seed from off-farm sources (Abdi & Nishikawa 2017). Despite benefits of breeder-improved varieties, over half of the farmers in SIMLESA reported that they did not have access to improved seeds and used local varieties for cultivation. Access to viable breeder-improved seed depends on large-scale structural features of the seed system and options for recycling improved materials. At the intersection of these two factors are breeders and distributors that operate to either reinforce or break down barriers to access.

Seed systems have organised and contributed to seed exchange but also created obstacles that explain low adoption rates across SIMLESA countries. Seed exchange systems in ESA have been classified into two distinct operating systems: informal or local, and formal (Almekinders & Louwaars 2008). Under this scheme, household producers, farmer groups and farmers markets make up the local system. The formal system encompasses public and private sector breeders, research and extension organisations and regulation institutions and seed companies or non-profit distributors. The systems are distinguished by their organisation of resources and activities and the main actors involved. The formal seed system has a linear seed value chain that progresses from development, testing and registration of new varieties to maintenance of parental lines, seed production and, finally, marketing and distribution (MacRobert et al. 2014). The formal seed sector follows seed certification procedures with third-party actors to manage seed quality (Almekinders & Louwaars 1999; Almekinders, Louwaars & De Bruijn 1994). In contrast to the linear progression of activities found along the formal system, activities in the informal seed system tend to be more embedded, utilising overlapping physical and social resources (Wilkus 2016). The term 'informal' has been used to describe seed networks operated primarily by small-scale agricultural producers. These are composed of seed that is sourced and circulated within and among household producers through seed-saving, selection and exchange practices using household producers' knowledge and social relationships (Sperling & Cooper 2003; Almekinders & Louwaars 1999).

Seed quality management practices have also been used to distinguish informal and formal seed systems. In the informal seed system, farmers exchange their own seed and quality is guaranteed by the seller without public sector regulation (Thiele 1999). In the informal system, seed quality can be determined by tests that can be conducted at the point of purchase (e.g. the buyer can place the seeds in water to see if they float, indicating that they are hollowed or insect-damaged) and sellers will sort seeds to distinguish grain versus seed quality material. In contrast, seed management, multiplication and certification activities in the formal seed system are categorically subject to evaluations under public regulatory systems.

Analyses of farmer seed stocks (Wilkus et al. 2018) and seed management (Sperling & McGuire 2010; Sperling, Scheidegger & Buruchara 1996) suggest that farmers in ESA access seed at multiple points in the formal, informal and intermediate seed systems. The informal seed market has been identified as the main source of seed for 60–80% of farmers in SSA (Daniel & Adetumbi 2004; Marfo et al. 2008). Informal sources have represented 84% of annual maize seed planted, with significant contributions from of each informal source (own harvest, another farmer, informal seed market) (Abdi & Nishikawa 2017). Household seed stock in Uganda (Wilkus et al. 2018) also displayed similar levels of diversity with a significant share of seed stock from each source, suggesting that farmers utilise a complex seed supply network to maintain seed stocks. In contrast, seed companies have historically reached a very limited subset of household producers. For instance, in 2005, the sector supplied 3,600 t of certified seed, which represented 6% of the national requirement (Almekinders & Louwaars 2008). Seed companies have also been reluctant to replace old varieties due to lack of competition and lack of information reaching farmers about new improved varieties (Abate et al. 2017). In Uganda, the few household producers who received seed from the formal sector typically received a limited quantity of breeders' seed on contract for multiplication (Wilkus et al. 2018).

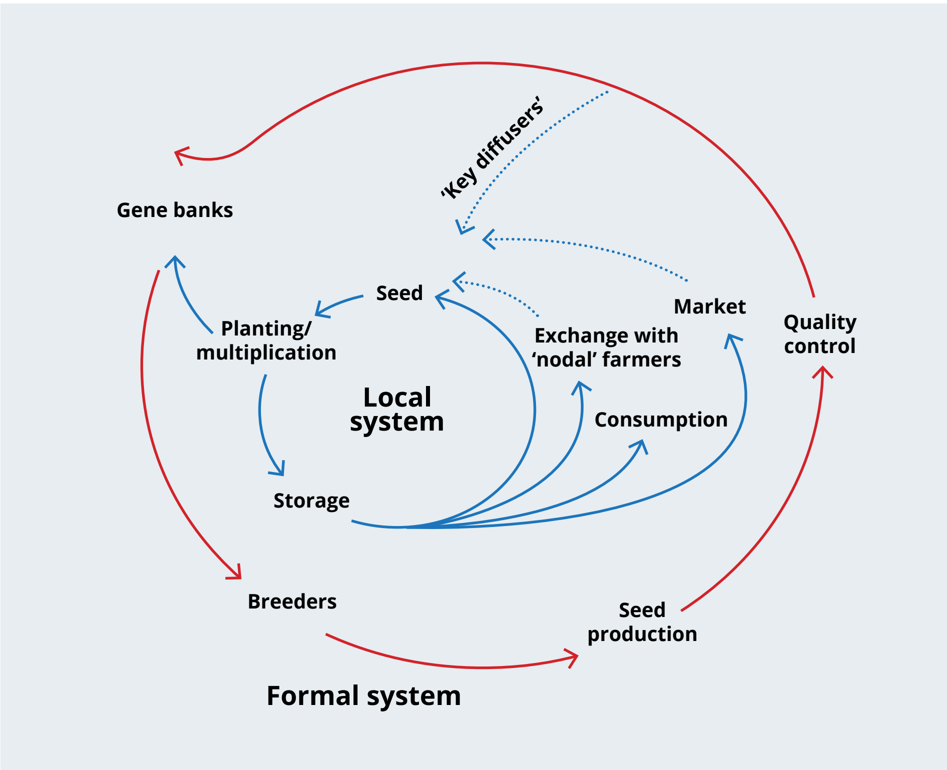

Figure 9.1 A heuristic model of the formal (red) and informal (blue) seed systems

Notes: Lines and arrows indicate access points and direction of seed exchange. Dotted lines represent seed exchange that recycles seed within a community of farmers.
Source: Adapted from Almekinders & Louwaars 2008

The local system in Figure 9.1 is depicted as the innermost ring. This ring represents a basic household seed-saving process where seeds are planted and multiplied. The seed harvested from that season is stored within the household as future planting material. Households might also eat the prior seasons' harvest, terminating future seed circulation in the local seed system. The original model presented by Almekinders and Louwaars (1999) was adapted in Figure 9.1 to include the concept of the nodal farmer (Abay, de Boef & Bjornstad 2011). The nodal farmer emerged out of evidence that farmers accessed seed through a common, trusted community member (i.e. the nodal farmer). Nodal farmers may also be the primary sources of seed loans or gifts that supplement seed stocks. Abay, de Boef and Bjornstad (2011) first characterised the nodal farmer, based on evidence from a barley seed network analysis in Ethiopia that some farmers linked otherwise distinct networks of seed exchange within the local seed system. In their survey of 130 household producers, Abay, de Boef and Bjornstad (2011) found that nodal farmers played an especially significant role when households experienced an unintended shock, like an illness in the family or an unintended expense, and their seed stocks were too low to provide enough material for planting. Informal interviews with household producers in Hoima, Uganda (Wilkus 2016) suggest that households tended to prefer nodal farmers over formal institutions, including public extension services, based on the trust that they garnered. Other households preferred to buy seed at a local market rather than take out a loan that would leave them indebted to community members.

In addition, the seed systems model presented by Almekinders and Louwaars (1999) suggests that household producers have one mechanism for accessing seed selected by formal system breeders, seed production and quality assurance institutions. Wilkus (2016) expanded on this model to include multiple points of access to breeder-improved seeds via the intermediate seed system, based on evidence from a 2013–14 survey of household producers in Uganda. The intermediate seed system includes partnerships that have been developed or activities that have been implemented to link formal breeding and seed distribution with household producers. In addition to recycling seed, the study found that household producers in Uganda accessed breeder-improved seed from nodal farmers, other household producers and micro-, small- and medium-size enterprises. They did this through participation in participatory varietal selection trials and participatory seed dissemination with public sector institutions; seed multiplication contracts with seed companies; or as managers, multipliers and benefactors of community seed banks (Figure 9.2). The role of the intermediate seed system is evident in Ethiopia, where local varieties (that existed two decades ago) were replaced by medium- to early-maturing varieties. Sixty per cent of maize growers obtained improved seed through farmer-to-farmer seed exchange, neighbouring farmer groups and micro-, small- and medium enterprises (Abdi & Nishikawa 2017).

The SIMLESA program used both the formal and informal seed systems to reach farmers with improved seed. Most of the maize varieties were distributed through the formal seed systems while legume varieties were distributed mostly through the informal seed sector. The private seed industry is most well developed in Kenya, Malawi and Tanzania and less developed in Mozambique and Ethiopia. The SIMLESA program collaborated with more than 40 seed companies of large, medium and small capacity. For fast seed scaling, some of the seed companies were given initial breeders seed to produce basic seed.

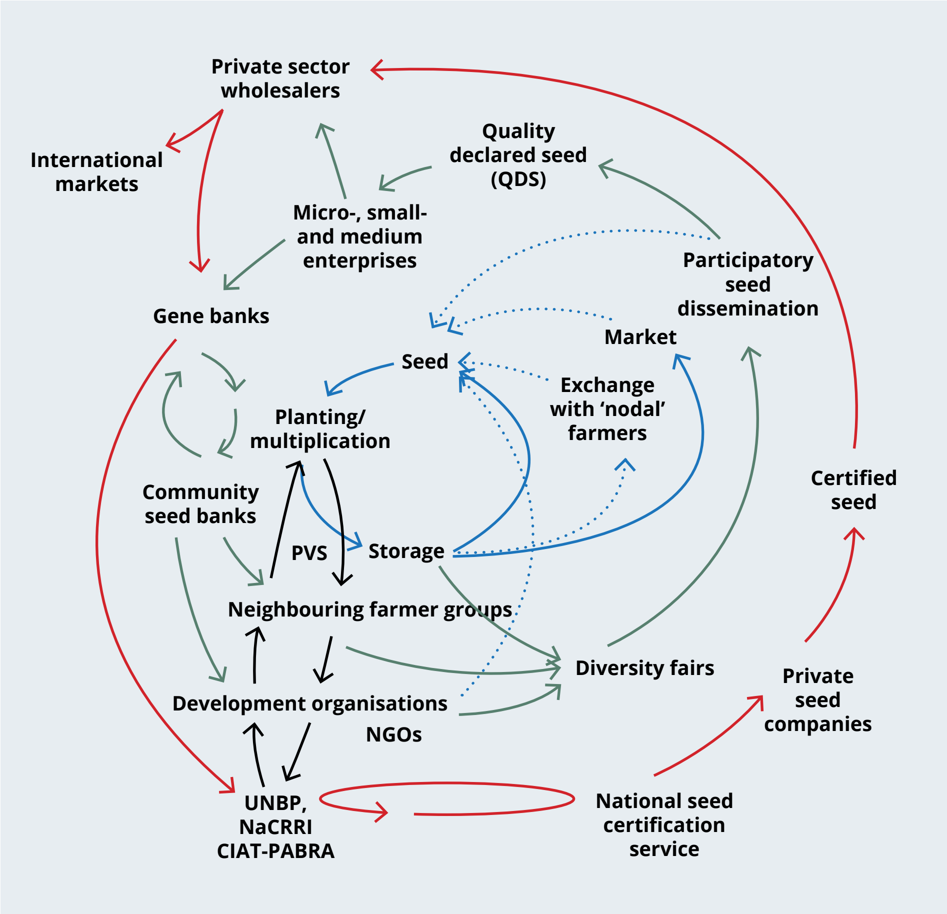

Figure 9.2 **A heuristic model of the formal (red), informal (blue) and intermediate (green) seed systems and main components of participatory varietal selection trials (PVS, black) in Uganda**

Notes: The black line represents the flow of seed through participatory varietal selection trials. Lines and arrows indicate access points and the direction of seed exchange. PVS = participatory varietal selection; NGO = non-government organisation; UNBP = Uganda National Bean Program; NaCRRI= National Crops Resources Research Institute; CIAT-PABRA = International Center for Tropical Agriculture (CIAT)/ Pan-Africa Bean Research Alliance (PABRA)
Source: Adapted from Wilkus 2016

In addition to the organisation and processes that make up the seed system, seed recycling potential is a major determinant of seed access. Recycled seed has represented a significant share of household seed stocks in ESA. Recycling can result in genetic contamination or admixture of hybrid, open-pollinated varieties and landrace maize varieties, which can result in yield loss. The extent of contamination depends on the crop's isolation from other varieties, which is challenging to manage under most farming system conditions in ESA (Morris, Risopoulos & Beck 1999). Even in the absence of contamination, inbreeding can reduce yield potential for recycled seed.

The recycling potential of seed varies significantly between two broad types of maize seed: hybrid and open-pollinated varieties (Denning et al. 2009). Conventional hybrids are produced through crossing genetically diverse inbred lines. The resulting first-generation progeny are said to exhibit hybrid vigour. Inbreeding from recycling the first-generation seed usually reduces yield by at least 20% in the first recycling generation (Morris, Risopoulos & Beck 1999). Therefore, the general advice is not to replant hybrid seed to produce the subsequent crop. In theory, yields should stabilise by the second recycling generation, but empirical studies have shown yield reductions continue to increase up to the third recycling generation (Ochieng & Tanga 1995). In Ethiopia, for example, yields of recycled top crosses reduced by 16%, 17% and 32% and those of double crosses decreased by 20%, 37% and 46% for the first, second and third recycling generations respectively (Japhether et al. 2006). Breeder-improved open-pollinated varieties are multiple-line synthetics and can often be recycled for up to three years without a significant loss in yield, but their yield potential is typically around 20–25% lower than hybrids (Pixley & Bänziger 2004). Farmers’ knowledge and management practices have shown some sensitivity to variability in recycling potential across varieties. For instance, on average, Ethiopian farmers renewed their open-pollinated variety maize seed lots every three years as yield losses become uneconomical (Abdi & Nishikawa 2017). Seed lot change among Ethiopian farmers was also driven by the need for annual hybrid seed renewal (Abdi & Nishikawa 2017). Annual hybrid seed renewal was among the top three reasons reported by farmers in Ethiopia for acquiring seed from off-farm sources, representing 14% of surveyed farmers.

Despite yield losses, recycling seed of hybrid maize varieties has been common practice for the majority of producers in Kenya and other SSA countries (Morris, Risopoulos & Beck 1999). Thirty per cent of maize production area in SSA was estimated to be planted under first-generation hybrid maize seed while the remaining 70% was under recycled maize varieties, which included breeder-improved hybrid maize varieties, and both breeder-improved and landrace open-pollinated varieties (Ligeyo 1997; Onyango 1997; Onyango et al. 1998). The maize varieties that were identified and released in SIMLESA included both hybrid and open-pollinated varieties (Table 9.3). Despite differences in seed recycling potential, farmer rankings did not indicate a preference for open-pollinated varieties over hybrids.

The choice to recycle has been attributed to both socioeconomic and biological factors (Akulumuka et al. 1997; Morris, Risopoulos & Beck 1999; Zambezi al. 1997). Main factors include the prohibitively expensive cost of certified seed, supply shortages of preferred varieties at accessible markets and management practices that discount varietal differences in yield losses from recycling (Wanyama et al. 2006). Farmers forgo benefits while saving on costs when recycling. One evaluation of yield losses and economic performance of hybrid maize production in Kenya determined that it remained economical to recycle hybrid maize varieties up to the third generation (Japhether et al. 2006).

Seed multiplication and dissemination strategies

The main obstacle to farmers adopting improved varieties is the timely availability of affordable, trustable, good-quality seeds. Therefore, a key component of SIMLESA activities was the organisation, support and evaluation of several modalities of seed multiplication and dissemination. Efficient and cost-effective multiplication and dissemination of seed is a complex task, considering the considerable investment that is made in anticipation of an uncertain demand and the limited shelf life of the marketable product (the seed). Effective production of seed is the main driver of success for seed companies. This remains a challenge for the public sector seed producers and farmer groups.

Maize seed production requires that growers meet strict seed production standards. With unlimited resources, seed companies plant their own seed so they can control conditions. However, land limitations mean that companies must go through community-based organisations and non-government organisations to contract with individuals or groups of farmers to grow seed on their behalf. Contract farming, however, has many challenges. It is difficult to achieve the isolation distances required to ensure genetic purity and seed quality in most of the communal farms. The coordination with farmers inevitably requires significant investment in training, developing agreements, inspecting, bulking and transporting seed. In addition, most smallholder farmers are rainfall reliant, exposing their seed production to the risk of drought.

The approach used for multiplying and distributing the varieties identified under SIMLESA was identified using various methods, one of which was to develop seed road maps (Figure 9.3). A seed road map is a plan to extend the reach of seed production activities. It involves a seed company or an institute in which seed production targets for certified seed are set based on the amount of breeder and foundation seed available, the multiplication rate for the particular crop and the expected demand for certified seed of the variety being produced. Each partner specifies the quantities of breeders and foundation seed that are available, or that need to be produced in a given time frame, to be able to produce desired certified seed. The amount of certified seed to be produced is determined by the projected demand from the various markets within specific time frames. In each season, different classes of seeds are produced to ensure that the target production of certified seed is met. The seed road map also supports promotional activities, like demonstrations that create demand. Under SIMLESA, the initial early generation seed was provided to seed companies to support rapid multiplication of certified seed.

Besides seed road maps, the program built seed production capacity for seed companies and community-based organisations. It provided technical backstopping on genetic purity and closely monitored technical issues on seed production (e.g. recommendations on isolation distances of various legumes and maize seed production). The program formed groups of farmers who multiplied legume seed. This approach reduced costs of inspection, bulking and transportation. It also identified specific products for each agroecology. These selections were based on performance and the complexity of seed production. A total of 40 maize hybrids and open-pollinated varieties reached farmers across the SIMLESA countries through these efforts.

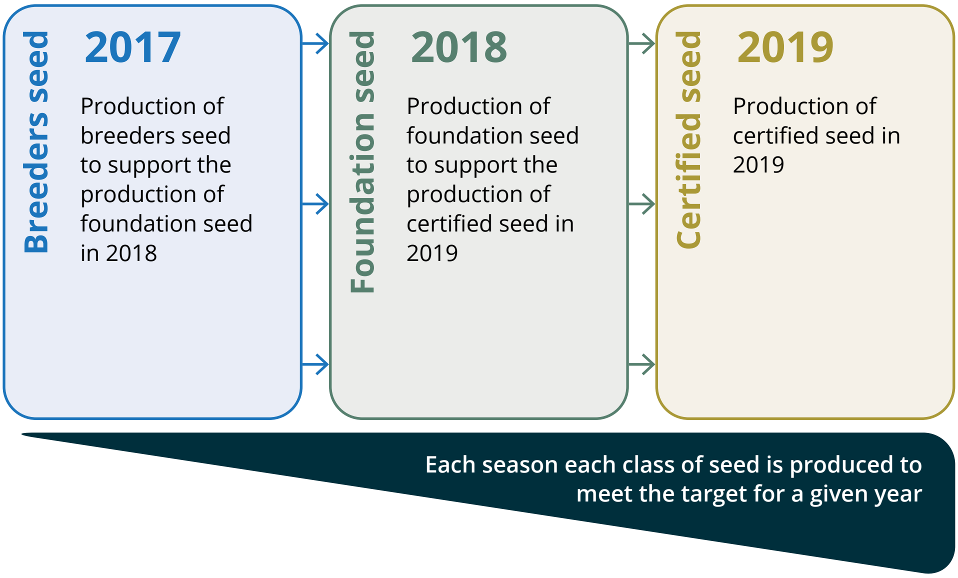

Figure 9.3 Systematic diagram of a seed road map

Private sector involvement in eastern and southern Africa

The private seed industry has made dramatic gains in ESA in recent years as the number of seed companies has increased four to five times, marketing both legume and maize seed (Langyintuo et al. 2008). However, the seed industry was composed of different players during the SIMLESA project (Table 9.5). The largest are multinational companies such as Monsanto, Corteva and Syngenta; large former national seed companies like Zimbabwe's Seed Co, the Kenya Seed Company and Zamseed; and emerging local seed companies that have received support from the Alliance for a Green Revolution in Africa (AGRA 2015). The value chains of multinational and former national seed companies all included research, seed production, processing and marketing. The emerging seed companies have lacked the capacity to develop germplasm and depend on the CGIAR centres such CIMMYT, International Centre for Research into Semi Arid Tropics and national agricultural research systems (NARS) for germplasm. While it is not necessary to be involved in all the steps of the seed value chain, emerging small seed companies are involved in seed production and marketing. More than half of the maize and legume areas are planted to traditional unimproved varieties. The majority of smaller seed companies produced less than 500 t of certified seed, which they market in rural areas. The multinationals and larger former national seed companies focused on high-potential and luxury markets close to urban areas, which had better infrastructure. The seed gap is serviced by the informal seed sector: mostly governments and non-government organisations participating in relief projects.

Within the SIMLESA project, most of the emerging seed companies sourced varieties of maize and legume from the CGIAR centres, national agricultural research systems or foundation seed companies, while seed production was contracted to farmers. In some instances, the processing of certified seed was also contracted to other seed companies that had the infrastructure to clean and package the seed into company bags.

Table 9.5 Seed companies involved in scaling SIMLESA products in ESA

Country	Seed company	Size			
		Large multinational	National	Medium	Small
Ethiopia	Ethiopian Seed Enterprise		x		
	South Seed Enterprise			x	
	Amhara Seed Enterprise		x		
	Oromia Seed Enterprise		x		
	Pioneer	x			
	Meki-Batu Union				x
	Alemayehu Farm				x
	Gadisa Gobena				x
	Anno Agro-Industry				x
	Ethiopian Veg Fru			x	
Kenya	Western Seed Company Ltd		x		
	Kenya Seed Company Ltd		x		
	Dryland Seed			x	
	Bubayi Products Ltd			x	
	Sustainable Organic Farming				x
	Western Kenya Seed			x	
	Growers association				x
	Freshco Seeds			x	
	Migotiyo Plantation Ltd				x
Tanzania	Meru Agro			x	
	Aminata Seeds				x
	Agricultural Seed Agency		x		
	Suba Agro			x	
	Tanseed International		x		
Malawi	Seed Co (Mw) Ltd		x		
	Demeter Agriculture Ltd			x	
	Funwe Farms Ltd			x	
	CPM- Agri-Enterprise Ltd				x
	Seed Tech Ltd				x
	Panthochi Ltd				x
	Peacock Investments Ltd			x	
	Multi Seed Company				x
	Mkomera Seeds				x
	Prime Seeds				x
Mozambique	Dengo Commercial				x
	Nzara yapera				x
	Woruwera			x	
	Phoenix			x	
	Klein Karoo		x		
	PANNAR	x			
	Bonimar				x
	Olinda Foundo				x

The future of seed systems in ESA

There is significant potential for the public and private sector to extend their reach to encompass a greater diversity of production environments throughout ESA. As research and development opportunities continue to emerge within the intermediate seed system, farmer participation in formal breeding efforts may help ensure that varietal development and distribution better support long-term adoption and farming systems benefits for rural farmers in ESA. Markets are growing for both hybrid and open-pollinated varieties. Although hybrid maize varieties have been primarily developed for high-potential areas, hybrid production has recently expanded across diverse conditions in ESA, with examples like the Central Rift Valley where it was grown by 30% of the farmers in 2013 (Beshir & Wegary 2014). This expansion of hybrid seed production has created an opportunity for private seed companies to invest in hybrid seed distribution in these regions. At the same time that hybrid seed adoption is increasing, recycling remains common practice. Although farmers are increasingly aware of yield reductions in recycled hybrid varieties, purchase of improved seed continues to be curtailed by unreliable or low supply of farmer-preferred varieties and the prohibitively high cost of new seed.

Open-pollinated varieties have generally accounted for approximately 18% of the formal maize seed sector in ESA (Langyintuo et al. 2010). Formal seed sector experience and the existing capacity to develop and distribute open-pollinated varieties varies across the SIMLESA countries. Open-pollinated varieties have consistently accounted for less than 20% of the formal seed sector in Malawi and Zimbabwe; however, they represent 71% of the formal sector in Mozambique (Kassie et al. 2012). While baselines may vary, development of open-pollinated varieties that compete with the most preferred hybrid maize may provide materials that farmers can grow without significantly losing yield as seed is recycled. Systems are in place to support development and dissemination of competitive open-pollinated varieties. Seed companies have favoured open-pollinated varieties over hybrids when promoting products to household producers because the lower cost of their seed production (compared to hybrid seed production) has allowed for the production of affordable seed (Pixley & Bänziger 2004). Breeding efforts by public sector institutions are continuing to generate gains in open-pollinated varieties (Masuka et al. 2017). At the same time, extension workers are promoting open-pollinated varieties of maize in many SIMLESA regions (Beshir & Wegary 2014). Although major breeding efforts, like the CIMMYT ESA breeding program, are placing increasing emphasis on hybrid development, we can expect open-pollinated varieties to remain a large component of the formal maize seed sector.

The supply of improved quality seed in ESA is expected to increase as the number of seed companies increase and enter the seed market in the next 10 years. Increased access to improved varieties will give smallholder farmers a greater supply of cheaper seed of preferred and diverse varieties. Newer varieties may completely replace older varieties or be used to complement seed stocks, with uncertain outcomes for the diversity of seed stocks (Wilkus et al. 2018). As the intermediate seed system continues to develop, the formal seed sector will increasingly be the source of seed, especially for cash crops. Breeding and seed dissemination faces challenges that emerge through the interaction of social, environmental and biological factors. Emerging challenges include market instability in the face of the COVID–19 pandemic, climate change and maize lethal necrosis disease, maize chlorotic mottle virus, sugarcane mosaic virus and fall army worm (Goergen et al. 2016; Mahuku et al. 2015). Seed system development that addresses these complex issues requires collaboration across disciplines. The seed system described in this chapter illustrates the extensive networks that have been developed to support collaboration across diverse stakeholders, sets of knowledge and resources. Seed companies are well positioned to collaborate with farmers to identify preferred traits and in situ genetic resources. They can also work with the CGIAR centres and NARS to source and disseminate new germplasm.

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10 Options to improve availability, nutritive value and utilisation of crop residue feedstuffs for ruminants

Mesfin Dejene & Rob Dixon

Key points

- Livestock, particularly ruminants (cattle sheep, goats) and equines, are essential in most smallholder farming systems for providing high-quality foods (meat and milk), transport, traction and manure as fertiliser. Increasing demand for animal foods is likely to provide market opportunities for smallholders.
- Poor nutrition of livestock from insufficient supply and low quality of available feedstuffs is a primary cause of low livestock productivity. Feedstuffs typically comprise low-protein fibrous materials that are limited in their value as a source of nutrition and energy or alternative uses as crop residue.
- Low-input manipulations of food crop production that increase the supply and nutritive value of feedstuffs from crop residues are possible. These have high potential to improve livestock productivity without compromising grain production for human food. This offers 'win–win' solutions for improved production of both food and crop residues that can be used as feedstuffs and provide more crop residues for conservation agriculture-based sustainable intensification.
- Such 'win–win' solutions are likely to involve technologies such as:
  - dual-purpose crop genotypes to increase the supply and feedstuff quality of crop residues
  - more selective allocation of crop residues for use as feedstuffs, for conservation agriculture, and for other uses
  - maximum use of animal excreta as fertiliser.
- An important limitation of most crop residues, especially cereals, as feedstuffs is their generally low nitrogen (protein) content. Food legume crop residues, which usually contain higher nitrogen concentrations, are useful to alleviate protein deficiencies in livestock diets. In addition, practical on-farm technologies that avoid potential problems are needed to safely and economically include non-protein nitrogen (e.g. urea) in ruminant diets.
- Optimal management of crop residues as livestock feedstuffs can also provide 'win–win' improvements by building on established known advantages of ruminants (e.g. greater use of diet selection, low-input inorganic supplements of nitrogen). Crop residue-based high-nutrient mixed rations are a promising technology in South-East Asia but need to be tested and demonstrated on-farm in eastern and southern Africa.

Introduction

The eastern Africa region is endowed with huge livestock resources representing the largest proportion of Africa's livestock population (Food and Agriculture Organization 2013). Livestock are central to livelihoods in rural Africa in general and in eastern Africa in particular, and are strategically important to food, security of high-quality foods and the economy (employment, direct income, intra-African and global trade) (Derner et al. 2017). Livestock also contribute substantially to gross domestic product and foreign currency earnings (Otte & Knips 2005). Mixed crop–livestock farming systems, in which crops and livestock are integrated on the same farm to maximise returns, are widespread in Sub-Saharan Africa (SSA) (Lenné & Thomas 2006). It is well established that livestock such as cattle, sheep, goats and equines play a key role in the sustainability, intensification and robustness of agricultural productivity in smallholder crop–livestock systems (World Bank 2009). In addition to providing milk and meat, livestock play a critical role in agricultural intensification through the provision of draught power and animal manure (dung and urine). The integration of livestock and crops allows for efficient recycling of crop residues and by-products as feedstuffs for livestock, and manure as crop fertiliser (Thornton 2010). Livestock reduce the risks from seasonal crop failures in mixed farming systems as they add to the diversification of production and income sources (Sansoucy et al. 1995). Importantly, livestock also provide a regular supplementary income to meet daily cash needs in many smallholder mixed farming systems.

The demand for animal protein in the form of meat, dairy products and eggs has been increasing rapidly, and is projected to continue to increase in coming decades (Delgado et al. 1999; Rosegrant et al. 2009). Growing demand has been attributed to factors such as population growth, urbanisation, increasing expectations, changing consumption patterns and general economic development. Delgado et al. (1999) estimated that in the five decades from the 1990s, the demand for livestock products will double and the most rapid increases will occur in developing countries. This growing demand for animal products provides opportunities for economic growth and improvements in livelihoods of the rural poor, albeit with increasing pressures and competition for resources. Based on these trends, increased productivity of farm activities has great potential for poverty-reducing growth (Otte & Knips 2005). Also, the ACIAR project ZimCLIFS demonstrated that, when crops and livestock are integrated, linking farmers to markets increased household income and nutritional status on existing land without a need to expand cropping area in Zimbabwe (Chakoma et al. 2016).

Despite the large livestock population in eastern Africa, the supply of livestock products is insufficient to meet demand. This can be attributed to low-input–low-output subsistence-oriented management practices, as well as general shortages and the low quality of feedstuffs available for livestock throughout the annual cycle (African Union–Inter-African Bureau for Animal Resources 2015). The feedstuffs that provide the nutritional base in smallholder systems are usually a combination of by-products of food crop production (especially cereals) and communal natural pastures, which are used opportunistically during the rainy season (Mekasha et al. 2014). Crop residues are especially important in the months after grain harvest, and during the dry season when pastures are scarce and at their lowest quality as feedstuffs. Substantial increases in pastures to provide feedstuffs are not feasible. Scarcity of land in relation to population density leads to a situation where it is generally not possible to allocate resources specifically for the production of fodder or pastures. Furthermore, there are often constraints associated with the management of livestock and pastures on common lands.

The availability of forage from grazing lands in eastern Africa has generally declined in recent decades, as population growth has increased demand for more lands for crop cultivation (Duncan et al. 2016). For example, a case study in Ethiopia revealed that over the last 30–40 years, grazing resources available to livestock keepers declined, resulting in increased dependence on crop residues and other feedstuffs from crop lands (weeds and crop thinning) (Mekasha et al. 2014). Furthermore, cereal crop yields have been stagnating in SSA for the last 40 years, with most increases in overall cereal production arising from the use of more land for cropping (Blümmel et al. 2013). Under business-as-usual scenarios, the feed base for livestock in eastern Africa will continue to depend heavily on an inadequate supply of crop residues, which are also generally too low in nutritional quality to maintain ruminant animals during the dry season.

Potential and limitations of crop residues as feedstuffs

As by-products of cereal and other food crop production in eastern Africa, the principal advantage of crop residues is that they require little additional investment in land, water or other farm inputs. Ruminant livestock can utilise highly fibrous low-protein materials such as crop residues and convert them into human food and useful services. This contrasts with monogastrics (such as chickens and pigs), which require relatively high-quality diets that may also be suitable for human foods. Another important consideration is that the amounts and quality of feedstuffs required for livestock, including ruminants, are highly dependent on the class of livestock and the level of production expected (e.g. as traction, meat, milk, etc.). Higher-producing animals (e.g. cows or goats that produce milk) require much higher-quality diets and more feedstuffs than animals in relative low production (e.g. those used for light transport). Therefore, the highest-quality available feedstuffs are usually allocated to the most productive animals. Limits on the quality and quantity of feedstuffs will often constrain production. When livestock have to depend primarily on crop residues as feedstuffs, it is inevitable that, at best, only modest levels of animal production are possible (e.g. as dual-purpose dairy systems with moderate milk production per animal, rather than the high-production dairy systems common in Europe or North America).

The use of crop residues as feedstuffs for livestock has a number of severe constraints. First, they are usually very high in fibre and low in essential nutrients. The characteristics of crop residues that most often constrain their use as ruminant feeds are:

- low dry matter digestibility (useful metabolisable energy)
- low nitrogen concentrations
- low acceptability to animals, including ruminants.

Generally, the amount of essential nutrients increases with increasing metabolisable energy intake which, in forage diets, is positively correlated with dry matter digestibility. The nitrogen concentration of most cereal residues, including maize stover, is usually much lower than the threshold needed even for low dry matter digestibility diets. This is often the primary limiting factor in utilisation of crop residues (Minson 1990). The general low acceptability of crop residues by ruminants also makes it difficult to achieve high voluntary intakes (Romney & Gill 2000; Forbes 2007). Extensive research and a vast body of literature has reported on the feedstuff value, the opportunities for improvement and the role of supplements in providing essential limiting nutrients to improve productivity of livestock fed diets based on crop residues (e.g. Dixon 1986, 1987, 1988; Doyle 1985; Doyle, Devendra & Pearce 1986).

It has been argued (Preston & Leng 1987) that some relatively high-quality by-products of crop production, such as protein meals, are of highest value when used as low-level supplements for ruminants being fed primarily on low-quality forages, such as crop residues. However, the general scarcity of suitable protein meals and the relative economic returns from poultry and ruminants usually means that most of the higher-quality crop by-products will be used for poultry production.

Knowledge of the variation in acceptability of crop residues across sources, especially when this is substantial, can be used to enhance their utility. Crop species (e.g. coarse-stemmed cereals, fine-stemmed cereals, food legume crops, horticultural crops), time of harvest (e.g. at grain or seed maturity or at some earlier stage of growth) and fractions (e.g. leaf, lower stem, upper stem, seed pods) vary widely in their value as feedstuffs for livestock. The characteristics desirable for feedstuffs may be unrelated to those needed for other purposes. For example, crop residues that are less fibrous, higher in nitrogen and green if harvested at a vegetative stage of plant growth are likely to be most useful as feedstuffs, but of low value for fuel or building. It has been shown that there is often substantial variation among the cultivars of many crops, which affect their feedstuff values (e.g. nitrogen concentration and dry matter digestibility of maize and common bean, Blümmel, Grings & Erenstein 2013; Dejene et al. 2018). Identification and use of cultivars with higher nitrogen and dry matter digestibility, and genetic selection and/or management manipulation of cultivars to increase their value as feedstuffs, have the potential to improve low-quality, residue-based diets and ruminant productivity. It is logical, and presumably usually occurs, for crop residues that are most fit for a particular purpose to be used as such. However, trade-offs in resource use will presumably occur where crop residues are in short supply and where the same characteristics tend to favour use as both a feedstuff and for other purposes, such as soil conservation.

Competing demands in crop–livestock agricultural systems

Allocation decisions are frequent when limited resources are used across farming system activities. Various characteristics, and the consequences (both short-term and long-term) of the alternative uses are a major part of what determines the best 'win–win' outcomes for the specific context of the mixed crop–livestock farms and the agroecosystems (Giller et al. 2009). In past decades, a common view, especially of specialised plant or animal scientists, has been that crop residues are low-value materials with few alternative uses. This is, in part, because they were considered too bulky to transport across long distances for uses such as for fuel. However, many studies have found value in multiple uses for crop residues and prompted the need to allocate limited supplies of crop residues across farm activities. For example, Shiere (2010) outlines the historical uses and approaches to the utilisation of straws and stovers (as dominant crop residues), and provides a comprehensive discussion about the changing demands for crop residues. Perhaps the greatest recent changes in demand for crop residues are associated with increased recognition of their use as surface mulch—an essential component of conservation agriculture-based sustainable intensification (CASI). Crop residue mulch complements minimum tillage, minimises erosion and maintains soil fertility. This changed role positions crop residues as a cornerstone of CASI production systems, with benefits beyond livestock production, and importance for the sustainability of the farming system as a whole. However, the requirement of CASI for large amounts of surface mulch may represent a large proportion of the crop residues produced, particularly in regions of lower cereal crop production.

This potentially generates a major competing demand for crop residues, rather than as feedstuffs for livestock. A number of general principles associated with use of crop residues as livestock feedstuffs have emerged to manage these trade-offs, which account for differences in investment options across regions and farming systems.

The varying levels of competition depend on the relative livestock and human populations, the nature and intensiveness of the established crop–livestock systems, farmer preferences, crop residue availability, crop residue demand and access to alternative resources (Erenstein et al. 2011; Valbuena et al. 2015). In regions where there are few livestock and/or where CASI is considered less appropriate, there is likely to be less competition. The opposite would apply in reverse circumstances, particularly where the production per hectare of both grain and crop residues are low. A key challenge will be to achieve 'win–win' outcomes for the region and the specific crop–livestock systems. One study of 12 locations across SSA and South Asia concluded that smallholder farmers tended to favour the use of crop residues for short-term benefits, specifically as animal feed, over mulching for soil fertility management (Valbuena et al. 2012).

Another important challenge is to distribute as much of the dung and urine from livestock as possible as fertiliser across areas of the cropping land, vegetable gardens and low-input plant production, and to do this in simple and culturally acceptable ways. The excreta of animals contain most of the nutrients present in the original feedstuff. The dry matter digestibility of a crop residue diet for livestock is usually around 45–55%, meaning that about half of the dry matter is excreted as faeces. Presumably the benefits of dung for soil organic matter is comparable to crop residue mulches or composts, although the carbon:nitrogen ratio will be lower and the rate of nitrogen mineralisation higher. However, dung will presumably tend to be less beneficial than mulch or other forms of surface litter for erosion control. A substantial proportion of the excreted nitrogen will be in urine rather than dung, and urine will obviously be more difficult to collect and recycle. Excretion of minerals such as phosphorus will comprise a large proportion of that in the original feedstuff.

Crop residue management also depends on the physical distribution of farming land, crops, homesteads, water, sites of threshing or processing of food crops and the need for oversight of livestock. These factors may influence the timely distribution and utilisation of crop residue products for livestock, and the feasibility of using crop residues as animal feed in specific situations (e.g. grazing of stubbles, hand-feeding). The low density of many crop residues and storage difficulties may also be important constraints. Based on these dynamics, Valbuena et al. (2012) suggest two intensification pathways to reduce trade-offs of crop residues use: improving crop residues quality and quantity, and livestock intensification in locations with high pressures and high trade-offs.

Options to increase and improve crop residues feedstuffs in eastern Africa farming systems

To address problems related to declining soil fertility in eastern Africa, options for conservation farming and related approaches were the focus of the SIMLESA program in maize mixed farming systems within the context of eastern Africa (Dixon et al. 2001). This included the investigation of low-input options to increase the amount and feedstuff value of crop residues from the most important crops and farming systems.

Crop residues from food legume crops, rather than cereals, were also investigated, although the production of food legumes was small compared to cereals. Legume crops were important in most farming systems, especially for providing high-quality high-protein foods and improving soil fertility. Their crop residues were expected to be higher in nitrogen content and consumed in greater amounts by ruminants than cereals (grasses) of comparable maturity and digestibility. These advantages of legume crops were well-recognised under SIMLESA, the N2Africa project and other related programs. Among the food legumes in eastern Africa, the focus was on common bean as the most widely grown food legume crop in these maize-based crop–livestock systems.

The research and development that has been conducted over recent decades in eastern Africa and elsewhere and can be used to improve the nutrition, management, genetics and health of livestock in smallholder farming systems has spanned four well-established and important approaches:

- low-input options to increase the quantity and quality of crop residues used as feedstuffs
- changing the number of livestock (as animal equivalents) that can be supported through annual cycles with the feedstuff resources in the region, and the allocation of feedstuffs to various animal species and production classes of animals (e.g. young, mature, lactating, etc.)
- the use of low-cost, low-input supplements to stimulate rumen digestion and maximise the capacity of ruminants to produce on low-quality feedstuffs
- management of the natural feeding behaviour of ruminants to allow them to select and consume the highest-quality forages available to them.

Choice of cereal genotype

One of the most practical low-input options for smallholder farmers to increase the amount and quality of cereal crop residues used as ruminant animal feedstuffs is the use of dual-purpose genotypes of maize that produce at least equal (and preferably higher) yields of grain for food as well as more stover, and stover of higher feedstuff value for ruminants (Blümmel, Grings & Erenstein 2013). This must be done while also achieving 'win–win' solutions, and without penalties on grain quality for food or increased risks of crop failure or land degradation. Extensive research over recent decades on use of other tropical cereal crop residues (e.g. sorghum and millet stovers) and temperate cereal crop residues (e.g. barley, wheat and oat straw) as ruminant feedstuffs has indicated that the same general principles apply across cereal crops.

The SIMLESA program focused on low-input management options. As maize is the most important cereal crop in eastern Africa, the livestock nutrition work focused on options to improve the amount and value of maize crop residues as ruminant animal feedstuffs. The effects of genotype, environment, and genotype × environment (G×E) interactions on yields of grain and stover, and stover feedstuff quality, were examined in a major experiment in the SIMLESA program (Dejene 2018). Comprehensive measurements of stover in these experiments enhanced the efficient use of research resources. In two annual cropping seasons (2013 and 2014), six maize genotypes (three early-maturing and three medium-maturing) were grown at three sites in the Ethiopian highlands (Bako, Hawassa and Melkassa) that were selected to represent a range of maize-growing environments (two subhumid and one semi-arid). The grain and stover were harvested at maturity. Feedstuff value of the stover was evaluated by measuring the dry matter digestibility and concentration of nitrogen and fibre fractions (neutral detergent fibre and acid detergent fibre) as key indicators of the available useful (metabolisable) energy and protein contents of the stover for ruminants.

There were substantial and significant effects of genotype and genotype by environment interaction on the yield of both grain and stover. The means (Table 10.1) had ranges of 1.8 and 1.2 t/ha, respectively. Yields ranged among genotypes by up to about 25% of the mean yield. Environment accounted for greater variation in grain (74%) and stover (80%) yields within the medium-maturing maize genotype group than genotype or genotype by environment interaction.

Table 10.1 Yield of grain and stover dry matter with three genotypes (G1, G2 and G3) of medium-maturing maize varieties

Genotype	Grain yield (t/ha)	Stover yield (t/ha)	Contents (%)		Digestible dry matter yield (t/ha)	Nitrogen yield (kg/ha)
			Dry matter digestibility	Nitrogen		
G1	5.8[c]	12.2[b]	50.0[b]	0.75[ab]	6.0[b]	88[b]
G2	6.9[b]	13.4[a]	52.3[a]	0.79[a]	7.0[a]	103[a]
G3	7.6[a]	13.1[ab]	49.9[b]	0.73[b]	6.4[b]	96[b]
Prob.	***	*	***	*	**	**
LSD	0.36	0.99	0.74	0.046	0.49	9.6

Notes: The quality of the stover as a feedstuff was measured as dry matter digestibility and nitrogen concentration. Values are means of two planting densities at three sites in each of two years.
Prob = probability of differences among genotypes; LSD = least square difference; a, b and c suffixes indicate significant differences across genotypes; *** = $p < 0.01$; ** = $p < 0.05$; * = $p < 0.1$.

The overall average dry matter digestibility (50.7%) and nitrogen concentration (0.76% nitrogen or 4.7% protein) of the stover were low, but as expected for this crop residue. Stover quality as dry matter digestibility and nitrogen concentration were higher for one (G2) of the three genotypes. These indexes indicated that, if these stovers were fed alone, the voluntary intake by animals would often be insufficient to provide the metabolisable energy for liveweight maintenance of the animals and the animals would probably lose liveweight. Furthermore, the stover would be protein-deficient, which would probably result in low voluntary intakes and often serious liveweight loss. Protein would probably be the first limiting factor for energy intake of the animals.

Stover feedstuff quality did vary within medium-maturing genotypes. The differences among genotype ranged up to 3.0% in dry matter digestibility and 0.11% in nitrogen concentration. Identification and feeding of maize genotypes with higher-quality stover would lead to some useful improvements in ruminant nutrition, but this would not solve the problem of protein deficiency. Environment accounted for the greatest proportions of the variation in the stover dry matter digestibility (79%) and nitrogen concentration (70%) within medium-maturing genotypes. The observation that grain yield was not correlated with stover quality (measured as either dry matter digestibility or nitrogen concentration) (Figures 10.1 and 10.2) was important, as it indicated that the quality of stover as feedstuffs for ruminants could not be managed by selecting for higher yields.

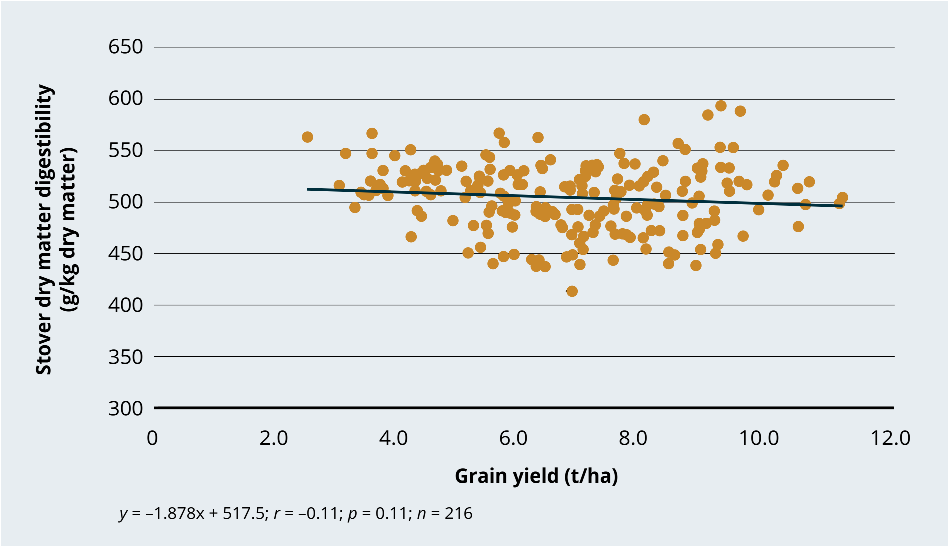

Figure 10.1 **Relationship between stover dry matter digestibility and grain yield in maize genotypes**

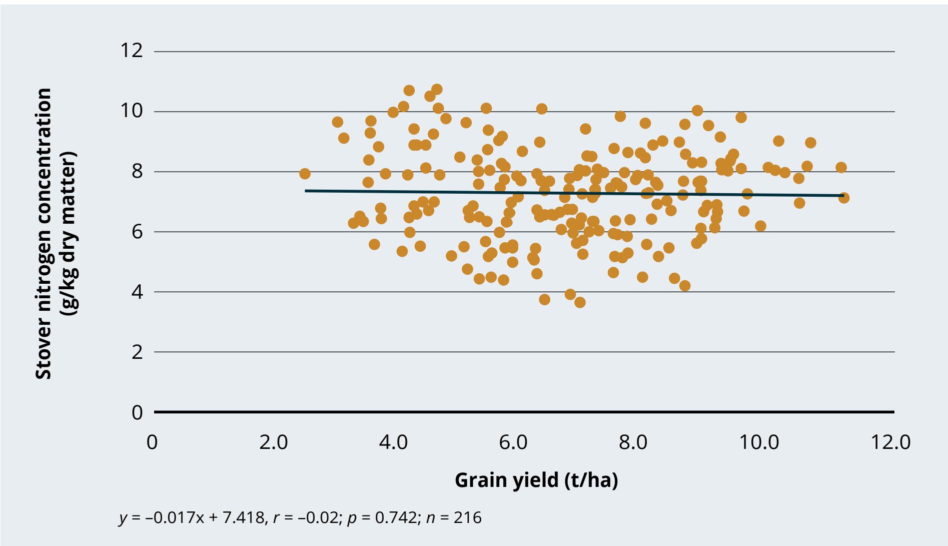

Figure 10.2 **Relationship between stover nitrogen concentrations and grain yield in maize genotypes**

Numerous studies have shown that the yields of grain and stover are positively correlated and that the harvest index is generally stable and constant across genotypes. This has been reported in previous studies in Ethiopia (Tolera, Berg & Sundstøl 1999; Geleti et al. 2011), elsewhere in eastern Africa (Ertiro, Twumasi-Afriyie et al. 2013) and South-East Asia (Anandan et al. 2013). Furthermore, genetic enhancement for dual-purpose attributes has confirmed the variation among maize parental lines in eastern Africa (Eritro, Zelleke et al. 2013) and South-East Asia (Zaidi, Vinayan & Blümmel 2013). A positive correlation was observed in the present study, and the absence of a close relationship was considered most likely to be associated with experiment errors. Importantly, using dual-purpose cultivars of maize is likely to increase the yields of both grain and stover. Increases in grain yield are highly likely to be associated with an increase in the quantity of stover available as feedstuffs.

Differences among cultivars for nitrogen concentration and dry matter digestibility of stover have also been reported for other cereal crops. Substantial differences in grain stover or straw attributes have been reported for cultivars of sorghum (Blümmel et al. 2010), pearl millet (Blümmel, Bidinger & Hash 2007; Ravi et al. 2010), wheat (Dias-da-Silva & Guedes 1990; Habib, Shah & Inayat 1995; Schulthess et al. 1995; Tolera, Tsegaye & Berg 2008), barley (White, Hartman & Bergman 1981; Erickson, Meyer & Foster 1982; Herbert, Thomson & Capper 1994) and rice (Capper 1988; Pearce et al. 1988; Flachowsky, Tiroke & Schein 1991). Digestibility measured in vitro has ranged by as much as 10–15%. Straw digestibility was not related to grain yield in most studies, suggesting that selection for increased grain yield is not likely to decrease the digestibility of straw (Reddy et al. 2003).

In conclusion, this aspect of the experimental program in SIMLESA supported the hypothesis that it is possible to select dual-purpose genotypes of maize with increased yields of both grain and stover. This agrees with reports about other regions and other cereal crops. The consequences for such selection on the quality of maize stover as a feedstuff for ruminants are less clear, but it does appear that adverse effects of feedstuff value as dry matter digestibility or N concentration are not likely.

Management options to increase the amount and feedstuff quality of cereal crop residues

The role of various crop management factors in affecting the productivity and quality of crop residues have been reviewed by Reddy et al. (2003), while Rotz and Muck (1994) extensively reviewed changes in forage quality during harvest and storage. Crop management options to increase the amount and quality of crop residue as animal feed include:

- modification of plant density
- thinning and/or stripping during vegetative growth
- maize cutting height at harvest
- increasing yield with fertiliser.

Modification of plant density

One simple management option for farmers is to modify planting density. Modern maize hybrids, which tolerate more environmental stress than older hybrids, have higher optimum plant densities for grain yield, mainly due to lower lodging frequencies (Nafziger 1994; Tollenaar 1989). Increasing plant density (e.g. from 4 to 10 plants/m^2) in maize is used to increase grain and whole-plant yield (Cox 1996; Tollenaar & Bruulsema 1988).

Many studies have focused on investigating the effect of row spacing and/or plant populations on maize grown for forage/silage, and mostly in temperate areas (Lutz, Camper & Jones 1971; Widdicombe & Thelen 2002; Sarlangue et al. 2007; Cox & Cherney 2011; Burken et al. 2013). This discussion will focus on studies most relevant to smallholder systems in eastern Africa and periods when harvest is at grain maturity.

The effects of increasing the plant density of maize from the recommended 5 plants/m^2 to 7 plants/m^2 were examined in the experiment described above. Increased maize plant density increased yields of both grain and stover, in the representative results for MM genotypes (Table 10.2) of grain by 0.6 t/ha and of stover by 2.4 t/ha (both $P < 0.05$). These comprised increases of 9.2% and 20.5% respectively. Stover quality as dry matter digestibility and nitrogen concentration were not affected by plant density ($P > 0.05$). Associated with the changes in dry matter yield, the yield of digestible dry matter per hectare was increased by 20.3% ($P < 0.05$). There was also a tendency for increased nitrogen yield per hectare.

Table 10.2 Yields of grain and stover dry matter at two planting densities

Density (plants/m)	Grain yield (t/ha)	Stover dry matter yield (t/ha)	Dry matter digestibility (%)	Nitrogen (%)	Digestible dry matter yield (t/ha)	Nitrogen yield (kg/ha)
5	6.5^b	11.7^b	51.1	0.78	5.9^b	89
7	7.1^a	14.1^a	50.4	0.73	7.1^a	101
Prob.	ns	**	ns	ns	**	ns
LSD	0.27	1.40	0.84	0.058	0.61	12.1

Notes: Values are means of three genotypes at three sites in each of two years. Prob = probability of differences; LSD = least square difference; ** = $p < 0.0$; ns = not significant; a and b suffixes indicate a significant difference in yields between the two density treatments.

Presumably an increase in planting density may be associated with potential disadvantages, such as suitability for only some regions, increased risk of crop failure in low rainfall years or higher costs of seed inputs. Inputs from crop agronomists and further information and validation are needed before establishing recommendations to farmers. Nevertheless, this management change appears promising for increasing the amount of maize stover available without adversely affecting the feedstuff value of the crop residues.

Thinning and/or stripping during vegetative growth

Another option is to use a higher maize plant density than recommended and harvest some of the maize during vegetative growth of the plant. This harvest may be of the entire plant (thinning) and/or defoliation of lower leaves (leaf stripping) during growth. A variation of the latter is leaf stripping after grain maturity to provide forage for ruminants. These practices are common in eastern Africa and are usually done in association with high seed rates.

Such early harvest may increase or decrease the grain production, depending on the timing, the severity and the environment. Asefa and Mekonnen (1992) reported that partial defoliation of maize leaves below the uppermost ears at high planting densities modified the photosynthetic efficiency of leaves. When leaves below the upper ear were removed, grain yield was increased by 11% at a high plant density (13.3 plants/m^2). The authors also concluded that defoliation should be delayed until 30 days after 50% flowering. In contrast, Lukuyu et al. (2013) showed that increasing plant density increased forage yields, but could decrease grain yields when the crop was thinned late in the growth of the crop. However, grain yields were maintained when maize was planted at high density and then progressively thinned for forage during the growing season, according to the crop situation or need for forage.

A number of reports have indicated that increased planting density and thinning practices by smallholder farmers are not uncommon through eastern Africa. For instance, Kassa (2003) reported that farmers in Hararghe, Ethiopia, used a high seed rate to enhance maize and sorghum biomass growth and then both thinned excess seedlings for use as feedstuffs and defoliated maize and sorghum leaves after crop maturity and before grain harvest. Similarly, a survey (Dejene 2018) indicated that farmers in the Misrak Badowacho district of Ethiopia practised leaf stripping of lower leaves (below the uppermost ear), although their objective was usually to intercrop common bean between maize rows from around the silking growth stage (Nielsen 2016) as well as provide maize fodder for livestock. This timing of defoliation was consistent with that suggested as optimal by Asefa and Mekonnen (1992), as discussed above. Another study (Lukuyu et al. 2013), showed that smallholder farmers in Kenya often adopt the management practice of planting maize at high density and systematically thinning the crop to obtain both fodder and grain.

In conclusion, these practices of high planting density and thinning for fodder are used by smallholder farmers. The consequences may be either increased or decreased grain yield. There is insufficient understanding of the crop physiology to predict the effects on yields. More understanding of the crop physiology and on-farm information is needed to provide recommendations to smallholders.

Maize cutting height at harvest

Routine harvest of maize at grain maturity usually involves cutting the maize plant at ground level, so the crop residue comprises all of the stover. However, in some regions of eastern Africa, maize at grain maturity is harvested with a 'high cut' at the second node below the lowest ear to provide top and bottom parts of the stover. The bottom will usually be left in the field, while the top is used for hand-feeding livestock. An important question is whether this practice changes the nutritional value of the top stover as a feedstuff for livestock.

As a general principle, the lower and more mature parts of a grass plant such as maize are expected to be more fibrous and lower in dry matter digestibility, and therefore lower in nutritional value. Also, the more fibrous rigid and hard structure of the lower maize stems will be expected to result in lower voluntary intake by ruminants. This principle is sometimes adopted in harvesting maize at a less mature stage of growth for preparation of maize silage with a cutting height 300–500 mm above ground level. This reduces the amount of crop dry matter harvested but has the advantage of increasing the nutritional value of the part of the maize crop that is harvested.

Two of the field sites (Bako and Melkassa) in the experiment described above were also used to obtain information on the consequences of using a high cutting height on the amounts of top and bottom stover, and the amounts of the various morphological fractions (leaf blade, stem and husk in the top component). The feedstuff value of each of the components was also measured. The results for the medium-maturing maize genotypes are given in Table 10.3, while those for both medium- and early-maturing genotypes can be found in Dejene (2018).

Table 10.3 **Yields of maize grain and maize stover harvested to provide top and bottom stover, by site and genotype**

Measure	Grain yield (t/ha)	Total stover yield (t/ha)	Top stover (% total)	Bottom stover (% total)	Top stover		Bottom stover	
					Dry matter digestibility (%)	Nitrogen (%)	Dry matter digestibility (%)	Nitrogen (%)
Site								
S1	7.2	9.9	64	36	52.1	0.86	42.1	0.62
S2	4.3	9.1	62	38	54.9	0.96	48.3	0.74
Prob.	**	ns	ns	ns	***	ns	***	ns
LSD (5%)	1.29	1.65	2.9	2.9	0.51	0.14	1.27	0.20
Genotype								
G1	5.2	8.7	66	34	52.8	0.89	43.3	0.70
G2	5.4	9.6	60	40	55.4	0.97	46.5	0.68
G3	6.6	10.2	63	37	52.3	0.86	45.8	0.67
Mean	5.7	9.5	63	37	53.5	0.91	45.2	0.68
Prob.	***	***	**	***	***	*	**	ns
LSD (5%)	0.46	0.51	2.6	2.6	0.86	0.08	1.74	0.08

Notes: Three medium-maturing genotypes (G1, G2 and G3) were measured at two sites (S1 = Bako; S2 = Melkassa). The mean yields and composition for the sites and for the genotypes, and the dry matter digestibility and nitrogen content of the top and bottom parts of the stover are given. Prob = probability of differences among genotypes; LSD = least square difference; ns = not significant;
*** = $p < 0.01$; ** = $p < 0.05$; * = $p < 0.1$.

On average, 63% of the stover dry matter was located in the top component of stover. Dry matter digestibility and nitrogen concentration were higher in the top component. Dry matter digestibility in the top component was 53.7%, compared to 46.3% in the bottom component. Nitrogen concentration was 0.97% in the top component and 0.75% in the bottom component. Differences in the composition of the two depth components explained differences in dry matter digestibility and nitrogen concentrations. Stems comprised 48.0% and 77.9% of the top and bottom components of stover, respectively. Leaf blades made up a similar proportion of the stover in both components. The stem from the top component was much higher in both dry matter digestibility and nitrogen concentration than that from the bottom component (49.1% and 42.4% dry matter digestibility, 0.78% and 0.52% nitrogen). Of the total digestible dry matter, 1.70 t/ha (37%) was in the leaf and husk fractions of the top stover and 1.40 t/ha (29%) was in the leaf of the bottom stover (Table 10.4). There was a similar distribution of nitrogen between the top and bottom stover fractions.

Table 10.4 Yields of maize grain and maize stover harvested to provide top and bottom stover, by fraction

Measure	Total stover yield (t/ha)	Per cent of top or bottom stover	Stover fraction yield (t/ha)	Dry matter digestibility (%)	Dry matter digestibility yield (t/ha)	Nitrogen (%)	Nitrogen yield (kg/ha)
Total stover	**9.50**	**–**	**–**	**51.0**	**4.84**	**0.89**	**85**
Top stover	**5.96**	**–**	**–**	**53.5**	**3.19**	**0.91**	**54**
Leaf	–	22.4	1.34	56.9	0.76	1.60	21
Stem	–	48.0	2.86	49.1	1.40	0.78	22
Husk	–	29.7	1.77	58.3	1.03	0.77	14
Total	–	100	5.96	53.7	3.20	0.97	58
Bottom stover	**3.55**	**–**	**–**	**45.3**	**1.61**	**0.68**	**24**
Leaf	–	22.2	0.79	59.7	0.47	1.57	12
Stem	–	77.9	2.77	42.4	1.17	0.52	14
Total	–	100	3.56	46.3	1.65	0.75	27
Prob.	–	–	–	***	–	***	–
LSD	–	–	–	0.82	–	0.066	–

Notes: The top and bottom were separated into leaf and stem fractions and husk was separated from the top component. Three medium-maturing genotypes were measured at two sites in each of two years. The mean yield and composition for the genotypes, and the dry matter digestibility and nitrogen content of the morphological fractions of the top and bottom stover are given. Prob = probability of differences among genotypes; LSD = least square difference; *** = $p < 0.01$.

The proportions of digestible dry matter and nitrogen in the various fractions of the stover, and the very large differences between leaf blade and husk versus the stem in feedstuff quality, have major and important implications for improving ruminant livestock production and achieving 'win–win' trade-offs in the use of maize stover. In regions where maize crop residues are abundant in relation to livestock demand, there appear to be excellent reasons to change the management procedure at mature grain harvest to a high cutting height, and use the top component for hand-feeding animals. Furthermore, if the amounts of maize stover to be hand-fed can be increased to perhaps twice that of animal intake (see below), the quality of the diet consumed by the animals will be higher in dry matter digestibility (although only modest in nitrogen concentration). In these circumstances if the leaf component of the bottom component stover is left in the paddock, it can be used by grazing livestock.

A key question is the suitability of the predominantly stem material of stover (whether as refusals from hand-fed animals or left in the field after grazing) for conservation agriculture, fuel and other uses. This needs to be resolved.

Increasing yield and crop residue quality with fertiliser

It is well established that the use of fertilisers (particularly nitrogen and phosphorus) will usually increase plant production, the amount of crop residue and grain, and the nitrogen concentration of the crop residue. This was demonstrated for maize and sorghum crops by Perry and Olson (1975), where nitrogen fertiliser increased the yield and quality of the crop residues, although responses also depended on the rate and time of application. This could potentially have large effects on the amount and feedstuff quality of the crop residues available for livestock. However, the maize grain/stover ratios may also be changed by increasing nitrogen application levels.

Similarly, increasing levels of nitrogen fertiliser application increased pearl millet grain and stover yields and the nitrogen concentration, dry matter digestibility and the metabolisable energy content of stover. This increased yields of both digestible and metabolisable energy of the stover (Bidinger & Blümmel 2007). Crude protein contents of the plant components of wheat varied with fertiliser levels and increasing fertiliser levels significantly improved the digestibility of the leaf, but not of the chaff (Kernan et al. 1984). Reddy et al. (2003) reported that application of nitrogen (up to 120 kg/ha) in cereals and phosphorus (up to 60 kg/ha) in legumes improved the green and dry fodder yields, as well as nitrogen, crude fibre and other quality parameters.

Some of the implications for availability of crop residues for both conservation agriculture and feedstuffs have been discussed by Vanlauwe et al. (2014), including appropriate fertiliser use as a fourth principle for conservation agriculture in smallholder systems in Africa. However, it has been argued that smallholder farmers have limited access to adequate amounts of off-farm inputs such as fertiliser due to low purchasing power and weak marketing chains (Chilowa 1998; Twomlow et al. 2008). Integrating grain legume crops in maize has been advocated as a good starting point for intensification and diversification options, due to their multipurpose nature (food, fodder and soil fertility) and the small initial capital investment required (Rusinamhodzi et al. 2012). In the context of Malawi, Ngwira et al. (2012) reported that intercropping maize with a leguminous crop such as pigeonpea under conservation agriculture presented a 'win–win' scenario due to crop yield improvement and attractive economic returns. This cropping system should also increase the potential for production of additional high-quality forage as well as maize and legume seed as food.

Choice of legume genotype

One option to increase the amount and quality of food legume crop residues as animal feedstuffs, as for cereal crop residues, is to select and use dual-purpose genotypes to increase the quantity and nutritional quality of feedstuff. As it is the most widely grown food legume crop in maize-based crop–livestock systems of eastern Africa, common bean (*Phaseolus vulgaris*) varieties were chosen for investigation. The crop residues of most food legume crops can be considered as the fractions of stem and leaf (collectively comprising the haulm) and the seed pod. Since the seeds and the pod wall are usually separated during shelling at the homestead, the pod wall can be considered as a separate product to the haulm.

The effects of genotype, environment and genotype × environment interactions on haulm and seed pod yield and their feedstuff quality were examined in the N2Africa program (Dejene et al. 2018). In 2013, a number of common bean cultivars (usually n = 9) were grown in four sites (Bako-Tibe, Mandura, Boricha and Shalla districts) in Ethiopia.

This study found substantial variation among the four sites in the yields of seed and haulm plus pod wall at seed maturity. Mean yields of seed and haulm plus pod wall ranged from 2.6 t/ha to 2.5 t/ha respectively at Shalla, and 0.79 t/ha and 0.74 t/ha respectively at Bako-Tibe, demonstrating the large effect of environment. There was also large variation among genotype at each site (CV of seed yields from 11% to 35%, and of haulm plus pod wall from 8% to 34%). The results for two of the sites, Shalla and Boricha, are given in Table 10.5 and are indicative of all of the sites.

Table 10.5 **Seed yield, haulm plus pod wall yield, pod wall proportion, dry matter digestibility and nitrogen (N), by site**

Site	Seed yield (t/ha)	HPW yield (t/ha)	Pod wall (% HPW)	Haulm		Pod wall	
				Dry matter digestibility (%)	Nitrogen (%)	Dry matter digestibility (%)	Nitrogen (%)
Shalla							
Mean	2.6	2.5	27	53.7	0.103	66.0	0.079
Prob.	***	***	***	***	***	***	ns
CV	11.3	7.5	2.9	4.4	13.5	2.6	21.7
Boricha							
Mean	1.7	2.2	29	41.0	0.072	62.0	0.088
Prob.	ns	*	ns	ns	ns	ns	**
CV	27.9	23.0	22.7	3.5	11.0	1.8	13.6

Notes: Nine genotypes of common bean were grown at the two sites. HPW = haulm + pod wall; Prob = probability of differences among genotypes; CV = coefficient of variation; ns = not significant; *** = $p < 0.01$; ** = $p < 0.05$; * = $p < 0.1$.

These results are consistent with previous reports showing large genetic variation in seed yield across common bean varieties (Haile, Mekbib & Zelleke 2012; Tadesse et al. 2014; Yoseph et al. 2014). Seed and haulm yields were correlated (Figure 10.3a). On average, the largest fraction of crop residues was in the stem (66%) followed by the pod wall (28%) and the leaf (6%). This low proportion of leaf was associated with extensive leaf loss during the interval approaching seed maturity, which decreased haulm quality. The mean nitrogen concentration of haulm ranged from 0.72% to 1.18%, and that of the pod wall from 0.79% to 1.08% across the sites, and was not consistently higher in either of these fractions. There were often significant differences among genotype in nitrogen concentration. Dry matter digestibility of the haulm was low and averaged 41% to 43% at three of the sites, but was substantially higher (54%) at Shalla. Shalla was also the site where yields of haulm and pod wall were highest. The dry matter digestibility of pod wall was consistently very high (62–66%) for crop residues. Also, there were often differences among genotype in dry matter digestibility of these two fractions. Seed yield was positively correlated with dry matter digestibility of the entire crop residues (Figure 10.3b) but was not as closely related to haulm quality as nitrogen concentration ($p > 0.05$).

The study showed the presence of considerable variability in seed and haulm plus pod wall yields and haulm plus pod wall nutritive value among varieties of common bean often grown by smallholder farmers in eastern Africa. It may be possible to select genotypes for higher yields of both seed and haulm plus pod wall, and selection for seed yield is likely to increase haulm yield. Furthermore, selection for seed yield is likely to be associated with higher dry matter digestibility of the haulm. In the haulm, leaf was much higher in nutritive value than the stem, but the proportion of leaf in the haulm was invariably low in this experiment (mean 6.4%, and always <9% of the haulm plus pod wall). This was presumably due to the extensive leaf loss as the plant approached seed maturity, which often occurs with food legumes and causes a major decrease in the nutritional value of the entire crop residue. Selection of genotypes that retain their leaf up to seed maturity should substantially improve the feedstuff value of common bean crop residues. Large variation among genotype in the leaf content of common bean crop residues has also been reported by Asfaw and Blair (2014). Substantial variation across genotypes in yield of haulm plus pod wall and in nitrogen concentration of the haulm plus pod wall attributes (although not of dry matter digestibility) indicated that there is opportunity to achieve substantial genotype gains in material readily available in eastern Africa.

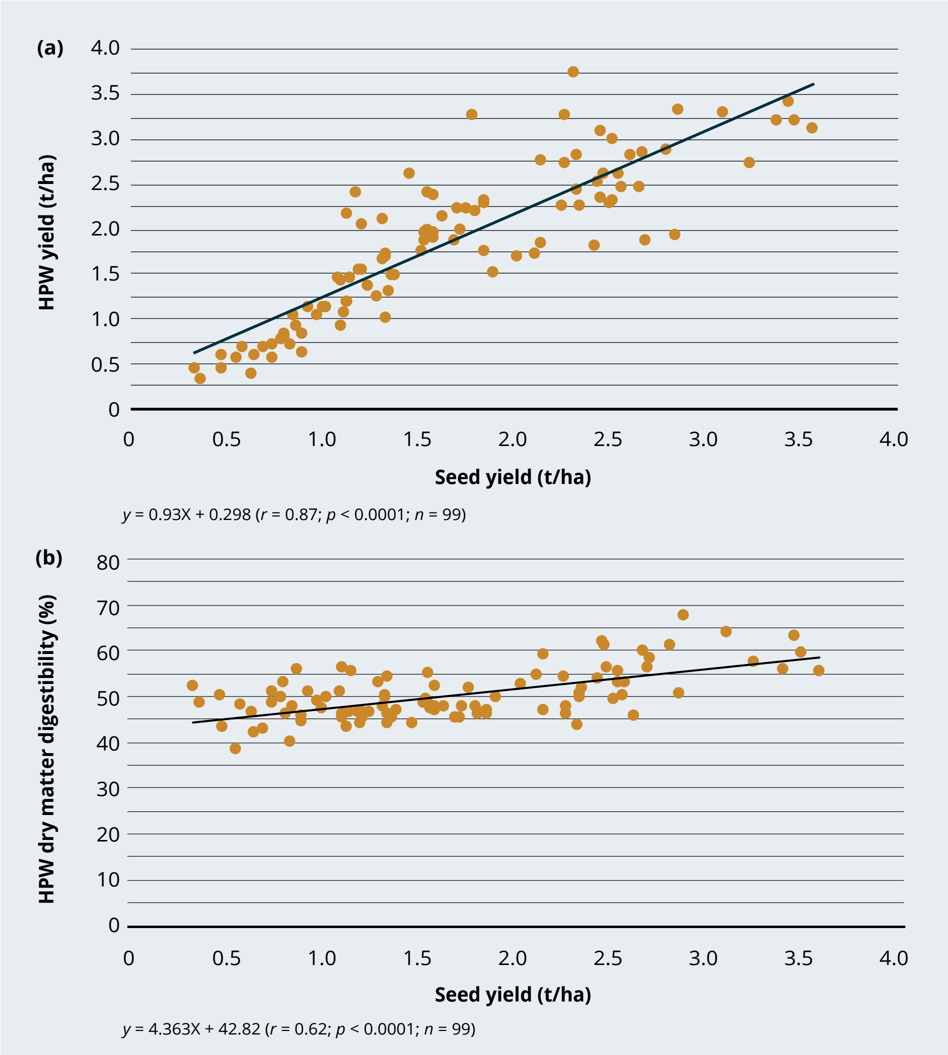

Figure 10.3 **Relationships between seed yield and haulm plus pod wall (HPW) (a) yield and (b) dry matter digestibility in common bean varieties at four sites**

The high nitrogen concentrations in both the haulm and the pod wall (1.5% and 1.6%, respectively, in a few of the genotypes investigated) showed that, in some circumstances, common bean crop residues can be a very valuable source of nitrogen. This can be used to balance the low nitrogen levels of other feedstuffs, such as cereal crop residues, and is an important reason to focus attention on food legume crop residues that will generally be higher in nitrogen concentration. However, research is needed to establish that the nitrogen in food legume crop residues is available to the animal. Firstly, the growing conditions and genotypes for high nitrogen content pod wall or haulm need to be understood. Given that genotypes within a site could have a large effect on nitrogen concentration, it appears to be a much more complex issue than simply soil nitrogen availability. Secondly, the pod wall in some food legumes contain antinutritional factors that potentially reduce the availability of the nitrogen to both rumen microbes and the animal. This would need to be resolved for common bean. Close collaboration among plant breeders, animal nutritionists and farmers is needed for effective screening of new genotypes to achieve these objectives.

Management of legume crops

There may be options associated with the early harvesting of legume crops for food to produce vegetables at early seed maturity, rather than harvesting mature seed. Such very early harvest will comprise only a small proportion of the crop, except perhaps for a few farms that are close to urban centres. However, when it is available, this legume crop residue is expected to be of very high nutritional value as a livestock feedstuff.

To investigate common bean legume crop residues at early harvest, the yield and haulm feedstuff quality was examined in the varieties harvested at seed maturity as described above. At this early harvest, the yield of haulm was much higher, and the yield of seed and seed pods much lower, than in the crop harvested at seed maturity. Also, the proportion of leaf, the haulm nitrogen concentration and dry matter digestibility were very high compared with the harvest at seed maturity (23.1% vs 6.9%,1.53% vs 0.85% and 62.2% vs 48.8% respectively). In addition, genotype by environment interactions were observed for yields of seed and haulm, and the nitrogen content and dry matter digestibility of pod wall.

In conclusion, the crop residues from early harvest of common bean, and probably also from the early harvest of other food legume crops, provided a very high-quality crop residue feedstuff in terms of nitrogen concentration and dry matter digestibility. This crop residue would be very suitable as a supplement for lower-quality feedstuffs. However, harvest at this early stage of crop maturity would presumably only be done when there is an attractive market for the legume pods as a vegetable for human food.

Animal management options

Allow animals to select the highest-quality crop residues fractions

It is well established that herbivores, including ruminants, are very discriminating in their selection of the 'best' plants and plant fractions when grazing. Ruminants usually select and consume a diet much higher in digestibility (i.e. metabolisable useful energy content and protein content) than the average on offer in a pasture.

These concepts are applicable to systems where animals have access to graze crop stubbles or stovers. In the context of hand-feeding crop residues, especially crop residues of thick-stemmed crop plants such as maize, sorghum and millet, ruminants generally preferentially consume the leaves rather than the thick stems (Fernandez-Rivera et al. 1994; Osafo et al. 1997; Savadogo, Zemmelink & Nianogo 2000; Methu et al. 2001). Many pen-feeding experiments have found that feeding excess amounts of such crop residues (e.g. offering up to three times more than the animal is expected to eat) and allowing the animal to select the leaf blade was a very effective way of increasing the voluntary intake of crop residues, the amounts of nutrients consumed, and productivity as milk or growth (Heaney 1973; Osafo et al. 1997; Zemmelink & 't Mannetje 2002). The obvious penalty is that the crop residue that is not consumed, and which might comprise up to half of the crop residues offered, has to be used for other purposes or discarded.

This approach should have the greatest potential in two hand-feeding situations. Firstly, when the livestock population and feedstuff demands for crop residues are low in relation to the amounts of crop residues available in a region and wastage may not be important. Secondly, where refused crop residue material is suitable for soil mulching or fuel, a 'win–win' situation should be possible, with substantial increases in animal productivity with little additional management input. There does not appear to be any reason why refused crop residue should not be suitable for soil mulching or compost, other than the increased labour associated with handling.

Supplementation of crop residue forage diets with protein as non-protein nitrogen and minerals

Crop residues, particularly those from cereals, are usually very low in nitrogen and a number of other essential nutrients, such as sulfur, phosphorus, calcium and micro-minerals. Of these, nitrogen and sulfur are most important, as when they are deficient the voluntary intake is immediately and severely reduced. An effective and economical way to provide protein in the diet of a ruminant is to provide non-protein nitrogen, usually as urea. Ruminants have the enormous advantage that the rumen micro-organisms can use inorganic sources of nitrogen and sulfur (e.g. non-protein nitrogen, urea, ammonium sulfate) to synthesise protein, which passes to the lower gastrointestinal tract for digestion. These rumen microbes provide protein and amino acids for the animal, even when the forage part of their diet is very low in protein. This is one of the principal reasons that ruminants can not only survive but also produce when fed diets that are very low in true protein.

An important issue and concern in use of non-protein nitrogen in forage diets for ruminants is that excess non-protein nitrogen, in forms such as fertiliser urea, may be toxic and cause mortality. However, management procedures to effectively avoid urea toxicity in ruminants have been developed. The feeding of urea as a supplement to cattle grazing low-quality dry season pastures in tropical countries is very common. For example, in the seasonally dry tropics of northern Australia, a large proportion of the cattle population is supplemented with non-protein nitrogen as urea to reduce liveweight losses when grazing degraded tropical grass pastures during the dry season.

Management options to provide urea non-protein nitrogen supplements with low risk are generally in the following categories:

- Providing the urea in hard feed blocks so animals can only consume small amounts. Feed-block supplements are widely used for this purpose in India.
- Slow-release forms of urea are available in Australia, Europe and the Americas. Some of these might be suitable for local manufacture.
- Using a sticky urea–molasses solution (only a small percentage of molasses in water should be needed) and distributing this over/through the daily roughage allocation with a watering can or similar. This was an early idea in Australia that was never adopted by the cattle industry due to the high labour requirement. However, it may be suitable for eastern Africa smallholder systems. Since this system has never been used widely (to the authors' knowledge), variations of the system would require careful testing under eastern Africa on-farm conditions to ensure the safety of livestock against urea toxicity.

Other approaches to providing appropriate non-protein nitrogen supplements should also be possible (Doyle 1987; Preston & Leng 1987; Dixon & Egan 1988). Non-protein nitrogen supplementation also needs to include some sulfur to balance the addition of the nitrogen as rumen microbial substrates and this should be straightforward with addition of some ammonium sulfate or elemental sulfur. Other mineral deficiencies (e.g. of phosphorus) are likely to be of secondary importance to the supply of energy and protein in crop residues diets for ruminants at a low level of production. The nutrition of ruminants that are fed crop residues diets in eastern Africa should be greatly improved if practical ways can be found to supplement animals with non-protein nitrogen while avoiding the risk of urea toxicity.

Chemical and physical treatment

The voluntary intake and digestibility of low-quality crop residues may be increased by chemical treatments such as with alkalis or acids, physical treatments such as grinding or soaking, or biological treatments with fungi (Doyle et al. 1991; Schiere 2010). Alkali treatment, in particular, received extensive attention during the 1980s. Using aqueous solutions of alkalis such as sodium hydroxide or urea (as a source of ammonia) can increase digestibility and voluntary intake (Pearce 1983). Urea treatment has the advantage that much of the urea nitrogen added to increase the dry matter digestibility is retained in the treated forage and increases the nitrogen (protein) content of the forage to at least alleviate the nitrogen deficiency of most crop residues.

These treatments have generally been found to be effective at the research level, but none appear to have been widely adopted at the small farmer or village levels in developing countries anywhere. Obstacles to adoption by smallholder farmers include:

- availability and costs of chemicals and/or machinery
- the need to handle and use potentially hazardous chemicals at the village level
- the need for substantial labour and additional water
- even after treatment, crop residue forages are only of moderate quality as feedstuffs.

These technologies appear to have limited potential in eastern African farming systems.

Another option to increase the use of crop residues is to incorporate them into densified total mixed rations, presumably for livestock where moderate rather than high levels of production are planned. This appears to be a promising approach in South-East Asia (Food and Agriculture Organization 2012) but needs to be developed, tested and demonstrated for on-farm situations in eastern Africa.

Conclusions

Livestock are an important component of many smallholder crop–livestock systems in eastern Africa, especially for provision of high-quality foods and a range of important inputs and functions.

As a consequence of the general scarcity of pastures and forages, crop residues from regional crops (particularly maize) are very important as livestock feedstuffs in eastern Africa. However, crop residues are generally low in nutritional value as feedstuffs and their use is an important cause of general poor productivity of livestock.

There are opportunities to increase both the quantity and feedstuff quality of crop residues through dual-purpose genotypes of maize and food legume crops, and management of crops (especially cereals) that at least maintain, and preferably increase, food grain production.

There are also opportunities to apply established knowledge, especially in livestock feeding management and low-input supplementation for livestock, for increased livestock productivity.

In most crop–livestock systems, there will be competing demands for crop residues as feedstuffs for livestock, conservation agriculture, fuel and other uses. This is being exacerbated by the increasing importance of crop residues for CASI practices. 'Win–win' solutions are needed to increase both food grain and livestock production while meeting the needs of conservation agriculture.

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11 Market and value-chain development for sustainable intensification in eastern and southern Africa

Moti Jaleta

Key points

- Smallholder farmers in eastern and southern Africa operate under incomplete and missing input and output markets. Farmers' decisions made under missing or incomplete markets are usually suboptimal in terms of resource use and benefits generated.
- The availability of inputs is key for smallholders to adopt yield enhancing technologies in maize production. For those areas with available inputs, the likelihood of using improved seed and chemical fertiliser declines the further the farmer is from these sources.
- Surplus maize and beans are mainly sold at the farm gate and village markets in Kenya and at district and village markets in Ethiopia.
- Conservation agriculture-based sustainable intensification requires functional value chains and reliable markets enhancing smallholder farmers' access to purchased inputs and outlets for surplus production.

Introduction

Access to markets and services is the first hurdle in ensuring smallholder farmers benefit from the agricultural development model of conservation agriculture-based sustainable intensification (CASI) (Gebremedhin, Jaleta & Hoekstra 2009; Shiferaw, Hellin & Muricho 2011). CASI requires access to inputs and markets for any surplus production (de Janvry, Fafchamps & Sadoulet 2008). Potential benefits of CASI therefore depend on farmers' access to functional value chains and reliable markets and services (Key, Sadoulet & de Janvry 2000; Fafchamps & Hill 2005). Policies and development initiatives aimed at supporting CASI need to emphasise the role of agricultural input and output markets in shaping opportunities for smallholder farmers.

SIMLESA countries have depended heavily on agriculture for employment, food and nutrition security, foreign currency earnings and raw materials for their industries. Most of the agricultural production of these countries comes from smallholder farmers who mainly produce for their own home consumption and sell only some surplus produce based on available markets (Barrett 2008; Alene et al. 2008). Sustainable intensification helps ensure increased production and productivity, with fewer impacts on biophysical resources. This, in turn, requires availability and accessibility of input and output markets, as well as other services that help smallholder farmers enhance the benefits derived from their natural resource base. Eventually, this can contribute to better food and nutrition security, reduced poverty and diversified livelihoods of smallholder farmers, without compromising environmental quality and natural resource bases that support long-lasting production and consumption systems. However, many smallholder farmers face substantial challenges that limit market access and participation in eastern and southern Africa.

Smallholder farmers are heterogeneous in their resource endowment, which affects their production orientation and marketing decisions. Such heterogeneity among farmers also calls for diverse business models to respond to their household or group-specific needs. Alternative business arrangements may be needed so that smallholder farmers can choose from and respond to market signals in their production orientations. The opportunities created at different levels of the value chain (e.g. input supply and delivery, production, post-harvest processing, storage and marketing) should accommodate all farmers and remunerate the level of resources (time, money and skill) they invest. To support smallholder farmers to adopt sustainable intensification technologies and practices, it is essential to ensure that there are functional value chains and that the existing value chains are inclusive of all farmer groups, without any socioeconomic discriminations.

Different business models could be sought to safeguard the accessibility of input and output markets, and the availability of essential services to smallholder farmers. Private businesses are the most recommended models in agricultural input and output markets, as they provide services to input buyers and output sellers based on profit. Positive profit margins ensure that more private business actors come in to reap the benefits, which eventually enhances competition and market efficiency (through reduction of input prices, rates charged for services provided, prices paid for outputs delivered, improved quality of service delivery including farm-gate purchase or delivery, input or service delivery on credit basis, etc.). Group marketing and cooperatives could also fill gaps when private businesses are lacking, either due to lower profit margins or smaller volumes of transactions that increase their transaction costs (Shiferaw, Hellin & Muricho 2011). The choice of business model depends on several factors. There are also cases where business models could change or evolve from one form to another, based on the existing business environment and the level of efficiency they could attain while surviving under competition (Jaleta et al. 2012).

In semisubsistence smallholder farming systems, benefits from agriculture are valued using market prices for some of the commodities traded in markets, and household-specific values are attached to agricultural inputs and outputs. In taking production decisions, farm household objectives are key, whether a farmer maximises profit or utility through consumption of homegrown products. In cases where most agricultural products are mainly produced for home consumption and most agricultural inputs are supplied within the household system, markets have less of an effect on household resource use and conservation decisions.

In areas where there is high population pressure and farmlands are small, agricultural intensification is one of the mechanisms or pathways that could enable food and nutrition security. Under such circumstances, intensification helps enhance agricultural productivity so more can be produced from the same resource bases by using better practices or by bringing in more productive technologies. Productivity-enhancing technologies are usually purchased from markets (e.g. improved seed, chemical fertiliser, herbicides, pesticides). The availability and accessibility of agricultural input markets is therefore critical. In addition, a smallholder farmer must be able to sell some agricultural products for cash to be able to purchase agricultural inputs. The intensification process has to sustain its own path by supporting the use of more inputs, technologies and practices through generating enough income to finance the purchase of these inputs.

This calls for better-functioning markets and value chains where farmers can participate with limited transaction costs. Markets and value chains should not discriminate against youth, women, poor or marginalised households. Inclusive markets and value chains ensure the sustainability of intensification practices. Moreover, responsive markets and value chains ensure the timely availability of agricultural inputs, which directly affects the adoption and intensity of use (Alene, Pooyth & Hassan 2000).

The purpose of this chapter is to support the argument that functional value chains and markets play key roles in encouraging the adoption of CASI practices by smallholder farmers.

Analytical framework

In assessing the role of maize and legume value chains and market linkages for the adoption of CASI practices in eastern Africa, we considered smallholder farmers' direct interface with input and output markets and how this influenced the combination of CASI practices farmers adopted in maize production. In addition to internal resource adjustments and changes in farm practices, the adoption of CASI practices by smallholder farmers required both farm and plot level investments. Purchased external inputs were used to maintain soil fertility and these new practices required new tools and equipment. In turn, the newly introduced technologies and practices needed to boost production that could surpass home consumption and be sold to generate additional income for farm households. This required the availability and accessibility of markets for maize and legume products. In addition, these markets had to provide competitive prices for maize and legume produce in order to make these enterprises profitable.

We propose that households with access to functional input and output markets that actively participated in these markets were better off in terms of overall farm production and could implement CASI practices that enabled them to make their farm profitable and encouraged them to make further investment. On the other hand, households with limited participation in input and output markets are not on the sustainable intensification path. In this paper, we endeavour to show the relationship between market linkage and the use of CASI practices that prevailed at the start of the SIMLESA program.

Data and methodology

Data used in this study were collected from SIMLESA intervention districts in Ethiopia and Kenya during 2010 (the first year of SIMLESA operations). A total of 898 and 613 sample households from five districts in Ethiopia and nine districts in Kenya were interviewed using a structured questionnaire. The survey data (at both household and plot level) included:

- plot characteristics
- input use
- crop production
- input and output marketing
- sources of inputs
- market outlets used in selling surplus produce
- household characteristics
- resource endowment
- physical distances of different markets
- availability of credit for input use
- farmer participation in credit market.

In explaining the links between the use of CASI practices and market linkage in the context of maize-producing smallholder farmers, we used both descriptive and econometrics analysis. In the econometric analysis (controlling for household, farm and village characteristics), the variation in the number of CASI practices a farm household undertook in maize production was explained using the physical distance of the main markets in which farmers participated for input purchase and sale of agricultural produce.

Results and discussion

CASI practices used by farmers

In assessing the role of markets on CASI practices, we considered maize–legume intercropping, crop residue retention, minimum tillage, use of fertiliser, maize–legume rotation and manure use. Almost all households growing maize were using improved varieties. The prevalence of different CASI practices in maize production is given in Table 11.1.

Table 11.1 Frequency of sample households using different CASI practices in maize production, Ethiopia and Kenya, 2010

CASI practice	Ethiopia (*N* = 869*)		Kenya (*N* = 613)	
	Frequency	%	Frequency	%
Intercropping	81	9.3	427	69.7
Legume–maize rotation	146	16.8	146	23.8
Crop residue retention	209	24.1	380	62.0
Minimum tillage	0	0.0	36	5.9
Purchased (improved) seed uses	475	54.7	448	73.1
Fertiliser use	629	72.4	552	90.0
Manure use	447	51.4	356	58.1

Note: * Of the total 898 sample households surveyed in Ethiopia, only 869 households (96.8%) grow maize.
CASI = conservation agriculture-based sustainable intensification

Combination of CASI practices used by farmers

CASI requires the adoption of a combination of improved technologies and practices. During 2010, in the maize-based system, the most common intensification technologies and practices included the use of improved maize seed, application of chemical fertiliser and manure/compost for soil fertility, intercropping and/or rotation of maize with legumes, crop residue retention in the field as mulch with the aim of enhancing soil organic matter, and no/minimum soil disturbance from tillage.

Considering these six technologies and practices in maize production, the baseline SIMLESA survey shows that smallholder farmers in Kenya applied more combinations of these technologies and practices than maize-producing farmers in Ethiopia (Figure 11.1). On average, maize farmers in Ethiopia used two to three of these technologies/practices, where maize farmers in Kenya used three to five of these practices. In both countries, there were few farmers who used none of the practices, and also few farmers who used all the six practices/technologies in maize production.

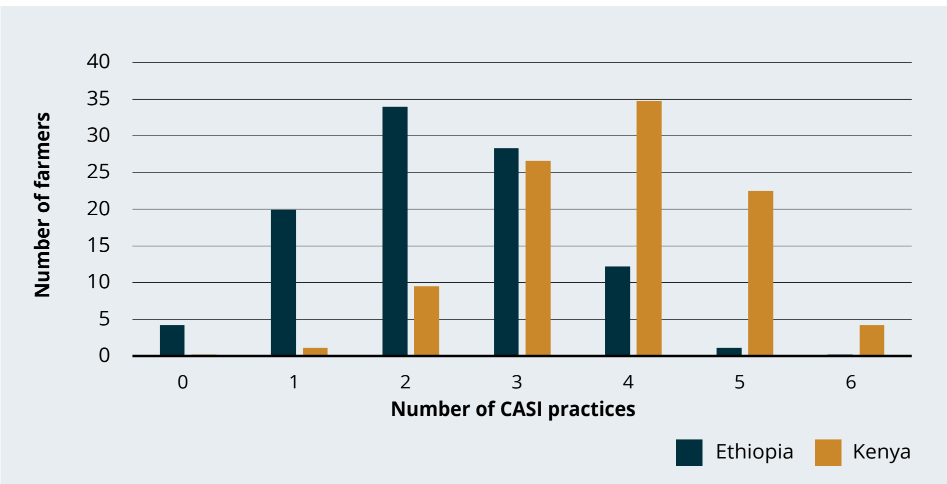

Figure 11.1 Use of a combination of CASI practices, Ethiopia and Kenya, 2010

CASI = conservation agriculture-based sustainable intensification

Physical access to markets

Compared to the sample households from Ethiopia, Kenyan farmers lived closer to agricultural input markets (Table 11.2). On average, Kenyan farmers could access key agricultural inputs at a walking distance of one hour, but lived far away from agricultural extension units. For Ethiopian farmers, extension units were only half an hour away from where they lived. This is consistent with the high extension agent to farmer ratio in Ethiopia as compared to most eastern and southern African (ESA) countries (Marenya et al. 2017).

Table 11.2 Physical distance from farms to main input sources, Ethiopia and Kenya, 2010

Input or service source	Distance from farm (walking minutes)			
	Ethiopia (*N* = 889)		Kenya (*N* = 613)	
	Mean	SD	Mean	SD
Village market	42.7	39.8	28.5	29.0
Main market	111.7	77.9	81.5	53.7
Seed market	56.2	64.5	55.2	46.9
Fertiliser market	56.8	67.0	56.8	49.9
Herbicide market	79.0	79.2	56.7	46.3
Cooperative unit	47.0	56.6	58.3	55.2
Farmer group	32.3	41.1	28.5	36.7
Agricultural extension unit	27.8	27.8	70.2	56.6

Note: SD = standard deviation

Cooperatives were the main sources of improved maize seed and fertiliser in Ethiopia. A large proportion of farm households that did not use chemical fertiliser and improved seed lived at least two hours away from cooperative shops (Table 11.3).

Table 11.3 Use of improved seed and inorganic fertiliser by distance to cooperative union, Ethiopia, 2010

Walking distance to primary cooperative or union	Fertiliser			Improved seed		
	Non-users No. (%)	Users No. (%)	Total No. (%)	Non-users No. (%)	Users No. (%)	Total No. (%)
≤1 hour	137 (23.2)	454 (76.8)	591 (68.0)	222 (37.6)	369 (62.4)	591 (68.0)
1–2 hours	18 (27.3)	48 (72.7)	66 (7.6)	24 (36.6)	42 (63.6)	66 (7.6)
>2 hours	85 (40.1)	127 (59.9)	212 (24.4)	148 (69.8)	64 (30.2)	212 (24.4)
Total	**240 (27.6)**	**629 (72.4)**	**869 (100)**	**394 (45.3)**	**475 (54.7)**	**869 (100)**

Table 11.4 compares credit need and access for Ethiopia and Kenya in 2010. Sample farmers in the two countries, on average, showed similar tendencies for credit for maize seed, fertiliser and chemical purchase. Among those farmers who needed credit for any of these three agricultural inputs, only 8–20% of the sample households had access to it. This suggests that farmers' access to financial markets limited their use of purchased agricultural inputs to intensify maize production.

Table 11.4 **Farmers who needed and accessed credit, Ethiopia and Kenya, 2010**

Input to be purchased	Ethiopia				Kenya			
	Needed credit?		If needed, got it?		Needed credit?		If needed, got it?	
	Yes No. (%)	No No. (%)	Yes No. (%)	No No. (%)	Yes No. (%)	No No. (%)	Yes No. (%)	No No. (%)
Seed	411 (45.8)	487 (54.2)	58 (14.1)	353 (85.9)	258 (48.3)	276 (51.7)	21 (8.1)	237 (91.9)
Fertiliser	444 (49.4)	454 (50.6)	90 (20.3)	354 (79.7)	300 (56.3)	233 (43.7)	34 (11.3)	266 (88.7)
Chemicals	161 (17.9)	737 (82.1)	15 (9.3)	146 (90.7)	185 (36.6)	321 (63.4)	20 (10.8)	165 (89.2)

Maize and legume product market participation

Surplus produce of maize and legume grain in Kenya was mainly sold at the farm gate. Half of the sample households in Kenya sold maize. Of these, about 63% sold it at the farm gate, 27% used village markets as their outlet and the remainder sold their maize surplus at district markets (Table 11.5). Only 2% of farmers sold at more than one outlet. Considering maize production volumes, on average each farmer sold 629 kg of maize at the farm gate, 228 kg at the village market and 160 kg at the district market.

Similarly, 57% of Kenyan farmers also sold legume grain (mainly common beans) at the farm gate. For legumes, 6% was sold at district markets and 37% was sold at village markets. Only 5% of legume sellers used more than one market outlet. In general, the farm gate was the main outlet for surplus maize and legumes in Kenya.

District markets in Ethiopia were usually the biggest market for rural farm households. This is where farmers bought a majority of their supplies and also sold most of their crop and livestock produce. The survey data showed that 70% of the sample households in Ethiopia sold maize. From the total dry maize supplied to market, 45% was sold at district markets. Farm gate and village markets were used to sell 26% and 29% respectively of the maize volume. On average, smallholder farmers in the study area sold 392 kg of maize at farm gates, 443 kg at village markets and 694 kg at district markets. Even though district markets were important outlets for maize producers, they were usually distant from farmers' homesteads.

In Ethiopia, from the total 13.8 t of legume supplied to market by the sample households, 60% was sold at district markets, 34% was sold at village markets and 5% was sold at the farm gate. Like maize, district markets were the main outlets for legume markets.

Table 11.5 Farmer participation in maize and legume markets, Ethiopia and Kenya, 2010

	Maize		Legume	
	Ethiopia (*N* = 889)	Kenya (*N* = 613)	Ethiopia (*N* = 889)	Kenya (*N* = 613)
Number of growers	869 (98%)[a]	604 (99%)	285 (32%)	313 (51%)
Number of sellers	616 (71%)[b]	332 (55%)	256 (89%)	257 (82%)
Proportion of grain sold at:				
Farm gate (%)	25.6	62.5	5.4	56.4
Village market (%)	29.0	27.4	33.9	37.4
District market (%)	45.4	10.1	60.2	6.2
Average quantity of grain sold at:				
Farm gate (kg/household)	391.9	629.0	39.5	178.6
Village market (kg/household)	442.6	227.7	176.1	78.3
District market (kg/household)	693.5	160.3	324.9	29.0

Notes: a = Percentage of total sample; b = Percentage of maize growers. Legumes include haricot bean, soybean, peanut, etc.

In contrast to Ethiopia, farm-gate marketing was a more more common outlet for Kenyan farmers than village or district markets for both maize and legume sales (Table 11.6). This marketing strategy could reduce the burden of transporting grain to the buyers and might give farmers better bargaining power and the prospects of better grain prices.

Table 11.6 Maize and legume value-chain actors at different outlets, Ethiopia and Kenya, 2010

Crop type	Buyer type	Ethiopia			Kenya		
		Farm gate	Village market	District market	Farm gate	Village market	District market
Maize	Cooperatives	2	4	7	4	0	0
	Wholesalers	33	147	275	147	78	14
	Assemblers	31	44	46	65	17	1
	Consumers	6	9	18	1	0	0
Legumes	Cooperatives	0	3	4	3	1	2
	Wholesalers	11	62	132	90	68	11
	Assemblers	0	15	20	50	27	2
	Consumers	1	3	8	1	2	1

Explaining CASI adoption by access to market and services

The results of a multivariate Probit analysis (Tables 11.7 and 11.8) show that the gender of the head of household, the number of livestock owned, walking distances to sources of agricultural inputs, selling points and information, land area under maize cultivation and the age and education of the head of household influenced the likelihood of adoption of intensification practices. Overall, sustainable intensification practices were more likely to be adopted by farmers who cultivated maize on larger land areas, although the factors that impacted adoption varied between Ethiopia and Kenya. The likelihood that intercropping was practised in Ethiopia was higher in male-headed households than female-headed households and declined as livestock increased. The likelihood that intercropping was practised in Kenya was also higher in male-headed households than female-headed households and declined with walking distance to the village market. The likelihood of intercropping in Kenya also increased with land area under maize cultivation, walking distance to the main market (rather than the village market) and walking distance to agricultural extension services.

The likelihood that the household practised crop residue retention in Ethiopia increased with land area under maize cultivation and walking distance to the village market. In Kenya, the likelihood of crop residue retention declined with walking distance to the village market.

The likelihood that the household used no or minimum tillage practices in Kenya was higher in male-headed households than female-headed households and increased with walking distance to the village market.

The likelihood of legume–maize rotation in Ethiopia was lower in male-headed households than female-headed households and increased with land area under maize cultivation. The likelihood of legume–maize rotation in Kenya increased with walking distance to the village market and was lower in households that were members of a marketing group than those that were not members.

The likelihood of fertiliser use in Ethiopia was higher in male-headed households than female-headed households and increased with land area under maize cultivation. The likelihood of fertiliser use in Kenya increased with the education of the head of household.

The likelihood of improved seed use in Ethiopia declined with the age and education of the head of household and walking distance to agricultural extension services and increased with land area under maize cultivation.

The likelihood of manure use in Ethiopia increased with the age of the head of household, the livestock owned, walking distance to their farmers’ group and walking distance to agricultural extension services. The likelihood of manure use in Ethiopia declined with the value of household assets and walking distance to the village market. The likelihood of manure use in Kenya increased with the number of livestock owned.

Table 11.7 Multivariate Probit model of adoption of CASI practices in Ethiopia

Explanatory variables	Intercropping		Crop residue retention		Legume–maize rotation		Fertiliser use		Improved seed use		Manure use	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Gender of household head (1 = male, 0 = female)	0.704*	0.367	–0.232	0.210	–0.395*	0.221	0.530**	0.207	0.098	0.202	–0.185	0.201
Age of household head (years)	0.006	0.007	–0.007	0.006	–0.006	0.006	–0.004	0.006	–0.013**	0.006	0.011*	0.006
Education of household head (years)	–0.002	0.030	0.002	0.023	0.028	0.024	0.031	0.024	–0.058***	0.022	0.034	0.022
Value of assets (1,000 Birr)	–0.001	0.003	0.001	0.001	–0.003	0.002	0.002	0.002	0.000	0.001	–0.002**	0.001
Maize area (ha)	–0.103	0.137	0.229***	0.072	0.284***	0.079	0.171*	0.088	0.270***	0.084	–0.120	0.074
Livestock owned (tropical livestock units)	–0.062*	0.030	–0.001	0.014	0.003	0.015	–0.012	0.015	0.005	0.015	0.045***	0.013
Walking distance to village market (minutes)	0.001	0.003	0.005**	0.002	0.001	0.002	0.001	0.002	0.001	0.002	–0.003*	0.002
Walking distance to main market (minutes)	–0.001	0.001	0.001	0.001	–0.002	0.001	0.000	0.001	0.000	0.001	0.001	0.001
Walking distance to fertiliser supply (minutes)	0.002	0.001	0.000	0.001	0.001	0.001	–0.001	0.001	0.001	0.001	–0.001	0.001
Walking distance to farmers' group (minutes)	–0.001	0.002	–0.002	0.002	–0.003	0.002	0.002	0.002	–0.003*	0.002	0.003*	0.002
Walking distance to agricultural extension service (minutes)	–0.006	0.004	0.002	0.003	–0.002	0.003	–0.004	0.003	0.003	0.003	0.005*	0.003
Constant	–1.473***	0.519	–0.734**	0.367	–0.347	0.380	0.157	0.356	0.550	0.346	–0.726**	0.343

*Notes: **, ** and * are significant at 1%, 5% and 10% level; CASI = conservation agriculture-based sustainable intensification.

Table 11.8 Multivariate Probit model of adoption of CASI practices in Kenya

Explanatory variables	Intercropping		Crop residue retention		No/minimum tillage		Fertiliser use		Legume–maize rotation		Manure use	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Gender of household head (1 = male, 0 = female)	0.273*	0.162	−0.087	0.156	0.524*	0.301	−0.042	0.191	−0.206	0.166	0.015	0.159
Age of household head (years)	−0.005	0.005	0.000	0.004	−0.009	0.007	−0.006	0.005	−0.002	0.005	0.002	0.004
Education of household head (years)	−0.024	0.018	0.014	0.017	−0.040	0.027	0.083***	0.023	−0.001	0.018	0.016	0.017
Membership of marketing group (1 = yes, 0 = no)	0.143	0.171	−0.112	0.158	0.108	0.256	0.010	0.206	−0.573***	0.201	0.148	0.164
Value of assets (1,000 Birr)	−0.077	0.386	0.019	0.361	0.349	0.488	0.242	0.546	0.163	0.362	0.556	0.413
Maize area (ha)	0.125***	0.044	0.051	0.035	0.036	0.046	0.018	0.043	−0.057	0.036	−0.034	0.033
Livestock owned (tropical livestock units)	0.047	0.044	0.037	0.037	−0.040	0.064	0.095	0.058	0.018	0.037	0.252***	0.047
Walking distance to village market (minutes)	−0.010***	0.002	−0.006***	0.002	0.006**	0.003	0.002	0.003	0.006**	0.002	0.003	0.002
Walking distance to main market (minutes)	0.006**	0.003	−0.001	0.003	0.002	0.008	−0.002	0.005	0.000	0.004	0.006	0.004
Walking distance to fertiliser supply (minutes)	−0.003	0.003	0.002	0.003	−0.002	0.008	0.003	0.005	−0.001	0.003	−0.011	0.004
Walking distance to farmers' group (minutes)	−0.002	0.002	−0.001	0.002	−0.004	0.003	0.001	0.002	−0.003	0.002	0.001	0.002
Walking distance to agricultural extension service (minutes)	0.002*	0.001	0.001	0.001	0.002	0.002	−0.001	0.001	0.001	0.001	0.000	0.001
Constant	0.459	0.337	0.199	0.320	−1.545***	0.538	0.681*	0.407	−0.384	0.347	−0.200	0.325

*Notes: **, ** and * are significant at 1%, 5% and 10% level; CASI = conservation agriculture-based sustainable intensification.

Conclusions

Conservation agriculture-based sustainable intensification of smallholder agriculture in maize-based systems is essential to enhance or at least maintain the current agricultural production and productivity in eastern and southern Africa. As most of the maize biomass is taken away from farm plots for different purposes, improving soil fertility and crop productivity using purchased agricultural inputs like chemical fertiliser and seed of improved varieties are common strategies used by most smallholder farmers. The feasibility of purchased input use and other intensification practices to ensuring the adoption of CASI practices largely depends on input and output market function and their accessibility for resource-poor smallholder farmers. Using SIMLESA 2010 baseline survey data from Ethiopia and Kenya, this paper examined this relationship. The main conclusions drawn from the analysis are summarised below.

Physical accessibility of input supply markets could enhance the uptake of improved agricultural technologies and support sustainable intensification of maize production. The proportion of farmers not using improved maize seed and fertiliser increased with distance from the supply source.

Creating the right incentives and a competitive environment facilitated effective markets for outputs, inputs and services that could support sound sustainable intensification aimed at food security and poverty reduction, with minimum negative consequences to natural resources and the environment. When targeting sustainable intensification of smallholder agriculture, policies and institutional arrangements that ensure smallholder farmers' access to both input and output markets is the key to encouraging smallholder farmers to purchase productivity-enhancing agricultural inputs. Moreover, availability and accessibility of agricultural produce markets also enable the sale of surplus produce arising from CASI practices. In addition to the input and output markets, other related facilities, like financial and insurance markets, could enhance farmers' ability to purchase agricultural inputs and facilitate sustainable intensification.

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12 Capacity building

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Key points

- Involvement and engagement of implementing partners at all planning levels is crucial.
- All stakeholders of SIMLESA required some form of training. This empowered them to deliver the program but, more importantly, it strengthened their capacity.
- Distilling and packaging information for different audiences was found to be very important when communicating findings.
- Regular feedback was a key feature for improving the training program during implementation.
- Most policymakers incorporated findings from the SIMLESA program into key messaging for extension services and in promotion of various farm implements.

Introduction

The European Union's web gate notes the difficulty of reaching global consensus on the definition of capacity building. It further suggests that 'in a strictly "institutional" sense, capacity building refers to the process of optimising the skills of individuals and institutional support of one or more organisations'. In the spirit of the Cotonou Agreement, one can define capacity building as the process aiming to facilitate, in conjunction with the stakeholders, a consolidation of their capacities at an individual, organisational and sectoral level to allow them to evolve and adapt to the new contextual requirements. This definition aligns with the SIMLESA program's intended purpose: to enhance member countries and, in turn, individuals working for the organisation with requisite skills to appropriately deal with the complexity of African agriculture in this context.

The capacity-building component of the SIMLESA program focused on both non-degree practical training and postgraduate degree training (MSc and PhD) for national and regional partners. Practical training included:

- enhancing skills in technology targeting
- risk analysis
- value-chain diagnosis
- impact pathway analysis
- cropping systems management and conservation agriculture
- integrated maize–legume modelling
- methods for participatory breeding and local quality seed production.

Furthermore, field extension agents received practical training and orientation during structured field visits. Additional training on gender integrated planning and soft skills was also provided for researchers and gender focal persons.

SIMLESA training courses played a critical role in helping international researchers meet national food security and resource conservation goals. By sharing knowledge to build communities of agricultural knowledge in developing countries, SIMLESA empowered researchers to aid farmers sustainably.

Capacity building, in all its dimensions, needs to consider the capacity of farmers. This entails accounting for local circumstances of youth and women who farm. What innovations may work for them, or not, and why? For example, poor farmers who largely depend on casual, off-farm work as their primary source of income may not invest in fertilisers, but they can benefit from improved germplasm. Each farmer has a diverse wealth of knowledge, based on beliefs, preferences and risk aversion levels, which influences their likelihood of experimenting and adopting new technologies. Adoption models based on economically rational decision-making have struggled to account for these farmer-level characteristics. Given this complexity of adoption processes, it is especially challenging to identify and recommend business opportunities and anticipate the impacts that adoption will have on markets.

In implementing a program like SIMLESA, different expertise was required from implementing partners. A multidisciplinary approach was needed to address various components of the program. Major weaknesses identified among implementing partners included:

- socioeconomics (development of tools, data collection, cleaning, synthesis, analysis, interpretation)
- agronomy (conservation agriculture, experimental design, sampling/data collection, statistical analysis, paper writing, communication, etc.)
- participatory variety selection (evaluation of newly developed/released varieties, selection/ranking, etc.).

Program-implementing staff from different countries had different skills and levels of training. They also had different levels of education and field experience. There was a need to retool these staff and give them exposure to modern tools, equipment and the skills to address challenges. To fill this gap, various training programs were planned and implemented during program implementation. This chapter reports mainly on the trainings conducted by the Agricultural Research Council of South Africa. However, there was substantial other capacity building conducted by other program staff from the International Maize and Wheat Improvement Center (CIMMYT), Murdoch University, the Association for Strengthening Agricultural Research in Eastern and Central Africa, the Queensland Alliance for Agriculture and Food Innovation (QAAFI), as well as the Commonwealth Scientific and Industrial Research Organisation, the Crawford Fund and ACIAR.

Capacity building in SIMLESA mainly addressed the establishment and strengthening of government institutions including research and development organisations, non-government organisations, community-based organisations, the private sector, farmers and individuals. The aim was to build sustainable capacity at all these levels but also create capacity across the value chain for sustainable development.

The key consideration that informed the strategies to strengthen SIMLESA institutions was to consider existing knowledge of the trainees to ensure that training built on that foundation. While African agriculture and local socioeconomic development is anchored on knowledge, skills and ability to apply practical wisdom, trust and relationships were considered fundamental. Trainees, particularly farmers, can have knowledge but lack the skills to convert it into practical outcomes. The ability to mobilise resources, methods and navigate environmental challenges might have been low due to a poor understanding of knowledge exchange processes.

However, most development interventions start at the skills level. They often have excessive emphasis on skills training, which does not adequately consider trainees' ability to apply what they learn from outsiders. Emphasis on outputs of development interventions also tend to ignore the application of knowledge, skills and abilities to produce better outcomes such as improved livelihoods and income, better decision-making processes, wealth creation and employment creation, among others.

Postgraduate education

Specialised programs and short courses on maize and legume production for MSc and PhD students were identified to help postgraduate students pursue their interests in various fields of study, and fulfil research requirements to attain their MSc and PhD qualifications. To ensure excellence, support was given by the program. This included matching each student with an expert supervisor, and facilitating applications and registration with appropriate universities. Table 12.1 indicates the range of topics explored by postgraduate students from various research institutions who undertook formal training.

Table 12.1 SIMLESA-funded masters and doctoral students at South African universities

Name/country	Degree/university	Theses	Graduation
Frank Mmbando Tanzania	PhD Agricultural Economics	Market participation, channel choice and impact on household welfare: the case of smallholder farmers in Tanzania	16 Mar 2015
Custódio Jorge Mozambique	MSc Agriculture North West University	Comparative analysis of nitrogen-fixing potential of inoculated and fertilised four different legume species under semi-arid region	24 Oct 2017
Gabriel Braga Mozambique	MSc Agriculture North West University	Effect of plant density on growth and yield of six soybean (*Glycine max* L. Merril) cultivars grown at three localities in South Africa	24 Oct 2017
Mekonnen Sime Ethiopia	PhD Agricultural economics University of KwaZulu-Natal	Common bean technology adoption, commercialisation and impact on household welfare	Dec 2018

Training was also conducted in Australia and other African countries. A total of 23 doctoral students were enrolled at numerous universities and 42 students were supported for MSc degrees at national universities under SIMLESA (Table 12.2).

Table 12.2 Academic support of national agriculture research systems personnel in SIMLESA countries

	Country of origin of postgraduate student	PhD	Country where training was held	MSc	Country where training was held
1.	Kenya	3	Kenya	1	Kenya
2.	Mozambique	1	Australia	2	South Africa
3.	Rwanda	–	–	1	Kenya
4.	Ethiopia	2	Ethiopia	18	Ethiopia
5.	Ethiopia	12	Australia	9	Ethiopia
6.	Malawi	3	Australia	2	Malawi
7.	Tanzania	1	South Africa	9	Tanzania
8.	Ethiopia	1	South Africa		
Totals		**23**		**42**	

The program developed customised short courses across the agricultural value chain to meet the participants' needs. Short courses exposed students to production information to facilitate skills acquisition and enable assimilation of key terms, theories and principles through practicals. These practicals equipped students with skills that could be applied in their home countries and universities. Table 12.3 shows the short courses offered in the SIMLESA program from 2011 to 2017.

Table 12.3 SIMLESA short-term training programs

Training type	Duration (days)	Dates	Country	Trained	Participants
Principles of biometry, conservation agriculture, soil health and innovation platforms	5	2011	South Africa	16	NARS scientists
Principles of CASI, innovation platforms and extension principles	5	2011	Ethiopia	32	NARS scientists
Climate risk analysis masterclass training with the support of Crawford Fund	5	10–16 Jul 2011	Tanzania	24	NARS scientists and extension
CASI, integrated weed and pest management, soil nutrition management and introduction to innovation platform	5	18–22 Jun 2012	Mozambique	41	NARS scientists andextension
CASI and innovation platforms	3	6–8 Aug 2012	Rwanda	23	Farmer groups, community associations, scientists and extension
Establishment of innovation platforms	4	12–15 Nov 2012	Tanzania	50	Southern Sudan Uganda Rwanda
Introduction to innovation platforms, CASI principles, nitrogen fixation, experimental design and field layout, agro-climatology principles, data collection and analysis	10	6–17 May 2013	South Africa	15	Agronomy scientists from Malawi, Ethiopia, Kenya, Tanzania, Uganda, Rwanda and Mozambique
Integrating gender for priority setting, planning and implementation	5	24–28 Aug 2015	South Africa	15	NARS gender specialist and SIMLESA management
Biometry and data analysis techniques	5	20–24 Feb 2017	Tanzania	30	Tanzanian research staff
Science communication	4	3–8 Mar 2014	South Africa	10	CIMMYT and NARS program leaders

Notes: NARS = national agriculture research systems; CASI = conservation agriculture-based sustainable intensification

Short-term training

The short-term training modules were divided into four major programs

1. cropping systems
2. innovation platforms
3. biometry
4. gender awareness.

Cropping systems management

The agronomy capacity building done by the Agricultural Research Council focused on helping SIMLESA partners to better understand the concepts and practices of conservation agriculture-based sustainable intensification (CASI). Researchers, extension staff and members of innovation learning platforms, as well as other SIMLESA partners (e.g. non-government organisations, seed producers, agrodealers) attended the in-country workshops.

Workshops were conducted in Ethiopia, Kenya, Malawi, Mozambique, Rwanda, South Africa and Tanzania. One hundred and fifty participants from these countries, as well as from Uganda, attended the workshops. The topics addressed were:

- soil analysis, fertiliser recommendations and calculations
- climate data collection, analysis, development of advisories for early warning
- conservation agriculture principles:
  - nutrient management, soil fertility, soil sampling and soil microbiology, Water Efficient Maize for Africa and Improved Maize for African Soils
  - integrated weed management, including safe use and handling of chemicals, calibration of sprayer
  - disease management
  - integrated pest management
- economically important of nematode groups.

The Agricultural Research Council shared their knowledge about grain production and trainees who attended in South Africa also had the opportunity to visit the Agricultural Research Council research facilities at the Grain Crops Institute (Potchefstroom), the Institute for Soil Climate and Water (Pretoria) and the Plant Protection Institute (Pretoria). The training approach was interactive and practical and conducted in a participatory manner by expert researchers and technicians. Table 12.4 shows the topics and outcomes.

Table 12.4 Technical modules on cropping systems management and intended outcomes

Topic	Outcome
Entomology	
Integrated pest management	Overview of entomology and push–pull systems
Insect classification	Presentations about the different insect orders Students did a practical where they identified insects through microscopes
Insect pests of maize	Presentations about target and non-target pests on maize
Insect pests of soya	Presentations about insect diversity and important pests in soybeans
Rearing of insects	Presentations about rearing insects and how to make medium Tour through the rearing facilities
Evaluation and monitoring of insects, laboratory, glasshouse, field and trial layout	Presentations about trial design Practical in glasshouse and field—how to collect insects, how to plant a trial, etc.
Visit North West University (NWU) entomology department	Networking with leading researcher at the NWU
Nematology	
Overview of the economically important nematode groups	Highlighted the impact of nematodes on the production of maize, peanuts, sunflower and soybean
Nematology lab • collect sampling equipment from the lab and proceed to the field for sampling to apply theory that they have learned into practice • glasshouse	Practical experience of nematode sampling
Extraction of samples	Practical experience of sample preparation
Microscope: works • How to make slides for ID • Hand out the manuals/notes	Outline of the manual What is a nematode? Importance of parasitic nematode in crop production What do they look like? Types of nematodes Symptoms associated with nematode damage (above- and below-ground symptoms) Association of weeds and nematodes in crop production Taking samples of nematodes When and how to take samples Tools required Control measures Principles of sustainable nematode control

Table 12.4 Technical modules on cropping systems management and intended outcomes (continued)

Topic	Outcome
Pathology	
Basic introduction into plant pathology	What is a plant pathogen? Disease triangle Bacteria vs fungi vs virus
Basic introduction into fungicides	What are fungicides? Systemic vs contact How to interpret labels How to apply correctly (with knapsack sprayers)
Maize and soybean diseases	A discussion of important maize and soybean diseases—expected impact within CASI system
Dry bean diseases	A discussion of important dry bean diseases—expected impact within CASI system
Mycotoxins	Impact of mycotoxins CASI and mycotoxins Research conducted at ARC-GCI
Role of insects in plant disease: session 1	Role of insects in cob rot Effect that CASI might have on stalk borer and cob rot
Role of insects in plant disease: session 2	Role of insects in maize streak virus transmission Effect that CASI might have on leafhopper populations and maize streak virus
Root and stalk rot under conservation agriculture	Principles
Practical session 1: media preparation	Practical experience of how to prepare media
Practical session 2: plating out of material	Practical experience of how to plate out material
Practical session 3: isolation of pathogen	Practical experience to isolate pathogens from Potato-dextose-agar (PDA) medium to split plates and from leaves to PDA
Practical session 4: storage of pathogen	Practical experience on methods to store pathogens (glycerol and freeze drying)
Practical session 5: maize streak virus trial demonstration	Demonstrate how the leafhoppers are maintained within the greenhouse, as well as how the greenhouse trial is conducted
Soil fertility and agro-climatology	
Soil analysis, fertiliser recommendations and calculations	Interpretation of soil analysis and calculation of required elements
Nutrient management, soil fertility, soil sampling	Importance and management practices to maintain the required nutrient status for the different crops
Climate data collection, analysis, development of advisories for early warning	Importance and interpretation of climate data
Nitrogen fixation laboratory	Practical experience
Visit Soygro (nitrogen fixation plant at Potchefstroom)	Practical experience
Introduction to soil microbiology	Understanding the importance of soil health
Techniques used in soil microbiology	How to sample and determine soil health

Table 12.4 **Technical modules on cropping systems management and intended outcomes (continued)**

Topic	Outcome
Weed sciences	
Weed biology and ecology	Definitions, characteristics, classifications, role of environment on germination, growth and spread of species
Weed management	Weed control principles, mechanical, cultural and chemical weed control, integrated, identification of weeds
Chemical weed control	Overview of herbicides, time of application, mode of action of some herbicides, species identification
Herbicide labels	Information on herbicide label and importance thereof, dosages, time of application, etc.
Sprayer equipment (including safe use and handling of chemicals)	Introduction to different nozzles, sprayers, etc.
Calibration knapsack and tractor sprayers	Practical exercise
Conservation agriculture cultivation practices	
Conservation agriculture principles	Understanding the principle of minimum tillage, crop rotation and residue retention
Visit conservation agriculture trials: on-farm trials at the farms Ditsim and Buffelsvlei	Practical experience
NAMPO harvest day	Networking with commercial farmers, input retailers, seed companies CASI mechanisation

Note: CASI = conservation agriculture-based sustainable intensification

Innovation platforms

The focus of this training initiative was to equip researchers with skills and knowledge on the establishment of innovation platforms. Innovation platforms workshops for southern and eastern Africa-based researchers were held in Mozambique, Rwanda, South Africa and Tanzania between 2012 and 2013.

A facilitator's manual was developed after the training as a support for post-training implementation of skills and lessons learned. The information included in the manual was originally prepared as handouts and several other sources of materials came from the adult education field, and years of training and facilitation of workshops in organisational development and change by the compilers. The manual (and the workshops) were designed as a tool to train trainers.

Key concepts and rationale

The linear model of technology transfer in agriculture is increasingly seen as inadequate to achieve rural innovation. Rather, an innovation systems model, in which a variety of individuals and organisations (stakeholders) interact in a complex relationship and build on identified opportunities, is increasingly being adopted to better suit the reality (Spielman 2005).

While individual stakeholders have made efforts to address poverty in the country, real impact to achieve global sustainable development is yet to be realised. SIMLESA considered a renewed emphasis on facilitating improved multistakeholder engagement for the integration of technological, policy and institutional factors was critical for finding solutions that would achieve broad objectives through collective action in innovation platforms (Figure 12.1). Agricultural innovation platforms (AIP) were established as grounds and pillars for multilevel, multistakeholder interactions to identify, understand and address a complex challenge and concomitant emerging issues and to support learning towards achieving the agreed vision (Tenywa et al. 2011).

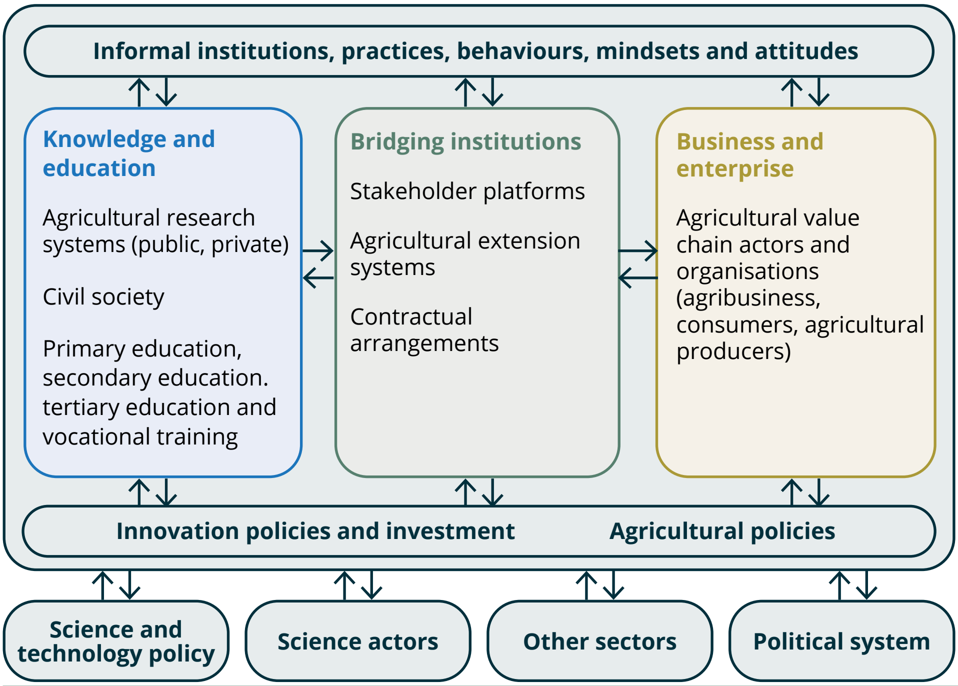

Figure 12.1 Linkages and actors in an innovation platform

The adoption of the innovation platforms model in the SIMLESA program was prompted by the recognition that improving rural innovation processes could not be achieved by simply questioning farmers about their constraints or needs, introducing new technologies or identifying markets. New technology does not automatically lead to impact at scale. Users only accept and adopt new technology if it responds to their needs. This means there must be an understanding of these needs. One mechanism to foster involvement of all stakeholders in the agrifood value chain was the innovation platforms approach. These platforms and partnerships were essential to foster research-for-development efforts towards innovations that led to impact at scale. SIMLESA assumed that the likelihood of success improves if users have been involved in the research from its conceptualisation, and if research organisations develop strategic partnerships to ensure that the knowledge they generate can move down the impact pathway and lead to innovation, products in the marketplace, uptake and use.

Strengthening the functional capacity of stakeholders to interact more effectively was achieved by enhancing abilities in communication, facilitation and management of partnerships and teamwork under the SIMLESA program. This was regarded as the basis for CIMMYT stakeholders to navigate complexity and find joint solutions to issues of common concern.

The innovation platform training workshops were participatory and featured interactive, learner-centred methods. The work in adult education shows that people, especially adult learners, wanted to participate in the learning process. They wanted to learn from their experiences, be challenged and draw their own conclusions from learning. The workshop participants' experiences and ideas on the design, implementation and management of Innovation platforms, was central to the learning process.

The facilitators advised the participants to read widely on adult learning principles and case studies on innovation platforms and multistakeholder processes as extra resources. An in-depth knowledge and understanding of these principles and practices was advantageous to the adoption of the innovation platforms model.

The workshops aimed to support skills development for trainers and facilitators and equip them with skills while also guiding them on how best to run workshops for other facilitators.

Establishment of innovation platforms

An important objective of innovation platforms is to stimulate continual involvement of stakeholders in describing and explaining complex agricultural problems, and in exploring, implementing and monitoring agricultural innovations to deal with these problems. By facilitating interaction between different stakeholder groups, innovation platforms provided a space not only for the exchange of knowledge and learning (Ngwenya & Hagmann 2011) but also for negotiation and dealing with power dynamics (Cullen-Lester et al. 2014), which can often be a problem in collaborative work. The following principles were important in establishing successful innovation platforms:

- diversity of stakeholders
- a shared problem or opportunity
- facilitation by a neutral person/organisation with convening authority
- initial success to motivate members to commit to the platform
- change resulting from the innovation that benefits multiple members
- exchanges and learning that remain central
- respect between members
- systems to ensure transparency and accountability.

The participants discussed these principles during the training workshops. The process outlined in Table 12.5 was proposed as a guide for forming innovation platforms.

A total of 58 innovation platforms were established under SIMLESA to assist in scaling out research and development technologies; help productive interaction of farmer groups, partners, extension, research and local businesses in sharing farming experiences at community level; and support viable marketing of agriculture produce for maximum benefits. For example, one of the innovation platforms focused on the identification of orange-fleshed sweetpotato value-chain actors for robust marketing strategies of the crop. The main actors were identified as seed producers (including researchers), root producers (farmers, rural communities), processors and traders (agribusiness was clustered to include input suppliers) and other professional bodies, including advisory services and policy makers. While the role of other actors was clear in other innovation platforms, in this case, the inclusion of policymakers was regarded as important for establishing dialogue to proactively address prohibitive and regulatory market restrictive frameworks. The distribution of innovation platforms at country level is shown in Table 12.6.

Table 12.5 Proposed process to guide formation of an innovation platform

Stage	Activities
Designing	Design the innovation platform in a manner that serves a common purpose. The design process is dynamic. Regardless of what plans are in place, confronting challenges and opportunities is always the priority.
Initiating	There needs to be a sound program idea that requires multistakeholder engagement. Research and learning organisations can act as convenors. A scoping process is recommended to narrow down the platform topic.
Stakeholder engagement	Stakeholder mapping and selection is the key to identification of action entry point studies and consultations. The workshops discussed: • Criteria for successful participation of various stakeholders for SIMLESA • Mechanisms for stakeholders to evaluate the process of their participation and impact of their involvement in the SIMLESA program • Assessment of analytical variables to describe participation and stakeholder engagement, for example: – Type of participation required of each stakeholder involved. – At what stage of the program should each stakeholder be involved? – Who is participating? – Who should make key decisions? – What roles should the different stakeholder participants play? – How is the stakeholder participation process managed?
Participation	Roles have to be discussed and agreed upon. These may change on reflection, and identification of new roles may mean new stakeholders are identified and asked to join the innovation platform. A management structure may be necessary.
Formalisation	There may be a need to formalise the innovation platform through registration.
Resource mobilisation	An innovation platform requires funds to keep it going and discussion of funds available within SIMLESA. Initially, donors would fund innovation platforms, but this is not sustainable in the long run.
Keeping the innovation platform going	Develop mechanisms to maintain member commitment. This is a major challenge, particularly in learning and research-oriented innovation platforms. Getting the right individuals from key organisations is critical. Individuals should not be too low nor too high in the organisation's hierarchical structure.

Table 12.6 Number of SIMLESA innovation platforms by country

Country	Ethiopia	Kenya	Tanzania	Malawi	Mozambique	Rwanda	Uganda	Total
Number of sites	7	5	5	6	4	5	2	**34**
Number of innovation platforms	20	9	10	6	6	5	2	**58**

In addition to established innovation platforms, towards the end of 2016, the SIMLESA program selected 19 partners to drive the scaling-out initiative under the competitive grants scheme. Details of the selected partners and expert mix (knowledge management, seed multiplication and extension services) are shown in Table 12.7.

Table 12.7 Competitive grants scheme partners

Country	Farmer association	Information and communications technology	Non-government organisation	Media	Seed	University	Church organisation	Level
Kenya	Secondary partners esp. agricultural innovation platforms	Secondary partners: Queensland Alliance for Agriculture and Food Innovation; Mediae Ltd		Mediae Ltd	Freshco Seed Co.	Egerton	National Council of Churches of Kenya	County
Malawi	National Smallholder Farmers' Association of Malawi	Secondary partners: Queensland Alliance for Agriculture and Food Innovation; Farm Radio Trust		Farm Radio Trust				National
Mozambique	Uniao Provincial Dos Camponeses De Manica	Instituto Superior Politécnico de Manica; Queensland Alliance for Agriculture and Food Innovation	Organização para o Desenvolvimento Sustentável da Agricultura e de Mercados Rurais	Instituto Superior Politécnico de Manica	Secondary partners	Instituto Superior Politécnico de Manica		National
Tanzania	Mtandao wa Vikundi vya Wakulima Tanzania	Secondary partners: Queensland Alliance for Agriculture and Food Innovation; Centre for Agriculture and Bioscience International (sometimes also referred to as CAB International)	Research, Community and Organizational Development Associates	Secondary partner	Suba Agro Trading and Engineering Co. Ltd	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.							

Conclusions

The training was designed to introduce the concept of innovation systems and the establishment of innovation platforms. It was anticipated that the participants would establish innovation platforms in their areas and countries of operation. The training was necessary to achieve SIMLESA's goal of integrating research and development.

However, training on its own is insufficient to support the adoption of doing research and development in new ways. In the future, SIMLESA could also lobby at the national and provincial/district level to ensure that the skills gained by trained researchers are used in ongoing and future initiatives.

It is encouraging to note the parallel development of a selected group of scientists from each country who can work towards providing the essential enabling environment to strengthen and institutionalise innovation platforms. A review of multicountry support mechanisms for innovation platforms is needed to draw specific conclusions.

Biometry

Biometry training was specifically requested by national agricultural research systems scientists to solve two major challenges of the SIMLESA program:

- planning of field activities
- analysis of accumulated data and interpretation of results.

The training needs assessment of the national agricultural research systems scientists revealed the need to focus on basics such as design of field experiments, data capturing, data analysis and interpretation of results. A plenary workshop provided basic statistical guidelines to familiarise researchers with different experimental designs and data analysis methods. In cases where data were already available, the first step was to check whether the researchers followed the correct procedure in capturing and analysing the data. This was done by:

- reviewing the researcher's methodology, survey instrument and dataset to better understand the study and develop a proper method for the analysis and interpretation
- one-on-one data analysis (using various statistical software packages including GenStat, SAS and XLSTAT) and discussing the output with the researcher
- assisting researchers to write up their articles or theses by summarising the results in the form of pivot tables and graphs in Excel.

A total of 120 scientists were trained over a three-year period. Table 12.8 shows the specific modules and services provided for each country.

Table 12.8 Biometry training and support

Course provided	Country	Number of trainees
2013		
Pivot tables	Tanzania	60
Statistical guidelines		
Data analysis with Excel		
Graphs with Excel		
2014		
Statistical guidelines	Zimbabwe Malawi Kenya Ethiopia Mozambique	30
Statistical consultation		
Data coding, exploration, interpretation of results		
2017		
Statistical guidelines	Tanzania	30
Statistical consultation		
Data coding, exploration, interpretation of results		

Gender awareness

The prevailing tendency in reducing the gender gap has been to see gender in development as a women's issue rather than as a critical requirement for effective development processes that address power relations between men and women in all aspects of economic, political, social and cultural development. In this respect, building capacity for gender integrated planning at the research program implementation level was identified as one of the key capacity development priorities for the SIMLESA program. Developing skills and tools for gender analysis and gender integrated planning at field level could help to bring about significant changes in the SIMLESA program that would support and sustain a strong focus on gender responsiveness and accelerate gender change in the agency skills of the program staff.

Improving food security and people's livelihoods is complex and calls for a comprehensive and multidisciplinary approach. Such an approach must include the collection, management and analysis of data for agriculture and rural development. This is needed for planning and policy purposes as well as for monitoring and evaluating the impacts of research interventions. Men and women often use different methods of farming and marketing, and they face different constraints and opportunities along the value chain. As a result, they have different concerns regarding improving crop yield or increasing plant resistance to disease. For example, women may grow maize as a subsistence crop, but men grow it as a cash crop. Women may also derive significant income from by-products, such as straw used as fodder for livestock. Consequently, male and female farmers often have different research interests and needs that can only be captured if gender issues are incorporated in setting the research agenda. Paying attention to gender differences can enhance the quality of research work at different stages of the research process. For example, testing and selecting plant varieties, promoting the adoption of findings, evaluating the results and improving staff quality may all require gender-sensitive approaches. Gender-disaggregated data highlights the need for accessible information and data as a starting point for any program or project.

To address the challenges identified above, SIMLESA Phase 2 aimed to wholly integrate and mainstream gender awareness within the country priorities and plans, across each of the five objectives. To meet this requirement, it was necessary to run a workshop that facilitated the tenets of SIMLESA Phase 2:

- ensure that gender is considered in all program aspects, including research and testing of technologies, scaling out efforts through innovation platforms and other frameworks, learning and training opportunities, and communication modalities
- improve scientific outputs on gender using existing SIMLESA Phase 1 datasets, and also through new qualitative and quantitative data
- report on all gender-related achievements and challenges in the annual reports.

The overall goal of the gender training workshop was to enhance the capacity of management, objective leaders, country coordinators and gender specialists to integrate and mainstream gender in the SIMLESA planning and implementation processes. The aim was to develop strategic gender research action plans that focus on gender transformative changes, and strong gender indicators for monitoring and evaluating the ongoing work. In addition, the roles of gender focal points were reconsidered, and the skills and tools needed for them to be effective in their role were identified. The specific objectives of the training were to:

- develop an improved understanding and knowledge of gender concepts for effective gender integration in SIMLESA
- initiate the scope for behaviour change/innovation to determine the set of gender intervention strategies and activities
- identify influencing factors affecting the final decision towards gender change in SIMLESA
- provide participants the opportunity to acquire gender change agency skills
- discuss and reach consensus on topics for strategic gender research in SIMLESA
- revisit the SIMLESA logical framework and discuss gender entry points, indicators and monitoring, and evaluation plans
- produce action plans for immediate application of gender integration in SIMLESA
- facilitate networking among members of the SIMLESA team.

A two-pronged approach was used:

1. focus on developing conceptual clarity, learning methods and tools for gender integrated planning at program planning level
2. focus on developing a team of scientists from within the national agricultural research systems that will work internally to support learning and change and can extend this learning to other agricultural research development practitioners.

This second focus required leadership training and engagement to create champions who would lead gender awareness, sensitivity and monitoring and evaluate the integration of gender in SIMLESA and other programs.

The gender training workshop factored coaching and mentoring into the training program. It was attended by the SIMLESA program leader, program manager, monitoring and evaluation officer, communications specialist and gender specialists from Ethiopia, Malawi and Mozambique.

Gender-explicit data collection training was conducted in 2016. The training included participatory development of data collection tools and pretesting of questionnaires and qualitative guides. On average, 10 people were trained in each country. Data were collected in the last quarter of 2016, analysed and a number of publications were developed. The main objective of the gender study was to apply a gender lens to two research questions:

1. Where and how can maize and legumes be scaled for sustainable intensification of maize-based farming systems?
2. What would the potential impacts be in the medium term across food systems in SIMLESA countries?

The survey methodology used included a rapid assessment approach and integration of gender into an agricultural value chains analytical framework. Focus group discussions and key informant interviews were conducted in the Arusha and Morogoro regions of Tanzania, Balaka and Kasungu districts of Malawi and Kakamega and Embu districts of Kenya. The survey products include many articles.

Follow-up training sessions were carried out in all innovation platforms and farmer groups in seven countries. A significant increase in yields and labour savings were reported by most innovation platforms during the reporting period (e.g. in the Musanze, Kamonyi and Bugesera districts of Rwanda, and the Nakasongola and Lira districts of Uganda, 'Voices from the field' reports).

The content was delivered through highly interactive learning and facilitation methods and included the following topics:

- An overview of SIMLESA
- Justification for new approaches for scientific agricultural research-for-development
- Theoretical constructs of gender
- Understanding gender concepts related to change in SIMLESA
- Gender analysis tools and methods
- Leadership styles and skills for behavioural change agents
- Communication
- Basics of monitoring and evaluation
- Planning skills and logical framework development
- Integrating and mainstreaming gender in SIMLESA country action plans.

Conclusions

The training was designed to address gender integration in the SIMLESA program because crucial program staff did not have the opportunity to integrate and mainstream gender in planning of SIMLESA Phase 1. The training was necessary to achieve SIMLESA's goal and was in line with SIMLESA's core vision regarding gender. Additional tasks to ensure there was effective integration of gender in SIMLESA 2 at country level include:

- clarifying budgets
- informing team members of the workshop resolutions
- gender mainstreaming
- strengthening the monitoring and evaluation framework
- developing the strategy for capacity building and the gender policy.

Gender work in SIMLESA was largely driven by a commitment to:

- understand the needs, preferences, experiences and challenges faced by male and female farmers
- facilitate equitable and effective participation of men and women
- foster and document patterns of benefits sharing among men and women.

Overall, the team aimed to bridge existing gender gaps in knowledge as well as in participation and benefit sharing among male and female farmers. The approach and processes put a face to the men and women whose voices SIMLESA targeted in its socioeconomic studies, as well as when the program tests and scales out alternative technologies in diverse contexts. Equally important, therefore, was the parallel development of a selected group of scientists from each country to work towards providing the essential enabling environment through which gender-responsive research and development could continue to be strengthened and institutionalised.

Science communication

Science communication is the presentation of science to the general public and relevant stakeholders for the purpose of disseminating the information for understanding and dispelling the myths of decision-making and mitigating risk. This often involves professional scientists developing appropriate resource materials for a target audience. It includes science exhibitions, journalism, policy and media production.

Science communication training was conducted with 10 CIMMYT scientists. The objective of the workshop was to assist and train scientists to develop media material highlighting the successes and lessons learned during the implementation of the SIMLESA program in the past four years.

The training focused on:

- packaging research/information for the media
- crafting and delivering messages using journalistic principles
- identifying photo opportunities
- design and layout of print media.

The major expected outcome was a SIMLESA kit of media materials such as magazines, pamphlets and video resources.

Discussions and role-playing in the form of mock interviews were used to explore different forms of communication. The role-playing videos were viewed and discussed to come up with a consensus strategy that would be adopted by the scientists.

In preparation for the development of print and video resources, the emphasis of the training was on non-verbal communication and strategies for conducting interviews. To identify and address bias in non-verbal communication skills, the trainees tested each other on their perceptions of key issues such as gender, clothing, body odour and other aspects of interpersonal relationships that may affect first impressions. The exercise was conducted over a two-day period followed by reflection on the third day, when videos captured throughout the process were discussed.

In preparing for interviews, particular focus was made on grooming and non-verbal communication. Much time was spent on mock interviews. The group decided to focus on the following messages:

- Ensure that you don't take the core message approach too far. If you attempt to get your 'nuggets' across to the exclusion of everything else, you may irritate and alienate the journalist.
- Find out in advance who your audience will be, and structure the content and tone of your messages appropriately.
- Be familiar with the publication or program and the reporter's style and approach before the interview.
- Listen to the entire question before answering.
- Plan answers for the five most difficult questions that you could be asked.
- Seek clarification if the question is ambiguous or unclear, or restate the question (to your advantage) in your answer.
- Use the ABC approach:
  - Answer the question.
  - Bridge to your key messages and lay out the facts.
  - Conclude by telling us what those facts mean.
- Use terms and language understood by your audience. Nationwide news broadcasts in the US are intentionally written at a Standard 8 level. If you have to use technical jargon, ensure that you are able to define or explain the term succinctly and memorably.
- Avoid value judgements or characterisations of any question. Simply respond to the central issue in the question.
- Avoid 'umm', 'ah', you know', 'to be honest' and other verbal distractions.

The practical development of SIMLESA print and video resources involved crafting the message, design and layout, and a SIMLESA video based on interviews of experiences of the scientists, extension workers, partners and farmers. The development process of these resources considered:

- Purpose: what is the messages and how is it crafted?
- Format: how is the message crafted?
- Audience: who is the messages intended for?

The criteria used to develop and evaluate the quality of pamphlets from the different SIMLESA activities was taken from Debbie Wetherhead (2011), who described the attributes of an effective message as:

- Concise: focus on three to five key messages per topic; write one to three sentences for each key message that should be read or spoken in 30 seconds or less
- Strategic: define, differentiate and address benefits
- Relevant: balance what needs to be communicated with what the audience needs to know
- Compelling: design meaningful information to stimulate action
- Simple: use easy-to-understand language; avoid jargon and acronyms
- Memorable: ensure that messages are easy to recall and repeat; avoid long, run-on sentences
- Real: use active voice, not passive; do not use advertising slogans
- Tailored: communicate effectively with different target audiences by adapting language and depth of information.

Focusing on these attributes, eight pamphlets were developed (Figure 12.2; Table 12.9). The pamphlets were distributed during SIMLESA planning meetings and farmer field days and used as promotional material in the different gatherings of stakeholders.

Figure 12.2 **SIMLESA pamphlets**

Table 12.9 SIMLESA pamphlets developed during the science communication workshop

Title	Compilers
Bridging gender gaps within SIMLESA	Isabel Cachomba, Colletah Chitsike and Frank Mmbando
Farmer-preferred maize varieties released to enhance food security in ESA	Dagne Wagary and Mekonnen Sime
Legumes for food, nutrition and income security in ESA	Alfred Micheni, Domingos Dias and Fred Kanampiu
Conservation agriculture technologies help to increase yields and save labour costs	Isaiah Nyagumbo, Fred Kanampiu and Domingos Dias
SIMLESA technologies benefit spill over countries	Drake Mubiru and Fred Kanampiu
SIMLESA improves Africa’s capacity for sustainable agricultural development, food and nutrition security	Gift Mashango, Malcom Gulwa and Sandile Ngcamphalala
Nurturing innovation platforms and empowering smallholder farmers	Leonidas Dusengemungu, Fred Kanampiu, Alfred Micheni, Isiah Nyagumbo and Domingos Dias
SIMLESA News Letter 2010–2015	Edited by Yolisa Pakela-Jezile, Mulugetta Mekuria and Fred Kanampiu

In addition, SIMLESA has produced 130 publications, 89 posters, 21 policy briefs and various communication products including national-level media coverage, national, regional and international conferences and participation by partners.

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