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SUSTAINABLE INTENSIFICATION OF MAIZE–LEGUME SYSTEMS FOR FOOD SECURITY IN EASTERN AND SOUTHERN AFRICA (SIMLESA)

LESSONS AND WAY FORWARD

ACIAR MONOGRAPH 211

SUSTAINABLE INTENSIFICATION
OF MAIZE–LEGUME SYSTEMS FOR FOOD SECURITY IN EASTERN AND SOUTHERN AFRICA (SIMLESA)

LESSONS AND WAY FORWARD

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ERIN WILKUS, MULUGETTA MEKURIA,
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ACIAR

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The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. ACIAR operates as part of Australia's international development assistance program, with a mission to achieve more productive and sustainable agricultural systems, for the benefit of developing countries and Australia. It commissions collaborative research between Australian and international researchers in areas where Australia has special research competence. It also administers Australia's contribution to the International Agricultural Research Centres.

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Cover: Maria Gorete (far right), farmer and SIMLESA project participant, plants maize with her daughters in Angonia, Mozambique. At the end of 2017, more than 230,000 farmers had adopted sustainable intensification technologies.
Photo: © CIMMYT. Photo by Peter Lowe.

Foreword

More than 1.3 billion people live in Africa, a number expected to almost double to 2.5 billion by 2050. Food insecurity and resource degradation in a changing climate are pressing concerns with geopolitical significance. For decades, agricultural researchers have been alarmed by the wide gap between the yields that are technically possible on African research stations, and those that are typically achieved in African farmers' fields. Leading researchers from Africa and internationally (including Australia) have long understood that it is insufficient to just focus on single interventions in one part of the system (e.g. better seed varieties, or improving fertiliser application). Durable, meaningful improvements can only be effected by understanding the whole farming system, including the policy and market contexts within which farmers operate.

For almost a decade, the Australian Centre for International Agricultural Research (ACIAR) brokered and invested in an ambitious, multidisciplinary applied research program in eastern and southern Africa to identify the pathways to sustainable intensification of diverse maize–legume farming systems.

The program, called the *Sustainable intensification of maize–legume cropping systems for food security in eastern and southern Africa*, and known as SIMLESA, typifies the work of ACIAR. ACIAR is mandated by the *Australian Centre for International Agricultural Research Act 1982* to work with partners across the Indo-Pacific region to generate knowledge and technologies to underpin improvements in agricultural productivity, sustainability and food system resilience. We do this by funding, brokering and managing research partnerships for the benefit of partner countries and Australia.

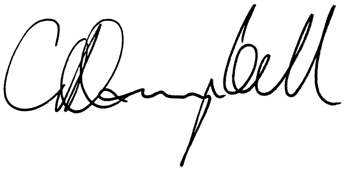
SIMLESA is one of the largest research partnerships ever funded by ACIAR. From 2010 to 2019, the program harnessed the energy and talent of researchers from eight countries in eastern and southern Africa, Australian Universities notably the University of Queensland in Australia and three international research centres belonging to the CGIAR system, all led by the International Maize and Wheat Improvement Center (CIMMYT).

SIMLESA is a flagship program that demonstrated to stakeholders at all levels, from farmers to business people, policymakers and ministers, the promise and opportunity of conservation agriculture-based sustainable intensification (CASI). It showed that holistic farming systems intensification; integrated combinations of reduced tillage, modern maize and legume varieties; retention of crop residue for preserving soil cover; and moderate doses of organic and inorganic fertiliser can deliver benefits to farmers and their environment. SIMLESA conducted a nuanced, rich and contextualised analysis of the benefits and trade-offs of the proposed innovations, which, overall, lifted production, reduced costs and helped farmers to better manage risk.

Constraints and obstacles to adoption of the innovations by farmers were studied and collective mechanisms to overcome these were tested. SIMLESA fostered many innovation platforms—multi-stakeholder, grassroots institutions that allow farmers, their suppliers and their customers to interact and collectively improve farming and food systems. Agriculture ministers from the eight partner countries strongly endorsed the CASI pathway in Uganda in May 2019. This reflects a key policy achievement of SIMLESA, paving the way to country-led expansion of SIMLESA practices and innovations in eastern Africa.

This majestic monograph, *SIMLESA: Lessons and way forward*, is a comprehensive, authoritative synthesis of selected results and lessons from this 10-year partnership, reflecting the hard work and hard-won lessons learned by more than 60 African and 15 international and Australian scientists.

Thank you and congratulations to the editors and authors of the 26 chapters of this book and the many more scientific articles that have been produced to document the SIMLESA project. This timely book should be useful to practitioners of CASI in eastern and southern Africa (and well beyond) for many years to come.



Andrew Campbell
Chief Executive Officer, ACIAR

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The SIMLESA effort was inspired by and dependent on the individual farmers and families from eastern and southern Africa who participated. They grounded the research and provided the motivation to make a real impact. The diverse team of SIMLESA researchers and scholars provided insight from a broad array of development histories and social and agroecological processes to relate the experiences of farmers and practitioners to broader trends and alternative perspectives. The effective collaboration by African agricultural research organisations, CIMMYT, ICRISAT, ILRI, Australian universities and ACIAR generated the directions and the enthusiasm to carry out the program and realise the SIMLESA vision. Individuals, including Dr Mulugetta Mekuria from CIMMYT and Dr John Dixon from ACIAR, were pivotal to establishing partnerships.

The research and coordination organisations included:

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- Ministry of Agriculture (Tanzania)
- Ministry of Agriculture, Irrigation and Water Development (Malawi)
- Instituto de Investigação Agrária de Moçambique (Mozambique)
- Agricultural Research Council (South Africa)
- Association for Strengthening Agricultural Research in Eastern and Central Africa (Uganda)
- International Crops Research Institute for the Semiarid Tropics (India)
- International Livestock Research Institute (Kenya)
- International Maize and Wheat Improvement Center (Mexico)
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Acronyms and abbreviations

ACIAR	Australian Centre for International Agricultural Research
ACMAD	African Centre of Meteorological Application for Development
ADOPT	Adoption and Diffusion Outcome Prediction Tool
AEZ	agroecological zones
AGREN	Agricultural Research and Extension Network
AIP	agricultural innovation platforms
AIS	agricultural innovation systems
AMESD	African Monitoring of the Environment for Sustainable Development
APSIM	Agricultural Production Systems sIMulator
ARC	Agricultural Research Council
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
ASCII	American Standard Code for Information Interchange
BARC	Bako Agricultural Research Center
C	carbon
CA	conservation agriculture
CAADP	Comprehensive Africa Agriculture Development Program
CASI	conservation agriculture-based sustainable intensification
CCAFS	Climate Change, Agriculture and Food Security
CEC	cation exchange capacity
CGIAR	formerly the Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
CMIP	coupled model intercomparison project
cm	centimetre
cmol	centimole
CV	coefficient of variation
CORDEX	Coordinated Regional Downscaling Experiment
CSA	climate-smart agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EIAR	Ethiopian Institute of Agricultural Research
ELD	Economics of Land Degradation
ENACTS	Enhancing National Climate Services
ESA	eastern and southern Africa
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food and Agricultural Organization
FISP	Farm Input Subsidy Programme
FURP	Fertilizer Use Recommendation Program
g	gram
GCM	general circulation models
GMES	Global Monitoring for Environment and Security

GPCC	Global Precipitation Climatology Centre
ha	hectare
hPa	hectopascal
HPW	haulm plus pod wall
IAASTD	International Assessment of Agricultural Knowledge, Science and Technology for Development
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IIAM	Instituto de Investigação Agrária de Moçambique (Mozambique)
IIED	International Institute for Environment and Development
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
IRI	International Research Institute for Climate and Society at Columbia University
ISPC	Independent Science and Partnership Council
ISPM	Instituto Superior Politécnico de Manica
K	potassium
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
kcal	kilocalorie
kg	kilogram
km	kilometre
l	litre
m	metre
mg	milligram
mm	millimetre
MG	megagram
Mha	million hectare
MSG	Meteosat Second Generation
Mt	million tonne
N	nitrogen
NARES	National Agricultural Research and Extension System
NARL	National Agricultural Research Laboratories
NARO	National Agricultural Research Organization
NARS	National Agricultural Research System
OA	Oxfam America
OC	organic carbon
PUMA	Preparation for the Use of MSG in Africa
QAAFI	Queensland Alliance for Agriculture and Food Innovation
RANET	Radio and Internet for the Communication of Hydro-Meteorological and Climate Related Information
RETIM	Reseau de Transmission d'Information Météorologique
RFE	African Rainfall Estimation Algorithm
SC	soil carbon
SI	sustainable intensification

SIMLESA	Sustainable Intensification of Maize–Legume Systems for Food Security in Eastern and Southern Africa
SLM	sustainable land management
SNNP	Southern Nations and Nationalities and People
SoRPARI	Somali Region Pastoral and Agro-pastoral Research Institute
SPSS	Statistical Package for Social Scientists
SSA	Sub-Saharan Africa
SST	sea surface temperature
t	tonne
WMO	World Meteorological Organization
yr	year
ZimCLIFS	Zimbabwe Crop Livestock Integration for Food Security
μg	microgram

Introduction

Agricultural intensification is essential to boost household food security and incomes for African smallholder families, to feed growing African cities and to contribute to the expanding global demand for food in the coming decades.

The maize mixed farming system, which extends from Ethiopia in the north to Mozambique in the south, already underpins food supply in eastern and southern Africa. However, effective intensification is threatened by widespread degradation of land and water resources from Capetown to Cairo. Scientists and policymakers also recognise that the pathways for intensification must be sustainable for decades to come, hence the concept of sustainable intensification and its association with conservation agriculture (as conservation agriculture-based sustainable intensification (CASI)). CASI has been embraced by many governments in the region—most notably in high-level events in 2015 and 2019 convened by the Association for Strengthening Agricultural Research in Eastern and Central Africa.

This publication is a valuable compendium of research-for-development achievements from the *Sustainable intensification of maize–legume cropping systems for food security in eastern and southern Africa* (SIMLESA) program. It covers many aspects of CASI, including climate variability, soil erosion, market access, crop and livestock productivity, and policy.

Overall, a large number of smallholder families adopted and benefited from SIMLESA research results before the program closed. In the words of Josefa Leonel Correia Sacko, Commissioner, Rural Economy and Agriculture of the African Union, 'looking at #SIMLESA's evidence, we can say that #conservation agriculture works for our farmers'.

Both sustainable intensification and CASI are associated with sustainable agriculture and land restoration, embracing environmental, economic and social aspects of sustainability and underpinning increased food production, diversification and food and nutritional security. Food security has been a concern of many societies since the dawn of settled agriculture about 10 thousand years ago, when fertile land resources were abundant and the global population might have been less than the current population of Malawi (19.1 million). Now there is widespread degradation of African land resources upon which the population of 1.3 billion primarily depends for food. The population of Africa is projected to nearly double to almost 2.5 billion by 2050.

Strategies to address agricultural intensification and food security challenges have evolved over the centuries. Beyond the simple Malthusian population and food production concept, some milestones in the evolving debate include the Club of Rome analysis in the 1960s, the Food Summit in the 1970s, the Bruntland environment and sustainable development report in the 1980s, the Rio Earth Summit in the 1990s, the United Nations Millennium Development Goals in 2000 and the Sustainable Development Goals in 2015.

Framed by the Millennium Development Goals in 2009, the SIMLESA program was formulated for the eastern and southern African region by African research leaders, international researchers from the International Maize and Wheat Improvement Center, Australian scientists and the Australian Centre for International Agricultural Research. At the time, the region suffered from rampant rural poverty and hunger, widespread soil erosion, extreme seasonal variation in food crop yields and striking gaps between farmers' actual and potential food crop yields. These conditions were prevalent across the maize mixed farming system in at least eight countries in the region, from Ethiopia to Mozambique.

To add to the challenge, national agricultural research institutes were under-budgeted in many countries and the once-strong multidisciplinary and participatory skills of farming system research teams had been eroded in favour of disciplinary research. Of great concern, there had been little improvement in food security, agriculture or resource management over the preceding decade.

Because of the prevalence of similar food production and security constraints across the maize mixed farming systems, SIMLESA was designed as a regional program. Rather than reinforcing the prevailing disciplinary research, for example strengthening varieties and fertiliser management research, the SIMLESA program sought different and new research approaches and themes to impact on the prevailing yield gaps, production risks, resource degradation and food insecurity in the region. The complexities of this multifaceted challenge called for context-specific participatory, integrated and systems research-for-development that would generate scalable, sustainable intensification technologies and knowledge.

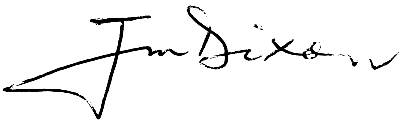
Conservation agriculture was a promising approach, building on earlier experimentation in the region to improve soil moisture (green water) management and soil health, and reduce maize and legume yield gaps and seasonal variability. Natural complements to the conservation agriculture theme were drought-tolerant maize and legume varieties. Preliminary analysis identified other complementary research themes, namely farming systems modelling, multistakeholder innovation platforms and appropriate-scale mechanisation. In order to assure widespread impact, complementary research-in-development on scaling models appeared potentially valuable, including socioeconomic constraints to adoption, commercial seed multiplication and distribution, and managed spillovers of research results between countries. During the formulation process, research on appropriate-scale mechanisation and socioeconomic constraints to adoption of CASI were spun off into complementary regional research projects.

The development of the research design in exceptionally close consultation with eight countries of the region and Australia underpinned two other distinguishing features of SIMLESA: strong national ownership of, and substantial national co-investments in, the program. During two phases over nine years, the program research generated technologies that significantly increased productivity, resilience and household food security. These were scaled to nearly half a million farm households and spilled over to neighbouring countries. The program results established the confidence of agricultural leaders in sustainable intensification as a pathway to food security and economic development.

The research results are documented in 40–50 scientific articles and summarised in administrative reports such as the final program report, and the research data are publicly available through international databases. However, as a complement to the scientific papers and administrative reports, this book contains a unique set of analyses of SIMLESA activities written by the actual researchers, comprising more than 60 African national scientists and 15 international and Australian researchers. In many respects, this book could be compared to the historical accounts of other major international research and development programs in Caqueza Valley (Columbia), Puebla Program (Mexico), the Green Revolution in India, Pakistan and Bangladesh or the rebuilding of Cambodian agricultural research early this century. It is yet another example of a successful large-scale international agricultural research partnership, which is the core approach of ACIAR, and of the immense value that arises from collaboration between Africa and Australia.

The 26 chapters of this book are grouped into five sections. Following the scene-setting opening chapters (Section I), the regional section (Section II) outlines key cross-cutting research as the context for Section III, in which the national multidisciplinary research teams—the voices of Africa—analyse national experiences. The fourth section discusses the potential for institutional reform and scaling of the research results in the region. The final section identifies possible ways forward, building on the SIMLESA results.

This book outlines many key lessons concerning CASI that can underpin improved productivity, soil health, resilience and food security, and ultimately contribute to the achievement of the United Nations Sustainable Development Goals. These are relevant, with adaptation, to all African regions, and it is hoped that African researchers, policymakers, research leaders and development agencies will find the volume of great value. More generally, this book will serve as a reference for those studying African agricultural science and food security. It will also be of interest to Australian and international scientists who wish to support the development of African farming and food systems.



John Dixon
University of Queensland
March 2020

SECTION 1

SETTING THE SCENE: THE MOTIVATION FOR SIMLESA

1 A program to design productive, resilient and sustainable agricultural systems

Mulugetta Mekuria & John Dixon

Key points

- In 2009, rural hunger and poverty was widespread in the maize mixed farming system of eastern and southern Africa, aggravated by stagnating agricultural productivity, degradation of soils and low levels of resilience to climate variability.
- The SIMLESA research program was an African–Australian partnership with the goal of sustainably boosting maize and legume productivity and reducing production risk, building research capacity and learning about adoptability of research results and effective pathways to widespread adoption and impact.
- Key innovative themes in SIMLESA included improved systems research methods, conservation agriculture-based sustainable intensification (CASI), soil management, resilience building to manage the severe climatic and market risks, crop and farming systems modelling and multistakeholder innovation platforms.
- The SIMLESA program identified CASI practices that increased maize and legume productivity, resilience and resource management in the maize mixed farming system across eight countries of eastern and southern Africa, and equivalent cropping systems in Australia.
- Improved research methods involved impact-oriented integrated innovative interdisciplinary systems approaches to field agronomy, market access, computer modelling and policy engagement.
- The SIMLESA design included research on socioeconomic constraints to sustainable intensification, improved maize and legume varieties, on-farm agronomic trials in high and low-potential agroecologies, livestock feed, and pathways to impact and engagement with national and regional policy forums on successful sustainable intensification for improved food and nutrition security in the region.

2009 problem setting

A large proportion of the world's undernourished population was concentrated across eastern and southern Africa (ESA). When the sustainable intensification of maize–legume cropping systems for food security in eastern and southern Africa (SIMLESA) program was designed in 2009 by the Australian Centre for International Agricultural Research (ACIAR), International Maize and Wheat Improvement Center (CIMMYT) and national agricultural research organisations from ESA, the region contained some 400 million people, with more than half living in extreme poverty. The main constraints included poor infrastructure, barriers to participation in the market, high climate variability and low productivity, and soil and environmental degradation. The dominant staple crop was (and still is) maize, grown in the maize mixed farming system with legumes, supplementary crops and small and large livestock (Dixon, Gulliver & Gibbon 2001). Maize provided the main source of food for most rural households and was also the basic staple food of most urban poor. Maize was produced alongside legumes, oilseeds and livestock by resource-poor farmers in complex and risky farming systems. Maize consumption varied across countries in the region from 40 to 100 kg/cap/yr. Legumes were an important dietary protein source for the rural poor. However, soil erosion was widespread and yields of major food crops had stagnated.

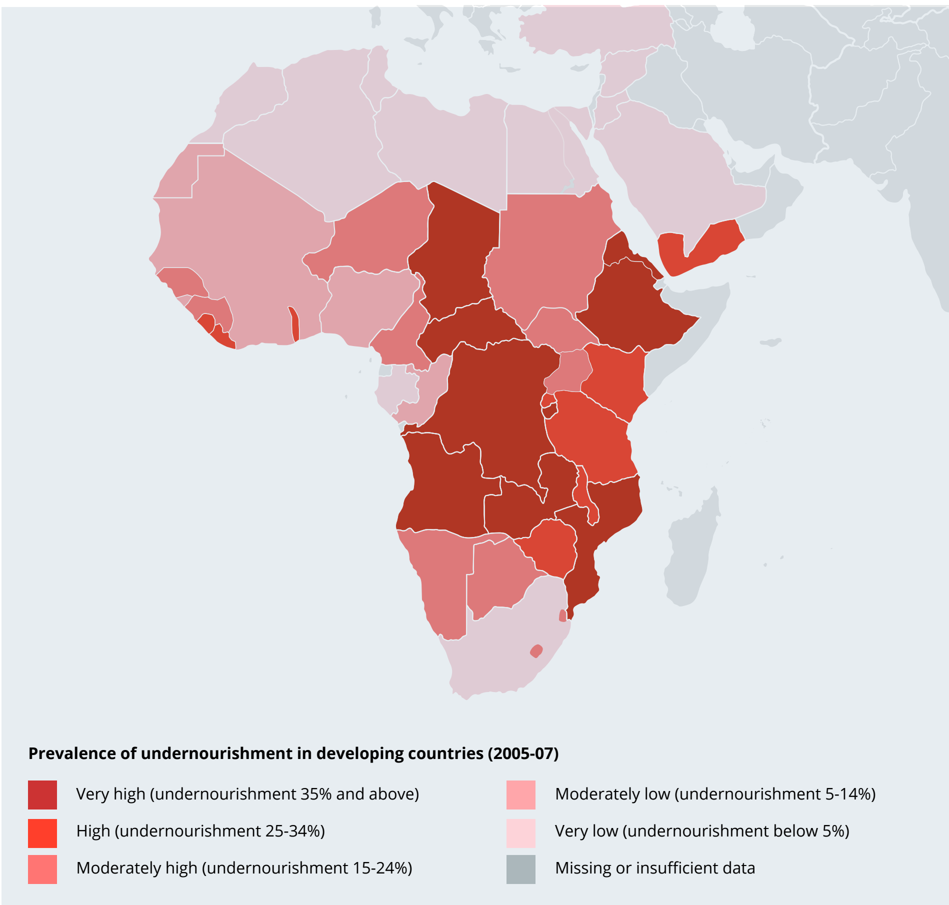


Figure 1.1 Hunger in eastern and southern Africa

Source: Food and Agriculture Organization Statistics Division (FAOSTAT) 2009

Farmers generally identified feed shortages as the most important constraint to livestock production, hence the importance of the adoption of improved forage and feed technologies. The feed shortages arose in part because forage legumes were not intercropped or rotated with maize, or produced elsewhere on farms.

The region was not self-sufficient in food grains and imported about 10% of total consumption (FAOSTAT 2009) resulting in extensive hunger (Figure 1.1). Approximately 20–25% of the imports were emergency food aid. Crop yields were low, of the order of 1 t/ha for maize and less than half that for many pulses. With growth in both population and income, the demand for maize was projected to increase by approximately 3–4% annually to 2020, leading to the need to increase maize production by at least 40%. Similar increases in the demand for pulses were projected, ranging from 2.3% for peanut to 3.7% for pigeonpea and 4.2% for chickpea. This indicated the need to increase total supply by more than 50% (relative to 2000) by 2020. Not only were production increases required, drought was also a major constraint limiting crop productivity. Intra-seasonal rainfall distribution was erratic and led to high levels of risk in food security. Given the prevalence of soil erosion and poor soil fertility, water use efficiencies for maize and legume production were low.

Improved household food security and farm incomes required significant increases in productivity and a reduction in downside risks to prevent households sliding back into hunger and poverty in poor seasons. Much of the past growth in food production had occurred through the expansion of cultivated area, which was increasingly scarce in many countries and had severe ecological consequences. Approximately 65% of the agricultural land in Sub-Saharan Africa (SSA) suffered from degradation. Uncertain rainfall, climate risks and rapid population growth were major challenges to the sustainable intensification of agricultural production, the enhancement of household livelihoods, reduction of rural poverty and improvement of food security.

Intensifying and diversifying the typically poor and risky rainfed smallholder agricultural systems has long been challenging, particularly in the context of widespread land degradation and weak local institutions for scaling out. Partly because of this context, the effectiveness of past research, especially component-oriented crop improvement and fertiliser management, had been limited, while low crop yields and rural poverty became protracted. It was clear that effective research required a new focus and different approaches to overcome these constraints and deliver benefits to many smallholders.

As nearly 80% of the rural population depended on agriculture for their livelihoods, investments in agriculture constituted the main opportunity to reduce poverty and environmental degradation and promote economic growth. Regional and national institutions were engaged in research to support the United Nations Sustainable Development Goals of reducing rural household food insecurity and poverty. Countries across ESA and Australia had previously worked with ACIAR on research to help smallholder farmers increase productivity and access to markets for inputs and their produce. The research initiatives were complex, given the interacting constraints to soil fertility, shortages of labour and agronomic skills, and cultural and societal heterogeneity and dynamics.

Further research was urgently needed to devise solutions for farmers who produced maize and legumes under these risky degraded conditions. Such research needed to be designed and conducted in the context of household livelihood systems and local institutional settings.

Seven drivers shape farming systems change and all were especially relevant:

- population, food security and poverty
- natural resources and climate
- energy (renewable and non-renewable)
- human capital, knowledge sharing and gender
- technology and science
- markets and trade (including labour and remittances)
- institutions and policies.

In relation to pathways out of poverty, African smallholder households faced five options:

- intensification of existing production patterns
- on-farm diversification
- growth of enterprise size
- off-farm income
- exit from agriculture.

Given the history of intensification in agricultural production in Asia and some pockets in Africa, which often depleted natural resources, there was a great need for research on sustainable intensification in the Maize Mixed Farming System of Africa (Figure 1.2). The ACIAR scoping study 'Enhancing food security in eastern and southern Africa' (ACIAR 2009) identified highly vulnerable regions across Ethiopia, Malawi, Kenya, Zimbabwe and Mozambique and relevant and actionable high impact for research-for-development.

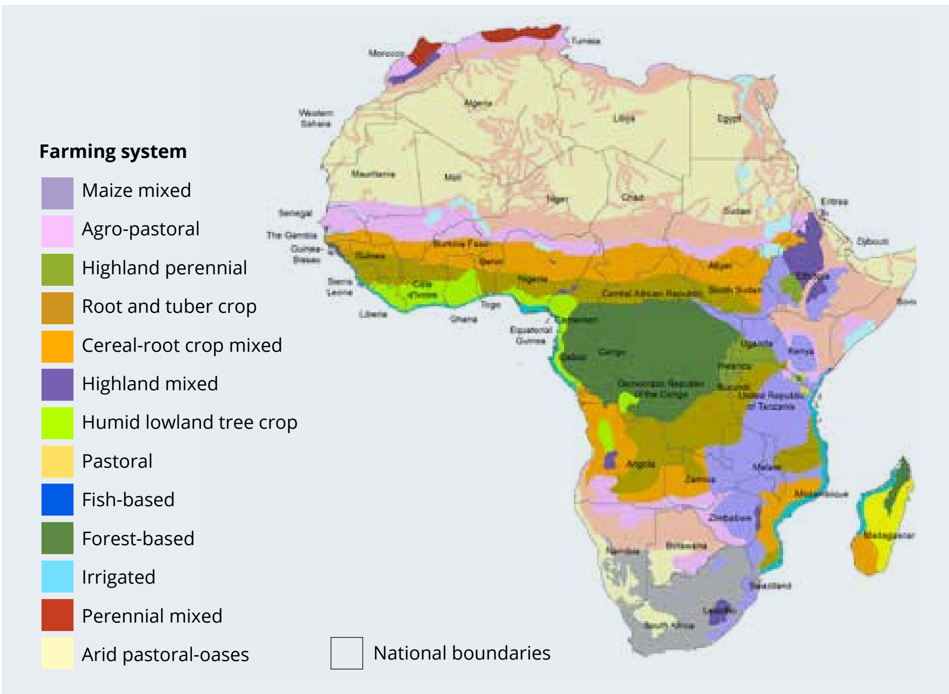


Figure 1.2 Principal farming systems of Africa

Source: Dixon, Gulliver & Gibbon 2001

Underlying rationale of sustainable intensification research

The key principles of sustainable intensification include resource conservation, resilient production systems and economic viability. These were the guiding principles for the formulation of the SIMLESA program (ACIAR 2010). Designed with the objective of contributing to the 'increase of the production of maize and legumes in the region while confronting soil and land degradation and high levels of economic and climatic risk, accentuated by severe climate change impacts', the program focused on generating new datasets from agronomic and systems research based on the concept of conservation agriculture-based sustainable intensification (CASI). The program aimed to test a new generation of drought-tolerant maize and legume varieties suited for CASI systems for expedited release, and to analyse the economic merits of the new agronomic production methods and practices. Further plans included the evaluation of potential benefits of methods to further integrate cropping and livestock enterprises in terms of income generation and nutrient availability within the farming system. The program intended to extend the analysis beyond the field level, to understand consequences for resource conservation, resilience and economic viability. Research was planned to identify constraints to value-chain development, technology adoption and market participation.

Wide consultation with CIMMYT, the Association for Strengthening Agricultural Research in Eastern and Central Africa and the National Agricultural Research System partners (ACIAR 2009) identified that improving the productivity and sustainability of the maize–legume cropping systems was a major regional priority. Conclusions from this consultation included that the intensification of maize–legume farming systems and the availability of markets underpinned the capacity of most households to achieve an improved allocation of limited resources (i.e. cash, land, labour) across alternative enterprises to develop more diversified and resilient farming systems across ESA.

Technological solutions alone would not, however, overcome constraints at the institutional and socioeconomic levels, which restricted adoption of newly developed seed varieties and farmers' access to inputs and output markets. These constraints, compounded by significant climatic variability, undermined farmers' and businesses' incentives to innovate and invest. Given these limiting factors, research on the potential and roles of intensification under the SIMLESA design focused on whole-farm-household systems and required close collaboration with a broad demography of farmers and local input supply and marketing institutions. To enhance the development and transfer of information on CASI systems, SIMLESA intended to strengthen multistakeholder interaction mechanisms for uptake and scaling out of CASI (including innovation platforms, agribusiness and value-chain interventions). The program also aimed to define impact pathways and innovation platforms that would form the enabling policy environment and necessary policy instruments for the sustainable intensification research and development programs.

SIMLESA vision

SIMLESA was focused on the development of innovations that would increase smallholder food crop productivity by at least 30% on average, and reduce risk by at least 30%. These were considered to be equal goals. Overall, the vision was to deliver integrated innovations that would be adopted rapidly and benefit substantial numbers of farm households—at least 650,000 smallholders by 2025—to learn about national pathways to impact. SIMLESA would go beyond 'research as usual' by investigating combinations of sustainable intensification practices and pathways to adoption and impact. This would support the delivery of multiple innovations and capacity to substantially boost farming systems productivity and reduce livelihood risk for hundreds of thousands of smallholders in line with the United Nations Millennium Development Goals. The challenge called for innovations that would generate benefits for a major share of the smallholder population. Productivity and diversification alone would not be enough; it was essential that the innovations also combat soil erosion and other land degradation. To achieve this, SIMLESA set out to develop and apply more integrative assessments that combined whole-farm systems models and input from the decision-makers and scientists in a co-learning process.

The SIMLESA design focused initially on maize, the major food crop in the Maize Mixed Farming System of ESA, and an associated food grain legume (the choice of which depended on the particular subsystem and country). To increase yields (and farm incomes), reduce soil erosion and improve soil health, CASI was chosen as the core production research focus. Notably, CASI combines the strengths of zero tillage, residue retention and crop rotation with improved varieties and sound agronomy. The SIMLESA formulation recognised that various challenges in the farming system often result in incomplete adoption of technology packages. The CASI concept included 'smart sequences' through which flexible clusters of technologies could be adopted sequentially and tailored to particular smallholder resources, existing production patterns, livelihood strategies and the institutional context. The SIMLESA vision included characterisations of existing maize–legume systems (baseline studies) and evaluation of CASI practices through on-farm and on-station exploratory and long-term experiments. Further major components of the SIMLESA approach included mechanisms for smallholders to access new maize and legume varieties, establishment and institutionalisation of innovation platforms, gender mainstreaming and partners' capacity building.

It was envisaged that SIMLESA field research on the maize–legume mixed farming system would focus on pairs of high and low productivity research hubs across five main countries (Ethiopia, Kenya, Tanzania, Malawi and Mozambique), supported by research on input and grain markets, private sector involvement and engagement with agricultural policy makers. Three additional spillover countries (Botswana, Rwanda and Uganda) were identified as opportunities for technology transfer and local adoption. Pilot scaling of the innovations to thousands of smallholders was considered important to confirm and demonstrate the adoptability of the technologies by smallholders, and for learning about the process of scaling by national public–private sector initiatives.

Multidisciplinary teams would conduct participatory transdisciplinary farming systems research, incorporating the analysis of value chains and 'pulling-down' knowledge and products from advanced research. This included characterising maize–legume production and value-chain systems, testing of promising smallholder maize–legume cropping systems, increasing the range of maize and legume varieties available for smallholders, developing regional and local innovations systems and substantial capacity building of agricultural researchers and the National Agricultural Research System organisations. Individual farmers and village groups would be incorporated into the program in the form of innovation platforms to build social capital, encourage farmer-to-farmer learning and establish linkage platforms with other farmers, researchers, extension workers, non-government organisations, input providers and traders. It was expected that this flexible, participatory systems approach would generate better results than commodity or disciplinary research. SIMLESA would therefore reduce a critical gap between research and extension, and appraise and demonstrate models for the scaling of CASI technologies in response to farmers' needs, country priorities and impact pathway capacities.

SIMLESA was to be an open-architecture program with the prospect for co-learning with other sustainable intensification programs funded by, for example, the Bill & Melinda Gates Foundation or the United States Agency for International Development. This design concept was in marked contrast to those of many research projects which are often internally-focused and often limited the interactions with other research and development initiatives or national and regional institutions. The SIMLESA partnership included eight National Agricultural Research System partners (five in the main countries and three in the associated spillover countries), two Australian universities and three CGIAR centres. The intent was for partnerships with non-government organisations and private sector actors to evolve according to the research needs. Complementary research was arranged on agroforestry, socioeconomic constraints along adoption pathways, small-scale mechanisation and crop–livestock integration. There was strong emphasis on country ownership and co-investment. During the widespread consultations on design, the Forum for Agriculture Research in Africa and the subregional organisations Association for Strengthening Agricultural Research in Eastern and Central Africa and the Centre for Coordination of Agricultural Research and Development for Southern Africa contributed to the priority core research questions and strategies for SIMLESA. The following transdisciplinary, multistakeholder and partnership approaches further distinguished SIMLESA from other research and development projects:

- integration (of disciplines, bringing various stakeholders)
- innovation systems
- impact orientation
- inputs access
- information
- institutions (markets and policy).

Strong management and governance were required for such a flexible adaptive approach. A regional program coordinator would be selected to work closely with eight national coordinators, the universities and CGIAR centres. Within the frame of the SIMLESA research questions, logical framework and resources, national teams would formulate their respective work plans. A strong monitoring and evaluation system was identified as a critical function for ongoing learning and decentralised adaptive management of SIMLESA. SIMLESA's directions and implementation would be overseen by a program steering committee comprising senior national representatives from participating countries and organisations, with independent co-chairs from Africa and Australia.

The overall vision envisaged research results in high- and low-potential sites in each of the five main countries, and sharing of results with the spillover countries, with a view to generate sustainable and scalable CASI options to improve food security while maintaining or enhancing agricultural resources. The regional research context envisaged two complementary regional 'sister' projects on socioeconomic constraints to adoption and appropriate-scale mechanisation for CASI, and one complementary national project on crop–livestock integration. The design assumed that SIMLESA would benefit from improved varieties from two major Bill & Melinda Gates Foundation-funded crop-improvement programs on drought-tolerant (later stress-tolerant) maize and tropical legumes. As noted earlier, there were also opportunities for cross-fertilisation with other major research programs on nitrogen and sustainable intensification being designed at the time for Africa.

A win–win proposition for farmers

Based on earlier experience in the region, CASI could be a win–win game changer in terms of intensification and sustainability, especially in relation to soil erosion. CASI is one of the few sustainable agricultural practices that is proven to generate increased productivity and improved soil health—two of the critical problems facing the ESA region. Results from on-farm trials of CASI technologies and socioeconomic analyses conducted in the SIMLESA region prior to 2009 clearly showed that CASI practices also reduce costs of production, thereby promising win–win outcomes, especially when combined with drought-tolerant varieties and other good agronomic practices. The retention of the stubble from previous crops reduced evaporation and contributed to increased yields while reducing weed growth and soil erosion. No-till minimised soil disturbance by direct seeding of crops into the stubble of previous crops without hoeing or ploughing. This saved labour (especially women's labour), oxen inputs and costs of other ground preparation, and contributed to improved soil organic matter and overall soil health. The third characteristic of CASI is crop rotation, and there would be opportunities for substantially improving traditional maize–legume cropping systems.

By increasing maize and legume yields, and generating sales income which can be used for food purchases later in the season, CASI could increase food production and reduce hunger. For many rural households, food security depends on productivity enhancement through improved maize and legume varieties and crop management. For the foreseeable future, the pathway to food security in ESA depends on smallholder productivity and technology improvement. A complementary pathway would be the market access pathway emerging from intensified maize–legume–livestock systems producing feed for livestock or for sale. The sustainable intensification principles outlined in the SIMLESA program would remain valid in both food and feed maize systems in regions where maize-based systems are dominant.

Risk management (specifically the reduction of downside risk) would be an important goal for poor farmers, most of whom operate in challenging environments and are at risk of falling into hunger and poverty from droughts, floods, pests and diseases, or market disruption. The evidence emerging from research in rainfed farming around the world suggests that CASI practices would reduce the probabilities of yield losses or crop failure without compromising average yields, thereby avoiding the classical high-risk, high-return trap of many intensification approaches. The SIMLESA program would also reduce other risks, including environmental impacts on soil fertility and increased carbon sequestration through climate-smart approaches for the maize mixed farming system.

SIMLESA objectives

Five initial objectives of Phase 1 are listed in Table 1.1. Phase 1 anticipated a foundation of participatory and multidisciplinary community diagnoses and value-chain assessments to target effective research on farmers' constraints (Objective 1). It was envisaged that core impacts for smallholders would arise from the integration of Objective 2 on the development of CASI agronomy innovations, Objective 3 on access of smallholders to appropriate varieties and Objective 4 on the strengthening of local innovation systems.

Building on the results and experience of Phase I, Phase 2 incorporated complementary elements of soil nutrient management, forage for livestock and knowledge sharing in innovation platforms to add substantial value to the research. Phase 2 had more explicit emphasis on CASI options (Objectives 1 and 2) and the inclusion of forages in the maize–legume cropping systems (Objective 2). Phase 2 also had a stronger emphasis on learning from scaling out, including comparisons of different approaches of scaling partners (Objective 4).

Table 1.1 Phase 1 and Phase 2 objectives under SIMLESA

Objective	Phase 1 (2010–14)	Phase 2 (2014–18)	Transitions and advances in Phase 2
1	To characterise maize–legume production and input and output value-chain systems and impact pathways, and identify broad systemic constraints and options for field testing	To enhance the understanding of conservation agriculture-based intensification options for maize–legume production systems, value chains and impact pathways	• strengthened focus on CASI research • refined the site and technology characterisation and testing • disaggregated farm adoption constraints, incentives and trade-offs • based on the general value-chain analyses of Phase 1, focused on testing specific chain interventions on seed biomass management, specifically crop residue management (an issue for rainfed CASI and livestock productivity)

Table 1.1 Phase 1 and Phase 2 objectives under SIMLESA (continued)

Objective	Phase 1 (2010–14)	Phase 2 (2014–18)	Transitions and advances in Phase 2
2	To test and develop productive, resilient and sustainable smallholder maize–legume cropping systems and innovation systems for local scaling out	To test and adapt productive, resilient and scalable CASI options for sustainable smallholder maize–legume production systems	• increased emphasis on ground truthing 'farm–ready scalable innovations'. Continued on-farm experiments to verify CASI 'smart' sequences, agronomic practices and nutrient management • expansion of on-farm evaluation of interactions among genotype, environment and management (including CASI) components of maize and legume production systems • enhanced interdisciplinary monitoring • fine-tuned innovations for crop–livestock farming systems • evaluated on-farm trials of sequenced CASI options for different types of maize–legume-forage/fodder farming systems
3	To increase the range of maize and legume varieties available for smallholders through accelerated breeding, regional testing and release, and availability of performance data	To increase the range of maize, legume and fodder/ forage varieties available to smallholders	• seed roadmaps for stress-tolerant maize varieties, higher yielding legume varieties and fodder/ forage relevant to CASI systems
4	To support the development of regional and local innovations systems	To support the development of local and regional innovations systems and scaling-out modalities	• emphasis shifted to local, bottom-up innovation systems and scaling approaches, supported by a competitive grant scheme to support and compare arrangements and models for scaling out with partner organisations • expanded engagement with and training of local seed companies
5	Capacity building to increase the efficiency of agricultural research today and in the future	Capacity building to increase the efficiency of agricultural research today and in the future	• advanced training on aspects of CASI research-for-development • enhance capacity of national and regional programs (integrating gender where relevant) through country workshops and free online courses on quality data collection, management and analysis

Note: CASI = conservation agriculture-based sustainable intensification
Source: ACIAR 2010, 2014

Targeted SIMLESA outcomes

Following program logic, the SIMLESA program was designed to produce 23 outputs to achieve the five objectives described in the previous section. Conventionally, outcomes are the situations resulting from the application or use of these outputs by the next users, often intermediaries along the pathway to impact. They often include policymakers, research systems, extension agencies and leading smallholders. The expected impacts included improved household food security of hundreds of thousands of farmers, widespread improvement in soil health, increased national capacity for modern systems-oriented research and revised policies supporting scaling of sustainable intensification.

In this context, some of the key intended outcomes of SIMLESA were:

- increased maize, legume and forage productivities (approximately 30%) and reduced seasonal yield risk (approximately 30%) on smallholders from CASI adoption in research sites
- substantially higher income to lift CASI-adopting farmers out of poverty through produce sales, reduced production costs and labour savings, enabling them to diversify on-farm and off-farm to other income-generating activities
- increased knowledge and skills of many smallholders (especially women) of CASI practices
- easier access for many smallholders to improved drought-tolerant varieties that complement CASI from small- and medium-sized seed enterprises
- farming women and men innovating and adapting CASI practices to local conditions, supported by agricultural innovation platforms
- awareness of and support to CASI research and scaling by key agricultural leaders, policymakers and small- and medium-sized seed enterprises at local, national and regional levels
- greater capacity of national researchers to design, implement, analyse and report systems-oriented trials on CASI and other sustainable intensification innovations
- stronger linkages between African and Australian researchers.

The outcomes included a number of aspects that were not common in agricultural research. The SIMLESA program aimed to demonstrate yield benefits combined with increased system resilience from the use of rotations in CASI systems as a form of climate-smart agriculture. SIMLESA planned to test the dissemination of improved maize and legume varieties by small- and medium-sized enterprises.

Through partnerships with many public and private sector research and development organisations, SIMLESA intended to establish awareness and a strong knowledge base for the use of sustainable intensification practices. Agricultural innovation platforms were perceived as a way to help farmer groups and partners exchange sustainable intensification experiences, share knowledge and identify viable market linkages. The innovation platforms would particularly benefit women. In relation to capacity building, both formal degree-level capacity building and on-the-job short-course training were a high priority, with heavy emphasis on the latter.

Engagement with high-level national and regional policymakers was another high priority, especially in relation to endorsing sustainable intensification and committing to the dissemination of SIMLESA research results in each country. The Association for Strengthening Agricultural Research in Eastern and Central Africa was well-placed to convene such high-level policy dialogues and identify a roadmap for institutionalising CASI and securing regional and national interest and investments.

In summary, through these outcomes, the program planned to facilitate the development of CASI practices and their adoption among 650,000 households by 2025 with increased yields, reduced risk and improved livelihoods, as well as strengthening research and scaling capacities and securing the interest and commitment of policymakers to the scaling of SIMLESA results.

Potential learning and implications for future investments

Co-learning with research, government, agribusiness and farmers is an important function for modern research programs. There was particular need for deeper knowledge on adapting CASI approaches to better fit mixed crop–livestock systems in different agroecological and socioeconomic environments. From a systems perspective, the increasing competition for limited resources (land, labour and biomass) between cropping and grazing farmers is critical. Improvements in crop–livestock integration both at farm and landscape/community level could address feed shortages during the dry season, increase the opportunity to return manure on cropping lands, increase the availability of animal protein in households and create the opportunity for adding value to animal products and associated value chains such as the feed market, dairy, meatworks and associated services.

Learning about institutional-level arrangements for effective integration is equally important. This would include pathways to promote the development and transfer of CASI for climate-smart agriculture and to enhance benefits from CASI technologies across diverse stakeholders. Capacity building, mainstreaming gender aspects and institutionalisation of innovation platforms are all key institutional factors. An enabling policy environment, and accompanying policy instruments for research and development, would be fundamental to the widespread adoption of sustainable intensification.

Australian involvement and investment in Africa was judged to be important for consolidating earlier learnings from previous research, and to answer new agricultural research questions that impinge on the economic transformation of African rural communities. To achieve transformative change, scientific, human and social capital must be built using fundamentally new approaches. These could involve:

- rebalancing research-for-development efforts from a focus at the field and farm levels towards the farm–community–value-chain systems
- moving from the analysis of specific commodities to whole-farm livelihoods and risk management to achieve rural economic growth
- focusing on increasing labour productivity for men and women and creating opportunities for youth in agriculture.

Readers' guide

Section I of this book sets the scene for the SIMLESA program. Having considered the background context, rational, vision and important themes of the program in this chapter, Chapter 2 discusses sustainable intensification and rural transformation. Chapter 3 emphasises the agroecological, socioeconomic, institutional and policy diversity in ESA and discusses some implications for the program. The implications of the extreme climatic variability and uncertainty of the region is presented in Chapter 4. Some approaches to agricultural innovation and transdisciplinarity are outlined in Chapter 5.

Section II outlines regional highlights, Section III outlines country highlights (with a strong focus on activities and outputs up to 2016), Section IV looks at institutions and scaling, and Section V discusses building on SIMLESA in the future.

Because of the diversity of authors, there is some variation in the use of particular terms throughout this book. For example, in some chapters, the terms 'outcome' and 'output' are used equivalently, although in correct use they have different meanings as explained earlier in this chapter. Both NARS (National Agricultural Research System) and NARES (National Agricultural Research and Extension System) are used; however, the latter is relevant where the discussion embraces both research and technology transfer or scaling.

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2 Sustainable intensification as a driver of agricultural and rural transformation

John Dixon, Mulugetta Mekuria & Daniel Rodriguez

Key points

- Sustainable intensification of agriculture is an integrative, transdisciplinary and participatory approach to improving productivity and agroecosystem health in which researchers, farmers, agribusinesses and public agencies co-learn about the intersection of agriculture, ecology, social sciences, governance and business.
- Effective sustainable intensification features six operational principles:
  - integration
  - innovation
  - impact orientation
  - information and capacity building
  - investment
  - institutions.
- These six operational principles are embodied in research-for-development approaches such as enhancement of pathways to impact, farmer field schools and multistakeholder innovation platforms.
- Well-implemented sustainable intensification generates agricultural transformation and wider rural development. Proven win–win farming and food system research and development practices for sustainable intensification include agroforestry, integrated farming systems and conservation agriculture-based sustainable intensification.
- Successful sustainable intensification for rural development requires investment in capacity building for transdisciplinary systems research-for-development and clear targets and metrics on indicators covering agriculture productivity, food security, risk, sustainability (environmental, economic and social), and benefits from the spillover of knowledge between regions, countries and farming systems.

Introduction

Globally, agriculture and rural development will need to generate healthy food for 9 billion or more people by 2050 and beyond as the world population stabilises, securing livelihoods for 2.5 billion farm households and providing ecosystem services for a healthy planet. When the SIMLESA program was conceptualised during 2009–10, rural areas were home to about half the global population, as well as the vast majority of poverty and hunger. Agricultural development was considered a key driver of national economic growth.

Farming (in the broad sense of cropping, forestry, livestock and fishing) was remarkably successful in doubling food production over the four decades from 1970 to 2010, largely through incremental gains in productivity with only modest expansions in cultivated land area. However, this period of agricultural intensification was associated with substantial environmental costs, for instance, depletion of aquifers, degradation of land and loss of biodiversity. Looking to the future, to meet the additional demands from a growing population and overcome the constraints imposed by a changing climate from a degrading natural resource base, incremental gains or business-as-usual approaches will not be enough to meet the global challenge of producing 50–70% more food than 2010. Although international trade will provide a proportion of urban food needs, many cities will still depend on food supplies from local farming systems, some of which are hotspots of resource degradation, low productivity and pervasive poverty. In such cases, transformational intensification will be needed to meet expanded local food demands, generate enhanced ecosystem services and dramatically reduce our carbon footprint.

These are not new insights. As the Asian Green Revolution was getting underway in 1968, Dr MS Swaminathan pleaded for 'converting the green revolution into evergreen revolution by mainstreaming the principles of ecology in technology development and dissemination' and elaborated on the evergreen revolution as 'increasing productivity in perpetuity without associated ecological harm' (see also Garrity et al. 2010, who presented a compelling case for evergreen agriculture). In a similar vein, the Australian scientist and educator Dr GL McClymont wrote in 1970, 'One of the great problems facing man … is the conflict between economic development and environmental degradation' (McClymont 1970), and called for integrated science, policy and education embracing evolution, ecology, economics and ethics (the perpetual pentagram). Shortly afterwards, the Club of Rome published the famous book *The Limits to Growth* (Meadows et al. 1972), which sold more than 30 million copies in more than 30 languages. Its core message was that continued high growth rates of consumption, population and production would exceed Earth's limits within a century. Growing recognition of the links between the environment and sustainable development led to the Bruntland Report, the Earth Summit in Rio, Agenda 21 and the Millennium Development Goals for the period 2000–15. Despite these clear strategies and targets, public and private investment in rural development and agricultural research declined until 2010, the number of malnourished increased and greenhouse gases and environmental degradation intensified.

Building on the foregoing assessments, the wave of analyses of the environment and development continued. In broad-ranging reflections on resources, climate, technologies and societies, Martin (2005) forecasted a global crisis—a 'turbulent canyon'—for human development around 2050, arising from the intense pressures on resources and societies, and challenged leaders to make fundamental choices in development trajectories.
In 2001, in the context of diminishing development financing for 2.5 billion smallholders suffering from severe environmental and institutional pressures, the World Bank updated its rural development strategy. For this purpose, the Food and Agriculture Organization (FAO) and the World Bank analysed drivers and trends in major farming systems in developing regions and identified strategic investment opportunities for sustainable reductions in rural poverty (Dixon, Gulliver & Gibbon 2001). While funding for agricultural and rural development increased, natural resources and rural food security remained under great pressure. Ten years ago, the UK's Chief Scientist, Sir Beddington, warned that the world faced a 'perfect storm' of food shortages, water scarcity and energy scarcity which threatened to unleash public unrest, cross-border conflict and mass emigration from the worst-affected regions (eds Beddington, Asaduzzaman & Clark 2012; Guardian 2009).

Without doubt, agricultural science, rural infrastructure and rural institutions generated impressive (and essential) gains in food production during the past 50 years and averted widespread famines. However, many of these gains took place across the temperate latitudes of the world and increased levels of inequality, depleted resources (including soil carbon, and aquifers in irrigated areas and social capital) and exceeded planetary boundaries. Breaking free of business-as-usual approaches requires paradigm shifts in approaches to sustainable intensification and rural transformation. As described in Chapter 1, the SIMLESA program, designed for eastern and southern Africa (ESA) during 2009–10 in response to pervasive food insecurity, rural poverty, stagnating and variable food crop yields and land degradation, was based on novel integrated and systems approaches to sustainable intensification.

This chapter lays out the basic thinking on sustainable intensification that underpinned the SIMLESA program design during 2009–10 and enriches the understanding of sustainable intensification with more recent experiences from this current decade.
It considers the interdependencies between agriculture and rural transformation to frame a brief overview of sustainable intensification and presents operational principles for effective implementation.

Agricultural and rural transformation

Almost half the global population lives in rural regions, where there is extensive resource degradation, severe poverty, hunger and malnutrition. Agriculture provides the main source of livelihoods for 60–90% of these rural populations, depending on the population density and farming system. Policymakers recognise that agricultural development is essential for national economic growth in practically all low-income countries (World Bank 2007). Historically, although there have been episodes of transformative farming systems development such as the Asian Green Revolution, much agricultural intensification has been commodity-specific, incremental and, in Africa, often project-driven. The impending global crises call for research and development practitioners to intentionally transform farming, food and rural systems for the achievement of the multiple facets of the United Nations Sustainable Development Goals.

The farm household system is the basic production and food consumption unit in agriculture, used in the broad sense to include forestry, fisheries and off-farm work. The multitude of decisions made by smallholder farm households, supplemented by community decisions, shape agricultural and rural development pathways within the frame of agroecological conditions, social and cultural traditions, institutions and government policies (Dixon, Gulliver & Gibbon 2001).The rural nonfarm populations also depend in part on local ecosystems, and underpin the operations of agricultural input and service chains and the produce marketing chains including local value addition and trade services.

The following paragraphs explore some of the various meanings that are associated with the term 'transformation'. From a farming systems perspective, transformation suggests a major recognisable and lasting change in the resource base, structure, function or productivity of farm household systems, implying a fundamental adjustment in the nutrient, energy, economic or other linkages between components of the farm household system or its linkages with the external environment. For the purposes of this book, a change of the order of 30% productivity increase and/or 30% risk reduction over a decade (approximately 3% per year) on a significant scale (i.e. over multiple districts or regions) is considered transformational. The nature of the changes could be extremely diverse, for example, expansion of farm resources or assets (increased farm size), mechanisation, establishment of irrigation, wider access to common property resources, intensification of crop or animal husbandry, diversification to new enterprises (e.g. dairy cattle, tree or cash crops, or value-adding activities), or deeper cooperation with farmers groups or expanded market engagements. These changes often generate increased farm productivity and household livelihoods (Dixon et al. 2020).

Other interpretations of agricultural transformation have been proposed. In the context of climate-smart agriculture, Vermeulen et al. (2018) defined transformation in farming systems as changes in farm inputs or outputs by at least one-third within a generation (25 years or less). This definition emphasises market engagement and implies a rate of change of a little over 1% p.a., or a similar order of magnitude to the current global average increase in productivity. Interestingly, many of the 25 cases analysed by Vermeulen et al. (2018) focused on single villages, essentially pilot scale, and emphasised diversification of the farming systems to higher-value enterprises.

From a development economics perspective, agriculture is one among other sectors that together underpin national development. As Jayne, Chamberlin and Benfica (2018) summarise, in demand-driven systems, agricultural transformation generally starts with growth in farm productivity, initiated by technical innovation, economies of scale or higher-return enterprises. In low-income economies, demand and supply need to be developed simultaneously by improving market access along with policy instruments that are pro-growth and pro-poor. These actions promote increases in returns to labour as the non-agriculture economy develops, and increases in household cash income and borrowing capacity, which further stimulates the demand for goods, services and jobs in other sectors of the economy. This is a richer concept and process than the common, oversimplified criticism that economic transformation of agriculture corresponds to commercialisation, land consolidation and increased farm size, specialisation and, in general, progress towards 'western' commercialised industrial farming.

The importance of nonfarm incomes in agricultural transformation cannot be overemphasised. In low-income countries, rural nonfarm activities often account for 35–50% of rural income, even prior to major agricultural transformation (World Bank 2015). Nonfarm income is particularly important for many African farm households (Barrett, Reardon & Webb 2001), especially for the landless and the near-landless. The rural nonfarm sector contributes to rural employment and poverty reduction, as well as spatially-dispersed national economic growth (Lee & Barrett 2001). The distributional impacts from development of the rural nonfarm economy can be significantly pro-poor, extending through linkages between the nonfarm and the farm sector. However, the poor require connectivity, education and skills, finance and legal rights to land in order to benefit significantly from opportunities in the rural nonfarm economy (Lanjouw & Feder 2001). Other constraints are associated with exclusion based on gender, age or identity. There are strong economic growth multipliers between farming (in the broad sense of crops, livestock, trees and fish) and the rural nonfarm economy (Dixon et al. 2004; Jayne, Chamberlin & Benfica 2018). Estimates of the strength of the farm/nonfarm economic multiplier suggest that each dollar of extra income of smallholders stimulates an additional dollar—even up to $4 of rural nonfarm income in some circumstances, which is critically important for growth of the rural economy and reduction of poverty. While important, the development of the rural nonfarm economy alone is not a magic bullet. A decade of World Bank investment in nonfarm economy growth has had only a modest impact on rural poverty (World Bank 2015).

However, the economic imperative usually takes little or no account of externalities or the impact of agricultural transformation on ecologies. In the absence of counterbalancing policies and regulations, such economic transformation of farming could intensify historical trends towards environmental damage and the growth of landless or slum-dwelling populations.

Clearly, there are critical ecological and socioeconomic links between farming and the broader landscape, our food systems and society (Renting et al. 2009). This century, agriculture is multifunctional, providing various services to society. Agriculture not only provides livelihoods for rural communities, but is expected to produce healthy and nutritional foods (Willet et al. 2019) and ecosystem services including carbon sequestration now and into the future (Intergovernmental Panel on Climate Change [IPCC] 2019). These interdependencies between agriculture and the wider landscape and society suggest the need to broaden the debate from agricultural development to rural transformation in order to secure sustainable development.

Furthermore, strong social relationships link farming and rural nonfarm activities in the same areas. Such mediating links are often associated with local government, local institutions, kinship, education, faith groups, local value chains and markets, and off-farm employment. Social transformation might arise from major changes in one or more of these links and can accelerate or retard economic or ecological transformations.

Of course, agricultural transformation progresses in various stages and rates in different farming systems and in different policy and institutional environments. From a systems perspective, transformation requires restructured incentive patterns and management processes that encourage farm households, rural businesses and public actors to accelerate progress towards rounded sustainable development at multiple scales. Public and private service providers can establish market and technology information services, strengthen value chains and fine-tune policies and regulations. Relevant outcome and impact metrics might be derived from selected combinations of United Nations Sustainable Development Goals indicators, suitably downscaled to the local situation, spanning rural hunger, poverty, environment and socioeconomic conditions. The early local signs of transformation can be increased management intensity (e.g. better weed, water or feed management), technology adoption and increased returns to labour. Ironically, on-farm diversification is more common than specialisation at the early stages of transformation. Diversification also generates a wider range of produce and farm inputs in rural town and city markets and sometimes substitutes imports.

Because of the demands on agriculture in the coming decades, the focus of this book lies on planned intentional transformation of farming systems (in contrast to slow incremental changes). The required intentional and rapid transformation in compressed development timescales is achievable through breakthrough innovations, major policy shifts or focused investment. Massive government investment in poor communities has successfully accelerated poverty reduction in China. The combination of technology (notably, improved varieties and crop management), infrastructure (especially canals and roads) and policies (including input availability and functioning markets) launched the Green Revolution in irrigated districts of India. The key to real transformation relies in the synergies and incentives created between the different actors in the value chain, as infrastructure, markets and education constraints are overcome. Agricultural transformation features conserved or enhanced environmental, human and social resources alongside increased total factor productivity, often most easily evaluated at the whole value-chain level. By extension, rural transformation requires conserved or enhanced resources, including institutional and social capital, which enables rural people to manage landscapes through stress and shocks.

The reframing of agricultural intensification in rural transformation is the first required paradigm shift. Because of the ecological, social and economic linkages, agricultural intensification of farming systems can contribute to, and be an integral part of, rural transformation. Complementary investments in agriculture and the nonfarm rural economy, especially farm input and produce value chains, promote sustainable agricultural and rural development. With this goal in mind, the next section of this chapter discusses the second required paradigm shift: sustainable intensification.

Sustainable intensification paradigm

The interdependency of farming, food, energy and natural resources was documented at least 2,000 years ago (Conway, Waage & Delaney 2010; Naylor 2014), and was probably well understood by early agriculturalists 10,000 years ago (Harari 2014). As population densities increased, trade-offs intensified between resource management and food productivity, especially as certain forms of production generated costly externalities, for example biodiversity loss and water and air pollution. As noted above, the debates over environment and development grew in the second half of the 20th century, with a wave of literature in the 1990s dedicated to sustainable development and indicators thereof. In relation to farming (in the broad sense of land use by humans), there were calls for an agroecological approach (Altieri 2002) and agroecological intensification (Cassman 1999), as well as a 'doubly green' revolution (Conway 1997) and an evergreen agriculture (Garrity et al. 2010). The sustainable intensification concept emerged from this wave of debate, gained recognition in the first decade of this century (when the SIMLESA program was designed) and was popularised during the second (current) decade. Godfray and Garnett (2014) maintain that the application of sustainable intensification is a 'must have', not an option. The debates over the nature and operationalisation of sustainable intensification are timely, as Godfray et al. (2010) and Cassman and Grassini (2020) remind us that there will be many difficulties in relation to the required development pathways to feed 9 billion or more people in 2050.

One widely-quoted definition of sustainable intensification is '… producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services' (Pretty, Toulmin & Williams 2011). The definition has been refined in many ways, for example, 'Sustainable intensification is defined as a process or system where agricultural yields are increased without adverse environmental impact and without the conversion of additional non-agricultural land' (Pretty & Bharucha 2018). In this chapter, we will simply consider sustainable intensification as increased (farm household or farming) system productivity while enhancing sustainability (economic, environmental and social).

As noted above, the rate of acceptance of sustainable intensification in the period up to 2009 was slow, relative to the explosion of applications and publications during the period 2010–16. In a review of 349 papers on sustainable intensification until 2016, Weltin et al. (2018) found only a couple of dozen papers during the 1990s and 2010s that demonstrated the potential of conservation agriculture and sustainable intensification as themes for SIMLESA program design. Figure 2.1 shows a detailed classification of the literature by scale (specifically farm to landscape) and scope and the four 'fields of action': agronomy development (36% of papers); resource use efficiency (28%); land-use allocation (10%); and regional integration focused on knowledge, networks, institutions and governance (26%). Disappointingly, only 30% of publications spanned two or more of the four fields of action, suggesting low levels of integration across broad themes. Integration across biophysical and socioeconomic sciences was not common. Interestingly, SIMLESA publications and science reports were concentrated in three of Weltin's categories: agronomy (especially conservation agriculture-based sustainable intensification (CASI)), resource use efficiency (including soil management, fertilisers and fodder) and regional integration (notably innovation platforms). Two recent books synthesise sustainable intensification challenges, successes and emerging thinking (Oborn et al. 2017; Pretty & Bharucha 2018).

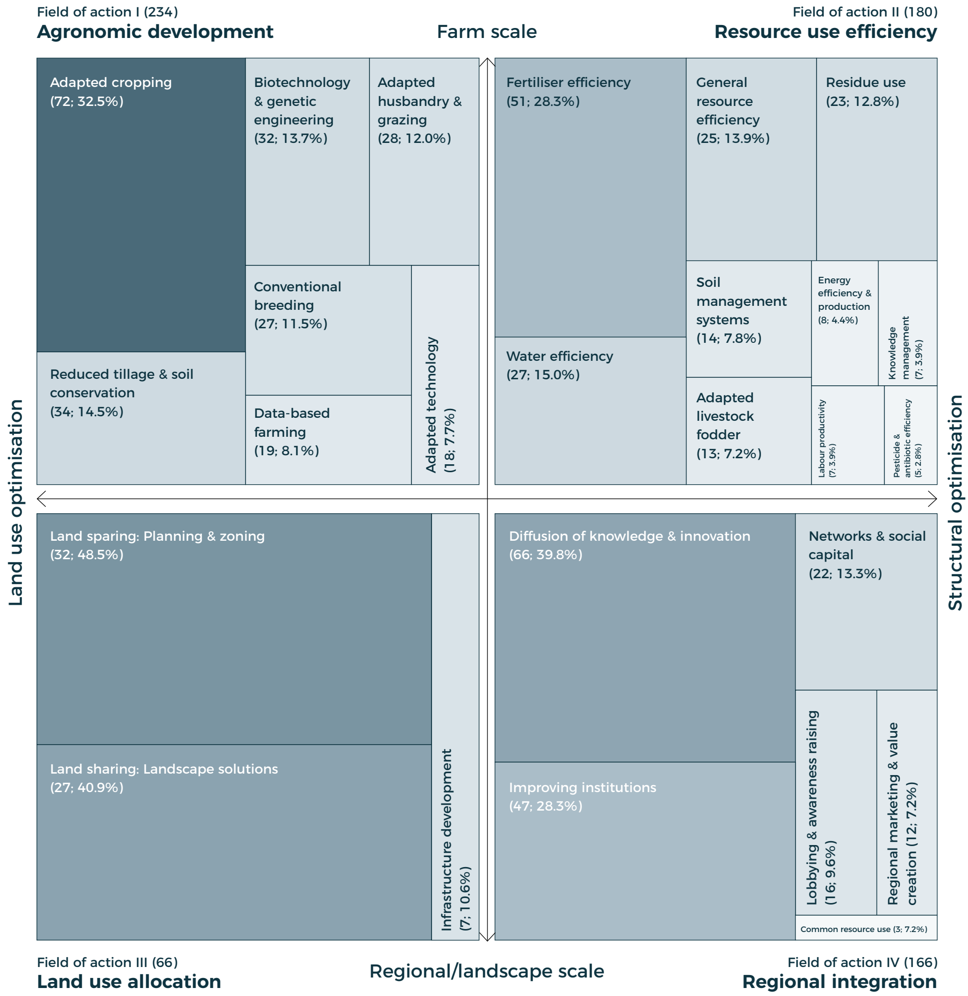

Figure 2.1 **Prevalence of sustainable intensification application areas by scale and scope in a sample of scientific articles.**

Note: Numbers between brackets indicate the number of studies.
Source: Weltin et al. 2018

From a biophysical perspective, sustainable production systems could be characterised by crop varieties and livestock breeds that have a high ratio of productivity to external or internally-derived inputs, avoidance of unnecessary external inputs, agroecological processes such as nutrient cycling and allelopathy, and minimised technologies or practices that have adverse impacts on the environment and human health.

However, farming systems also have intrinsic economic, human, social and institutional aspects. The following additional characteristics are also relevant to sustainable intensification: adequate returns to labour and resources, satisfactory livelihoods/ minimised poverty, household management, food and nutrition security, functioning local social capital, institutions and governance, resilience, and capacity to manage risk and adapt to external stresses and shocks. These additional characteristics were of particular relevance to SIMLESA, as food insecurity, poverty and riskiness of farming systems in ESA were drivers of the program design.

While sustainable intensification places the emphasis on ends (outcomes/impacts) rather than means (sustainable intensification neither privileges specific approaches nor excludes specific practices) (Garnett et al. 2013; Godfray & Garnett 2014; Pretty, Toulmin & Williams 2011), it is useful to consider common processes of successful sustainable intensification. Conway (2012) proposes three main sustainable intensification components for developing countries: ecological intensification (e.g. conservation agriculture, agroforestry and integrated pest management), genetic intensification (improved cultivars and breeds) and market intensification (effective value chains, institutions and policies), which African, regional and national organisations are supporting.

Based on a recent global assessment of sustainable intensification, Pretty et al. (2018) noted several steps towards sustainable intensification: efficiency improvements (in input use), substitution (of resources or inputs) and redesign of enterprises or the farming system, and argue that redesign is essential for widespread impact of sustainable intensification. In the first of a series of assessments of sustainable intensification uptake and impact, Pretty et al. (2006) analysed 286 cases in 57 developing countries. They found increased crop yields (average 79%), better water use efficiency and carbon sequestration (35 t C/ha/yr) on 12.6 million farms covering 37 Mha, distributed across the eight FAO World Bank farming system categories (see Dixon 2019). The seven clusters of sustainable intensification practices (also referred to as resource-conserving technologies) were:

- integrated pest management
- integrated nutrient management
- conservation tillage (or conservation agriculture)
- agroforestry
- aquaculture
- water harvesting
- livestock integration into farming systems.

In a second assessment focused on Africa five years later, Pretty, Toulmin and Williams (2011) reported, with respect to 40 cases in 20 countries, a doubling of food crop yields (by 2.13 on average, representing extra food availability of 557 kg/household/yr) supplemented by substantial diversification on 10.4 million farmers managing 12.75 Mha. In addition to the sustainable intensification practices found in the 2006 study, this 2011 assessment included crop varieties and livestock breeds, soil conservation and intensive small patches (e.g. home gardens) and also commented on several novel policies and institutions that support sustainable intensification. More recently, Pretty et al. (2018) examined 400 projects in 100 countries worldwide and identified a total of 163 million farms (29% of the global farm population) covering 453 Mha of agricultural land (including pasture). Counting projects which had at least 10,000 farms or 10,000 ha of sustainable intensification redesign in at least one farm enterprise, the most prevalent sustainable intensification redesign approaches were conservation agriculture (17 million farms), integrated cropping (8 million farms), pasture/forage (1.4 million farms), enrichment with trees (30 million farms), improved irrigation water management (18 million farms) and intensive patches of sustainable intensification (68 million farms). The assessment underscored a key principle that sustainable intensification is often complemented by sustainable on-farm diversification (Dixon et al. 2020).

For expository purposes in this chapter, three clusters of sustainable intensification innovations have been considered. CASI includes aspects of integrated farming systems, for example cereal–legume integration through intercropping or rotations, and crop–livestock integration. Two institutional innovation clusters (value chains/market access and innovation platforms) are relevant to sustainable intensification in many farming systems across different continents, and are briefly discussed in the following paragraphs. CASI combines the strengths of the principles of conservation agriculture (minimum soil disturbance, vegetative soil cover and rotation) and complementary sustainable intensification practices (such as improved varieties, fertiliser, vaccines and weed management). When adjusted to local farming conditions, CASI increases whole-farm productivity while enhancing economic sustainability, environmental sustainability or social sustainability (Thierfelder et al. 2018). The global conservation agriculture area is expanding by about 10.5 Mha/yr and reached approximately 180 Mha in 2017 (Kassam, Friedrich & Derpsch 2018). Under farmers' circumstances, CASI generally leads to higher yields, savings of labour and costs for ground preparation and weeding, system resilience and improved household income and household food security (Dixon et al. 2019). Many researchers observe increased soil carbon and reduced soil erosion over the medium term. Often CASI generates increased water and nutrient use efficiencies. CASI is therefore a valuable component in sustainable intensification packages in many farming systems.

Another technical innovation cluster comprises grain or forage legumes as intercrops or rotation crops. In a meta review of performance in Africa, Franke et al. (2018) show increased cereal yield of 0.49 t/ha for cereal–legume systems compared with cereal monocropping in the absence of N fertiliser, and increased yield of 0.32 t/ha when N fertiliser is used. Cereal–legume crops benefit soil health, livestock, human nutrition and livelihoods, and are particularly valuable elements of CASI packages in rainfed farming systems. Considering the global prevalence of mixed crop–livestock farming, improved crop–livestock is an important and transformative innovation. The integration improves biomass and nutrient cycling on farms, improves soil health, strengthens system resilience and integrates well into CASI. Rodriguez et al. (2017) analysed the trade-offs between the retention of crop residues in fields, as mulch, and the provision to livestock, primarily for maintenance. In fact, sustainable intensification through crop–livestock integration is considered a priority climate-smart investment for rural development (Herero et al. 2010).

While there is a long tradition of research on local agricultural markets focused on smallholder access, chain efficiency and stability, and market integration (Jayne, Zulu & Nijhoff 2006; Marenya et al. 2015), sustainable intensification dialogues often overlooked such fundamental drivers of productivity and sustainability. Moreover, Schut et al. (2016) report that institutional innovations (for markets, credit, services, etc.) are essential to address 69% of the constraints to sustainable intensification in the east African highlands, and this may be true also for many other farming systems. Relatedly, local institutions and social capital are critical elements for African and Asian sustainable intensification. Makini et al. (2013) and Misiko et al. (Chapter 5) emphasise the role of community innovation platforms to foster co-learning, innovation, coordination of stakeholders and access to services and markets. The foregoing group of three innovation clusters (CASI legumes, markets, local institutions) are crucial for sustainable intensification in ESA, and the potential for agricultural and rural transformation.

Operationalising sustainable intensification

The core challenge for sustainable intensification has not been conceptual, but rather in the operational aspects of practical formulation, testing, piloting and scaling, evaluation, etc., over the full program or project cycle. The context for implementation is the prevailing research and development cultures, existing individual and organisational capacities, current institutional and policy settings and power plays of major stakeholders. Most science leaders and policymakers share the goals embedded in sustainable intensification. However, there are questions about the adequacy of available win–win practices for transformative sustainable intensification, and the implicit trade-offs between development, food security and societal outcomes. Powerful stakeholders with vested interests are inclined to defend or expand their positions. Perhaps one of the greatest practical challenges has been the momentum of existing practice and pathways in risk-averse bureaucracies.

Against this background, this section proposes the framework of six operational principles (introduced in Chapter 1) to facilitate effective engagement and implementation of sustainable intensification at all stages of the program cycle:

- integration
- innovation
- impact orientation
- information and capacity building
- investment
- institutions.

These operational principles, which framed the implementation of SIMLESA, are elaborated below.

Integration

Systems theory and integration have been emphasised in sustainable intensification strategies from Meadows et al. (1972) to Oborn et al. (2017) but have often been ‘missing in action’ during implementation. Of course, farmers practise complex systems management beset with great uncertainty on a daily basis—predominantly in sound ways, as discovered by early farming systems research in the 1970s (Dixon, Gulliver & Gibbon 2001)—whereas sustainable intensification scientists aspire to effective systems analysis to identify and test improvements to complex systems function and performance. Leeuwis and Wigboldus (2017) remind us of the multiple levels of systems (from crops and herds, to national and global), whereas most sustainable intensification analysis concentrates on farm household and farming system/landscape levels. They also illustrate the variety of systems thinking about natural (or biophysical) and social (or socioeconomic) systems that are used to analyse sustainable intensification, including hard, functionalist, soft, cognitive, political and social/institutional, and the fundamental importance of intertwined biophysical and socioeconomic strands.

Many of these aspects of systems thinking were explicit or implicit in various applications of, or stages of development of, farming systems research. In practice, farming systems research offers a functional set of interdisciplinary practices for participatory diagnosis, on-farm research and participatory evaluation of research results that could be adapted or built on (especially in relation to landscape aspects) for a wide variety of sustainable intensification contexts. Of course, these techniques will continue to develop for a wide variety of research and development applications. For the sustainable intensification case, several areas warrant fine-tuning and further methodological development (Norman & Atta-Krah 2017), as has been occurring in part with the shift of development research orientation from research-for-development to research-in-development, in which traditional research is extended to include research on pathways to adoption and impact and aspects of wider development.

While farming systems research systematically targeted research efforts towards particular areas and differentiated farming systems and household types, there would be advantages in fine-tuned techniques for farming system zonation, household typologies and targeting (see below). Relatedly, sustainable intensification research teams would benefit from techniques for analysing linkages across multiple scales. Methods for participatory research would benefit from enrichment in relation to stakeholder roles and expectations. Two gaps in modern farming systems research methods are low-cost techniques to understand better farmer and agribusiness behaviour and decision-making in the face of uncertainty, and rapid analysis of household food and nutrition security. Greater choice of techniques would be desirable for the analysis and follow-on of in-community research on institutional systems and local policy settings that influence sustainable intensification systems.

Scaling pathways and partnerships are intrinsic elements of sustainable intensification. Scaling requires enriching farming systems research and development techniques for linking site-specific research results to wider recommendation domains, development institutions and policies such as the farming systems development approach pioneered by the FAO three decades ago (FAO 1989, 1990). Successful scaling focuses on strengthening local systems rather than transferring or disseminating practices (Woltering et al. 2019). One of the key choices in sustainable intensification systems research and scaling is the choice of partners. While a robust set of system analysis tools are available, a great challenge is the engagement with and mainstreaming of impact-oriented systems approaches into the activities of research partners, where all too often predetermined research pathways focused on disciplines and commodities prevail.

Innovation

For decades, national agricultural innovation systems, were analysed without much attention to the conditions and drivers that foster innovation at organisational and disciplinary interfaces, or to the wealth of innovation occurring within farms and communities. Guidelines and compendia of experience were available (e.g. World Bank 2006). Global innovation indexes ranked countries, although without specific attention to agricultural or rural transformation that underpins sustainable intensification.

In practice, agricultural and rural innovation is a continual process of method, practice, technology and institutional improvement, which can be fostered by conducive environments for experimentation and learning. Conway (2014) suggested that innovation for sustainable intensification should focus on multiple benefits, engage with multiple partners, work at multiple scales and use multiple approaches. In this sense, farmer innovation as part of sustainable intensification could be stimulated by local institutions that reward innovation, reduce the risk of experimentation and encourage farmer-to-farm learning. A variety of farmer alliances, multistakeholder forums and innovation platforms (Makini et al. 2013) can bring together farmers, research, extension, agribusiness and district officials for coordination and co-learning in environments that are conducive to farmer and business innovation. Local leadership is the key for operational continuity and continuity of incremental improvements (viewed from a national perspective). In relation to aspirational goals at a higher level, transformation can stem from 'system innovation … concerned with the reconfiguration and realignment of a diverse array of societal elements … for inclusive and sustainable growth' (Hall & Djikman 2019).

Impact orientation

Clear pathways to impact (or theories of change) are an essential early element of systems research design, and improve the relevance and effectiveness of the research. Effective pathways for impact in sustainable intensification are often systems-oriented, novel and knowledge-intensive, and are generally more complicated than the dissemination pathways for improved varieties or fertiliser. The sketching of sustainable intensification adoption and impact pathways requires clarity on project outputs, users' outcomes and beneficiary impacts, and their relationships and linking processes—essential to ensure that the activity impacts embrace sustainability as well as intensification. Ideally, the sketching can be workshopped by a multidisciplinary group of research and development professionals, supported by adoption assessment tools such as the Adoption and Diffusion Outcome Prediction Tool (ADOPT) (Kuehne et al. 2011) or scaling assessment tools (Woltering et al. 2019). Ideally, periodic updates of the understanding of impact pathways is best practice, to take account of emerging knowledge of the target system and of shifts in the institutional and policy environment.

A precondition for impact pathway specification is clear targeting of the sustainable intensification research to regions, farming systems and household types. Dixon, Gulliver and Gibbon (2001) and Dixon et al. (2020) define a farming systems framework that comprises 72 major farming systems in developing regions, including 15 in Africa. Each farming system has a population of farm households with relatively similar livelihood patterns and broadly similar development needs. Globally, 15 farming systems account for 80% of smallholder food production and a substantial share of rural food consumption. Considering the drivers and trends of farming systems change over a 15-year period, the analysis identifies potentially transformative strategic investments. The African Science Agenda incorporated the Africa farming systems framework (Figure 2.2) for regional targeting. (This framework is an update of the classification used during SIMLESA formulation presented in Figure 1.2.) Garrity, Dixon and Boffa (2017) argue that 70% of African poverty is found in five farming systems, of which two are the future food bowls and engines of agricultural growth in Africa. Amede et al. (2017) provide an example of a national farming systems framework, originally developed for the Comprehensive Africa Agriculture Development Programme's national investment planning, which would facilitate national targeting of sustainable intensification.

Figure 2.2 **Major farming systems of Africa, 2015**

Source: Dixon et al. 2020

The population of farm households within a particular major farming system have relatively similar livelihood patterns and broadly similar development needs, which facilitate the high-level organisation of development interventions. There is also heterogeneity within each farming system population, within which specific farm household types are identifiable. For decades, researchers often grouped farm household types according to their access to resources, but Wilkus, Roxburgh and Rodriguez (2019) demonstrated an advanced method of categorising rural households.

It is often said that management requires measurement. Dixon (2013) listed sustainable intensification metrics as one of four critical areas requiring elaboration and practical development. Substantial progress has been made in this area (e.g. Sustainable Intensification Assessment Framework, Musumba et al. 2017; Stewart et al. 2018, which could be applied during diagnosis, monitoring or evaluation).

Information and capacity building

Notwithstanding the emphasis of sustainable intensification on ends or outcomes and impacts, most successful sustainable intensification has been characterised by knowledge-intensive innovations (e.g. integrated pest management, CASI, agroforestry). Accordingly, effective methods are required for knowledge sharing to key stakeholders including farmers and service providers in order to empower decision-making on adoption and adaptation of sustainable intensification. Additionally, the spillover of research results of knowledge of successful applications of sustainable intensification is a high priority.

Investment

Public and private investment is required for sustainable intensification. Compared with conventional agricultural intensification, similar investments in rural transport and energy infrastructure would be appropriate. However, most sustainable intensification is less capital and input-intensive (e.g. less pesticide use) than conventional intensification, which suggests careful consideration of the role of the private sector, and perhaps an emphasis on small and medium-sized enterprises rather than larger corporate companies. Conversely, similar volumes of produce processing and marketing are probable. Importantly, sustainable intensification tends to generate more stable productivity than conventional intensification, and supply is expected to vary less in drought-prone farming systems.

Institutions

Institutions (in the sense of the mechanisms that govern the behaviour of a set of individuals within a given community or population, or 'rules of the game'), governance and policies create an enabling environment and incentives for adoption of sustainable intensification. Some researchers argue that institutions are a more powerful driver of sustainable intensification than technologies. Regardless of relative importance, systematic analysis of institutions is essential in systems research for sustainable intensification.

Conclusions

In the coming decades, the transformation of agriculture and rural nonfarm economies will underpin national and regional progress towards poverty reduction, food and nutrition security, resource management and equitable economic development. Nearly half the population of the world lives in rural areas, and their predominant source of food and livelihoods is plant and animal husbandry to feed themselves and the cities. The magnitude of the challenge to meet the United Nations Sustainable Development Goals in 2030 and feed more than 9 billion people in 2050 is immense. Consequently, the intensification of agriculture is essential, especially in hotspots of low productivity, resource degradation, food and nutrition insecurity and poverty in eastern and southern Africa. Such intensification must be sustainable—maintaining or enhancing agricultural resources and agroecosystem health to ensure the viability of future farming and food systems—and integrated into the wider rural development processes that underpin food system value chains and provide employment for growing rural populations. Effective sustainable intensification of agriculture is an integrative, transdisciplinary and participatory approach in which researchers, farmers, agribusinesses and public agencies co-learn about the intersections of agriculture, ecology, social sciences, governance and business.

Rapid intentional transformation is urgently required in the eastern and southern African hotspots of poverty, hunger, low productivity, high risk and degrading resources, in contrast to slow incremental development. From a farming systems perspective, transformation implies a major, positive, recognisable and lasting change in the resources, structure, function or productivity of farm household systems—implying a fundamental adjustment in the nutrient, energy, economic or other aspects linking components of the farm household system, value chains and external institutions. In contrast to some well-managed, highly productive farming areas, many African hotspots require transformational changes on a significant scale, of the order of 30% productivity increase and/or 30% risk reduction over a decade (with commensurate improvements in livelihoods). There are no simple technological or institutional fixes for sustainable intensification. The pathways to agricultural and rural transformation can be quite diverse and depend on the local farming systems and institutional context.

Effective sustainable intensification features six operational principles:

- integration
- innovation
- impact orientation
- information (and capacity building)
- investment
- institutions.

Practical implementation requires multidisciplinary teams and multistakeholder forums for coordinated transdisciplinary activities that meet needs of local communities and national stakeholders. There are many proven approaches that can underpin locally-adapted transformational sustainable intensification, for example integrated farming systems or CASI.

A major investment in individual, organisational and institutional capacity building and knowledge sharing across farming systems and countries is required for effective sustainable intensification for rural transformation. A sound understanding of pathways for agricultural and rural transformation, recognising the agroecological, socioeconomic and institutional dimensions of the development processes, is essential. Clear sustainable development targets and indicators facilitate co-learning and adaptive management of implementation towards the local, national and regional development goals.

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3 Sustainable intensification in the face of socioeconomic, policy and agroecological diversity

Paswel Marenya & Daniel Rodriguez

Key points

- Households and communities have variable levels of capacity (e.g. financial capital, labour) and capabilities (e.g. skills) to sustainably intensify farm production.
- Agricultural technologies and policies need to be tailored to specific social and economic conditions and agroecologies to remain suitable across farming systems.
- Technology adoption by farming households may require the infusion of capital from three different sources:
  - in situ savings from within profitable and self-sustaining commercially productive farms
  - linkages with financial markets and institutions that make credit and financing and subsequent investment options available to farms
  - ex situ savings from nonfarm income sources.
- Income diversification has potential to benefit smallholder farmers, although the exact linkages between nonfarm income and agricultural development needs to be more closely studied.
- An understanding of the following topics should be explicit in future research, extension messages and policies to support adoption of sustainable agricultural intensification:
  - indicators of natural resource and agroecosystem persistence, resilience, autarchy and benevolence
  - relationships across multiple aspects of production.

Introduction

Food security remains at the top of the development agenda in eastern and southern Africa (ESA). In slightly over three decades, five countries of ESA (Ethiopia, Kenya, Malawi, Mozambique and Tanzania) are expected have a combined population of about 534 million people, nearly double their 2017 level of 260 million (World Bank 2017). All other things being equal, more food will need to be produced to keep up with this growing population. To do this, two critical choices will have to be made: bring more land into agriculture or find ways of increasing yields on existing agricultural land while protecting the environment and natural resource base. These circumstances show why there is an urgent need for what has come to be called sustainable intensification in agricultural development research and discourse. As a means to an end and a social goal in itself, sustainable intensification refers to the possibility of increasing crop yields and improving food and nutrition security without exerting negative environmental impacts or expanding the agricultural frontier. Sustainable intensification requires adoption of production practices that enhance crop yields and help reduce environmental risks to crop production. These practices have to be adopted on a large scale by millions of farmers in Africa to support system-wide change and achieve long-term impacts.

However, this task is not made any easier by the heterogeneous socioeconomic conditions, institutions, policies and agroecological contexts for which sustainable intensification is to be achieved. Efforts span the subhumid regions in the Ethiopian Rift Valley, the low-lying areas of the Lake Victoria basin in Kenya and Tanzania, the marginal southern regions of Malawi, the relatively humid highlands of Kenya's South-Central Rift and the highland maize zones of Ethiopia. These maize-growing areas are home to millions of smallholder families with varying socioeconomic conditions and access to critical enabling factors such as climatic conditions, soils, water resources, input markets, economic opportunities and public services. These diverse circumstances present both opportunities and challenges for sustainable intensification. In this section, we outline these opportunities and challenges to highlight the most promising areas for policy to remove constraints and the private sector to take advantage of opportunities.

We first discuss the issue from a micro-level perspective with a focus on household-level variation in resource capabilities. We then discuss the role of markets in shaping incentives and opportunities. This is followed by a discussion of how livelihood considerations more generally need to feature in the promotion of sustainable intensification. We then discuss changes in the utility of sustainable intensification technologies under different agroecologies. Finally, we review the critical role of the national policy environment in determining whether sustainable intensification can be established.

Heterogeneous physical, financial and human resource endowments

The majority of adoption incentives have been identified in regions like North and South America, where strong and supportive agribusiness infrastructure exist. In this context of large-scale production, sustainable intensification has reduced costs. The general principle appears clear: sustainable production systems such as conservation agriculture must have a strong profitability proposition. However, generalisations are difficult to make, due to the partial, incomplete, site-adapted or complex elements of sustainable intensification practices. More complex analysis of 'outcomes and impact' at a finer resolution are needed to demonstrate how targeted interventions can improve on-farm incomes, poverty, sustainable resource use and other indicators of long-term impact.

Farmers' own resources, capacities and technical information have influenced adoption of conservation agriculture. Changes in family labour demands have substantially impacted incentives for adoption, especially in ESA. Reduced labour requirements from minimum tillage have been treated as one of the most important advantages of conservation agriculture in ESA. However, previous studies have not fully accounted for trade-offs with a broader range of household activities. Complementary practices such as herbicide use to control weeds, or more frequent weed removal by hand, can undermine labour savings from minimum tillage (Nyamangara et al. 2014). Labour saved from minimum tillage might not confer enough advantages for conservation agriculture to be beneficial to all groups of farmers.

Opportunity costs of learning and experimentation with conservation agriculture packages have hampered adoption of conservation agriculture. Successful implementation of conservation agriculture has also decreased with restricted access to credit or capital for renting or purchasing equipment, fertiliser, herbicide or labour. Farmers' perceptions can also reduce adoption if farmers believe conservation agriculture practices are less profitable than their current practices. They may abstain from adopting conservation agriculture because their previous attempts were disappointing, or fail to experiment altogether because of inaccurate information about their profitability. Many examples of non-adoption are due to a lack of knowledge and skills needed to implement new practices effectively or efficiently. The literature points to various factors that will constrain adoption based on local circumstances, including agroecological conditions and policy (Feder & Umali 1993; Marra, Pannell & Ghadim 2003).

Household resources (or lack of them) can facilitate (or undermine) sustainable intensification, creating benefits for those with adequate resources who can invest in sustainable practices and enjoy higher productivity and welfare. Those starting off with limited resources underinvest in their farms, which perpetuates poverty, resource degradation and further disinvestment. Moreover, farmers' knowledge, information and technical capacities are crucial for modern agricultural intensification. The impact of wealth (livestock, value of farm equipment and amount of land owned) on adoption behaviour further suggests that adoption would increase with access to credit and microfinance (Boucher, Carter & Guirkinger 2008).

Farmers' social connections, access to resources such as informal credit or group marketing, or reciprocal labour have played a more significant role in adoption behaviour where public agricultural extension services are lacking than in those areas where extension is strong. Sustainable intensification adoption in ESA has been mainly mediated not by the equity-enhancing forces of public goods or financial markets, but by farmers' own idiosyncratic capabilities. Rigorous evidence is needed to better understand farmer-level incentives for adoption in this context. Farmer education, extension and information delivery systems are critical. We will return to these issues in later sections. Broadly accessible public goods, especially information and credit, can support widespread sustainable intensification. This can be a way of levelling the playing field for a diverse community of farmers whose concerted action is needed to achieve sustainable intensification.

Markets and incentives for sustainable intensification

A core pillar of sustainable intensification is the financial viability of intensification at the farm level. This will almost always be mediated by market behaviour and agricultural value-chain linkages. Markets are the key shapers of incentives and opportunities that guide farmers' investment decisions. From an agronomic point of view, it is hardly contestable that most sustainable intensification practices are sound and necessary for sustained biophysical viability of a farm. Assuming farmers have the resources to implement them, the issue of profitability remains. There are instances where farmers will refrain from implementing better sustainable intensification practices because they are not profitable. This issue is distinct from that of access to resources.

Conservation agriculture, for example, is an input- and knowledge-intensive practice. It depends on off-farm resources. Successful conservation agriculture practices require specialised machinery and equipment as well as seed, chemicals, fertiliser and advisory services on optimal combinations and timing of applications. The private sector—including sellers of equipment, input retailers, custom hire service providers and financial services providers—is the key supplier of these inputs. In many situations in ESA, where small-scale farmers do not fully participate in markets, significant benefits can be gained from adjusting business models, private sector investment incentives and basic market infrastructure. Efficient markets need a well-functioning public sector to provide the framework and the enabling environment for their proper functioning. Investments in research and extension, and also regulatory structures, are still needed for the efficient operation of markets. Public investments (such as subsidies) can also be effective tools to jump-start investment.

The quality of natural capital plays a large role in shaping the management choices that farmers make in investing in these stocks of capital. Demand for natural capital (e.g. soil nutrient or moisture stocks) is further derived from market demand for tradable outputs. Therefore, investment decisions are indirectly affected by market access and other economic conditions. These factors vary across countries and regions within countries. For example, it is clear that regions with relatively better market access will also tend to have higher adoption rates of tradable inputs such as fertilisers. These variations have been important even within villages and farms (Marenya & Barrett 2009; Tjernström 2017).

Diversity in farming and livelihood systems

As the primary driver of agricultural intensification and productivity growth, technology adoption among farming households may require the infusion of capital from three different sources. The first avenue would be in situ savings from within profitable and self-sustaining commercially productive farming. The second would be through linkages with financial markets and institutions that make credit and financing available for farm investments. In the absence of financial or credit markets, the third source of finance for farm investments may be ex situ savings from nonfarm activity among those who have diversified into nonfarm income sources.

Access to nonfarm sectors and other livelihood strategies can influence production profoundly because in situ savings are one of multiple livelihood sources that influence each other. Broadly, agricultural development linked to sustainable intensification will take place in an economic system with the potential to help or frustrate this process. The symbiotic link between farm and nonfarm activities is often discussed at the sectoral and macro levels, but seldom at the household and micro levels.

The importance of nonfarm income has been studied and discussed in academic and policy circles for a long time. In a 20-year old study that summarised evidence from 25 studies from a broad set of countries, Reardon (1997) reported that, in developing countries, rural nonfarm income was typically 45% and could range from 22% to 93% (de Janvry & Sadoulet 2001). However, Ellis and Mdoe (2003) reported that poverty was largely correlated with lack of land and livestock in Tanzania, indicating limited labour markets outside farm production. Evidence from a low production region of Ethiopia has suggested that off-farm income can lead to reduced input use and even land degradation (Holden, Shiferaw & Pender 2004). This case study suggests that some disinvestment in agriculture happens when other opportunities arise. Overall, nonfarm income and income diversification is generally associated with greater welfare among rural households. Furthermore, the more lucrative nonfarm income sources are characterised by significant entry barriers such as education in the case of high skill wage employment or capital in the case of high-income business enterprises. The empirical evidence suggests that only those with high initial endowments (savings, skills, education and social contacts) are able to diversify into lucrative nonfarm activities. Diversification for the majority is limited to low-skill activities and largely informal enterprises (Reardon 1997). This form of diversification will do little to increase average incomes or reduce income risks (Barrett, Reardon & Webb 2001).

A diversified income base can support agricultural technology investments. Diversification of income activities has been treated as a strategy of investing in activities with low- or negative-income covariance to hedge against production risks. Additional income sources can also be used to finance farm investments, especially in many rural areas where credit market failures are pervasive. On the other hand, productive agricultural enterprises can also generate profits that can be invested in nonfarm enterprises, creating a synergistic relationship in the macro-economy. Which pathway prevails is an important question for agricultural policy. If nonfarm income is a significant source of agricultural capital, focusing on enabling rural households to engage in nonfarm enterprises should be part of agricultural development. If agricultural profits are seldom invested back into agriculture and returns on investment are low, policies to enhance the profitability of on-farm production (through market integration or improvements in rural infrastructure) can be critical to the agriculture sector.

Notwithstanding the possibilities and limits of income diversification among smallholder farmers, the exact linkages between nonfarm income and agricultural development need to be more closely studied. The following questions must be addressed:

1. Are savings from agricultural income reinvested in agriculture or non-agriculture?
2. Are savings from non-agricultural incomes reinvested in agriculture or other opportunities (e.g. children's education, expanding small businesses)?
3. Which smallholder farming households maintain the most lucrative on-farm economic activity?

Agroecological variations and their implications for sustainable intensification

In ESA, a more balanced approach to agricultural intensification must deliberately focus on better natural resource management and agroecosystem health. Without a more agroecologically sensitive focus, sustainable intensification in eastern and southern Africa is unlikely. This is especially true given the rainfed nature of the regions, its low levels of inputs and high resource degradation challenges. This implies major strategic reorientation. Investments in natural resource management (e.g. reducing soil degradation, replenishing soil nutrients and moisture conservation) are important new elements that need to be addressed.

The key ecological principles of persistence, resilience, autarchy and benevolence can guide this new agroecologically based paradigm shift in sustainable intensification (Royal Society 2009). In terms of persistence, the agricultural system will have the capacity to deliver on productivity and food supply for extended periods of time, thereby being predictable and stable. Agricultural resilience is important because it ensures that households and the whole sector can withstand stresses from climate, social, economic and environment change. Resilience is achieved when the system can absorb these stresses without changes in the underlying qualitative structure. An agroecological perspective would also require that the agricultural system can deliver the needed food and fibre through the use of resources found within the system (autarchy). Reliance on external inputs that are often not available within national borders risks undermining the resilience of agroecosystems. Finally, sustainable intensification can only happen if the production system is benevolent, producing the desired outputs without depleting the natural resource base.

The application of sustainable intensification principles will require site-specific adjustments based on particular agroecological features of the production environment. In high-potential and humid environments, high external input production systems are possible with annual crops. High biomass yields and pasture availability (natural or managed) means that residue competition for feed is low and sufficient mulch cover can easily be achieved in conservation agriculture-based sustainable intensification (CASI). Weed management will be challenging in these environments, even with an abundant supply of mulch. This means conservation agriculture-based methods of sustainable intensification in humid environments will invariably require use of herbicides. In subhumid (or moisture-stressed) environments, biomass yields are likely to be lower and competition for mulch from livestock feed is likely to be higher. The significant trade-off between the use of crop residues as mulch or livestock feed in these subhumid environments requires that CASI technologies are adjusted to reduce competition. Livestock intensification and feed efficiency can offer a means of reducing competition. In areas where crop–livestock intensification is possible (where average land sizes allow this), the use of nutrient recycling through animal manures may be critical.

Conceivably, in marginal environments, perennial crops and agroforestry may offer a better sustainable intensification pathway. These perennial production systems can conserve fragile or marginal environments (e.g. hillsides or floodplains) because they require minimum soil disturbance and tillage. Reduced or no-tillage systems are likely to be the most sustainable land management option, due to challenges of moisture stress in these environments.

Diversity in policy environments

Bringing vast areas of agriculture in eastern and southern Africa into sustainable intensification requires policy support. Policies can play a significant role when initial resource constraints (including labour, finance, knowledge and skills) are binding for many farmers. Providing time-bound, conditional support policies can give farmers an initial push to implement a package of recommendations and help them commit to adopting these practices. Various policy designs can effectively ensure that farmers sustain these practices after this support ceases. For example, herbicide vouchers can be conditioned on adoption of conservation agriculture.

Given the interrelatedness of natural resource management practices and external inputs such as fertiliser, agrochemicals and seeds, it is important that policies or programs that support sustainable intensification take an inclusive approach. In some ways, it requires considerable policy rethink. The current trends in many countries is that natural resource management is treated as a secondary (not a primary) adjunct to sustainable intensification. Part of this rethink will probably involve mainstreaming natural resource management in agriculture and high standards of agronomy. There are three key policy areas that can resituate natural resource management within and alongside sustainable intensification discourse and underpin the success of sustainable intensification:

1. focusing on information delivery
2. improving market access, lowering costs of agricultural inputs and enhancing inclusive credit markets
3. taking an integrated agricultural policy approach to sustainable intensification.

Sustainable intensification requires that farmers’ agronomic and resource management skills are improved through consistent and high-quality extension services. One proposal is that agricultural policies related to extension and information delivery to farmers should focus on increasing the amount of agricultural information available to farmers, making these messages as site-specific as possible and ensuring they are delivered with regular frequency to keep them up to date. This goal in providing extension services may require the involvement of a diverse array of actors.

Improved market access can lower costs and help ensure that inputs are affordable. An example of the impact of costs on technology adoption relates to subsidies. Research has shown that input subsidies have powerful effects in the adoption of sustainable intensification agricultural practices. Continued reliance on subsidies can be problematic in the long run, when competing development needs strain budgets. In order to achieve sustainability in cost reduction and enhance farmers’ access to inputs, the following principles should be considered. Improving infrastructure networks into rural areas and supporting agribusiness finance will help improve input supply chains in ways that are likely to be more effective and long-lasting than subsidies. Considerations can also be given to providing financial safety nets.

Technology development and extension can apply more integrated approaches. Research under SIMLESA and related projects has shown that the best outcomes for crop income occurred with simultaneous adoption of multiple sustainable intensification practices. Future research, developing extension messages and prioritising policies to support adoption of sustainable intensification require an understanding of relationships between multiple aspects of production. In each case, custom packages for particular locations and groups of farmers should be researched, disseminated and supported.

Conclusions

The population of the SIMLESA countries is projected to double in 30 years. The call for sustainable intensification is indeed an urgent one. Global food security remains an important development imperative as social, economic and environmental changes are having significant impacts at the global scale. Arable land and other resources such as water are becoming more and more limited. Achieving global food security has to be done amid these changing conditions. Farming systems are called upon to deliver multiple streams of benefits. Adequate food to ensure nutrition security is a major goal. Imparting resilience to farming systems amid all these changes are critical. The conservation and protection of the natural resource base is necessary to sustain resilient food systems.

The capacity of agricultural households and communities to sustainably intensify has varied across farming systems. The diversity of circumstances that affect the nature of sustainable intensification must be examined on a case-by-case basis. Agricultural technologies and policies must be tailored to specific social and economic conditions as well as agroecologies. An approach that does not consider these variations is likely to miss the goal of sustainable intensification. In this chapter we have outlined a broad set of variations that must be considered and interventions that should be tailored accordingly. These diverse conditions span socioeconomic, policy and agroecological dimensions.

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4 Farming under variable and uncertain climates

Erin Wilkus & Daniel Rodriguez

Key points

- Climate variability is strongly associated with yield variability and production risk, which have major negative consequences for food and nutrition security in eastern and southern Africa.
- Conservation agriculture-based sustainable intensification (CASI) practices have been especially effective at reducing the impact of weather shocks and generally provide the most viable option for poorly resourced smallholder farmers.
- Adoption of CASI practices for managing climate variability, drought and dry spells across eastern and southern Africa has depended on farm exposure, sensitivity and risk levels.
- The benefits of CASI practices have been greatest when applied in coordination with climate and weather-related conditions.
- Climate-based recommendations for implementing CASI practices have supported three forms of decision-making:
  - adaptation—production and operational management decisions that are implemented on a 3–6-month timescale
  - tactical/transformational change—investment in infrastructure used for new operations on a 6-month to 6-year timescale
  - land-use change—transformation at the landscape level that takes place over a period of six years or more.
- With improved skill, climate predictions and decision-support tools could play a fundamental role in identifying the most promising proactive management options for farmers.

Introduction

Sustainable intensification practices have been promoted as sets of productive innovations that can improve farming system performance under variable climates. The yield gains coupled with reduced yield fluctuations, labour requirements and environmental impact commonly associated with sustainable intensification practices suggest that these innovations can increase the adaptive capacity and minimise downside risk associated with climate variability. This chapter discusses climate-related risks of maize production systems in eastern and southern Africa (ESA) and opportunities to minimise risk through climate-informed conservation agriculture-based sustainable intensification (CASI) practices.

Decision-support tools have been developed to inform household adoption of climate-informed, CASI practices. With input from skilled climate projections, seasonal forecasts and complex farming systems models, these tools have produced management recommendations that would dramatically improve household performance, if adopted. The main challenges in ensuring adoption of recommended sustainable intensification practices have been related to user confidence in weather predictions and climate forecasts. The skill level of climate prediction models and collaboration across stakeholders have shaped that confidence considerably. Research and development capacity have underpinned the skill of prediction models and the accuracy and relevance of decision-support tools.

Climate and seasonal variability in eastern and southern Africa

A global phenomenon, climate variability, has had major implications for agricultural production worldwide, explaining a third of the variability in global crop yield from 1979 to 2008 (Ray et al. 2015). Climate variability has been especially high in ESA. For example, rainfall variability has been higher for most of Africa than other continents, contributing to the greater frequency and unpredictability of volatile extreme weather events, particularly drought (Boko et al. 2007).

Production systems in ESA have been highly sensitive to climate variability given the predominance of rainfed low-input systems, market volatility, patchy and hazardous infrastructure and the limited availability and affordability of technology and information (Washington et al. 2006). These characteristics have amounted to high levels of dependence on natural resources which, compounded by non-climate-related development challenges, have been among the most widely cited constraints on the adaptive capacity of these farming systems (Kalognomou et al. 2013). From 1981 to 2010, yield variability in ESA was more sensitive to climate variability than most other regions of the world. An estimated 21% of the increase in maize yield variability in Kenya and Tanzania over this period was attributed to increased variability of the agro-climatic index (Iizumi & Ramankutty 2015).

Extreme events, which have increased with climate variability, have had significant consequences for yield variability, uncertainty and downside production risks (Cooper et al. 2006; Osborne & Wheeler 2013). Droughts have been responsible for a disproportionately large part of agricultural-related losses in ESA (Easterling et al. 2000; Kunkel, Pielke Jr & Changnon 1999). For example, during the 2015 El Niño year, an estimated 40% of the maize-growing area in this region experienced occasional drought stress, and drought-induced yield losses were estimated at 10–25% of total area under production (Fisher et al. 2015). A quarter of the maize crop area was especially sensitive to the 2015 drought, producing half of the expected yield for the season (Fisher et al. 2015).

Climate variability and extreme weather events increased from the late 1970s to 2010s (Fauchereau, Trzaska, Richard et al. 2003; Fauchereau, Trzaska, Rouault et al. 2003; Richard et al. 2001). This trend is expected to continue, increasing faster and reaching levels exceeding other regions of the world (Boko et al. 2007). Climate projections for the A1F1 emissions scenario[1] of the US Geophysical Fluid Dynamics Laboratory's general circulation model predict that the incidence and uncertainty of drought events in SIMLESA countries will be higher by 2020 (Orlowsky & Seneviratne 2011). In eastern Africa, drought occurrence and precipitation variability are both expected to increase. In addition, the entire rainfall distribution in eastern Africa is expected to shift in a positive direction during the wet seasons, reaching precipitation rates that will likely produce more intense high rainfall and flood events (Shongwe et al. 2011; Tebaldi et al. 2006). South-western Africa is projected to become drier (reduction in soil moisture) and experience an increase in the frequency of consecutive dry days (Orlowsky & Seneviratne 2011; Sillmann & Roeckner 2008; Tebaldi et al. 2006) with dry conditions and droughts intensifying towards the end of the 21st century (Hoerling et al. 2006).

Precipitation, intra-annual rainfall distribution pattern and extreme events have been the most difficult climate components for models to forecast (Downing et al. 2009; Gitau et al. 2014). Complex interactions among small-scale, discrete individual convective cells or patchy non-convective precipitation contribute to high levels of spatial and temporal rainfall variability with very localised points of particularly heavy rainfall or aridity. These interactions and the complex spatial and temporal variability of ESA (Hulme et al. 2005), coupled with diverse soil types and management practices, have created different drought frequencies and drought stress patterns across the region (Tesfaye et al. 2016). The majority of drought events recorded since the late 1970s occurred over the 'short rain' season from October to December. The especially high level of interannual rainfall variability of the 'short rain' season in eastern Africa (coefficient of variability: 74%) (Downing et al. 2009) has made these drought events especially hard to anticipate and manage.

The historic uncertainty and diversity of climate-related production challenges in ESA is expected to continue under future climate projections. These variable climates are characterised by frequent and devastating climate events that are spatially and temporally heterogeneous. Climate-informed decisions can play an especially beneficial role under these conditions.

Managing risk in variable climates

As one of the global hotspots for increasingly variable and uncertain climates and a region where production is highly sensitive to climate variability, ESA has faced significant downside risks. Agricultural production (Lobell et al. 2008), livestock systems (Thornton et al. 2009) and food security (Hertel, Burke & Lobell 2010) have been considered among the processes most at risk (Boko et al. 2007). Environmental consequences have also included severe problems of soil degradation, nutrient and organic matter depletion, water contamination and eutrophication and loss of biodiversity, especially below-ground diversity (Lal, Singh & Mwaseba 2014). Social consequences have included volatility in household nutrition (Lewis 2017), famines (Tebaldi et al. 2006) and increased mortality (Delbiso et al. 2017). The drought of 2010–11, described by the international community as the 'worst in the last 60 years', had particularly devastating consequences (Novella & Thiaw 2012). This drought was exacerbated by a failed 'short rain' season in 2010 and very poor March–May 2011 rains throughout much of ESA, triggering famine and the displacement of thousands of people.

1 The A1F1 scenario developed by the Intergovernmental Panel on Climate Change (IPCC) is a future with very rapid economic growth, a global population that peaks in mid-century and then declines, and rapid introduction of fossil fuel intensive technologies (IPCC 2000).

Farmers' expectations of climate-related risk have varied with different levels of exposure and sensitivity across agricultural systems (Table 4.1). In 2008–09 and 2010–11, the majority of household members in the SIMLESA program believed droughts would become more frequent in the future (with the exception of Mozambique 2008–09 and Ethiopia 2010–11). At both the country and community level, farmers also expressed varying levels of concern over drought incidence in the future. Farmers from Tanzania expected a particularly high frequency of drought events over the next 10 years.

Table 4.1 **Drought exposure and risk among SIMLESA households**

Country	Survey period	Experienced drought in the last 10 years (% of households)	Number of drought events over the last 10 years	Average reduction in yield from drought over the last 10 years (%)	Average reduction in income from drought over the last 10 years (%)	Believed droughts will become more frequent in the future (% of households)	Expected number of droughts in the next 10 years
Ethiopia	2008–09	81	2.1	41	35	60	2.7
	2010–11	50	1.2	43	39	27	3.0
Kenya	2008–09	90	2.8	44	29	66	4.3
	2010–11	90	1.9	39	33	89	2.9
Tanzania	2008–09	26	3.4	55	46	84	4.7
	2010–11	95	3.3	46	43	79	4.4
Mozambique	2008–09	18	2.1	43	45	23	2.0
	2010–11	57	1.3	25	24	63	3.2
Malawi	2008–09	97	2.5	33	25	80	3.1
	2010–11	69	1.5	45	43	74	3.5

CASI practices

CASI practices have offered a broad set of management practices commonly promoted to both increase and stabilise yields, thereby minimising production risk (Kassie et al. 2015). Some studies have found that certain CASI practices (fertiliser and mulch) increased yield potential under optimal growing seasons but had little benefit when applied under poor growing conditions, i.e. increased both upside and downside risk (Rigolot et al. 2017). Based on this assessment, sustainable intensification practices had little benefit for risk-averse farmers, who are characteristically more concerned with production under poor conditions. However, agronomic field trials have indicated that CASI practices can support agroecological processes that make these practices especially effective at absorbing weather shocks. CASI practices have also provided additional strategies to minimise downside risks of climate and weather variability under certain conditions.

One example of a climate-informed CASI practice is the selection of crop varieties that are most suitable for growing conditions. For instance, drought-resistant varieties bred under the Drought Tolerant Maize for Africa project had higher and more stable yields under heat stress and unanticipated weather events compared to alternative varieties (Kostandini, Rovere & Abdoulaye 2013). The yield increases from the Drought Tolerant Maize for Africa project improved varieties minimised downside risk by about 15% for producers in Ethiopia, Tanzania, Malawi, Mozambique and Uganda. CASI practices have enhanced soil moisture holding capacity and nutrient retention while minimising soil erosion and leaching (Allmaras et al. 2000; Antle & Diagana 2003). This effectively decreased variability across moisture, temperature and biotic conditions, increasing farming system resilience under climate variability.

Combinations of CASI practices have been especially effective at reducing climate-related risks. Field studies in Mozambique demonstrated that the frequency of maize yields below the 25th percentile was 37% lower in Manica and 9% lower in Tete with full adoption of minimum tillage, residue retention and crop rotation compared to conventional practice (Dias et al. 2017). Additional studies found that use of improved varieties, fertiliser application, minimum tillage and residue retention by SIMLESA households increased yields, shifted the crop yield skewness distribution in the positive direction (Kostandini, Rovere & Abdoulaye 2013) and reduced yield variability (e.g. 3–4-fold in Tanzania; Sariah et al. 2017).

When compared with the conventional practices of SIMLESA households, CASI practices have also tended to have fewer field management constraints, conferring increased adaptive capacity at the household management level. SIMLESA exploratory field trials specifically found that labour requirements for field preparation and sowing tended to decrease substantially with no-tillage practice, making it easier for households to adjust planting dates based on climate and weather conditions. This flexibility can have major yield benefits. Phenological and agronomic studies have shown that yield levels can be highly sensitive to planting date. Planting date has explained a significant proportion of maize yield variability, especially in tropical areas with variable rainfall and dry conditions, like those observed in Kenya (Jaetzold & Schmidt 1982). Delayed planting explained almost 40% of the maize yield variation under the dry conditions of Teso, Kenya and 15–20% in other trials in the region (Tittonell et al. 2007). In the Kakamega site, where rainfall variability was the major factor affecting yield security, delayed planting explained 21% of yield variability. In many sites such as this one, delayed planting in the first rainy season further delayed harvest and prevented planting of a second, short-season maize crop (Fertilizer Use Recommendation Program 1994; Tittonell et al. 2007). With fewer field preparation tasks, the no-tillage practice was associated with more timely sowing and higher consequential yields in the SIMLESA exploratory field trials in Mozambique (Dias et al. 2017; Sariah et al. 2017). The reduced labour requirement of conservation agriculture practices relative to conventional methods also increased flexibility in weeding times in the SIMLESA exploratory field trials in Mozambique. Early weeding under conservation agriculture increased maize productivity by 50% (Dias et al. 2017).

Benefits of climate information

The benefits of sustainable intensification practices have depended on climate and weather-related conditions (i.e. management by environment interactions). Seasonal and weather forecasts, decadal projections and long-term climate models (Table 4.2) that anticipate future growing conditions can be used to plan management practices for the near or long-term future. Farming systems models such as the Agricultural Production Systems sIMulator (APSIM) (Holzworth et al. 2014) have additionally utilised forecast information to estimate expected returns on investment from various sustainable intensification practices (Roxburgh & Rodriguez 2016). Skilful climate predictions can therefore play a fundamental role in proactive identification of management options that minimise risk and enhance performance of household production systems.

Table 4.2 Major types of climate forecasts

Type of forecast	Description
Weather forecast	A deterministic forecast of the future state of the atmosphere. A weather forecast is based on a numerical model that has been initialised with observations to track the time evolution of individual weather features, typically using multimember ensembles in a probabilistic format on timescales of around a week.
Seasonal forecast	The estimated likelihood of a forthcoming season deviating from climatology.
Projection	An estimate of future climate features that is dependent on the externally forced climate response (e.g. the response of changes in anthropogenic greenhouse gases) established in a particular emission scenario.
Decadal and multidecadal projection	The possible changes to the statistics of climate processes and variables (e.g. mean annual rainfall or the frequency of drought events). Decadal climate prediction is based on the output of a numerical model that has been initialised with observations and run with multiple ensemble members either with a single model or a multimodel ensemble on timescales of 1–30 years.
Climate projection	The distribution of weather over time, dependent on the atmosphere.

Decision-making tools that combine skilful climate predictions and farming system models have provided climate-informed recommendations for implementing sustainable intensification practices. These recommendations have supported three forms of decision-making (Table 4.3):

1. Adaptation: Production and operational management decisions that are implemented on a 3–6-month timescale
2. Tactical/transformational change: Investment in infrastructure used for new operations on a 6-month to 6-year timescale
3. Land-use change: Transformation at the landscape level that takes place over a period of six years or more.

Table 4.3 **Decision-making approaches and climate and weather-related data that support sustainable intensification practices aimed at minimising production risks**

	Adaptation	Strategic transformation	Land-use change
Climate data	Weather and seasonal forecast	Decadal projection	Climate change projection
Risk	• Delayed or failed germination • Pollination damage • Pest damage • Reduced grain fill, high moisture grain at harvest time	• Insufficient food • Nitrogen loss • Nutrient leaching • Soil erosion	• Natural disasters • Population exceeds carrying capacity
CASI management approach	• Time land preparation, planting, weeding and harvesting to be synchronised with crop phenology under the season's weather conditions • Select crops and crop varieties that perform best under the season's weather conditions	• Crop rotation scheme and fertiliser applications that ensure availability and retention under weather conditions • Resilient tillage and plot design practices • Crop insurance	• Infrastructure planning (e.g. dams) • Expansion or conversion of cultivated land

Note: CASI = conservation agriculture-based sustainable intensification

Weather and seasonal forecasts, which report expected rainfall events up to a week in advance and provide an evaluation of the upcoming season relative to the previous season, can inform adaptation decisions and relevant sustainable intensification practices. Simple seasonal forecasts have served important roles in anticipating production challenges. Nyamwanza et al. (2017) observed that most risk analysis in the agriculture sector has focused on operational and tactical dynamics that are most directly informed by seasonal forecasts. For instance, these helped identify and warn against drought in the early 1980s (Tyson & Dyer 1980).

Decadal climate models have bridged the gap between seasonal forecasts and climate change projections. Early investment in decadal climate projections (or 'near-term' climate predictions) emerged out of the United Nations Intergovernmental Panel on Climate Change's Fourth Assessment Report and was largely motivated by efforts to understand the likelihood of adverse or extreme events (Vera et al. 2010). Indicating trends in major weather and climate events (e.g. drought), decadal climate models are well-suited to inform strategic transformation approaches. Decadal projections have potential utility for both direct applications in household production systems and institutional/policy spaces. Although decadal climate modelling methods are relatively new, they can play a significant role in complementing operational and tactical planning based on seasonal projections. Over 90% of small-scale producers included in case studies covering Malawi, Tanzania and Zimbabwe stated that climate information on the 1–10-year timescale, especially rainfall in the next 1 to 3 years, would assist in the selection of appropriate crops and varieties, resource allocation and planning off-farm diversification activities (Nyamwanza et al. 2017). They could also provide a strong basis for strategic planning and anticipatory adaptation, and guide long-range investment. Decadal information also has the potential to serve a major role in supporting crop-improvement efforts for breeding schemes that often involve many years of implementation before varietal release. Decadal projections can therefore help ensure that varieties are adapted to climate and weather conditions at the time of release.

Climate change projections that reflect patterns of change over broad areas across multiple decades can finally serve a distinct role in supporting land-use decisions (e.g. infrastructure planning). They have provided insight into broad and long-term processes. Climate projections have identified spatial interdependence of many observed patterns and relationships between production, water, energy and food security. These relationships can guide policy and institutional-level decisions and establish investment priorities for infrastructure and land-use planning (Conway 2016).

Opportunities to inform CASI practices

Climate services in ESA increased in both volume and quality in the 1990s as data collection and the complexity and skill of underlying analyses increased. With more accurate and targeted information for household production, these services played an increasingly central role in identifying opportunities for adaptation and strategic investments for management under variable climates. Since the late 1990s, most climate services have been developed and disseminated by regional climate outlook forums and national meteorological services with marginal support from other scientific institutions, intermediaries and boundary organisations like environmental consultancies and applied university research centres (Singh et al. 2017). First established in SSA in 1997 as part of the World Meteorological Organization's Climate Information and Prediction Services project, regional climate outlook forums were developed to provide real-time regional climate outlook products. Since their creation, regional climate outlook forums have continually operated in this region longer than any other region in the world (Hansen et al. 2011).

Regional climate outlook forums and national meteorological services have remained at the forefront of efforts to develop climate-information websites that provide forecast information for agricultural production including the likelihood of foreseeable climate fluctuations and extreme events as well as vulnerability and risk assessments (Hansen et al. 2011). The national seasonal forecasts developed by regional climate outlook forums have been based primarily on statistical regressions developed over 1–2 weeks preforum and capacity-building trainings that occurred over that period. Over the 1–2-day forums that followed, the forecasting tools were evaluated and the expected impacts and contingency plans were considered with stakeholders. In 2010 alone, the Greater Horn of Africa Climate Outlook Forum held 25 regional climate outlook forums covering short and long rainfall seasonal forecasts for the region (Hansen et al. 2011). With ongoing support from the World Meteorological Organization, the World Meteorological Organization Global Producing Centers and other international climate centres (e.g. the International Research Institute for Climate and Society at Columbia University [IRI], UK Met Office, Métréo-France), national meteorological services and various users from regional hubs have collaborated to develop, distribute and discuss potential applications of consensus rainfall forecasts.

National meteorological services have played a significant role in applying and communicating consensus forecast information. One of the strongest in Africa, the national meteorological service of Ethiopia, demonstrated a leadership role in communicating consensus forecast information (Dinku et al. 2014). In 1987—10 years prior to the first regional climate outlook forums—Ethiopia's national meteorological service started regularly issuing daily, monthly and seasonal weather reports (Patt, Ogallo & Hellmuth 2007).

Three climate institutions in addition to the national meteorological services have operated in Africa to develop and communicate climate information:

- African Centre of Meteorological Application for Development (ACMAD), based in Niamey, Niger
- Drought Monitoring Centre, based in Harare, Zimbabwe
- IGAD Climate Prediction and Applications Centre (formerly Drought Monitoring Centre) based in Nairobi, Kenya (Washington et al. 2004).

The objective of ACMAD was originally to support various socioeconomic sectors of Africa by providing meteorological and climate information, especially short-term weather and seasonal forecasts. ACMAD has also contributed to capacity building and on-job training, development and transfer of new technologies to the NMSs of ESA members (Washington et al. 2004). The drought monitoring centres in Nairobi and Harare have been prominent actors in providing decadal climate diagnosis information with seasonal outlooks for ESA (World Meteorological Organization 2003).

Uptake of climate-informed management practices

Uptake of climate-forecast information and investment in CASI practices in ESA has been variable and often low. An evaluation of decision-making processes among large and small-scale producers in South Africa, Malawi, Tanzania and Zimbabwe found that, in 2017, information obtained from formal sources rarely factored into farmers' decision-making (Nyamwanza et al. 2017). Sixty per cent of large-scale commercial seed-maize producers in Malawi and 70% of small-scale producers in Tanzania did not base any decisions on climate or weather-related information received from formal sources. Despite an increasing volume of global and regional climate models, there have been even fewer examples of uptake and application of long-term climate information (including decadal and multidecadal) for decision-making at subnational scales (Singh et al. 2017).

Many reasons, from institutional to household-level, have been put forward to explain the limited role that climate information has played in management and investment towards CASI practices in ESA. The utility and usability of climate information have been broadly discussed as the main factors limiting uptake and adoption. Utility here refers to the skill of weather predictions and climate projections at lead times and spatial scales of decision-making for a given farming system. Inadequate utility, discussed by farmers in terms of prior experience with forecasts that provided inaccurate information at the spatial scale or environment of their production system, is the most commonly cited reason provided by producers for rejecting available climate information. Usability, or access and interpretability of existing climate information, has also been discussed extensively in adoption literature (Bradford & O'Sullivan 2013). A pervasive question around improving usability has been how best to communicate the uncertainty surrounding climate predictions (Hewitson et al. 2017).

One proposed reason for low levels of investment in climate-informed practices is risk aversion. The majority of farmers in SIMLESA countries have operated under conditions where social safety nets were rare and had little capacity. Rural finance institutions in these regions have not been able to cover the cost of spatially correlated climate-related losses, leaving most regions without financial instruments for risk sharing. With high and uninsured risk exposure, the majority of producers in ESA have tended to internalise risk and exhibit downside risk aversion through adoption of low-risk, low-return strategies (Meinke & Stone 2005). Management decisions are considered (and optimised) for adverse conditions, rather than average or predicted conditions (Hansen et al. 2011). These risk-minimising practices effectively minimise the chances of unexpectedly low yields rather than maximise the potential upside benefits (Kostandini, Rovere & Abdoulaye 2013). Examples include selection of less risky but also less profitable crops and cultivars, allocating household labour to less profitable off-farm activities and avoiding investment in productivity innovations (Marra, Pannell & Ghadim 2003). Case studies of household production in ESA have demonstrated how this precautionary strategy has caused substantial loss of opportunity and placed an upper limit on returns, often reinforcing a state of poverty. In Zimbabwe, the majority of surveyed farmers acknowledged the benefits of adjusting area planted, crop or cultivar and planting date according to the seasonal forecasts; however, most respondents exhibited downside risk aversion and did not act on the information (Phillips, Uganai & Makaudze 2001).

Examples of uptake and adoption by farmers have offered insight into the conditions that have supported climate-informed management practice. A review of the literature supplemented by interviews with experts found that the most successful examples of climate-informed decision-making were predominantly based on daily, weekly and seasonal climate information for decision-making over short time horizons (Singh et al. 2017). Farmers have been more likely to change varieties than adjust other management practices. Ugandan farmers indicated that forecasts from the Ugandan Department of Meteorology, along with their own knowledge and observations, helped them decide whether or not to plant slower-maturing crops for a particular season (Peterson et al. 2010). In an adoption study based in four villages of Zimbabwe, spanning 2002–03 and 2003–04 growing seasons, 57% of farmers who received climate-forecast information reported that they changed their management—primarily, time of planting and cultivar selection (Patt, Suarez & Gwata 2005). In the Machakos district of Kenya, the majority of farmers surveyed in 2001 who had received forecast information reported adopting management recommendations that were based on the forecasts (Ngugi 2002).

Room for improvement

Benefits of climate-informed CASI practices depend on a long chain of complex analysis with high levels of error and uncertainly. Significant technical and analytical capacity is required to generate climate-related data, estimate impacts on farming systems, communicate climate and weather information and establish an enabling environment for investment in CASI practices. Meinke and Stone (2005) argue that this requires greater collaboration among climate scientists, agronomists and rural sociologists (Figure 4.1). Options that emerge out of this collaboration are based on the combined insights in management, future climatic conditions and livelihood options. This transdisciplinary lens arguably places climate-informed CASI practices within a more realistic, technology-adoption context.

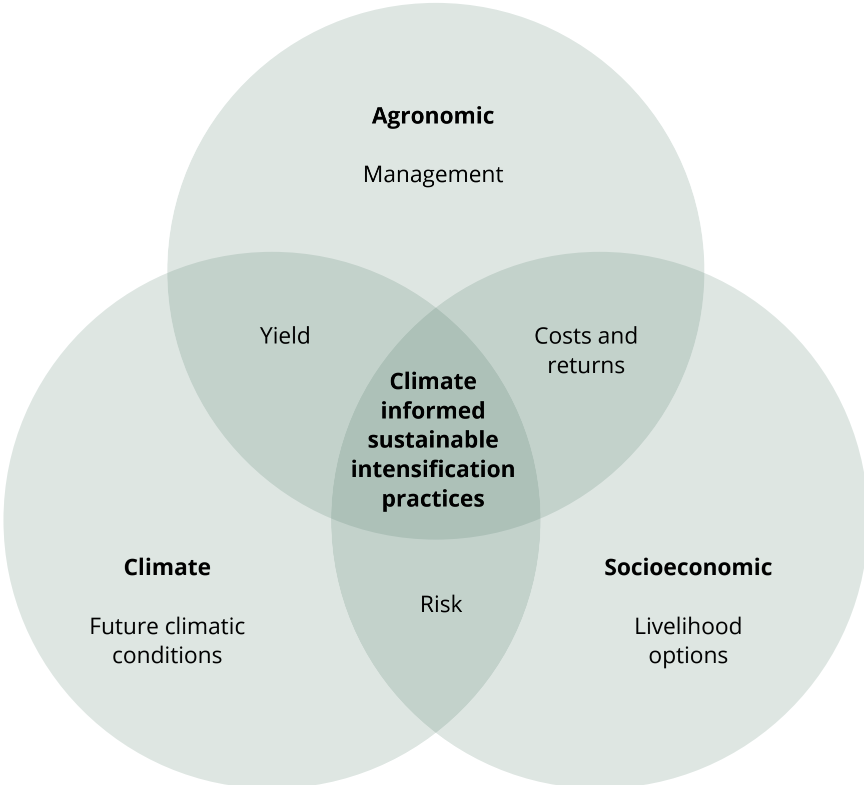

Figure 4.1 **Venn diagram of climate-informed sustainable intensification practices**

Many scholars and practitioners have further argued for greater collaboration with farmers. They cite the importance of explicitly linking forecast information to the concerns (not limited to consequences for production) and experiences of farmers (Peterson et al. 2010). Various initiatives have set a precedent of including producers and ensuring that forecasts are discussed in relevant terms. For instance, the IRI developed the Social Network for Index Insurance Design platform for the capacity-building component of the R4 Rural Resilience Initiative in Ethiopia where community design teams from each targeted village worked with project partners to verify the accuracy of historical meteorological and agricultural data based on recollections of their own experiences with drought (Norton, Turvey & Osgood 2013). In this case, producers had direct access to climate information and climate experts had direct access to farmer knowledge and needs. Knowledge gaps and communication barriers that could otherwise limit adoption could be identified through this two-way exchange (Sharoff et al. 2012). ACMAD was also made more effective through their direct involvement with producers. To disseminate 10-day climate outlooks for the Sahel (an ecoclimatic and biogeographic transition zone in Africa that spans Sahara to the north and the Sudanian Savanna to the south) in a way that was relevant and relatable for target producers, ACMAD conducted pilot demonstration projects during the summer of 2002 and 2003 (Washington et al. 2004). The demonstration plots established proof of concept for the farmers while also facilitating further training for local national meteorological services forecasters.

Coordination across public and private sector stakeholders including community members, extension agents and researchers has greatly enhanced the role of individual actors. Many partnerships have been formed that bridged disciplines and aligned stakeholders. Seasonal forecast information has been increasingly applied to coordinate input and credit supply by private agribusiness, food crisis management by the public sector, and regional trade and agricultural insurance programs (Hansen et al. 2011). For instance, the IRI together with the Global Climate Observing System established the Enhancing National Climate Services (ENACTS) initiative to bridge gaps in availability, access and use of national climate data. A novel aspect of this initiative was their collaboration with formal insurance providers and their active role in linking insurance providers with farmers (Dinku et al. 2014). Through an understanding of climatic, agronomic and socioeconomic components and the various stakeholders involved, the ENACTS initiative recognised index insurance as a potential tool for both managing climate risks and enabling productive opportunities in the ESA agricultural sectors. Osgood et al. (2008) demonstrated substantial benefits of applying seasonal forecast information to insurance schemes. Implemented 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) and reduced losses in El Niño years (when drought and insufficient rainfall would often damage crops), doubling cumulative gross revenues from existing schemes (Osgood et al. 2008).

Other initiatives have worked collaboratively to provide rainfall-based index insurance to farmers. Through partnerships with local non-government organisations (e.g. Relief Society of Tigray), government agencies (Ethiopian Ministry of Agriculture, Ethiopian National Meteorological Agency), financial institutions, and farmer communities, the IRI provided rainfall-based insurance to farmers in Ethiopia under the R4 Rural Resilience Initiative launched by Oxfam American and the World Food Program (Dinku et al. 2014).

In addition to the many actors involved in providing local knowledge and disseminating climate-informed sustainable intensification practices, insurance projects have relied heavily on multiple climate data providers. The R4 Rural Resilience Initiative project used the African Rainfall Climatology satellite rainfall data, produced by the National Oceanic and Atmospheric Administration’s Climate Prediction Center and other satellite-based climatological products (e.g. ENACTS) and the National Meteorological Agency’s rain-gauge networks to design and trigger index insurance contracts.

The history and state of climate research and extension for agricultural initiatives provides a foundation of climate services and collaborations across disciplines and stakeholders that is central to the adoption of climate-informed CASI practices. However, the most state-of-the-art weather and climate predictions and decision-support tools still report with high levels of uncertainty (see Chapter 7). This has limited the utility that these initiatives can offer to farmers. Investment in resources for climate data collection and analysis can bolster these efforts.

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5 Agriculture innovation under multiple constraints: the value of transdisciplinary approaches

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Key points

- Research-in-development and research frameworks that link knowledge generators and users are well-suited to address the multiple challenges of innovation, meet country needs and create opportunities for agriculture.
- An adaptive research approach has broadened adoption of conservation agriculture-based innovations across a diversity of agroecologies.
- Multidisciplinary teams (e.g. economists, agronomists, breeders, system modellers, anthropologists and extension specialists) help address the multiple constraints in complex problems.
- Collaborations have been central to positive developments.
- Multidisciplinary teams that produce transdisciplinary research work from the premise of sharing a desired impact.

Introduction

Complex problems require multidisciplinary teams working to produce transdisciplinary research outcomes that involve the users in the co-design, testing and adoption of innovations. Even though we recognise the value of disciplinary approaches (e.g. breeding, soil sciences) the poor track record of the Green Revolution in Africa (i.e. poor adoption) and South-East Asia (i.e. poor environmental outcomes) calls for alternative approaches.

This paper discusses the value of multidisciplinary teams conducting transdisciplinary research in the SIMLESA program. The most distinctive hallmark of SIMLESA is its research-for-development design, where promoted site-specific practices evolved through an interactive, participatory, trial-and-error fashion.

To anchor the program in transdisciplinarity, the SIMLESA research framework was structured by interrelated, intersecting and interdependent work themes. All themes were designed to contribute to a shared desired impact across disciplines. The program grew out of dialogues with participating farmers and National Agricultural Research System partners, and was implemented by a team of economists, agronomists, breeders, system modellers, anthropologists, extension specialists and others.

These interdependencies supported multiple benefits, amid challenges and delays, given that the methods were new to the research team, farmers and managers. Benefits included economic impacts such as food surpluses sold by smallholders for income. Social benefits included increased access to agricultural resources by women and youth, especially through agricultural innovation platforms and increased nutritional security for households, particularly the adoption of improved legume varieties. The program also improved capacity among National Agricultural Research System partners, including improvement of skills for policy engagement. The framework allowed for each discipline to apply a distinct approach, rather than a unified methodology.

Innovation, and agricultural innovation in particular, has been classified in different ways (Kaine, Hill & Rowbottom 2008). SIMLESA treated the concept of agricultural innovation as a process, practice or artefact by which new agricultural sustainable intensification portfolios (knowledge, tools, options, evidence and benefits) are generated and implemented in varied contexts. SIMLESA was primarily concerned with innovations that were expected to increase yield, reduce economic risk and increase environmental outcomes (Sunding & Zilberman 2000). Discussions by SIMLESA practitioners concentrated on portfolios that were contextually optimal, socially appropriate and provided benefits to the parties involved (Poole 2006). It was a process in which social actors created value from knowledge (World Bank 2006).

Research went hand in hand with agricultural innovation efforts. A transdisciplinary approach is understood as a key component of sustainability research, i.e. generation and implementation of agricultural portfolios or other solutions (Brandt et al. 2013). Transdisciplinary research refers to an investigation by different disciplines working jointly with clients (e.g. farmers, agribusinesses, policy) to create new concepts, methods and transformational innovations that integrate and transcend discipline-specific approaches to address a common problem (Jahn, Bergmann & Keil 2012). These problems occur within complex farming contexts. Transdisciplinarity is about situation, knowledge and learning (Mitchell, Cordell & Fam 2015).

It also seeks to encompass the people, the technology, infrastructure and cultures, or the 'innovation systems' of the place (World Bank 2006). 'Innovation systems' refers to organisations and private and public stakeholders that are interconnected in different ways and possess the technical, commercial and financial competencies and inputs necessary for innovation (World Bank 2006). Portfolios that result from agricultural innovation must therefore address underlying contextual causes. Consequently, innovation and the processes that facilitate it emerge from particular social, economic and physical contexts and are shaped by the [non]existence of favourable conditions in which it can flourish (Inter-American Institute for Cooperation on Agriculture 2014).

Multiple constraints to innovation

There are numerous economic, social, physical and institutional conditions that foster or constrain innovation (World Bank Institute 2013). These constraints range from local to international, and from short- to long-term. This section only discusses perennial issues in the Sub-Saharan Africa (SSA) context.

Resources

The first priority in innovation is often to provide innovators with resources (finances, services and knowledge) by building a suitable support system (Aerni et al. 2015; Herbel et al. 2012). Even when finances (including credit sources) are available, the innovation loop is often incomplete. Innovation requires a complete support system that, among other things, entails knowledge supply, skills and capacity mentoring. In SIMLESA, the majority of collective smallholder innovations occurred under agricultural innovation platforms. However, a key constraint was lack of public and private investments. Investments are critical in alleviating the most limiting constraints in SSA (Aerni et al. 2015).

There are many structural systems and institutions in place across SSA, which have adequate staffing. However, these institutions are rarely effective, due to the absence of enabling environment and investments. Low funding, enforcement of performance targets, systems of rewards and sanctions, mobility to foster linkages and skills development curtail innovation in most SSA countries. Experience in Tanzania shows the importance of reforming the institutional framework underpinning agriculture as well as complementary reforms and investments that support generation of agricultural innovation (World Bank 2011). These may lead to a national system of innovation: programmatic arrangements that ensure transdisciplinarity is harnessed for sustainable intensification. A national system of innovation is required due to the existence of multiple constraints that can only be overcome through change that spans many disciplines. Agricultural innovation initiatives under multiple constraints requires investments in capacity through skills development, training and mentoring. A national system of innovation can be made possible through technology, skills and resource transfer (e.g. the case of Australian technical assistance to Africa under SIMLESA).

Climate change

Academically, climate change can be viewed as a motivating factor for innovation. However, in the contextual realities of the African smallholder, a combination of compounding constraints include little or no early-warning systems, no resource stocks, gaps in social inclusion and persistent macro-ecological limits (Salami et al. 2010). Climate change is depleting stocks of natural resources that are critical for rural innovation and causing price rises that operate as additional barriers to innovation.

First, resources (especially energy and nutrients) from the environment that sustain agricultural innovation are not limitless (Mace 2012). Local resources are linked to the global system. Their utilisation, or over-utilisation, displaces other users in the production system and causes negative balances somewhere else. Climate change aggravates the widespread disruptions in many villages and towns, which add up on a global scale. Because the typical African smallholder has no capacity to exploit resources elsewhere in the world, their innovation capacity is limited. International donor assistance can add significant value to local innovation by mobilising otherwise improbable resource flows.

Climate change is a serious constraint because it cannot be addressed by a single discipline. Constraints related to climate change emanate from a complex nexus of issues where ecological and evolutionary sciences, natural resource management, poverty alleviation, equitable and sustainable growth, individual rights and responsibilities and the governance of the environment all converge (Mace 2012). The climate change challenge therefore requires the interplay between clients (i.e. farmers, the public and private sectors) and a multidisciplinary team of researchers. Sustainability research needs robust foundations in environmental sciences, including macroecology, social sciences and economics. These are rarely mutually harnessed under the same smallholder programs.

There are many ways that the problem of climate change can be viewed as constraining innovation. Often the focus needs to be on extremes in SSA, which cannot easily be measured in standard economic analysis. Climate change disproportionately affects poor communities because the poor cannot afford to innovate. Poverty is maintained and exacerbated under these conditions because restorative management systems of impoverished areas are typically inadequate at reversing most environmental resource damage.

Policy

Regulatory frameworks include legal impediments, trade hurdles, governance and investment obstacles. Long-term gains in agricultural sustainable intensification require cross-border trade and laws that facilitate investments. International, national and local efforts are needed to eliminate these legal constraints.

Environmental sustainability is a deeply embedded challenge for the production system. The established goals of agriculture (production) have employed methods that depend on and consume limited environmental resources. 'Successes' in agriculture result in increased food production, which often leads to population booms (Hopfenberg & Pimentel 2001). Huge populations result in land fragmentation and degradation (Caldwell & Caldwell 1994; Rosegrant & Sombilla 1997). Agriculture is therefore often a key cause of habitat loss (Caldwell & Caldwell 1994). This is the trend in all SIMLESA countries. The pursuit of national food security goals and export income in SSA often results in compromised ecological goals, including biodiversity conservation.

Usually, more land is converted from pastures, forests or fallows, disrupting critical ecological life support functions. Such continual disruptions of the ecological balance means that smallholders must restore it even as they engage in increasing productivity. This makes the Millennium and Sustainable Development Goals elusive without new innovation and an agriculture sector further facilitated by nonfarming policies. SIMLESA has treated conservation agriculture-based sustainable intensification (CASI) as a feasible pathway to environmental sustainability (Misiko 2016).

The starting point is not agricultural innovation on its own, but bridging science and policy. First, policy on agricultural innovation is generally narrow (Yatich et al. 2008). Second, even when strongly formulated, policy provisions are clumsily enforced. Usually, there are no instruments with in-built incentive mechanisms to encourage broad and systematic rural innovation. There is therefore a disconnect between grassroots practices and actual policy proclamations related to agricultural innovation. The key question SIMLESA grappled with was, how effectively can conservation agriculture-based innovations be sustained or scaled in highly imperfect policy contexts of eastern and southern Africa (ESA) without a national system of innovation?

Skills and knowledge

Skills and knowledge are critical elements of innovation. Financial resources and legal frameworks are only useful when knowledge and skills are in place. Skills and knowledge are complicated to address. They require long-term commitment and follow up to support training. For instance, SIMLESA's agricultural innovation platforms were carefully applied over three years to develop leadership, business and other competencies. Competencies at the national level, especially in institutions of research, are the core human resources that emanate from sound educational systems. Unfortunately, ESA had a widening skills gap, weak training programs (e.g. vocational, college) and emigration of educated citizens (a brain drain).

The success of agricultural innovation under multiple constraints depends on the capacities of research institutions. The SSA context requires agile systems. Successes that do not adapt for new constraints are lost over time. For instance, breeding methods that do not improve constantly to generate climate-smart, socially acceptable, marketable varieties, cannot be relied upon for sustainable intensification. The agile/responsive (research and extension) organisational orientation of the Rwanda Agricultural Board was critical to the transdisciplinary approaches that allowed for the implementation of agricultural innovation platforms. Agricultural innovation platform development under SIMLESA was slow in the absence of flexible organisational orientation of National Agricultural Research System partners (Misiko et al. 2016; Salami et al. 2010). SIMLESA adaptive research played the necessary role in applying conservation agriculture-based innovations to different ecologies. The contextualised research products created platforms for the ongoing development of transdisciplinary innovations. Good policy and supportive investments have been neccessary to realise greater agility among institutions, promote research and access up-to-date information (Herbel et al. 2012).

What SIMLESA and other processes have not addressed is how different regimes of intellectual property rights may play out under transdisciplinary approaches (Kumar & Sinha 2015). The role of transdisciplinary innovation in such a scenario shift is unclear, due to fragmented intellectual property claims. A critical question, as transdisciplinary approaches are mainstreamed, is how intellectual property rights help or hinder transdisciplinarity and innovation in public research.

Social

Agriculture is beset with numerous challenges of social exclusion. This relates to age, disability, ethnicity, religion, gender, sexual orientation, health status, marital status and residence. It also includes wealth status (Brandt et al. 2013). Among these, agricultural sciences usually focus on gender and youth. Indeed, women make essential contributions to agriculture in SSA, but the nature and extent of their roles differ widely and are always dynamic. Women in SSA generally have less access than men to productive resources and opportunities. The gender gap in ownership and access to assets, inputs and services limit innovation at farmer levels or in institutions. In rural SSA, however, the concept of 'same status' is widely elusive on multiple fronts. The exclusion of so many sections of the farming community is a formidable constraint to rural innovation. For instance, exclusion is pronounced in response to ethnicity, gender, marital status, residence and age, and affects people's property rights and access to social goods and services. Multiple disciplinary backgrounds including demography, anthropology, psychology, economics, medical psychology, geography and gender specialists are necessary for addressing these various disparities.

Value of transdisciplinary innovation in SIMLESA

In spite of significant milestones in agricultural innovation, there is an ever-existent gap between achieved and desired impacts that is maintained by emerging and evolving challenges (Herbel et al. 2012). Current challenges bring many pressures to bear on agriculture. One of these is population growth, as illustrated above. Another is the unmanaged growth of emerging SSA economies and increasing instability associated with land, water, energy shortages and politics.

Figure 5.1 illustrates the gap between competitive and sustainable agriculture that can be bridged through transdisciplinary research. This is the idea of SIMLESA: addressing some of the numerous yet related challenges through transdisciplinarity in the quest to make agriculture more competitive—generating food, incomes and employment, while at the same time becoming socially and ecologically sustainable.

The most distinctive hallmark of SIMLESA is its research-for-development design. As shown in Figure 5.1, SIMLESA research pillars were inherently targeted to study, while at the same time trigger, sustainable intensification transformations. Furthermore, SIMLESA had no single 'mesmerising' innovation. Instead, innovation belongs in the 'project sum'. For instance, the transdisciplinary approach of SIMLESA enabled it to overcome the key shortcomings and criticisms of conservation agriculture. Criticisms of conservation agriculture were:

1. it takes too long for field and social benefits to accrue
2. it is not possible without mechanisation
3. the initial costs are prohibitive.

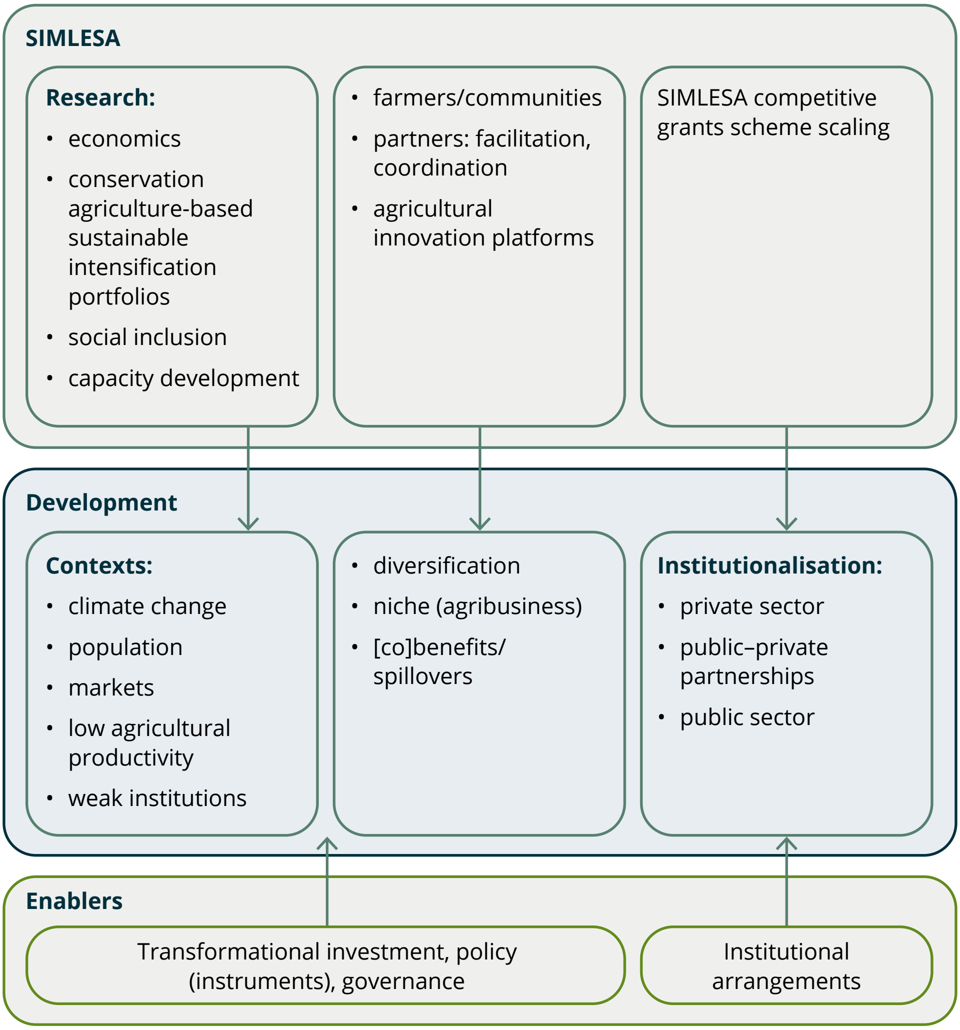

Figure 5.1 **SIMLESA and the innovation gap (SIMLESA integrated field research, economics, capacity, social inclusion, with agricultural innovation platforms and a competitive grant scheme)**

In view of these, SIMLESA did not specifically promote or research conservation agriculture, but rather applied CASI principles. In other words, the project was designed to achieve the goals of conservation agriculture, while at the same time avoiding land degradation, improving livelihoods and reducing inherent downside hazards and common drawbacks that afflict smallholder farming but which are often overlooked within a single disciplinary framework. SIMLESA took concrete steps to acknowledge and bridge knowledge from diverse disciplines. The program set up agricultural innovation platforms as a research pilot, to identify a set of prioritised problems that were consistently identified across disciplines. It then tested the concept that partner alliances, when built on these shared interests, would elevate smallholders.

SIMLESA cut short the time it takes to realise field productivity and economic benefits by utilising agronomic knowledge and germplasm developed earlier. Germplasm appropriate for the different contexts were identified, tested and produced under partnerships with seed companies. The most critical innovation resulted from the combination of these varieties with the application of adaptive agronomic principles. These include early planting and adaptive spacing, based on SIMLESA field trials. By relying on a 'fourth principle' of CASI—efficient use of fertiliser—yields were not compromised in fields with long history of over-cultivation. By efficiently and uniformly applying N and P fertiliser, there were no gaps in yield, one of the most counterproductive outcomes of residue retention (i.e. mineral immobilisation). Besides yield, there are many competing uses of residue under smallholder conditions. The program researched adaptive methods of integrating forage with maize-based cropping cycles. There was immense emphasis on multiple-purpose legumes, whose canopy play a similar role as crop residue in covering the soil. This gave farmers options to increase the availability of biomass, mitigated trade-offs between the use of crop stubble as mulches, and diversified farmers' sources of livelihoods (e.g. the sale of high-protein forages).

Based on the experience of SIMLESA, transdisciplinarity is not an absolute or definitive means. It cannot be measured quantitatively, but rather can be assessed based on the organisation of work itself and its impact. Figure 5.2 illustrates how SIMLESA's work themes intersected. There were interdependencies among multiple disciplines ranging from economists, agronomists, breeders, program managers, business modellers, anthropologists, extension specialists and others. These interdependencies generated multiple benefits but often required more time than may be necessary for disciplinary or commodity approaches.

The main lesson of the SIMLESA transdisciplinary architecture is that programs that aim to address the multiple challenges of innovation must be structured to enable research-in-development. Components in Figure 5.2 correspond with innovations in field options, advances in marketing, agribusiness/value chains for rural livelihoods, novel institutional arrangements and scaling schemes, mentoring for capacity and social inclusion. These are united in their ultimate goal of creating holistic impact.

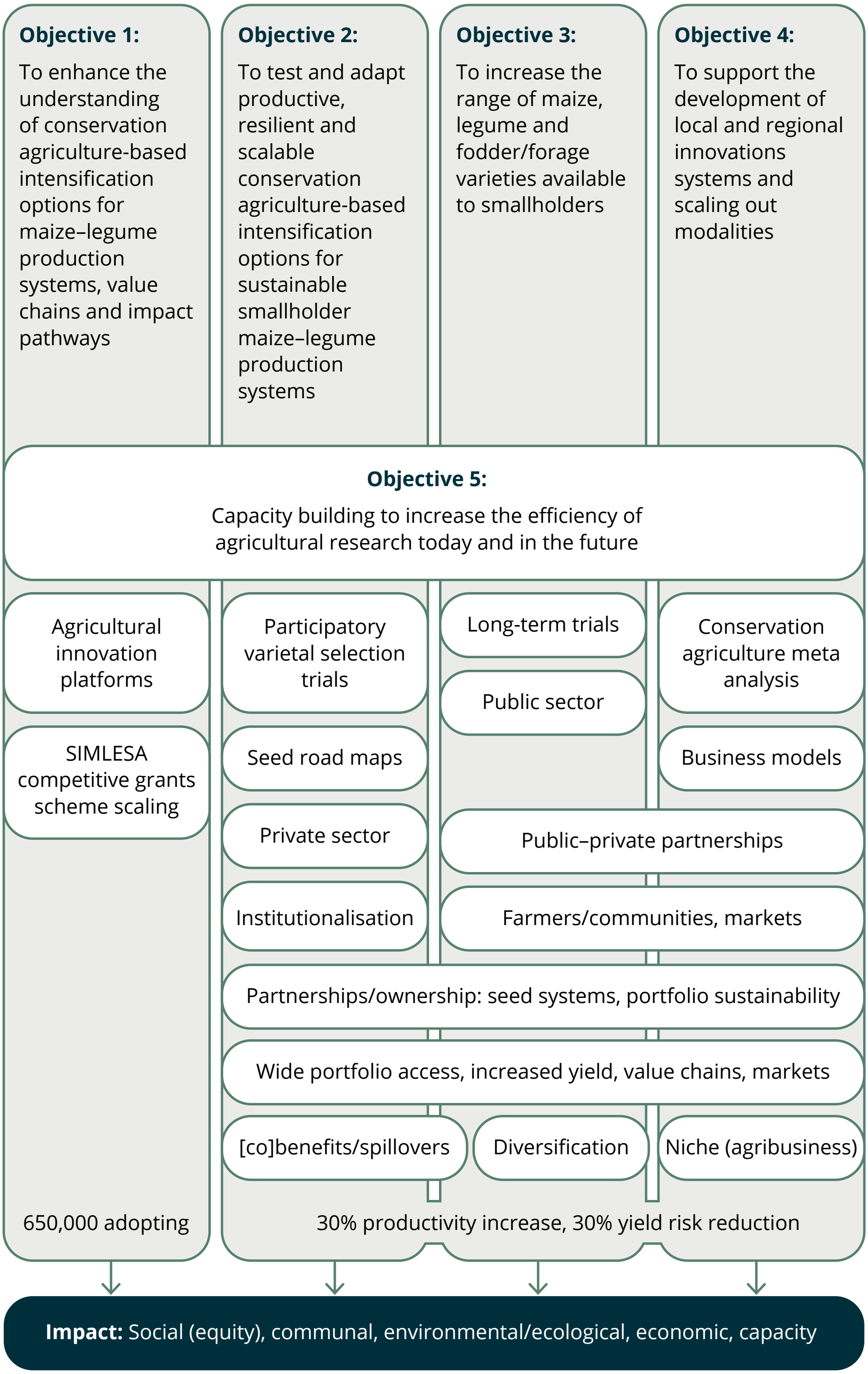

Figure 5.2 SIMLESA transdisciplinary architecture

SIMLESA transdisciplinarity and sustainable impact at scale

Figure 5.2 illustrates five categories of SIMLESA impact. Impacts of SIMLESA research include social, communal, ecological and economic. Economic impacts include increased food security, including surpluses sold by smallholders to increase their incomes. The most transformational changes have resulted from successful agricultural innovation platforms. For instance, Kieni and Rhotia agricultural innovation platforms, in Kenya and Tanzania respectively, have triggered many spillovers as a result of generating and selling maize and legume yield surpluses. This has included increased food supply for the urban population, increased overall economic activity in neighbouring rural markets and improved service provision through agricultural innovation platform-based investments in supply of farm inputs, especially herbicides.

Through Objective 1, SIMLESA transdisciplinary leadership undertook research-in-development in markets and value chains. Lessons from these were widely utilised under agricultural innovation platforms. Agricultural innovation platforms are a 'bring-it-all-together' commercial vessel among rural smallholders. They are a conduit for:

- microfinance—negotiating low interest rates or 'group collateral' (against loans). This approach has the potential to bring financial services to millions of smallholders currently considered unloanable. Several agricultural innovation platforms have benefited from innovative microfinance instruments by embracing collective trust. This is the only collateral among many rural poor, whose farming is characterised by highly seasonal investments, risks and returns (Peacock et al. 2004).
- bulk sourcing—reducing costs (Herbel et al. 2012). Collective input sourcing is a common practice among successful agricultural innovation platforms. The most common collectively sourced input is herbicide.
- collective marketing (e.g. pooling transport, price negotiations).

Agricultural innovation platforms were the cornerstone of success under the market conditions of the SIMLESA program, where markets were not operating to promote social inclusivity. The SIMLESA scheme triggered the development of a market-focused capacity for agricultural services that benefits the rural poor through pilot trainings in business modelling. Research in business models focused on determinants of successful interventions through different indicators. Agricultural innovation platform experience showed that farmer trainings were a transformational strategy in the complex contexts of SIMLESA. It is the central determinant for any practical implementation of market-focused strategy, as illustrated by successful agricultural innovation platforms. Training was more effective because it included transdisciplinary modules, rather than a single market-oriented focus. Such transdisciplinary elements of SIMLESA ensured that marketing/value-chain approaches were attuned to aspects of the program like gender inclusion, sustainable intensification and group management. SIMLESA was therefore a system of interlocking building blocks, which was a lesson in the design of practicable innovation programs in SSA.

Environmental impacts of SIMLESA are difficult to measure in the short term. However, SIMLESA environmental/ecological benefits can be deduced. Enhanced sustainability of maize–legume systems through sustainable intensification technologies have been widely documented. This results from more fertile cropping soils, and community-based activities such as efficient herbicide application that have enhanced biodiversity. The logic in SIMLESA's choice of CASI practices was to realise both productivity and ecological benefits. SIMLESA was therefore anchored on the notion that CASI practices would lead to yield gains and reduced soil degradation. The full range of environmental impact can be known when the rate of increase of food production has accommodated both individual consumption growth and population growth with little expansion of cropland.

Social impacts include the reduction of women's labour because of no or minimum tillage. Based on SIMLESA experiences, other priority areas include increasing access to agricultural resources (including agribusiness skills) and financial services/assets for women and young people, continually investing in other labour-saving and productivity-enhancing options that reduce farming costs, and infrastructure enhancements that add value to the labour of marginalised communities (Food and Agriculture Organization [FAO] 2011; Salami et al. 2010)

Beyond SIMLESA, successful Rwandan agricultural innovation platforms illustrate how research-led processes can enhance women-friendly farming and access to and control of value-adding technologies. Agricultural innovation platforms in SIMLESA certainly created more resilient farming communities and increased nutritional security for households, especially through the adoption of improved legume varieties. The agricultural innovation platform approach also enhanced young people's interest in farming, especially through service delivery. The project targeted policies to reduce soil degradation, and supported entrepreneurship and the formation of appropriate regulations for value chains, agricultural innovation platforms and village innovation. SIMLESA policy contributions were additionally designed to improve social inclusion in agriculture and rural labour markets.

In summary, social inclusion is a well-founded concept. Closing the gender gap in agriculture can generate significant gains for the agriculture sector and for society (FAO 2011). If agriculture offered equal access to productive resources among men and women, yields would sustainably increase by 20–30%. Gender inclusion alone could raise total agricultural output in SSA by up to 4%, and in turn reduce hunger by about 17%.

There is improved capacity among National Agricultural Research System partners to find solutions to complex problems. This includes better capacity for policy engagement, hinged on solid evidence and effective delivery of sustainable intensification solutions to smallholders. Through SIMLESA transdisciplinary research, National Agricultural Research System partners were able to foster formation of functional value chains to support innovation. Institutional capacity is also critical in the coordination and management of research and related partnerships. The transdisciplinary design of the SIMLESA program also bolstered the National Agricultural Research System partners by coordinating technical assistance activities and consolidating national seed systems. It also enhanced leadership and partnership capacities and program/project management. However, any attempts to sustain these gains based on the SIMLESA model will require more public sector investment in basic research. It may also require organisational change in management to effectively accommodate transdisciplinary approaches. National Agricultural Research System partners will need to act beyond mere development of new agricultural technologies on issues like antitrust and the effective and efficient regulation of sustainable intensification options.

A critical element in capacity strengthening has been the support of Australian professionals and institutions. Advancements in agricultural innovation in Australia have been shared with SIMLESA countries and beyond, with significant social rates of return. More than 20 students from a wide range of disciplines representing SIMLESA graduated from Australian universities with masters or doctorate qualifications. These professionals are now in leadership positions in SIMLESA and other critical National Agricultural Research System programs in Malawi, Tanzania, Ethiopia, Mozambique and Kenya. There is a consistent pattern of participation and technical exchanges demonstrating strong interdependence between African countries and Australia and along the public–private spectrum. These exchanges have happened in a wider context, led by the International Maize and Wheat Improvement Center (CIMMYT).

CIMMYT's leadership has been particularly effective in promoting broad agricultural capacity in developing countries through innovations in maize and scaling systems. The impacts include non-government organisations and private sector actors with enhanced sustainable intensification skills. SIMLESA directly benefited smallholders through training and mentoring for skills, business niche identification, membership contributions, formalisation (i.e. registration as cooperative or community-based organisation) and investments (e.g. in machinery, storage, transport). This was achieved through bringing essential (commercial) services closer to thousands of rural households, who would ordinarily not be able to access them. These services included new market channels and stronger transaction capacities. This enhanced the capacity of farmers (both male and female) and commercial firms to build and support input/output supply chains.

Transdisciplinarity challenges and way forward

In the absence of a solid research framework, transdisciplinarity is prone to confrontation among siloed disciplines (Ramadier 2004). For instance, social science approaches to piloting agricultural innovation platforms involved more group discussion and facilitation compared to agronomic desires for field experimentation. Under SIMLESA, transdisciplinarity required conflict management that benefited at times from scientific approaches to generate methodological hybrids (Brandt et al. 2013). This means blurring the boundaries of methodologies; for example, striking a balance between the extent of farmer involvement in field experiments and their engagement in piloting business models. Under SIMLESA, transdisciplinarity was not just about uniting disciplines. It was necessary to go beyond unity and think about knowledge linkages through a research framework (Brandt et al. 2013). A framework was critical to ensure best practice (Jahn, Bergmann & Keil 2012). There is a need for coherence between process and knowledge production and the realities of research-in-development. There is often incoherence emanating from disciplinary attitudes. Transdisciplinarity does not need to be preceded by unity of methodologies, but rather desired impacts. SIMLESA's transdisciplinary approach was most successful when each discipline defined their own pathways to a desired impact, which is illustrated by SIMLESA objectives. The greatest benefits of transdisciplinarity occurred when efforts were directed at areas of agreement and opportunities to resolve gaps; for example, through the integration of qualitative and quantitative approaches.

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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

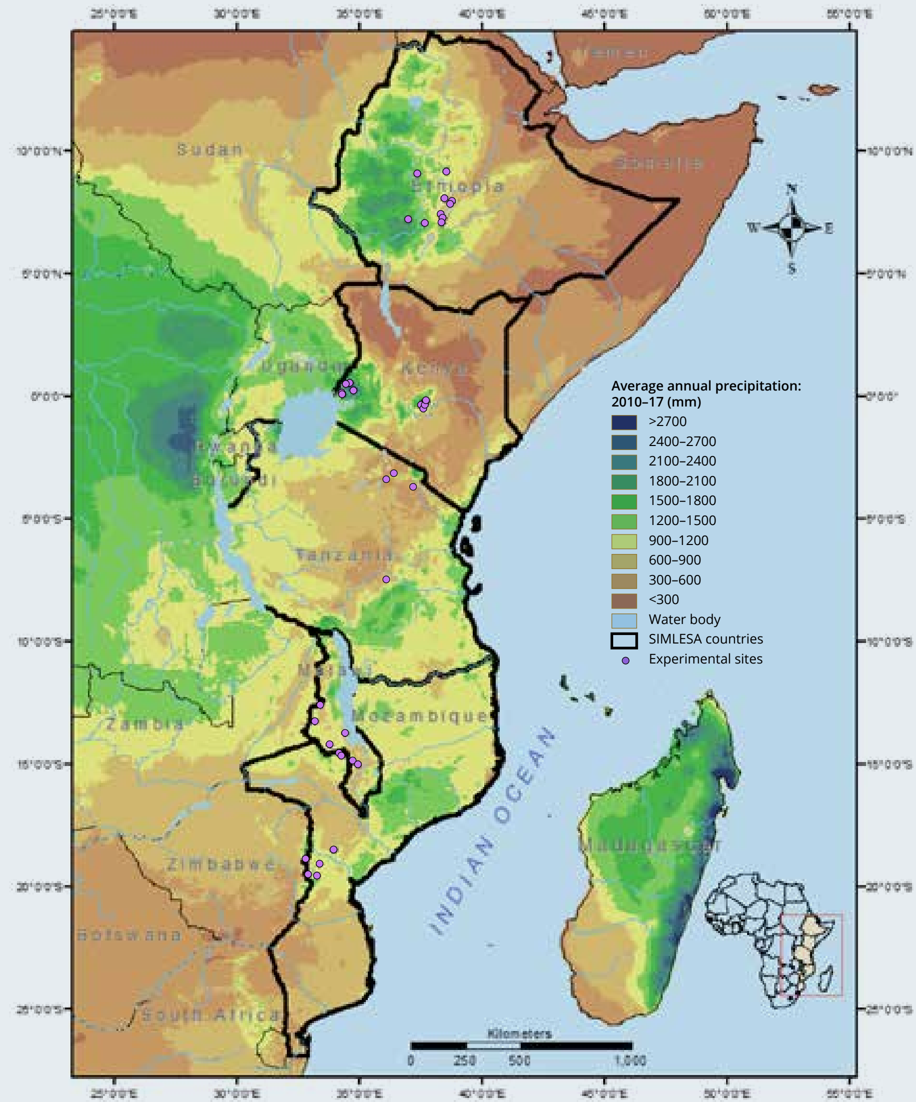

Figure 6.1 **Five SIMLESA countries, location of experimental sites and average annual precipitation (2010–17)**

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).

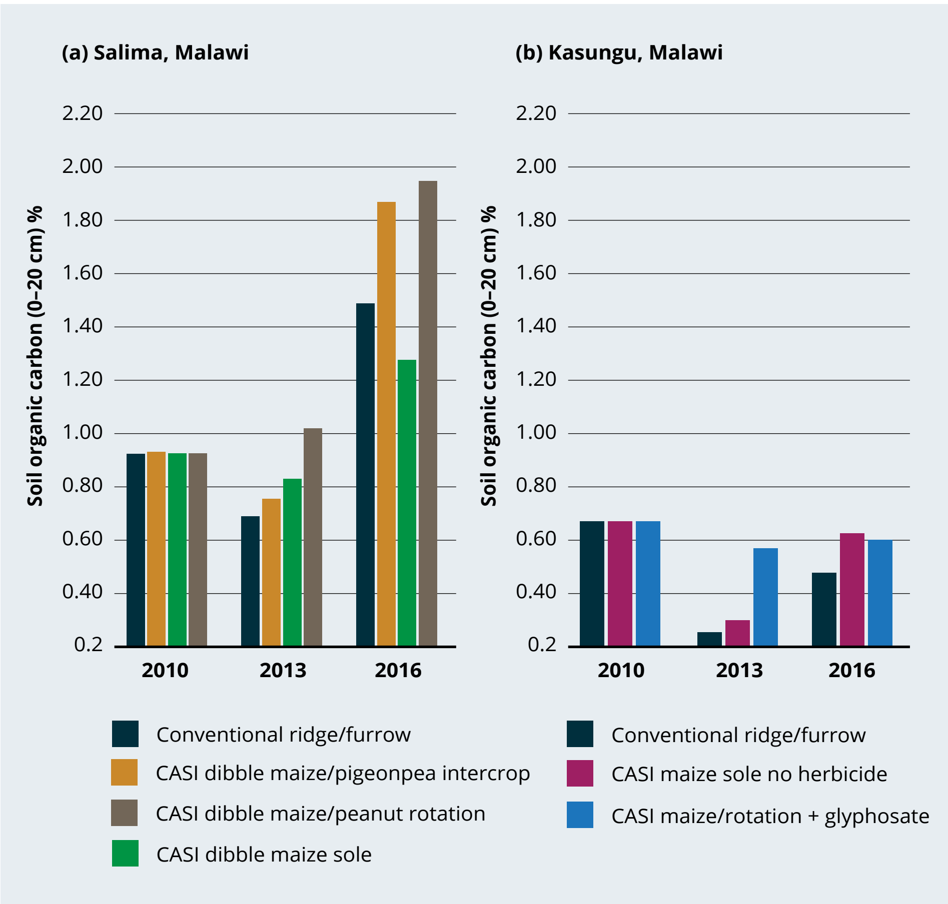

Figure 6.2 **Soil organic carbon under CASI across cropping systems over time in (a) the lowland district of Salima, Malawi and (b) the mid-altitude district of Kasungu, Malawi**

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.

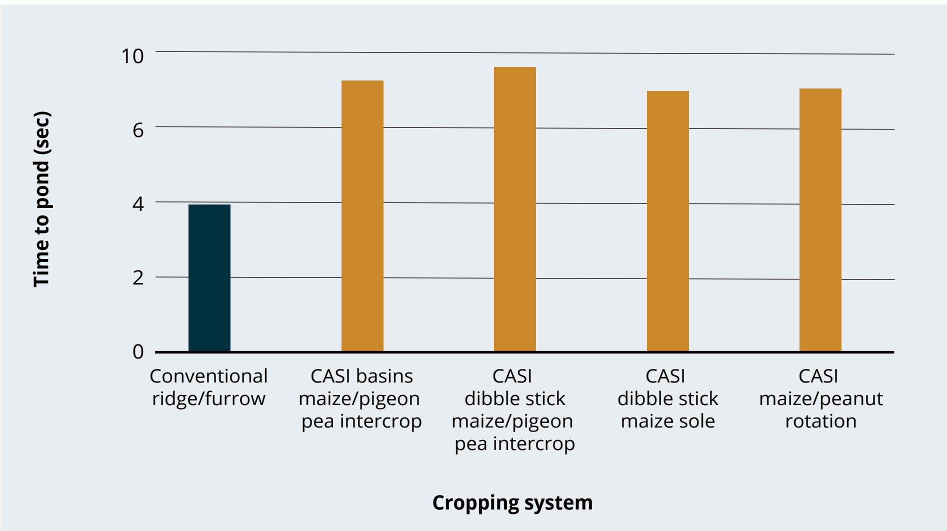

Figure 6.3 **Mean time to pond water infiltration assessments in the lowland communities of Balaka, Ntcheu and Salima (Malawi) in 2013, for conventional agriculture and CASI basins, dibble stick, dibble stick intercropping with cowpea and peanuts**

CASI = conservation agriculture-based sustainable intensification

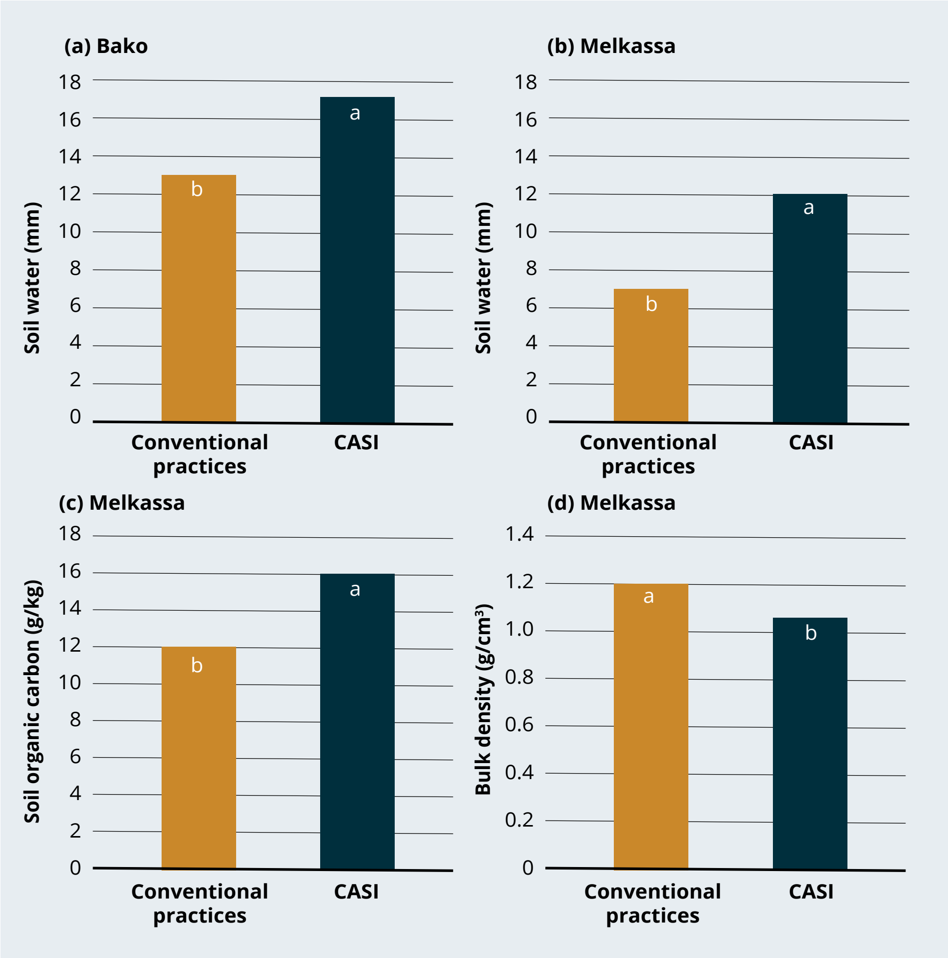

Figure 6.4 Soil water content, soil organic carbon and soil bulk density with conventional practices and CASI practices at Bako (humid) and Melkassa (semi-arid) in Ethiopia

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**

	Macrofauna		Mesofauna	
Treatment	**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.

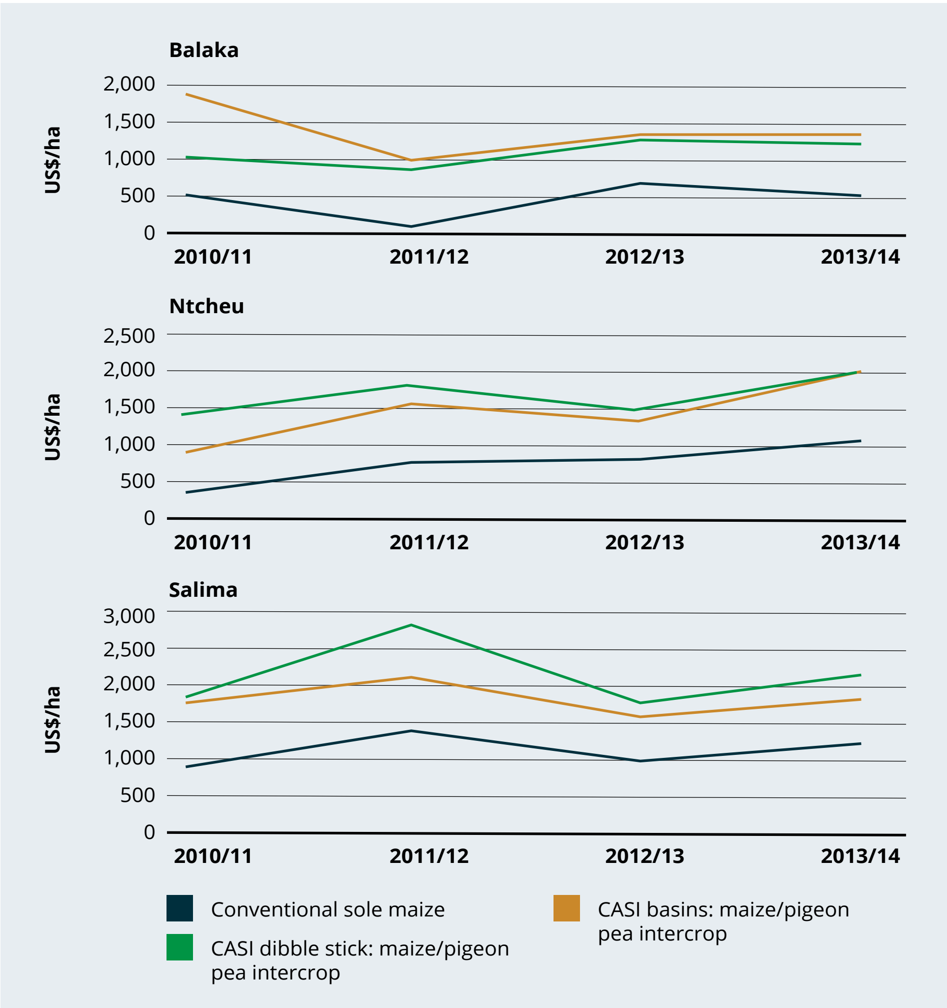

Figure 6.5 **Gross margin analysis of CASI practices in Malawi for conventional sole maize cropping, conservation agriculture in basins and with dibble stick**

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).

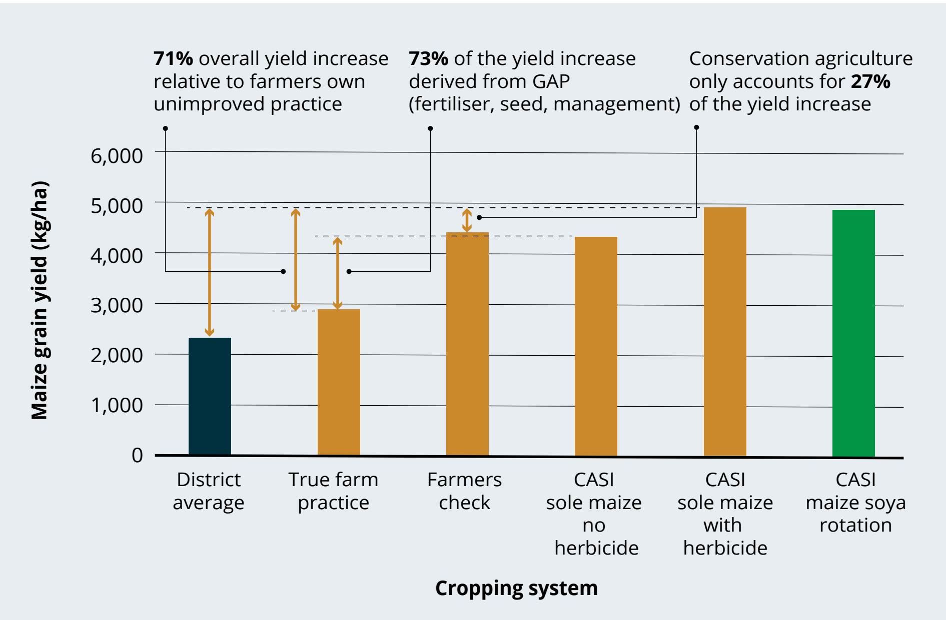

Figure 6.6 **Mean maize yields from Kasungu district, Malawi, over six seasons (2010–11 to 2015–16) relative to local averages and true farmer practices and CASI**

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

Erin Wilkus & Daniel Rodriguez

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).

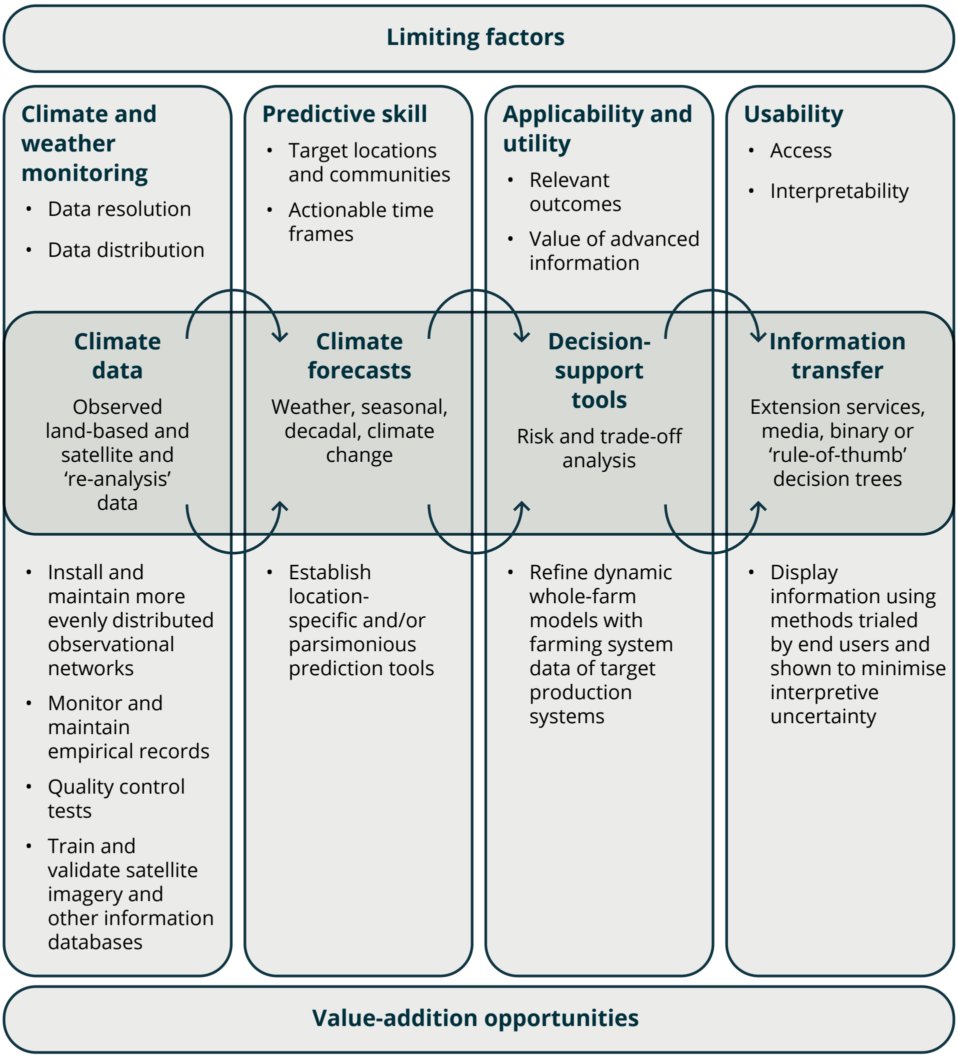

Figure 7.1 Research and development pipeline for climate-informed decision-making in agriculture

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[2], 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).

2 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.

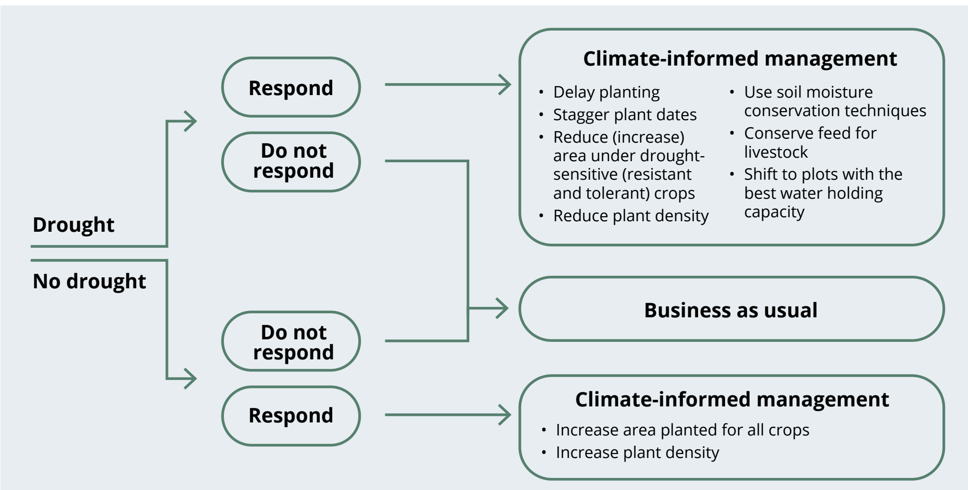

Figure 7.2 **Farmers' decision-making process using a binary seasonal forecast**

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[3] (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).

3 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[4] 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[5] at least one sustainable intensification practice[6] promoted by the project by December 2016[7] (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%)[8] (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%).

4 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.
5 An adopter is a farmer who has used a technology for more than one year in at least 25% of their cultivated land.
6 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.
7 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).
8 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**

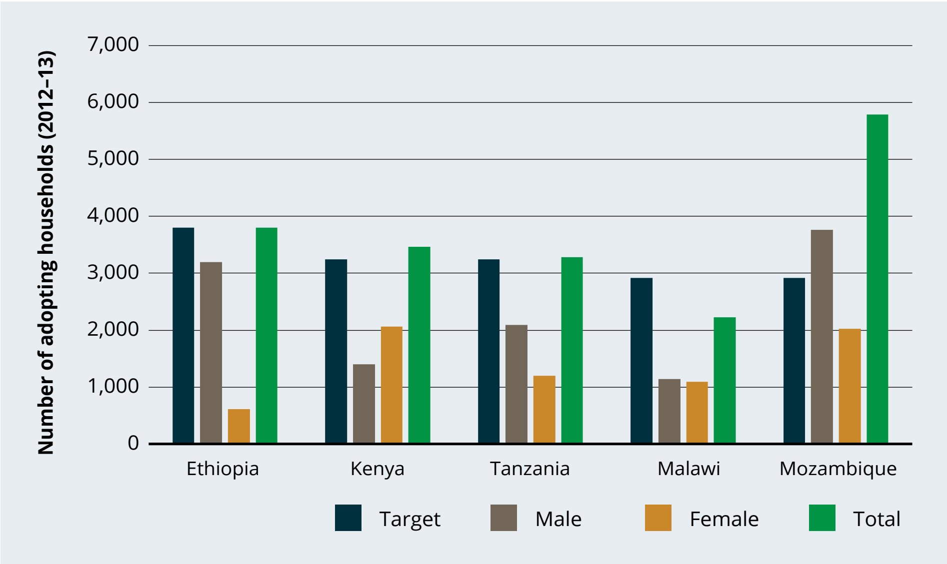

Figure 8.1 **Gender-disaggregated data of SIMLESA technology adopters in 2012–13 by country (estimated number of farming households) compared to the target population of 16,112 farmers**

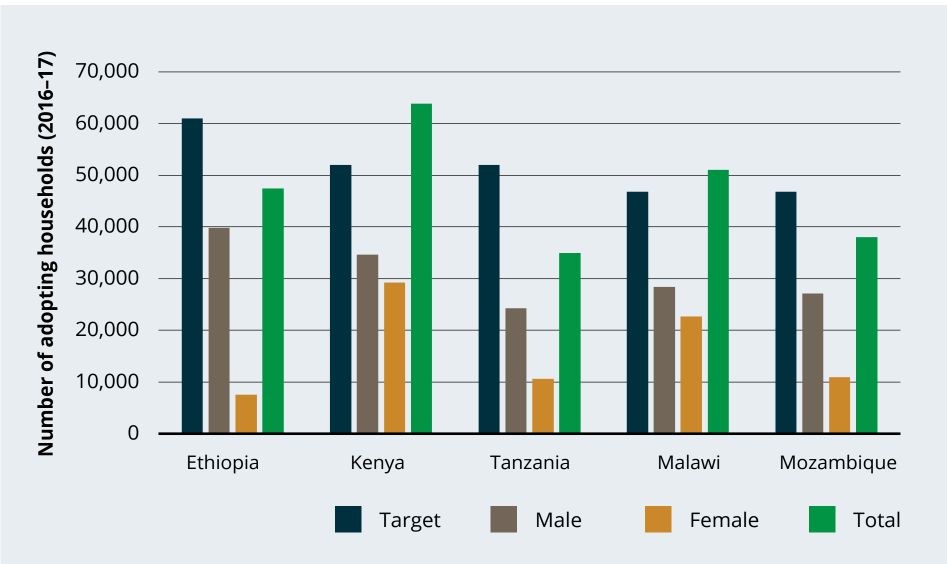

Figure 8.2 **Gender-disaggregated data of SIMLESA technology adopters in 2016–17 by country (estimated number of farming households) compared to the target population of 258,493 farmers**

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).[9] 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[10]. 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.

9 The information was obtained from the documented records of the KIAI AIP members.
10 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).

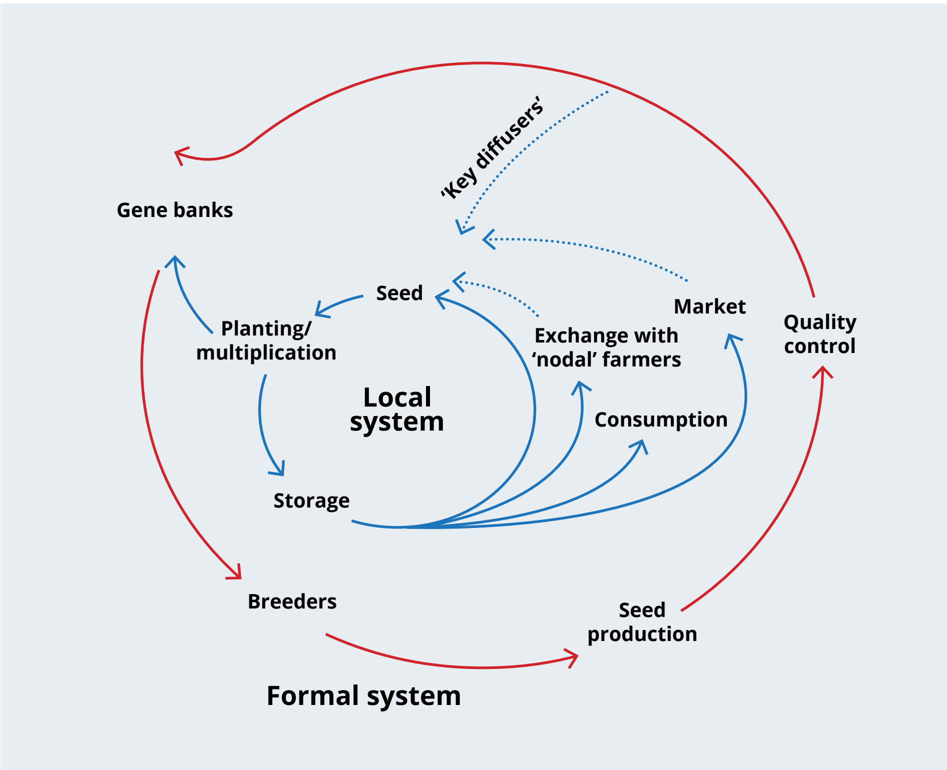

Figure 9.1 **A heuristic model of the formal (red) and informal (blue) seed systems**

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.

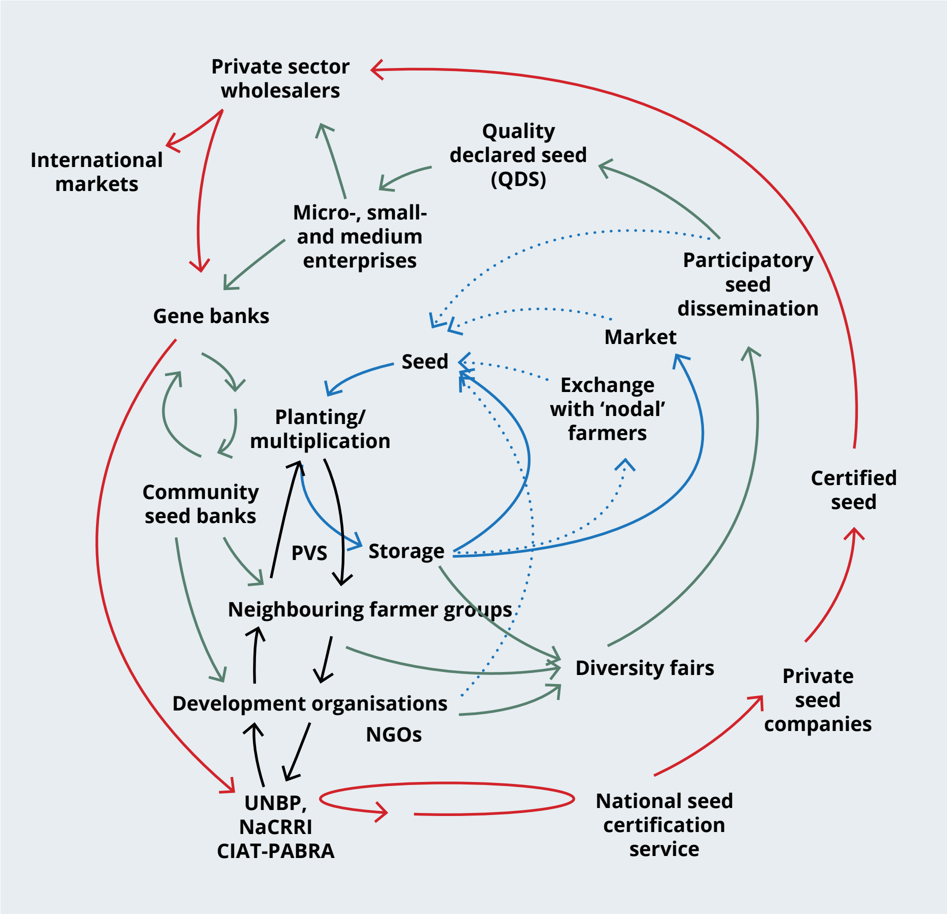

Figure 9.2 **A heuristic model of the formal (red), informal (blue) and intermediate (green) seed systems and main components of participatory varietal selection trials (PVS, black) in Uganda**

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.

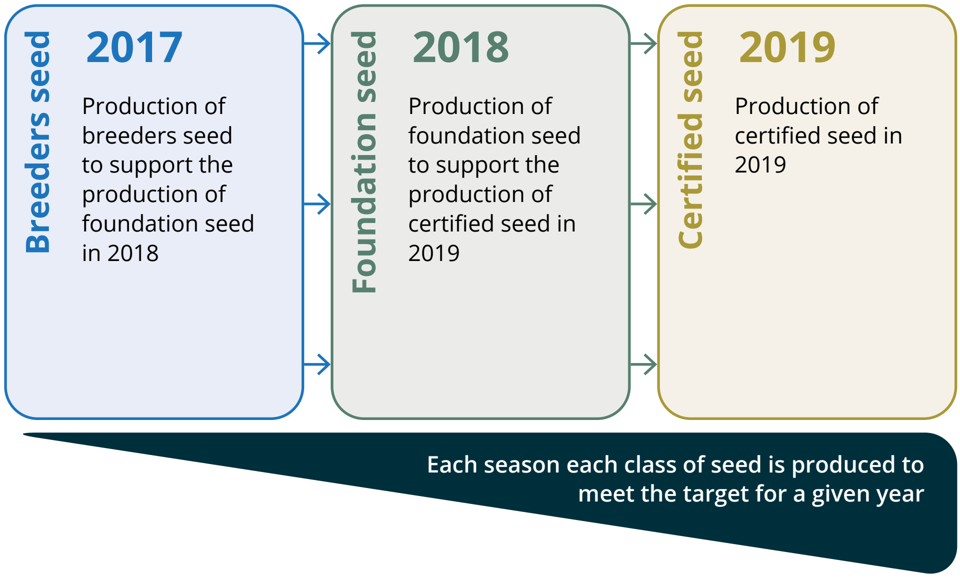

Figure 9.3 Systematic diagram of a seed road map

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.

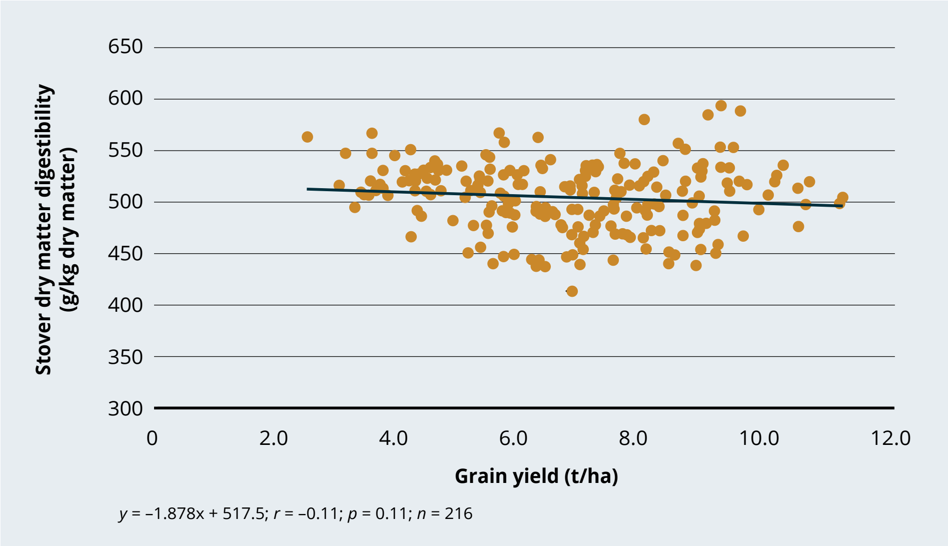

Figure 10.1 Relationship between stover dry matter digestibility and grain yield in maize genotypes

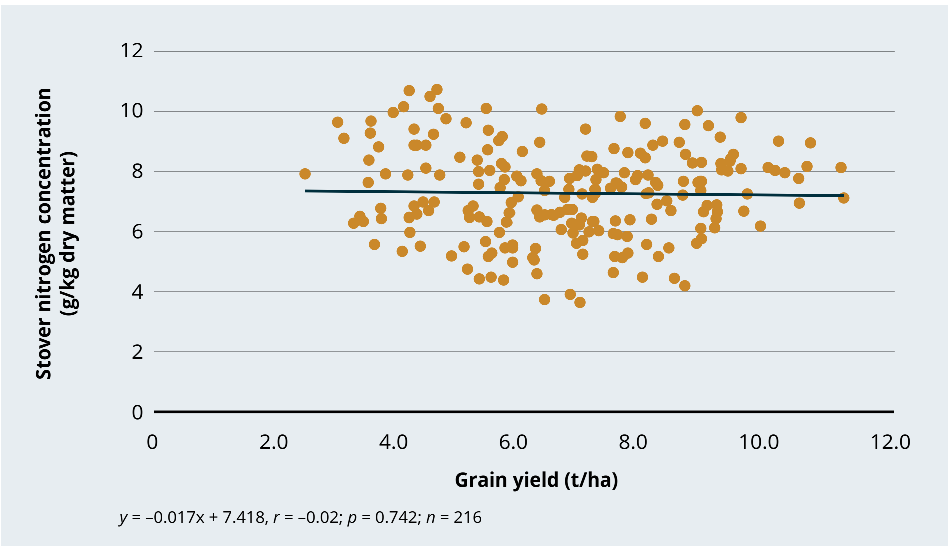

Figure 10.2 Relationship between stover nitrogen concentrations and grain yield in maize genotypes

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.

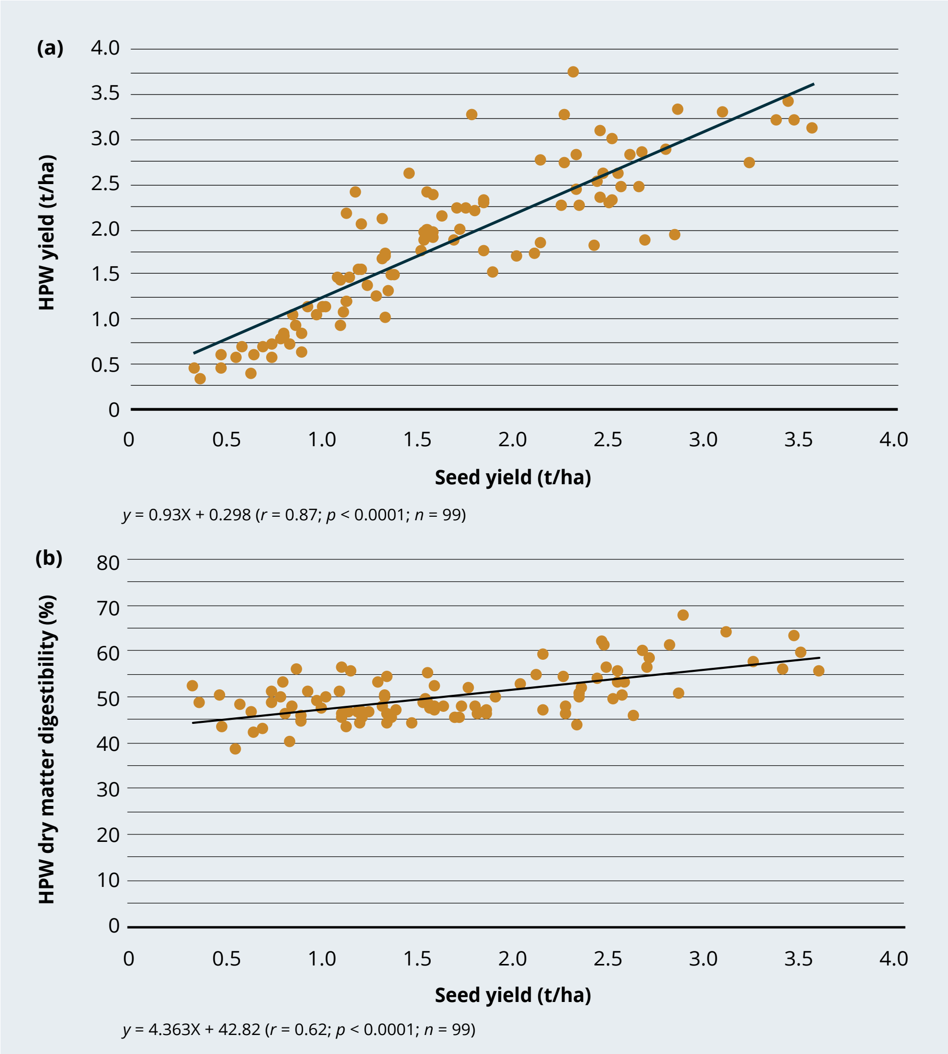

Figure 10.3 **Relationships between seed yield and haulm plus pod wall (HPW) (a) yield and (b) dry matter digestibility in common bean varieties at four sites**

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.

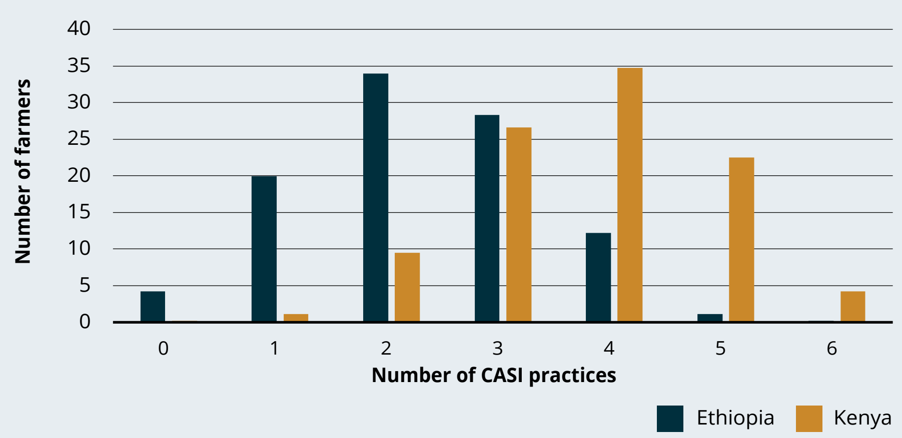

Figure 11.1 **Use of a combination of CASI practices, Ethiopia and Kenya, 2010**

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).

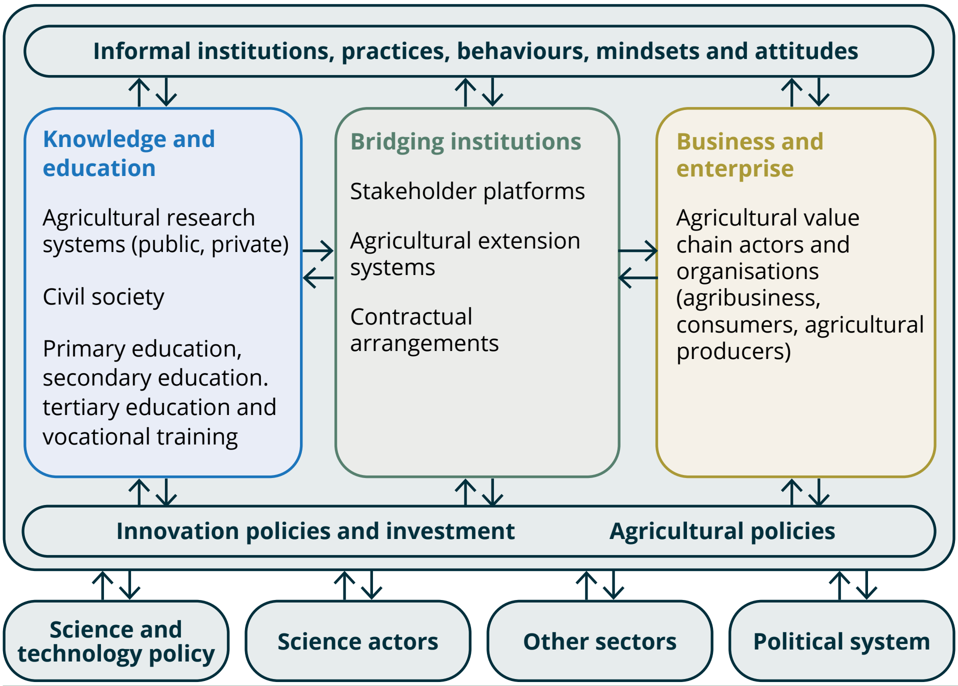

Figure 12.1 Linkages and actors in an innovation platform

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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SECTION 3

HIGHLIGHTS FROM COUNTRY INITIATIVES

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

Daniel Rodriguez

Key points

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

Introduction

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

1. there is significant potential for conservation agriculture-based sustainable intensification (CASI) in Queensland's semi-arid tropics
2. there are still opportunities to bridge yield gaps[11] and increase production efficiencies in dryland cropping
3. there is need for research programs that are more transformative and generate new opportunities to diversify farming systems and sources of income in a changing climate.

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

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

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

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

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

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

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

In the northern regions of Australia, the grains industry has been characterised by sizeable yield gaps[12] (Clarke et al. 2019), small profit margins (Roxburgh 2017) and large-scale production systems that grow a limited number of commodities. Climate variability, poor terms of trade for traditional commodities and high labour costs have contributed to this condition. Market factors have also constrained large-scale farmers to produce a small number of commodities. The strategy of diversifying cropping systems would require better access and management of a diversity of input and output markets, as well as a wider range of transport, storage and export options and infrastructure for smaller volumes of high-value produces. Across the northern grains region, the high handling cost of exporting containerised produce has limited farmers' opportunities to diversify cropping activities and generated low-cost, large-scale, risk-averse rainfed farming systems (Figure 13.1).

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

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

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

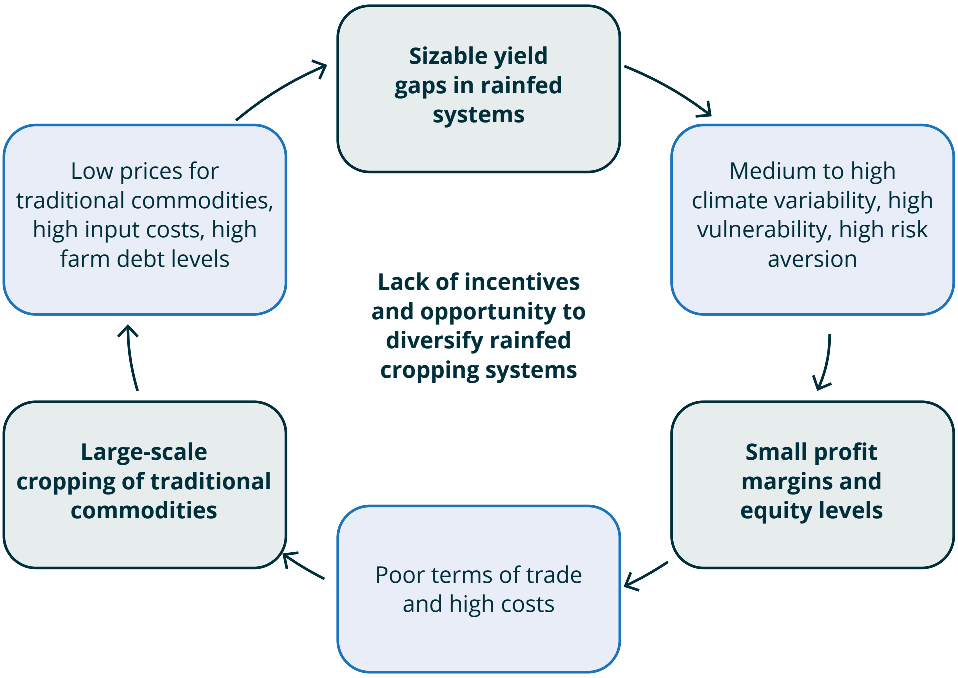

Figure 13.1 **Drivers of and constraints to farmer-led diversification of rainfed cropping systems in Australia's northern grain region**

Optimum crop designs to reduce yield gaps

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

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

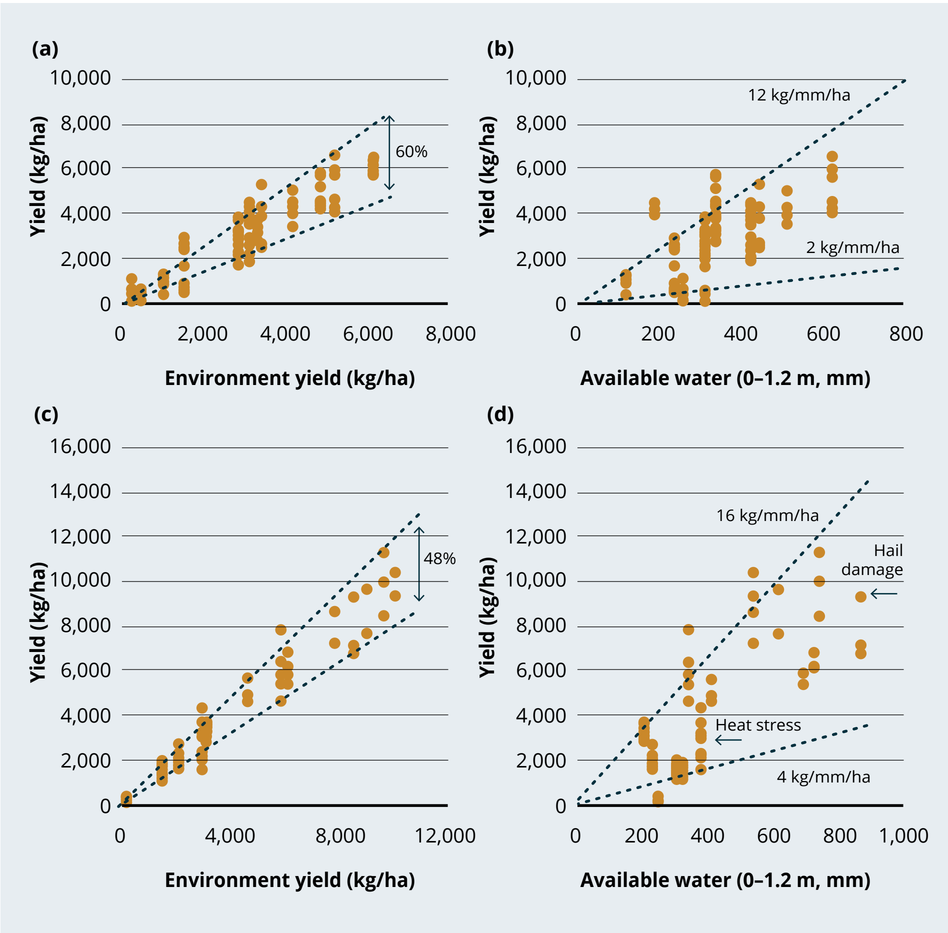

Figure 13.2 **Yield of sorghum (a and b) and maize (c and d) hybrids across management combinations (i.e. plant densities, row configurations, sowing times) versus the average site yield (a and c) and total available water (b and d) for on-farm trials across the northern grains region of Australia sown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

Both sorghum and maize datasets were analysed in three stages:

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

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

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

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

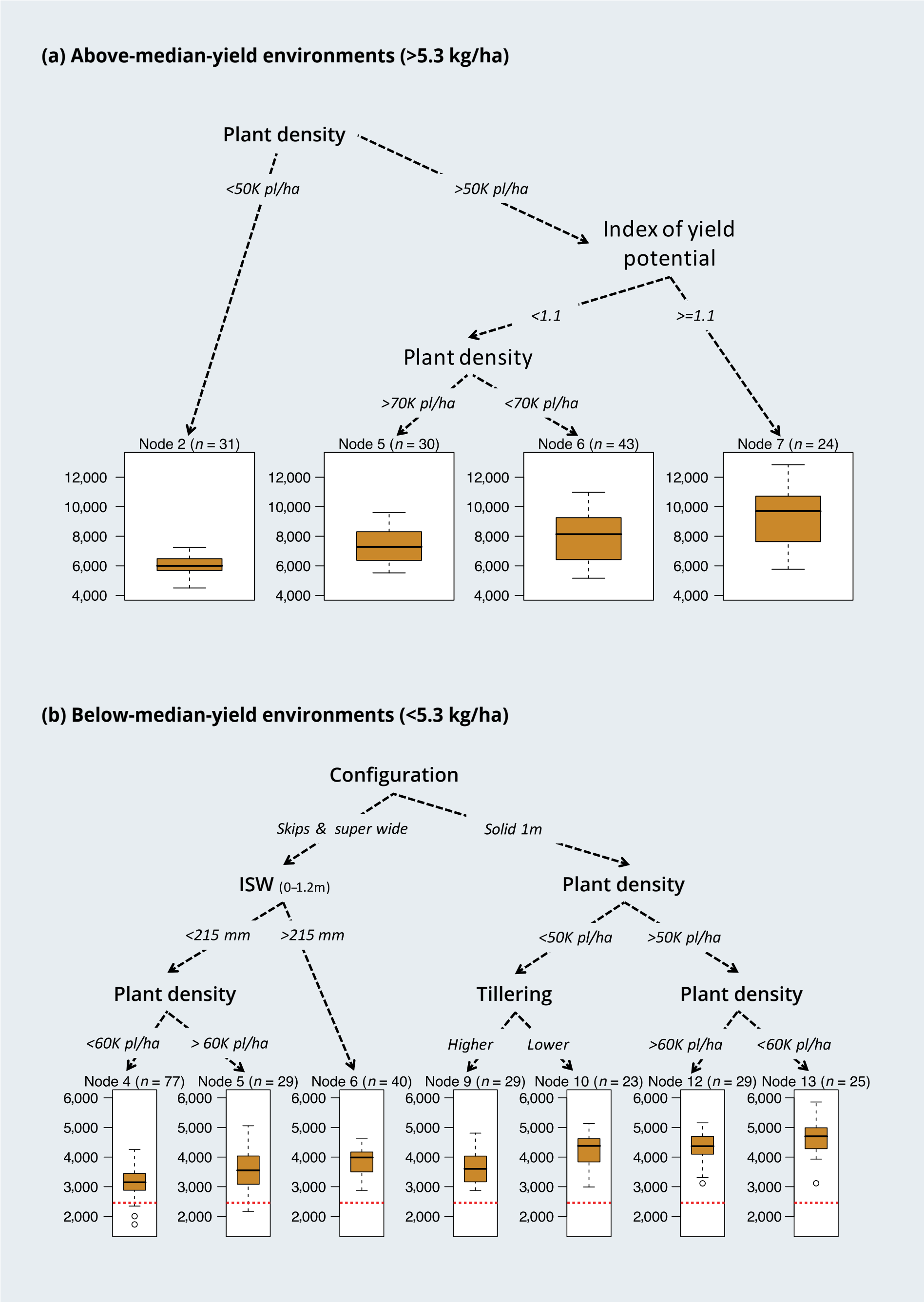

Figure 13.3 **Rules of thumb to identify high-yielding crop designs (genotype and environment combinations) for sorghum production in high- and low-yielding environments**

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

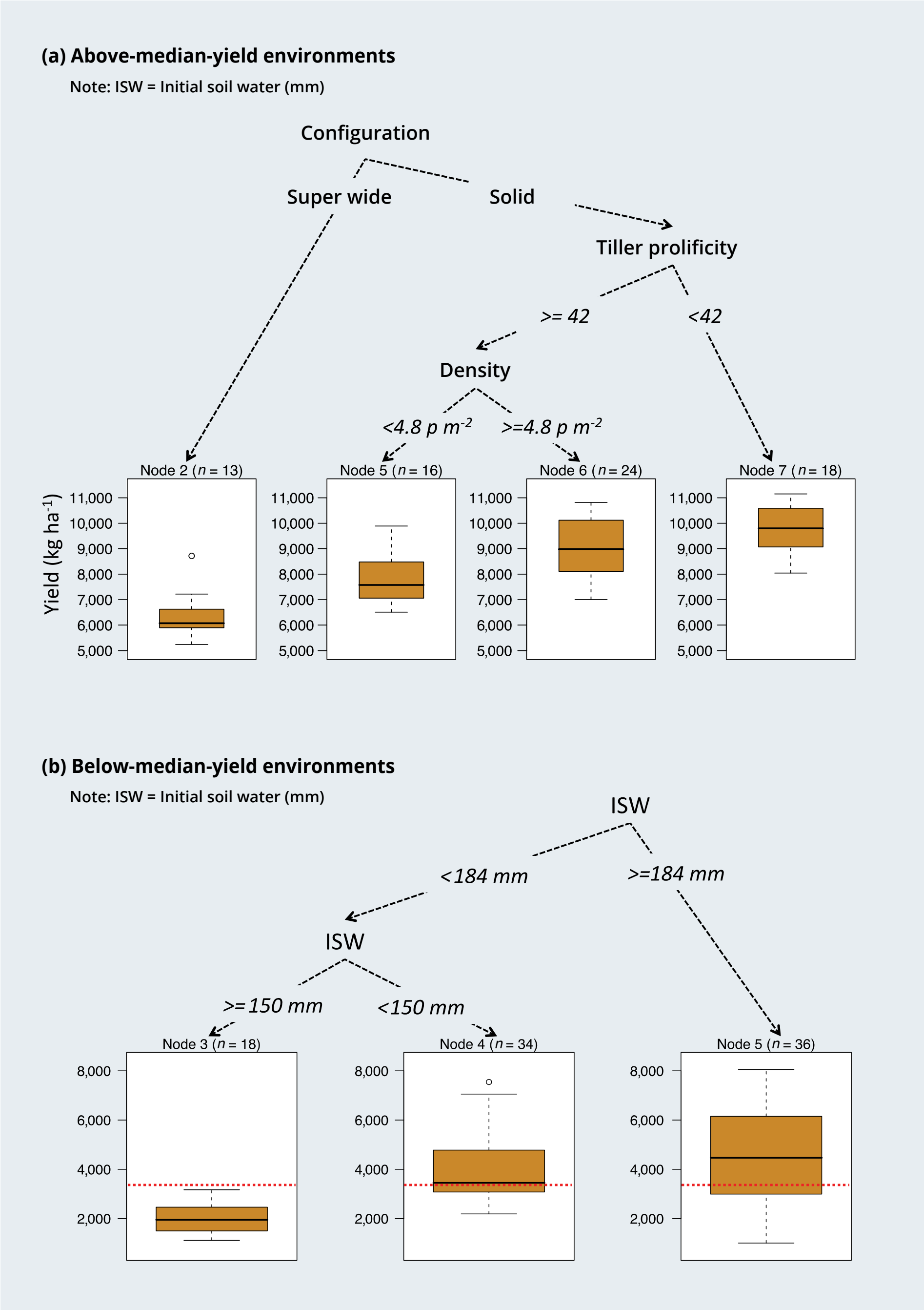

Figure 13.4 **Rules of thumb to identify high-yielding crop designs (genotype and environment combinations) for maize production in high- and low-yielding environments**

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

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

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

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

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

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

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

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

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

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

Increasing efficiencies of external inputs

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

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

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

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

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

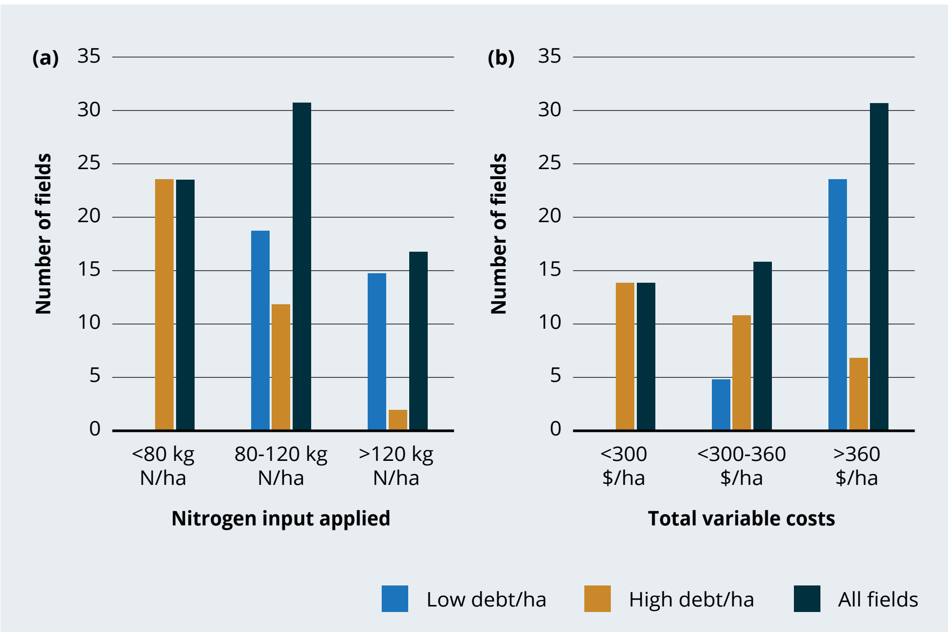

Figure 13.5 **(a) Use of nitrogen fertilisers and (b) total variable costs for farms with above- and below-mean debt.**

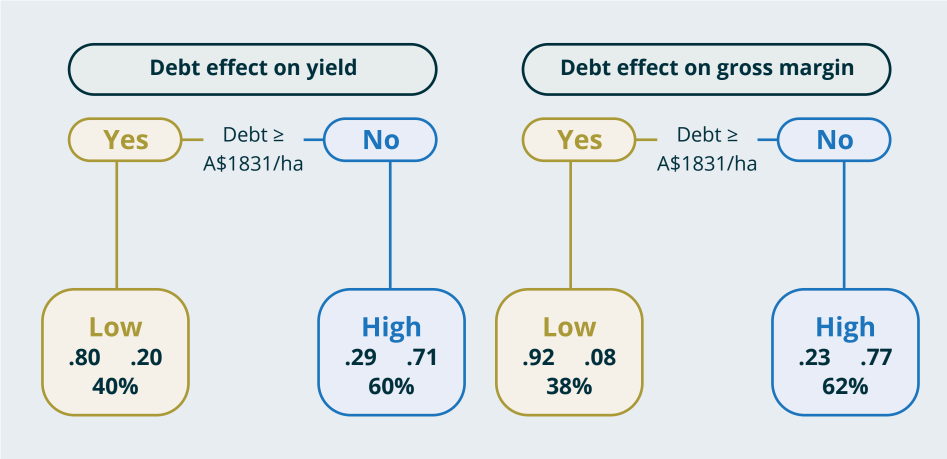

Figure 13.6 Classification tree for the effects of farm debt on (a) sorghum yields and (b) gross margins

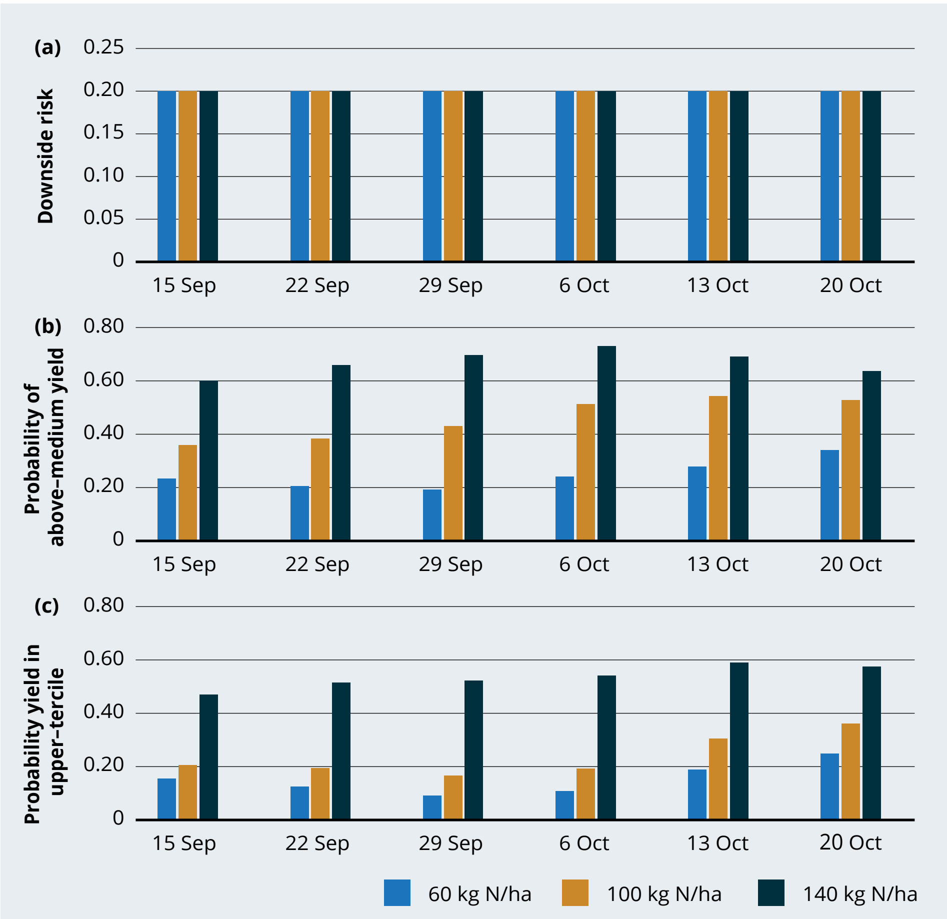

Figure 13.7 Likelihood of achieving (a) yields lower than 1.5 t/ha, (b) above-median yields and (c) yields in the upper tercile

New opportunities from a changing climate

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

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

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

Conclusions

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

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

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

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

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

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

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Key points

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

Background

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

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

Importance of maize and legumes and their production challenges in Ethiopia

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

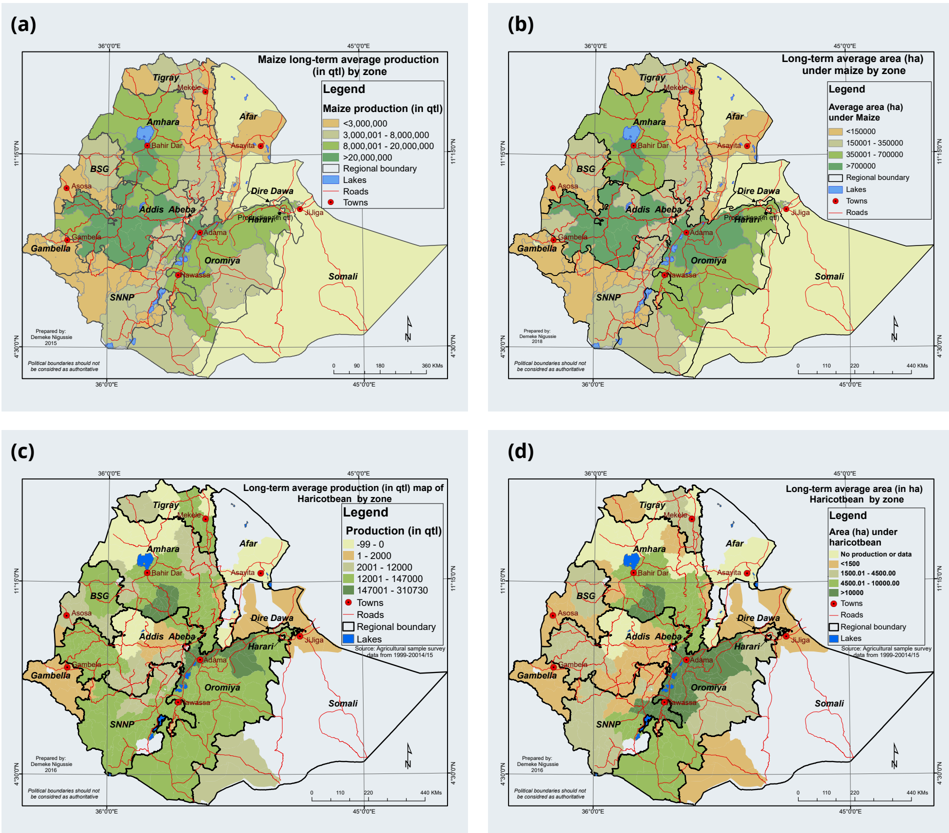


Figure 14.1 Long-term average maize production in Ethiopia by (a) weight and (b) area; long-term average common bean production in Ethiopia by (c) weight and (d) area

Note: Quintal (qt) = 100 kg

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

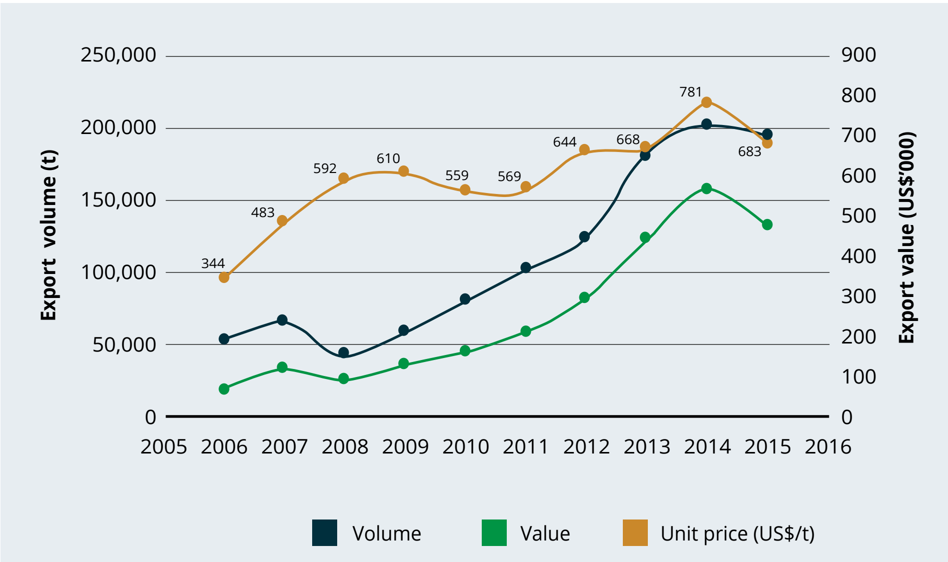


Figure 14.2 **Ethiopian common bean export volume, value and price per tonne, 2006–15**

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

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

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

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

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

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

SIMLESA program objectives in Ethiopia

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

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

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

Agroecologies

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

Research teams

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

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

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

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

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

Findings

Farming systems and household characteristics

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

Farm households were composed of an average of seven members (the range was 4–15) of fairly equal number of male and female members. Female-headed households made up 14.3% of the total. Household heads had an average age of 39 (standard deviation = 12) with about four years of formal schooling. The number of households per kebele[13] averaged 746 (standard deviation = 290). The farm households owned small areas of land (1.29 ha), of which 90% (1.16 ha) was used for crop production and the remaining for residence and grazing (Bekele et al. 2013). The per capita land holding was 0.1 ha, making further land division difficult and sustaining food security through crop production challenging without intensification. The per capita land holding was 0.28 ha in 1995 in Ethiopia (Food and Agriculture Organization 2001), meaning there was a 35.7% reduction in just 15 years.

Regarding household labour in crop production and marketing, men and women participated in maize and legume land preparation, planting, weeding, harvesting and grain marketing. The proportion of men's involvement in field operations was higher in land preparation, planting and harvesting while the participation of women and children was greater in weeding. Marketing of grain harvest was a joint decision between couples, and neither of them had exclusive decision-making power (Bekele et al. 2013). This represented a positive move towards gender equity and equality, signalling the community's recognition of women's need to participate in the issues that affect a household's livelihood. This result is in line with that of Beshir, Habtie and Anchala (2008), who documented the practice of joint decision-making in resource use among farm households in crop–livestock farming communities of both Christians and Muslims in Adama district in the Central Rift Valley of Ethiopia. Other than crop farming, livestock constituted a large part of farm household livelihood: 77% of maize–legume-growing households owned cows, 87% had other livestock and 43% kept donkeys. The average holding of animals was 2.88 tropical livestock units[14] (TLU), among which cattle constituted 2.36 TLU (Mulwa et al. nd).

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

Financial viability of CASI practices

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

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

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

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

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

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

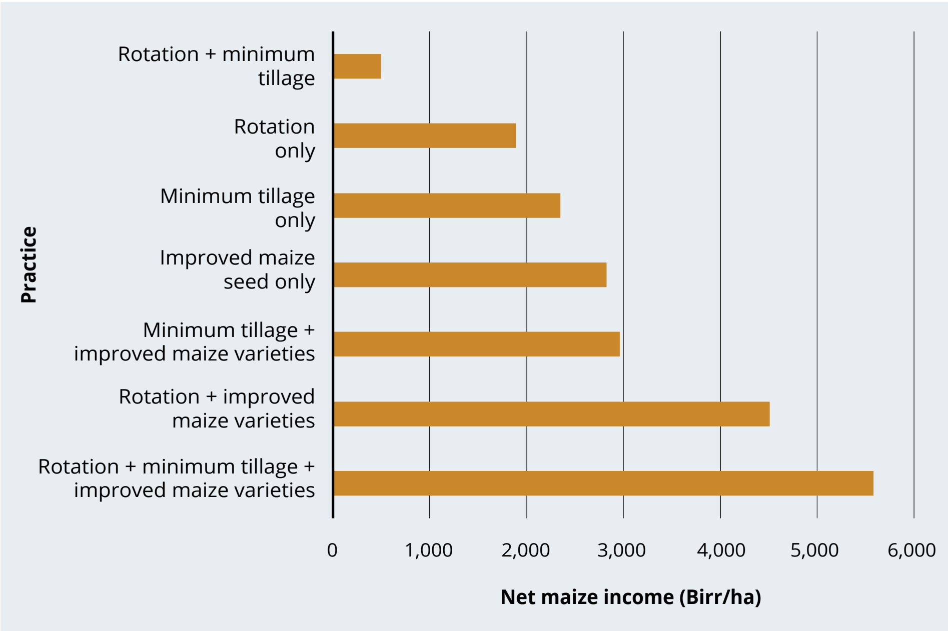


Figure 14.3 **Impact of agronomic practices on maize variety performance and net maize income in Ethiopia**

Source: Mekuria & Kassie 2014

Adoption status of sustainable intensification

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

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

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

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

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

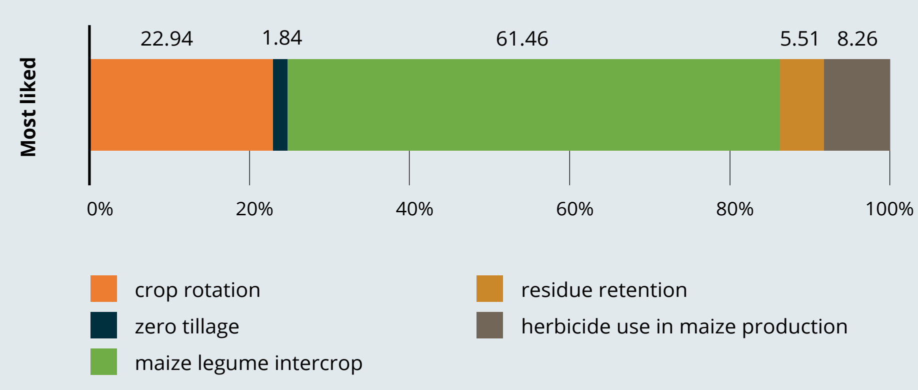


Figure 14.2 Ethiopian common bean export volume, value and price per tonne, 2006–15

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

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

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

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

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

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

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

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

Contribution of CASI practices in increasing yield and reducing downside risk

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

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

Increased rainwater productivity under CASI practices

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

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

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

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

Soil moisture and soil erosion

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

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

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

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

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

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

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

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

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

Yield and seasonal rainfall variability

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

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

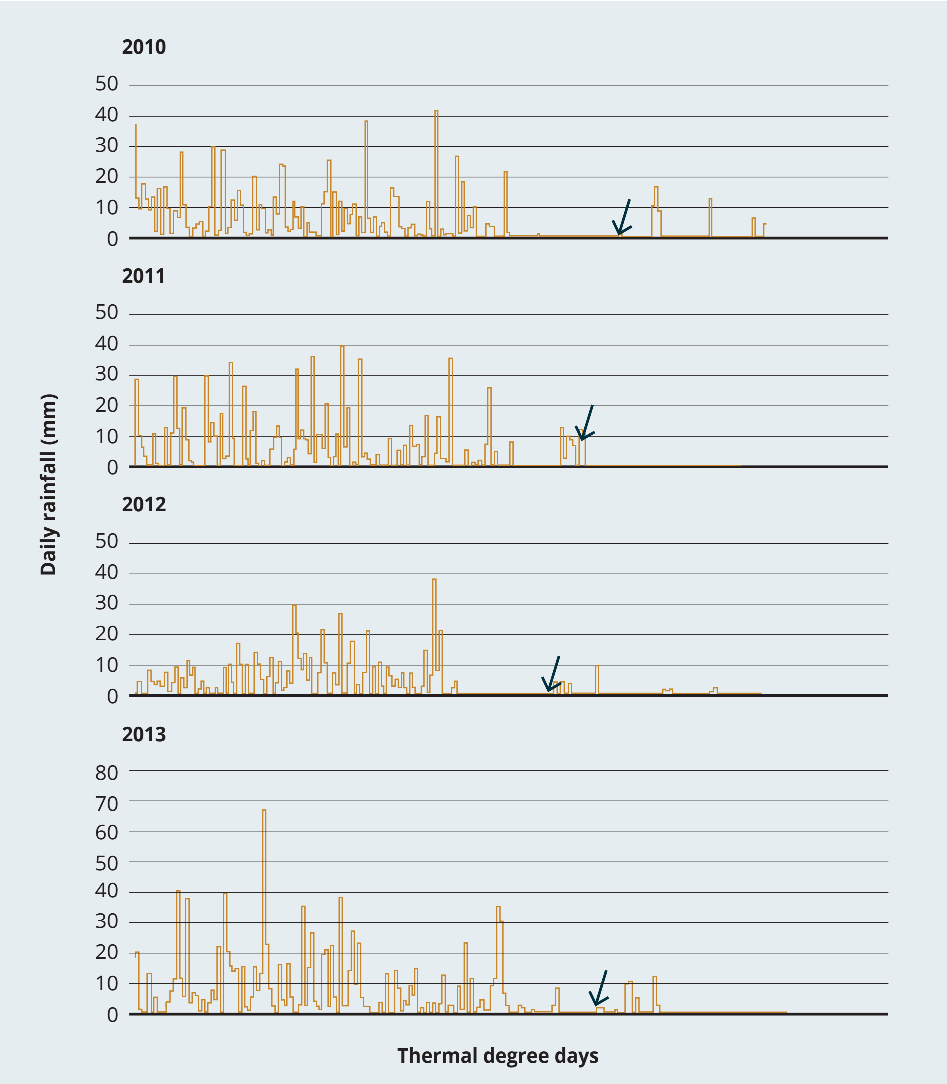


Figure 14.5 **Daily rainfall and thermal degree days during the common bean–maize cropping systems, 2010–13**

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

Grain yield, land productivity and income

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

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

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

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

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

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

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

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

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

Environmental sustainability

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

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

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

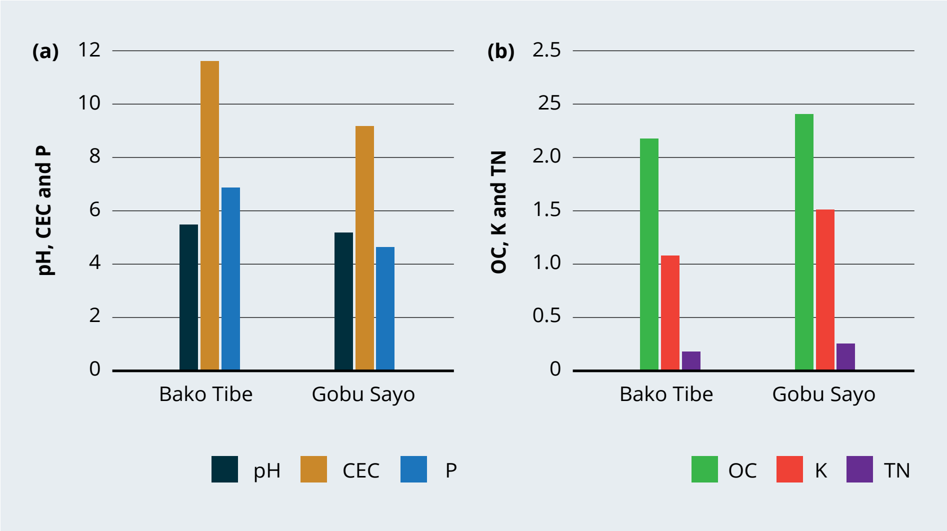


Figure 14.6 **Chemical properties of soil influenced by different cropping systems with tillage practices (across locations during 2010–12 cropping seasons)**

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

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

Maize, grain and forage legume varieties

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

Participatory variety selection of maize

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

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

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

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

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

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

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

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

Source: Elmyhun, Abate & Merene 2017

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

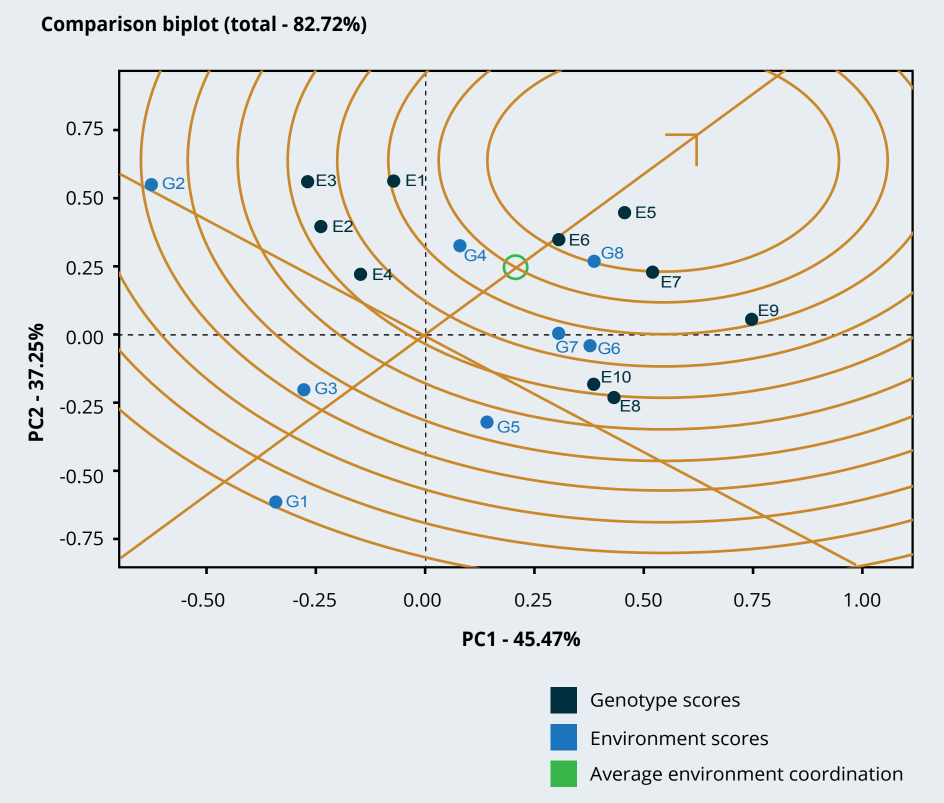


Figure 14.7 **Comparison of maize hybrids for their suitability in north-western Ethiopia**

Source: Elmyhun, Abate & Merene 2017

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

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

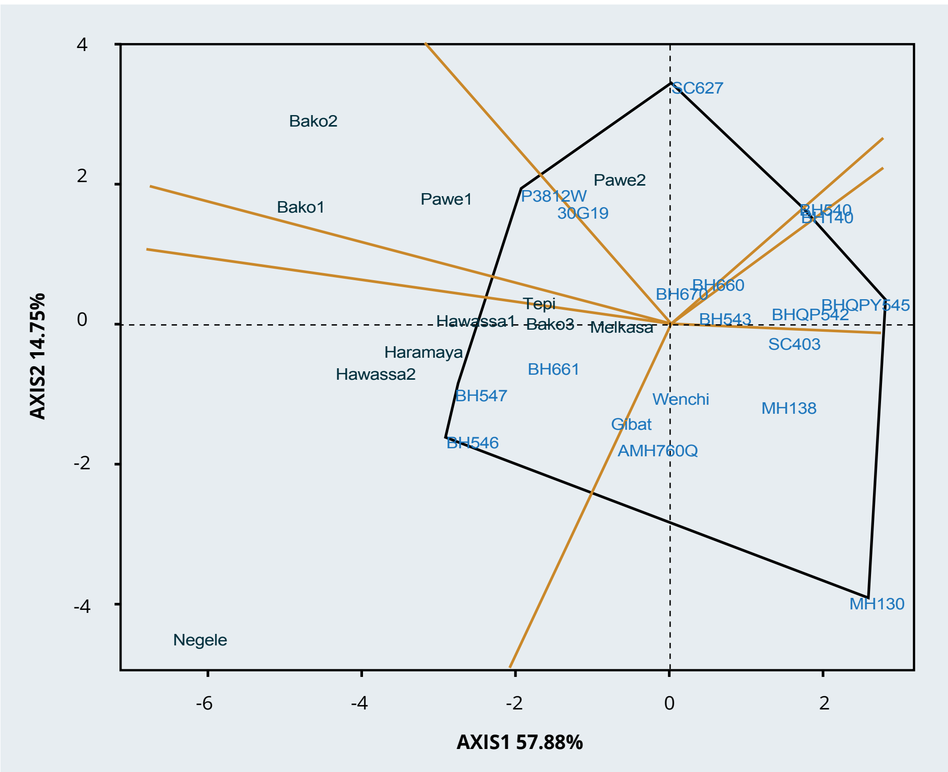


Figure 14.8 **Maize-growing mega-environments constructed using genotype plus genotype-by-environment biplot for 19 maize hybrids evaluated across 11 environments**

Source: Wolde et al. 2018

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

Participatory variety selection of grain legumes

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

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

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

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

Participatory variety selection of forage legumes

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

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

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

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

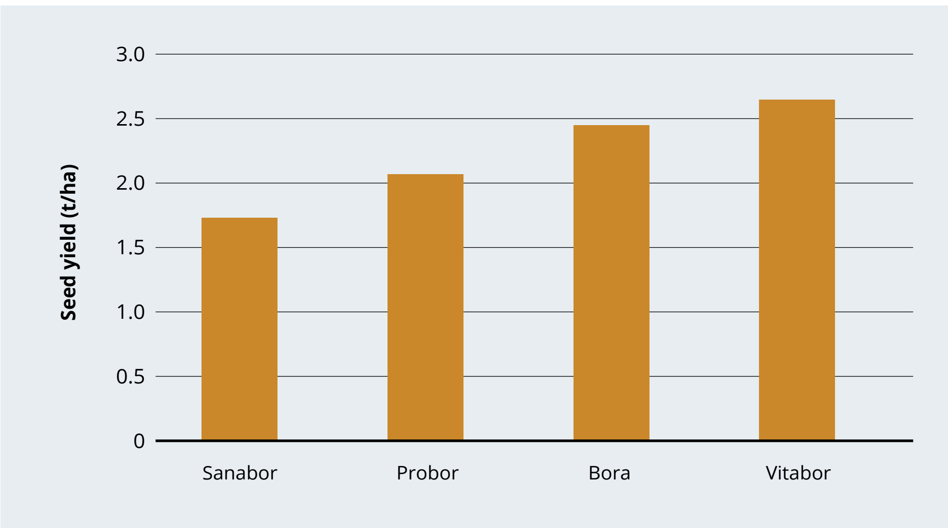


Figure 14.9 **Seed yield of sweet lupine varieties evaluated across Ethiopia**

Table 14.15 Traits of Sanabor and Vitabor sweet lupine varieties

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

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

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

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

Seed production and dissemination of selected maize and legume varieties

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

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

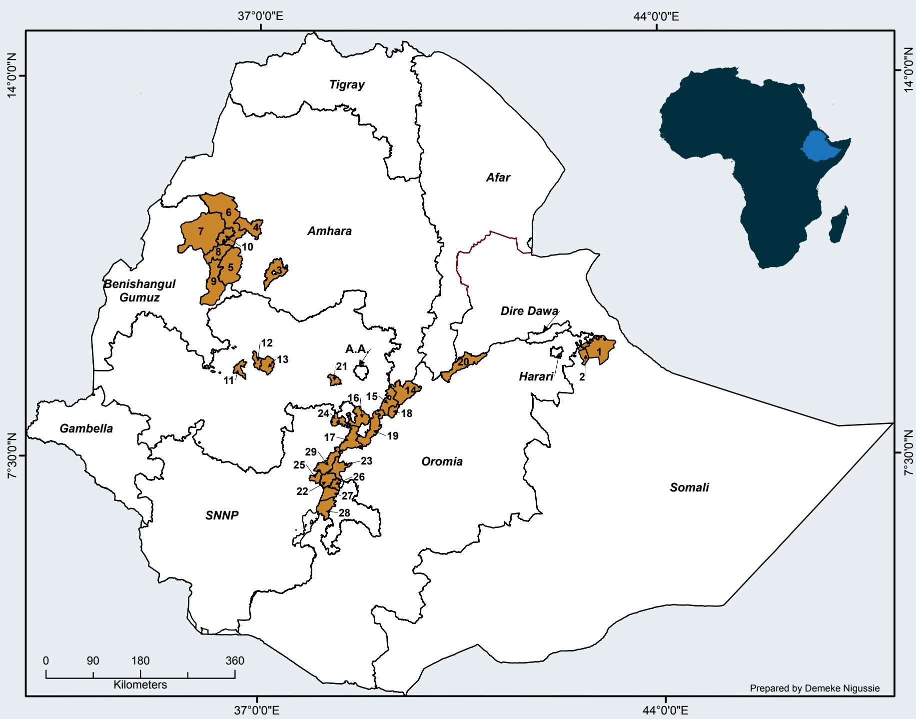
Taking SIMLESA output lessons to scale

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

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

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

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



SIMLESA project area districts

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

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

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

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

Gender roles in maize–legume production

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

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

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

Source: Own field study, April 2017

Gender roles in maize and common bean production

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

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

Conclusions

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

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

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

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

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

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

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

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15 Intensification of maize and legumes in Kenya

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Key points

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

Introduction

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

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

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

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

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

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

What was the situation in 2010?

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

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

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

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

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

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

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

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

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

Crops grown mainly for export

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

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

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

Crops grown mainly for local consumption

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

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

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

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

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

What did SIMLESA do?

Program objectives

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

The program evaluated three principles of conservation agriculture:

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

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

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

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

Program sites

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

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

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

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

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

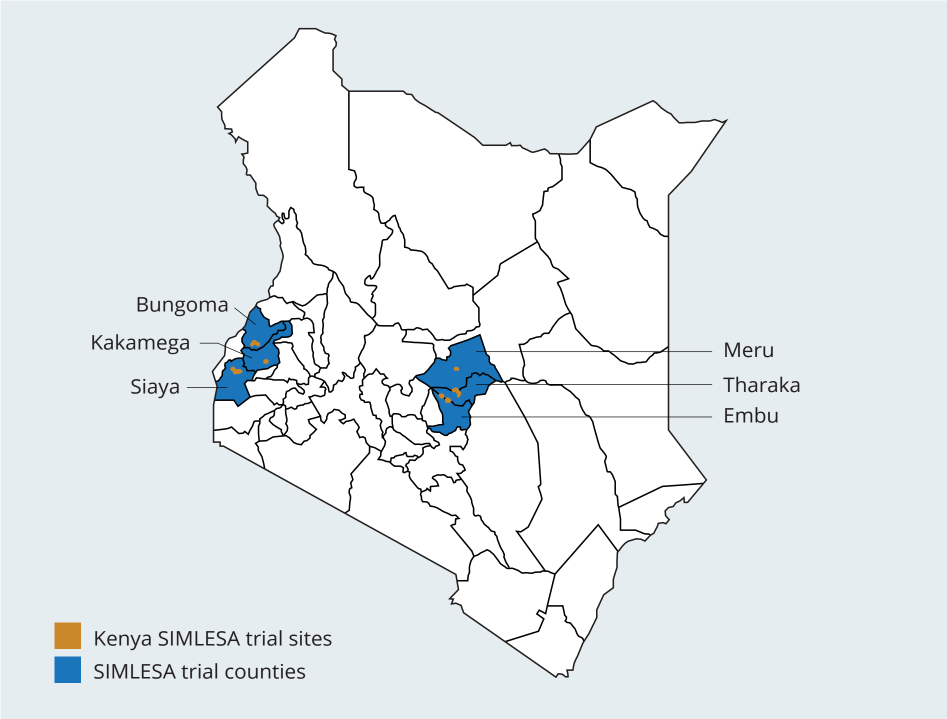

Figure 15.1 **SIMLESA trial sites in western and eastern Kenya**

Implementation

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

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

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

Participatory variety selections

More-productive newly released and pre-release maize, legume and fodder varieties were identified from the national research programs (Drought Tolerant Maize for Africa, International Maize and Wheat Improvement Center, International Crops Research Institute for Semi Arid Tropics, International Livestock Research Institute, Tropical Legumes 2, seed companies and Egerton University) in a participatory manner with farmers. A total of 47 maize[15], 39 legume[16] and 12 fodder[17] varieties were tested under the participatory variety selection approach. Multiple crops were evaluated in participatory variety selection trials. These included maize varieties under intercrops with common bean, pigeonpea, soybean, peanut and cowpea. These were tested under CASI systems in farmers' fields. Fertiliser was applied according to KALRO recommendations. Trials were carried out by farmers with support from research and extension providers. Evaluations were carried out separately by female and male farmers, and reports compiled. Researchers conducted separate evaluations. Data were triangulated to identify the best-performing varieties. The same studies were conducted on research stations.

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

Testing CASI options

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

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

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15 **Maize varieties tested under participatory variety selection** KALRO Embu: KH500–39E, KH500–38E, KH631Q, Embu 225, Embu 226, Embu Synthetic, KDV1, KDV5, KDV6, DK 8033, MZ 1202(H529), 12 ML 1, Pioneer 2859W, Pioneer 30G19

KALRO Kakamega: KSTP 94, KH633A, IRWS 303, KAK SUT2, KM0403, H520, H624, KM0221, KH533A, GAF 4, DH014, KM0111, KM0311, KM1001, H527, KM0404, KM0406; commercial varieties: DK8031, H513, DH04, WH105, WH505; farmers' varieties: Nya Uganda, Obabari, Sipindi, Duma 49, Namba nane, Panadol, DK 8031, H614, Duma 43, H624, H513

16 **Legume varieties tested under participatory variety selection** KALRO Embu: bean (KAT B9, KAT B1, KATX 56, KATX69, Embean 14, KK8, KK15, Embean 7, Embean 118, Chelelang, KKRII05/Cal 130, Ciankui, Tasha, KAT RM-01, KKRII05/cal 14B); pigeonpea (KAT60/8, ICEAP 00554, 00040, 00850, 00557, KAT60/8, CPL 87091); cowpea (K80, M66, KVU-27–1); farmers' varieties: bean (Mwitemania); pigeonpea (Kendi, Ndombolo)

KALRO Kakamega: bean (KK8, kk071, kk072, kk15, kk20, Emben 14, KAT B9, KAT B1, KATX 56, KATX69, KK Rosecoco, KK Red Bean 16); soybean (SB19, SB 25, SB3, EAI3600); peanut (ICGV-SM 99568, ICGV-SM-12991, ICGV-SM-90704); farmers' varieties: beans (Nya seje, Rosecoc); peanut (Red Valencia)

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

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

Table 15.1 Tillage methods selected by farmers for testing

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

Adoption monitoring of SIMLESA technologies

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

Capacity building

Building credentials

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

Gender mainstreaming

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

Monitoring and evaluation training

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

APSIM model training

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

What did we learn?

Baseline survey and farming systems characterisation

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

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

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

Table 15.2 Household characteristics in Kenya

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

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

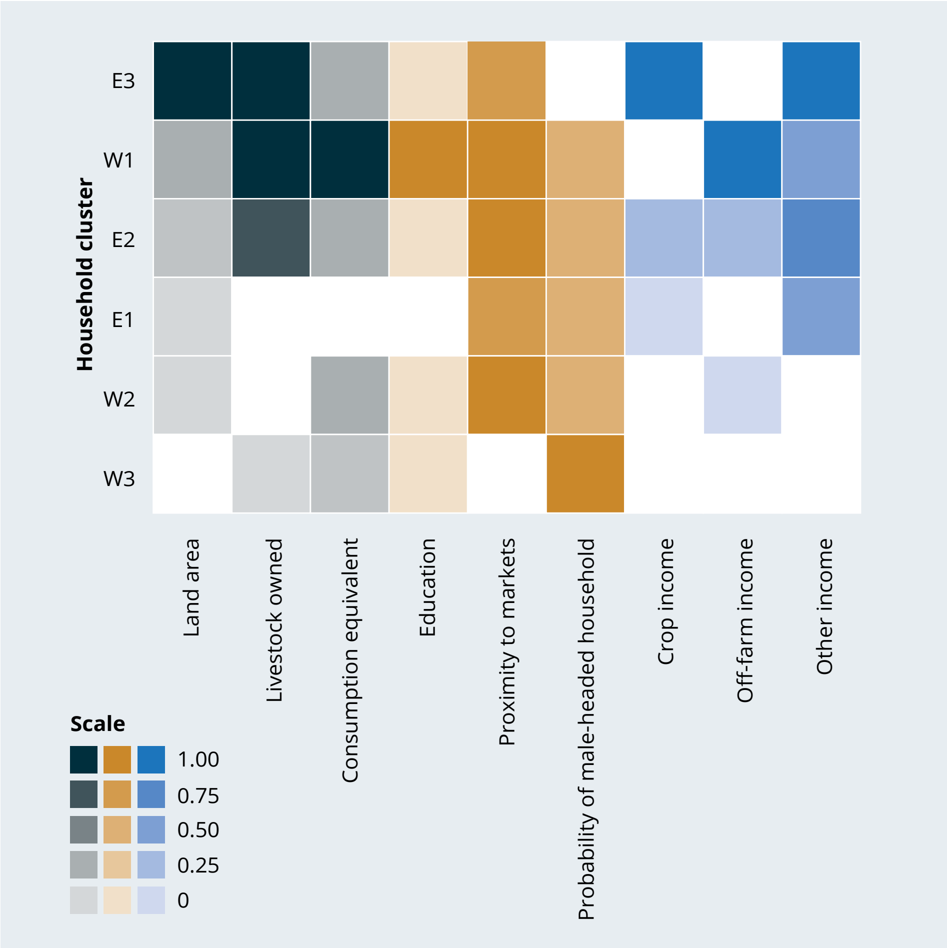

Figure 15.2 **Heat map of the characteristics and livelihood strategies of farmer groups from western (clusters W1, W2 and W3) and eastern Kenya (clusters E1, E2 and E3)**

The intensity of colour indicates the value of the farm system variable for a household group relative to other groups (0–1, light to dark, respectively). Three types of farming system variables were used: food availability levels (black), social mobility factors (orange) and sources of income generation (blue). Food availability variables were the median values for land area, tropical livestock units and consumption equivalents within each group. The social mobility factors were median education level (years of formal education), proximity to markets (walking minutes) and the probability of being a male-headed household within the group. Income generation components were median income levels from crop sales, off-farm activities and other non-crop farm sales.
Source: Wilkus, Roxburgh & Rodriguez 2019

Participatory variety selection trials

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

Table 15.3 Maize varieties selected and endorsed by farmers

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

Note: OPV = open-pollinated variety

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

Table 15.4 Legume varieties endorsed by farmers

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

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

Table 15.5 Fodder varieties endorsed by farmers

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

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

CASI practices endorsed by farmers

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

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

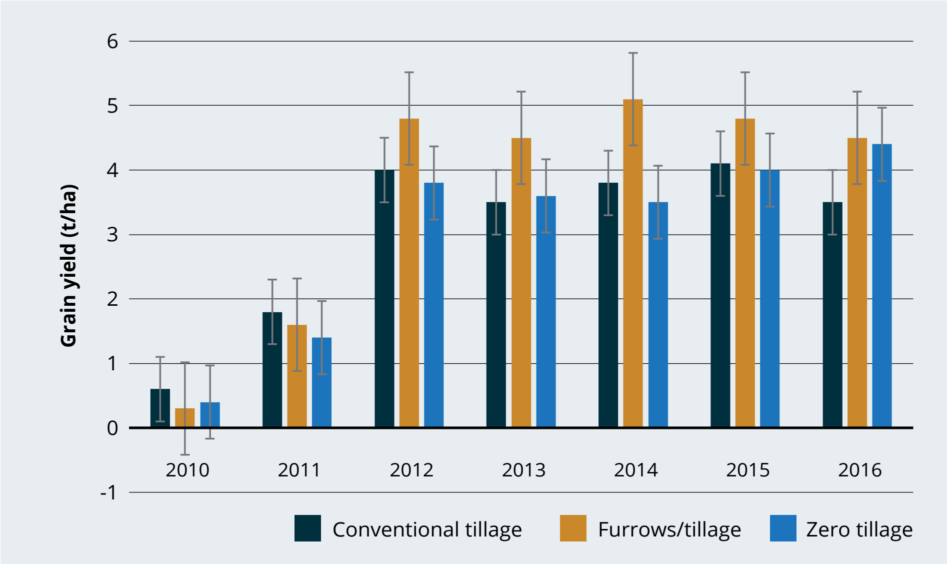

Figure 15.3 **Average annual maize grain yield under different tillage practices in eastern Kenya SIMLESA sites, 2010–16**

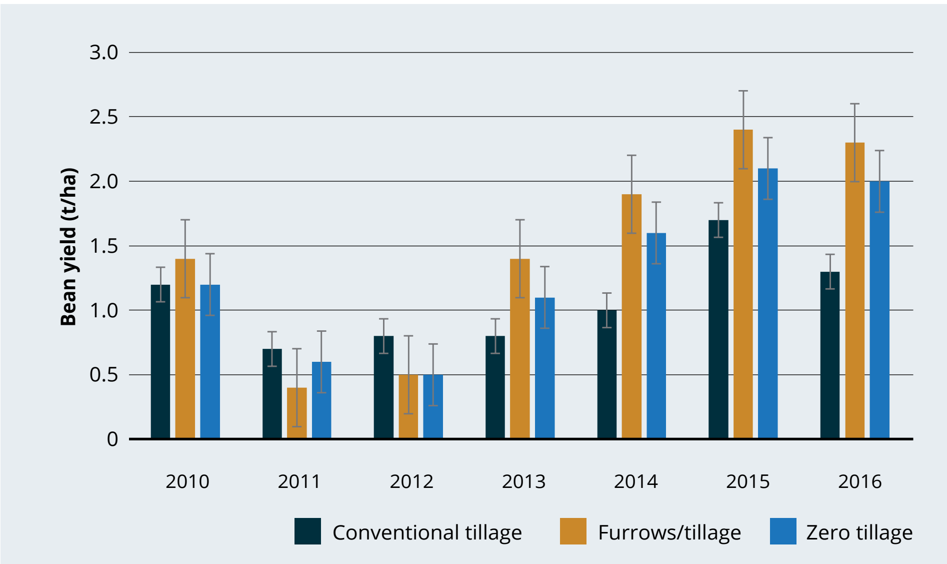

Figure 15.4 **Average annual bean yield under different tillage practices in eastern Kenya SIMLESA sites, 2010–16**

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

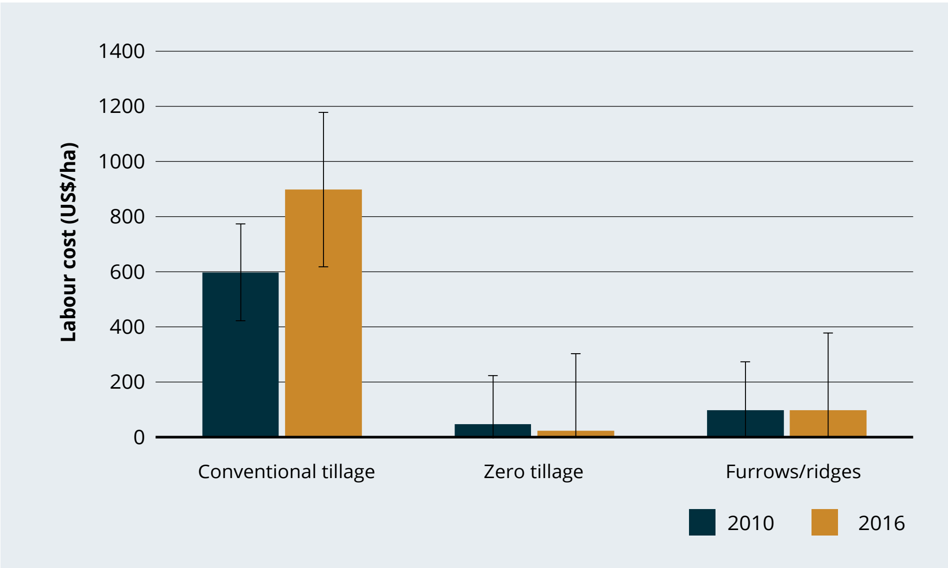

Figure 15.5 **Labour costs of different tillage practices in eastern Kenya**

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

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

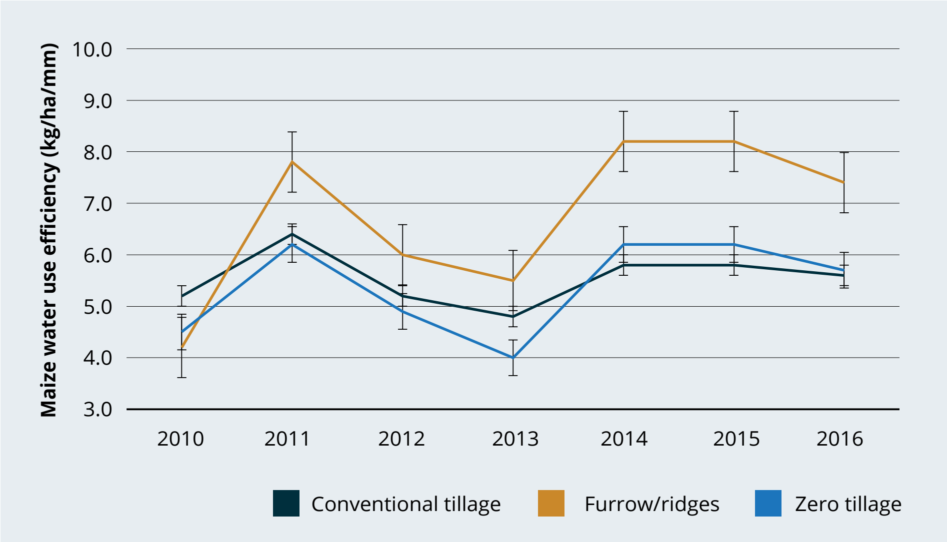

Figure 15.6 **Effect of tillage practices on crop water use efficiency in eastern Kenya**

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

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

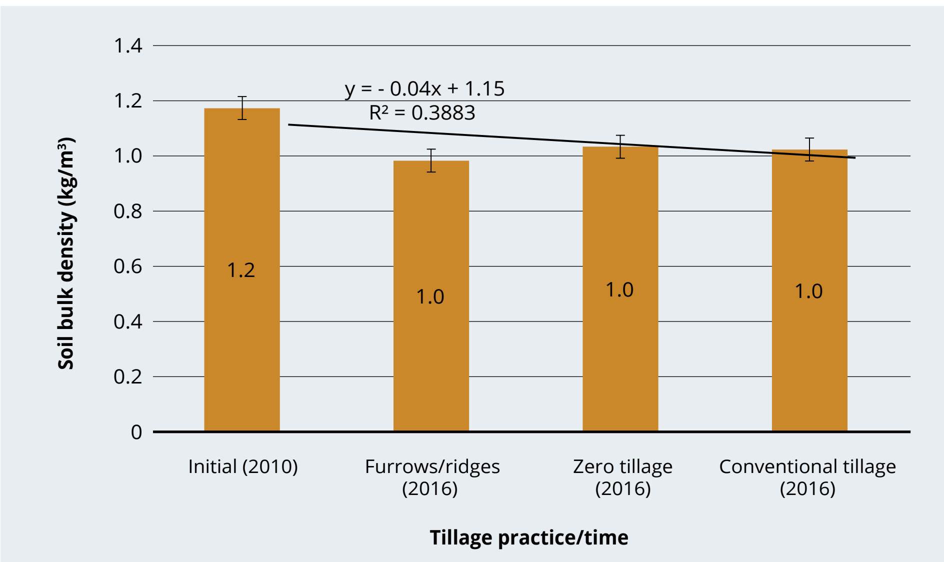

Figure 15.7 **Effect of tillage practice on soil bulk density in eastern Kenya, 2010 and 2016**

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

What was the impact?

Innovation platforms

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

The partnerships developed under the innovation platforms contributed to:

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

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

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

Table 15.6 Scaling out of SIMLESA technologies and activities

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

Development of seed road maps

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

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

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

Table 15.8 Key seed companies and partners

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

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

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

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

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

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

Adoption rates of SIMLESA technologies

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

By 2016[18], a number of farmers beyond the targeted SIMLESA households had heard of and adopted SIMLESA technologies and practices based on knowledge gained from SIMLESA participants. Adoption patterns suggested that the most common and effective approaches of disseminating program technologies and practices were visits to demonstration sites (96.6% of respondents), attending field days (73.7%) and exchange visits (39.2%). The most popular crops were DK 8031, KDV 6 maize varieties and Embean 14 bean variety, known by 44.3%, 20.7% and 15.5% of respondents, respectively. Furrows and ridges, residue return and fertiliser use were known by 30.4%, 18.7% and 13.4% of respondents, respectively.

What should we do next?

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

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

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

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

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

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16 Sustainable intensification of maize and legume farming systems in Tanzania

John Sariah, Frank Mmbando, Lameck Makoye & Bashir Makoko

Key points

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

Introduction

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

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

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

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

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

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

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

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

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

What did SIMLESA do?

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

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

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

Program sites

Karatu

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

Mbulu

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

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

Selian Agricultural Research Station

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

Ilonga Research Station

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

Program objectives

On-farm trials

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

On-station trials

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

Researcher and extension capacity building

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

Table 16.1 Course and number of trainees by gender

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

What we found

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

The average yields for various crops during 2010 were:

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

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

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

Household characteristics

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

Land ownership

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

Table 16.2 Household demographics

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

Table 16.3 Land ownership at district level

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

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

Technology adoption

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

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

Table 16.4 Adoption of CASI practices at household level

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

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

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

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

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

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

Number of adopters

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

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

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

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

Farmers' sources of information

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

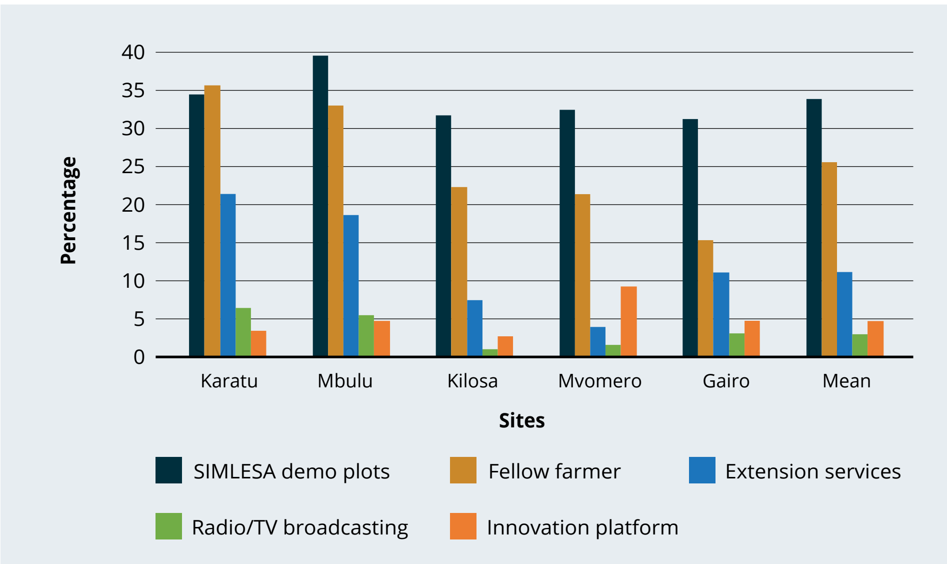
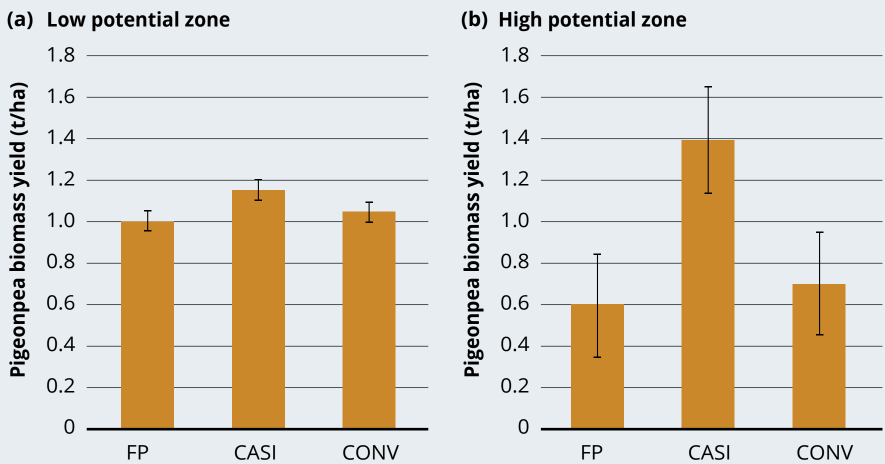


Figure 16.1 Farmers' sources of information about CASI practices

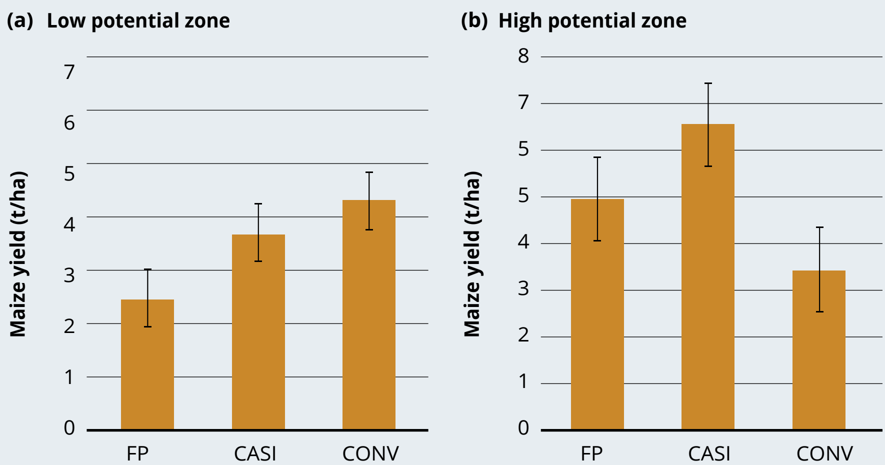
On-farm testing of sustainable and resilient climate-smart technologies

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



FP = Farmers' practice; CASI = conservation agriculture-based sustainable intensification;
CONV = Conventional agriculture

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



FP = Farmers' practice; CASI = conservation agriculture-based sustainable intensification;
CONV = Conventional agriculture

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

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

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

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

Note: CASI = conservation agriculture-based sustainable intensification

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

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

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

Adoption of CASI increases resilience to climate change

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

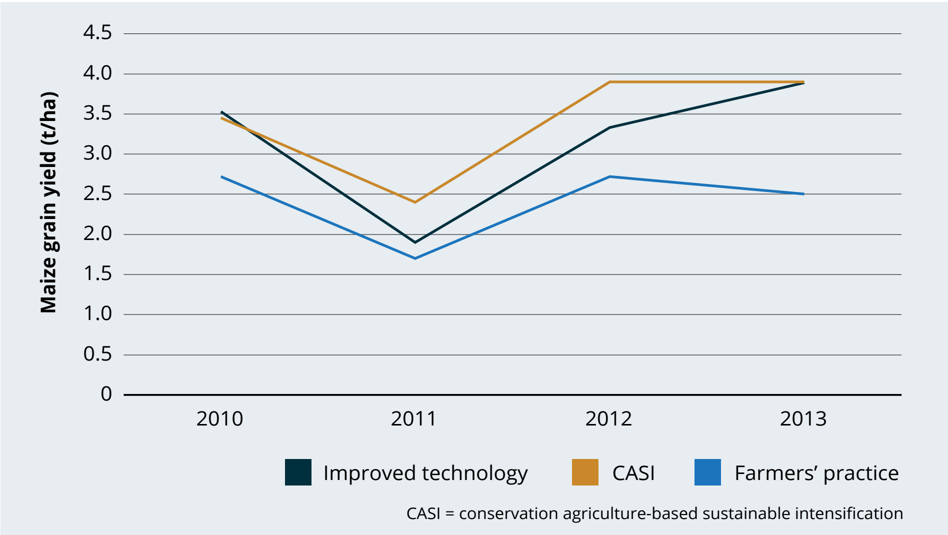


Figure 16.5 **Response of different practices in varied seasons, 2010–13**

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

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

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

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

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

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

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

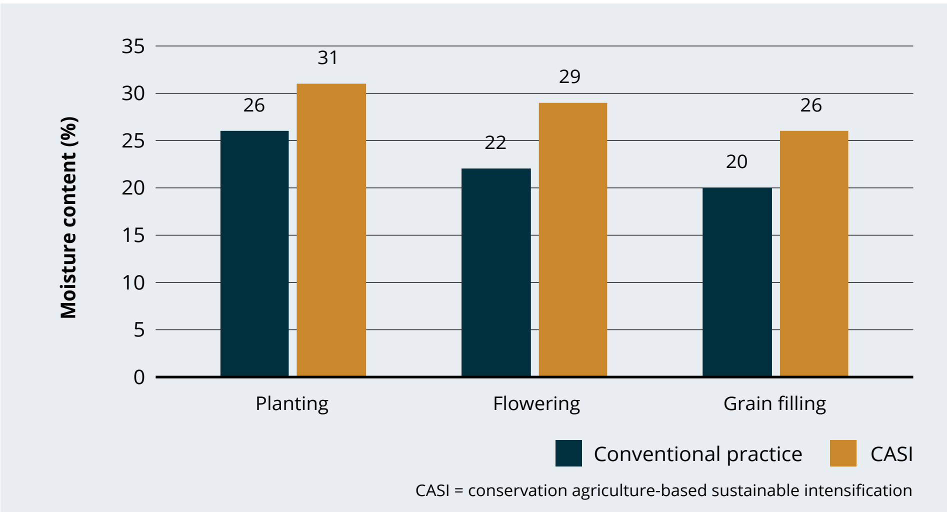


Figure 16.6 Average soil moisture level at different stage of plant development at Selian Agricultural Research Station

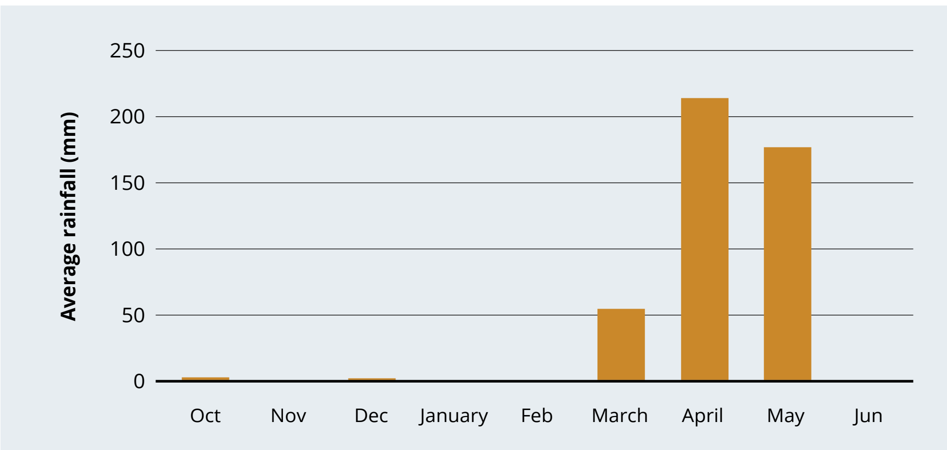


Figure 16.7 Average monthly rainfall at Selian Agricultural Research Station

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

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

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

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

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

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

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

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

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

Yield across maize varieties

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

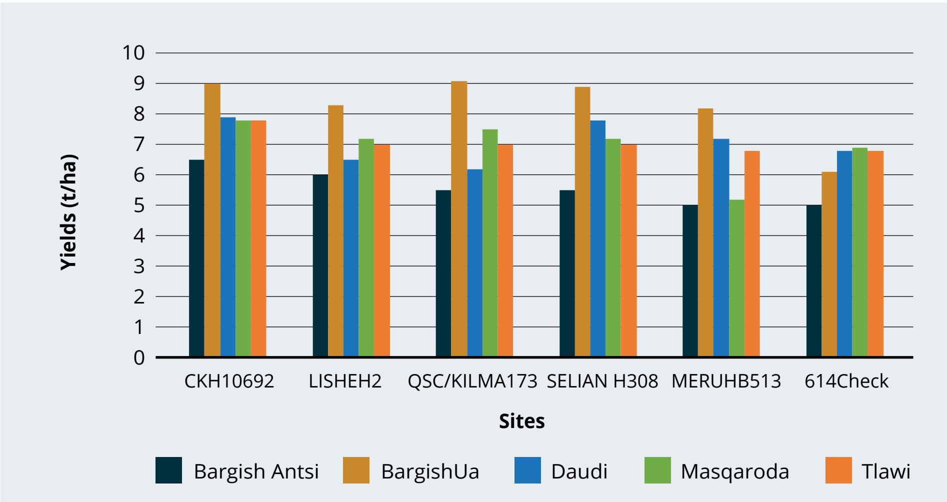


Figure 16.8 **Yield of maize varieties, Mbulu**

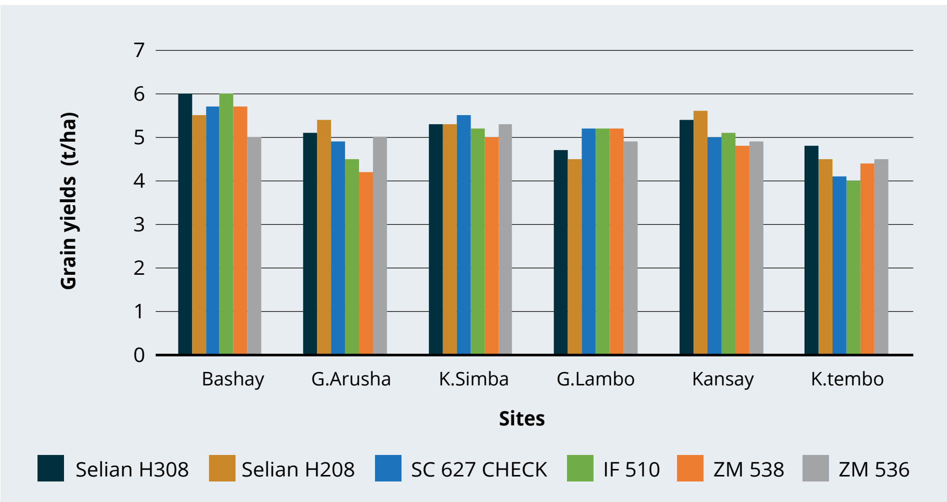


Figure 16.9 **Yield of maize varieties, Karatu**

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

Table 16.13 Maize grain yield mean performance, Kilosa

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

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

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

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

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

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

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

What did we learn?

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

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

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

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

SIMLESA successes in Tanzania

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

Conclusions

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

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

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

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

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

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Key points

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

Introduction

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

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

What was the situation before 2010?

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

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

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

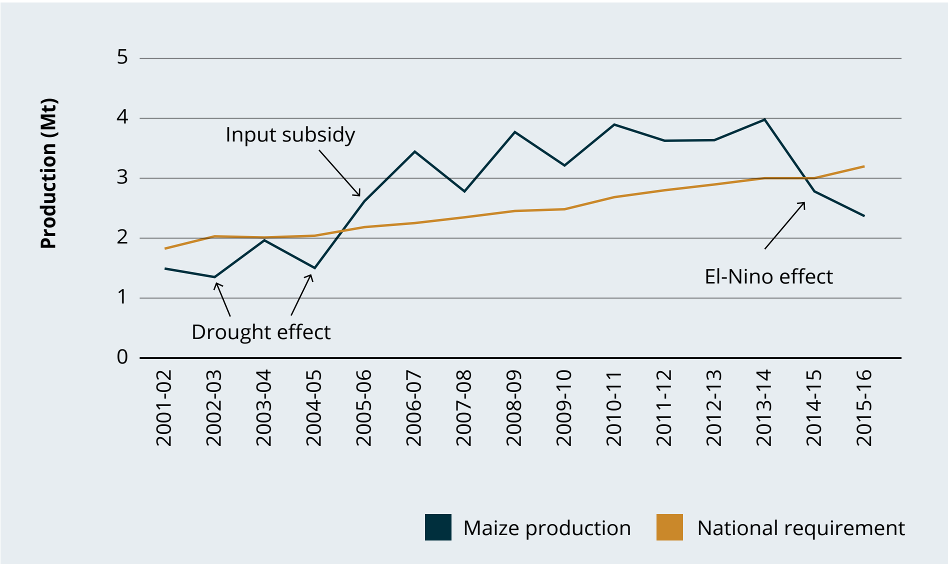

Figure 17.1 **Maize production and national food requirement**

Source: Government of Malawi 2016a

Climate risk

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

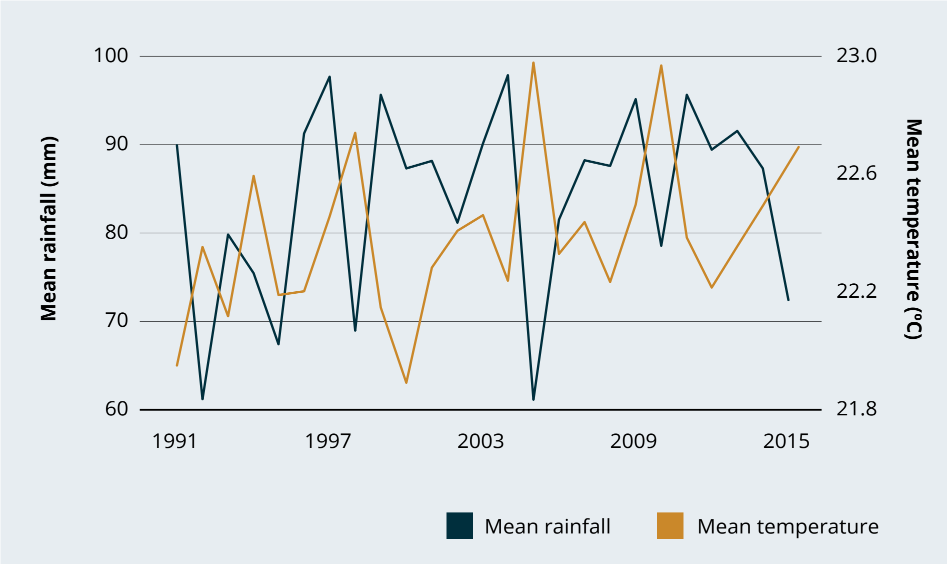

Figure 17.2 **Average rainfall and temperature, 1991-2015**

Source: World Bank Group 2017

Government subsidy program

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

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

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

Conservation agriculture

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

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

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

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

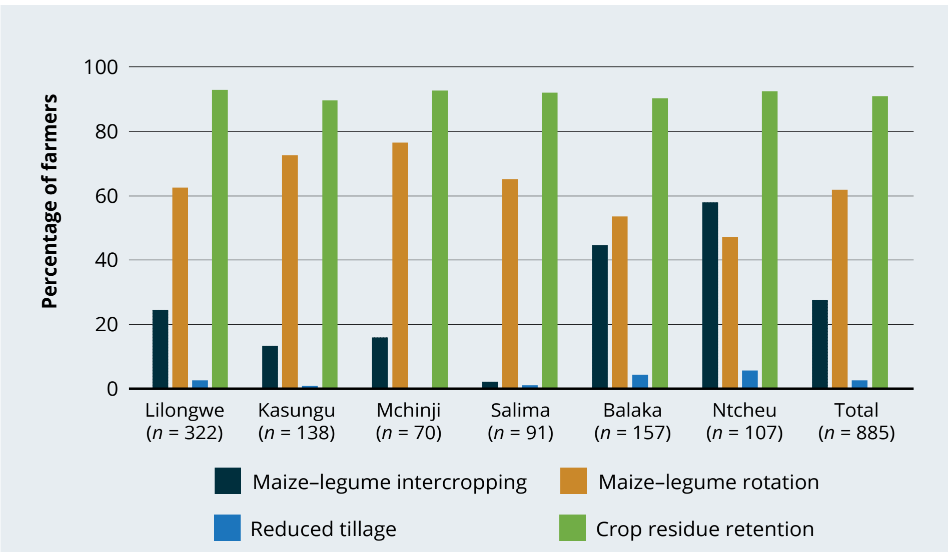

Figure 17.3 Technology use in Malawi, 2010

Source: Mulwa et al. 2010

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

What did SIMLESA do?

Local project partners

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

Project sites

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

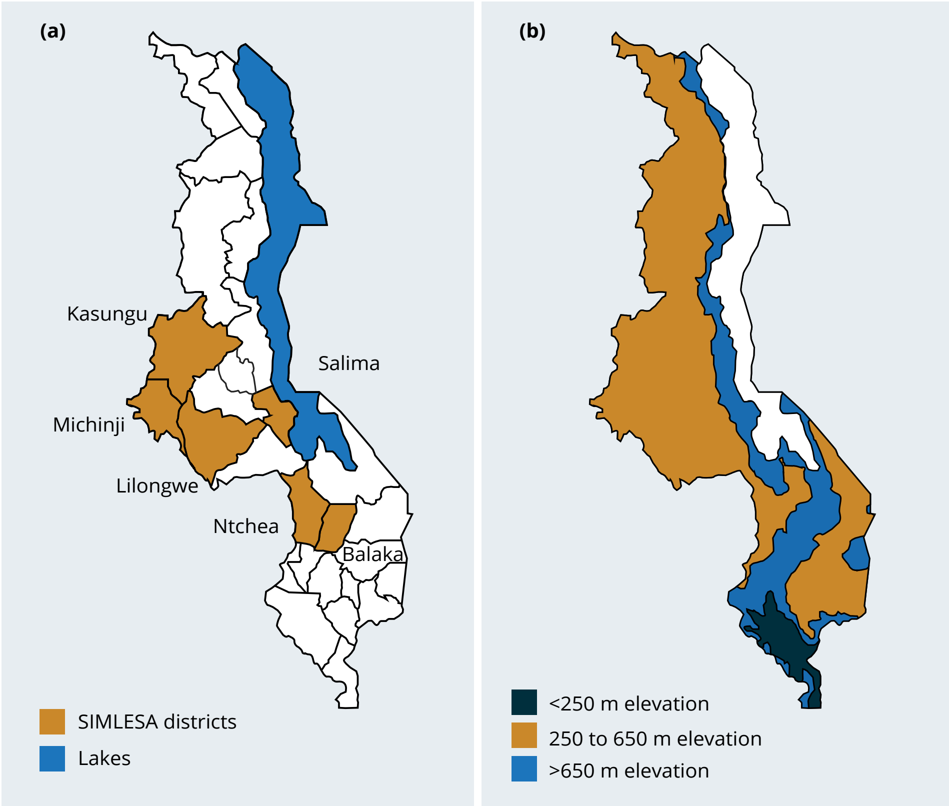

Figure 17.4 (a) SIMLESA districts and (b) agroecological zones based on elevation

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

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

Adoption monitoring and identification of social constraints

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

Long-term CASI trials

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

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

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

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

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

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

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

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

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

Varietal trials

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

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

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

Knowledge-sharing platforms

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

Capacity building

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

What did we learn?

Yield gains

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

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

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

Notes:

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

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

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

Performance across agroecological zones

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

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

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

Farmers' preference

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

Table 17.5 Technologies preferred by farmers in SIMLESA districts

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

Note: CASI = conservation agriculture-based sustainable intensification

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

Dissemination pathways

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

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

Table 17.6 Scalable technologies

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

What was the impact?

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

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

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

Adoption of CASI technologies

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

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

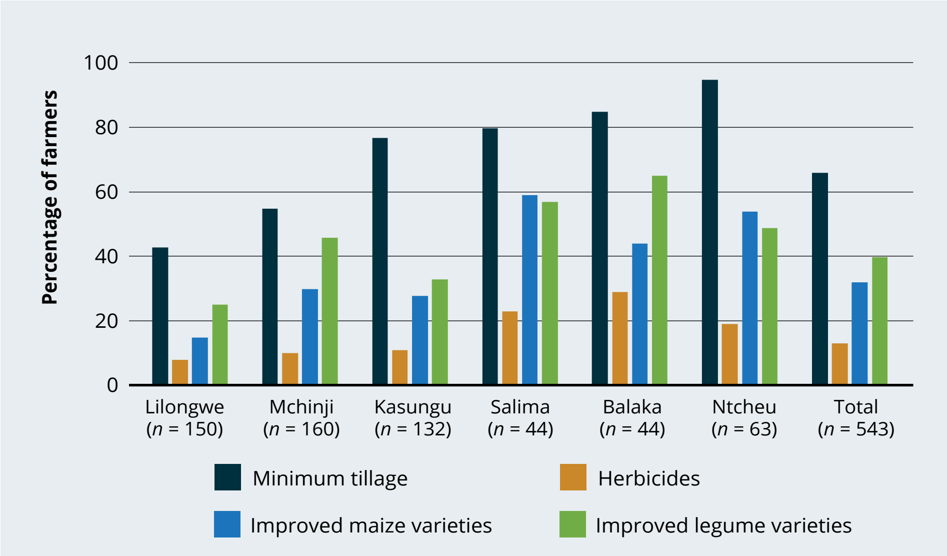

Figure 17.5 **Technology adoption, 2013**

Source: Government of Malawi 2013

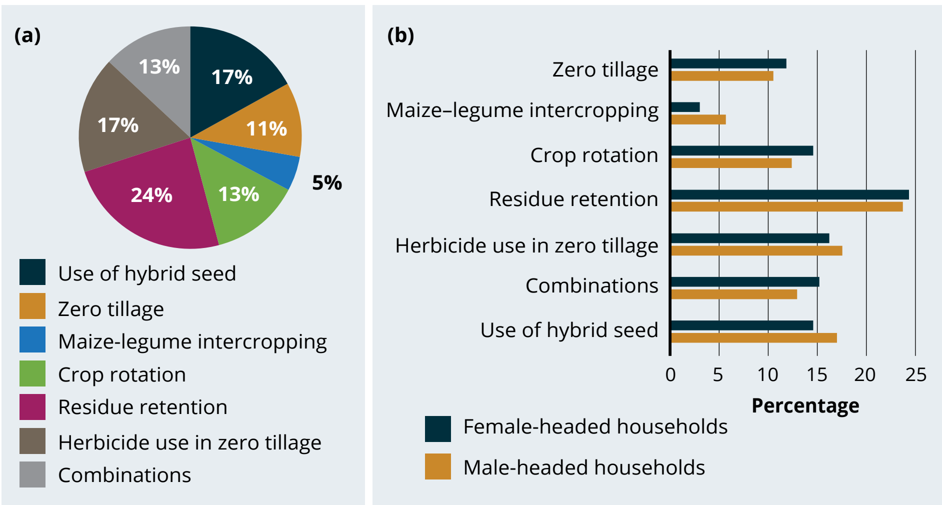

Figure 17.6 **Technology adoption by (a) total sample and (b) gender of household head, 2015**

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

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

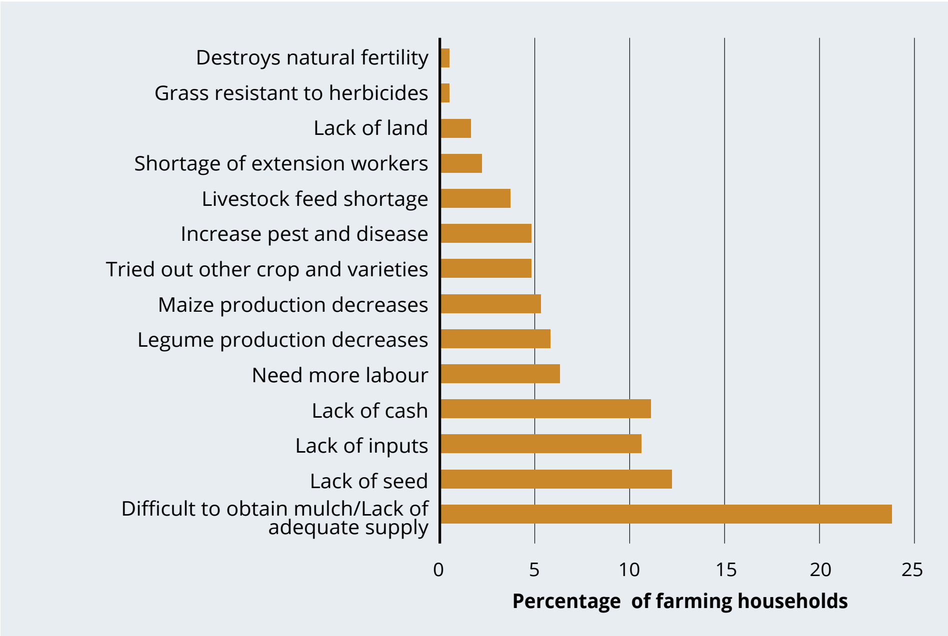

Figure 17.7 **Reasons for disadoption of technologies, 2013**

Source: Government of Malawi 2013

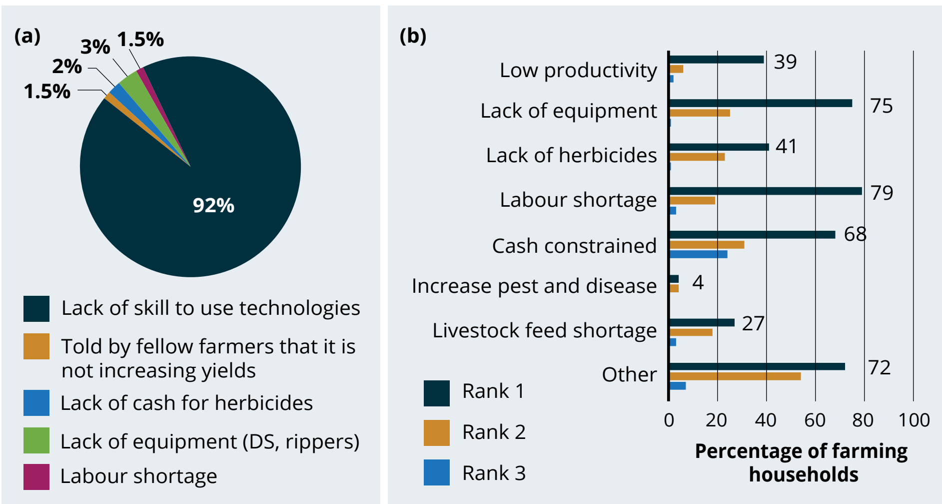

Figure 17.8 **Disadoption of technologies by (a) overall main reason and (b) ranked reasons, 2015**

Source: Government of Malawi 2015

Impact on yield and income

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

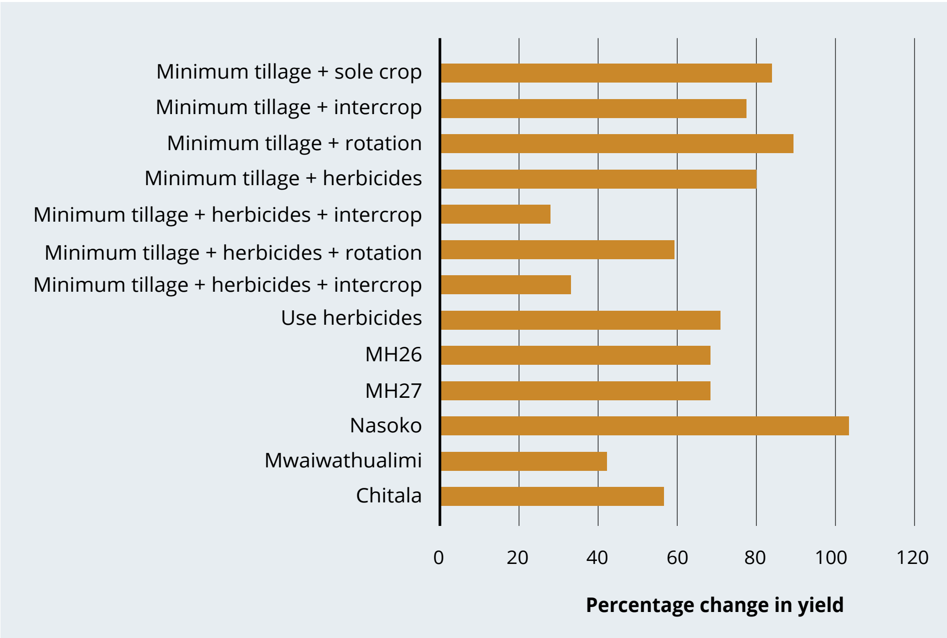

Figure 17.9 **Average change in maize yield (2010–13)**

Source: Government of Malawi 2013

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

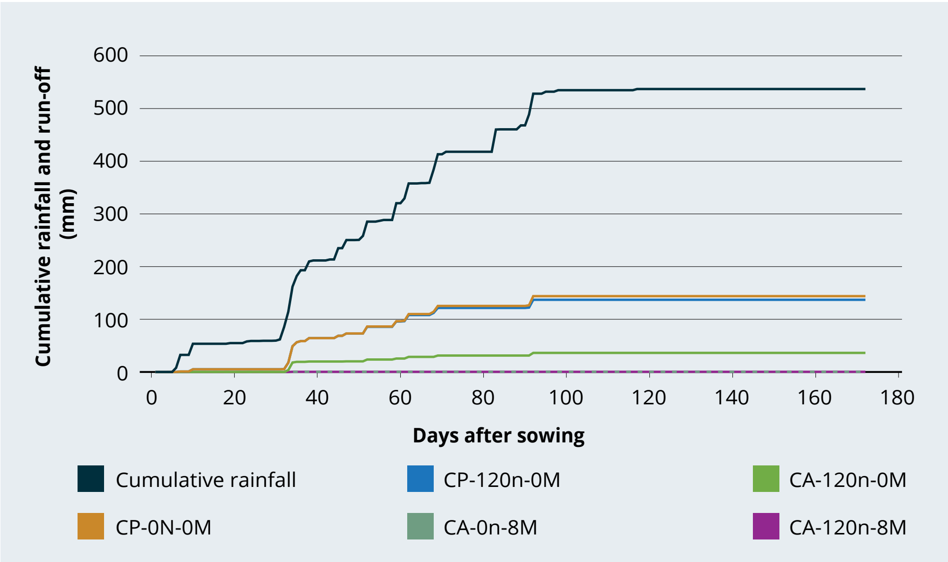

Figure 17.10 **Cumulative run-off at different rates of nitrogen and crop residues**

Source: SIMLESA farm trials

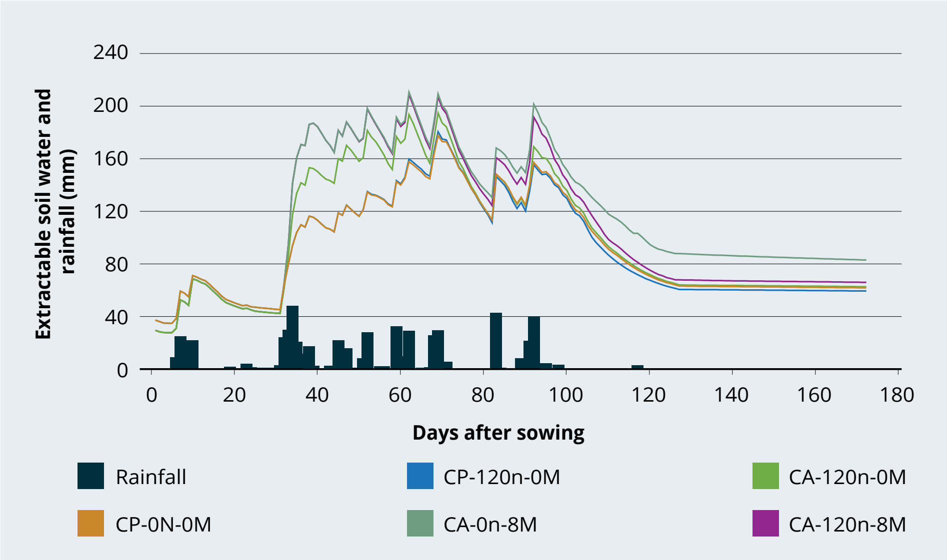

Figure 17.11 Extractable soil water at different rates of nitrogen and crop residues

Source: SIMLESA farm trials

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

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

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

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

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

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

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

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

What should we do next?

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

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

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

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

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

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

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

Key priorities

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

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

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18 The sustainable intensification of agriculture in Mozambique

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Key points

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

Introduction

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

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

Figure 18.1 Location of SIMLESA communities in central Mozambique

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

What was the situation in 2010?

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

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

- Manica (AEZ R4, R6, R10)
- Sofala (AEZ R5, R4, R6)
- Tete (AEZ R6, R7, AEZ)
- Zambezia (AEZ R7, R5, R8, R10).[19]

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

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

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

What did SIMLESA do?

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

Evaluating the benefits of local CASI packages

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

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

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

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

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

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

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

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

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

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

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

Selecting improved maize and legume seed varieties

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

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

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

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

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

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

Preliminary scaling-out activities and results

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

Assessing downside risk from CASI adoption

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

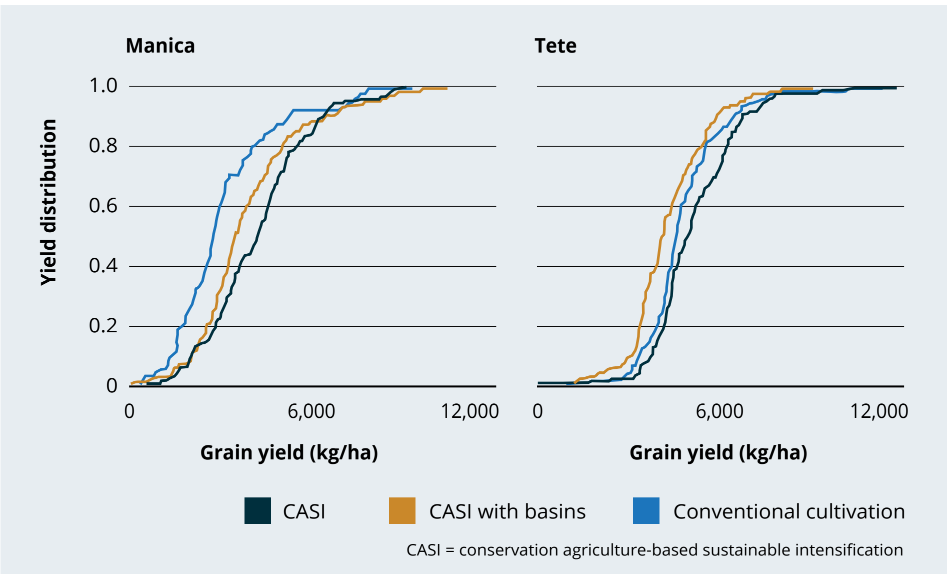

Figure 18.2 **On-farm maize yield distributions in Tete and Manica provinces for full adoption of CASI with and without planting basins vs conventional tillage with local fertiliser recommendations and improved seed**

Results of modelling residue management interaction with soil type

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

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

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

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

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

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

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

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

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

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

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

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

What did we learn?

Evidence for increased environmental sustainability

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

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

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

Table 18.6 Soil carbon and nitrogen changes, Chimoio, Mozambique

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

Note: s.e. = standard error

Improvements to gender equality

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

Improvements made in gender equality included:

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

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

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

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

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

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

Improvements and knowledge acquired for the private sector

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

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

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

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

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

Key messages

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

Households

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

Extension officers

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

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

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

Policy

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

Policy recommendations included:

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

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

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

Agribusiness

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

What was the impact?

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

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

Immediate impacts include:

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

What should we do next?

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

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

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

On the output side, gaps include:

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

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

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

On the output side, opportunities include:

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

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

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

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

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

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

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

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

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

Key points

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

Introduction

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

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

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

What was the situation in 2010?

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

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

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

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

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

Land degradation

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

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

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

Photo: James Lwasa, 2013

Figure 19.2 **Hand hoeing in Uganda**

Photo: Drake N. Mubiru, 2014

Productive and sustainable practices, tactics and strategies

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

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

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

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

What did SIMLESA do?

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

Project objectives

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

The specific objectives were to:

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

Project sites

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

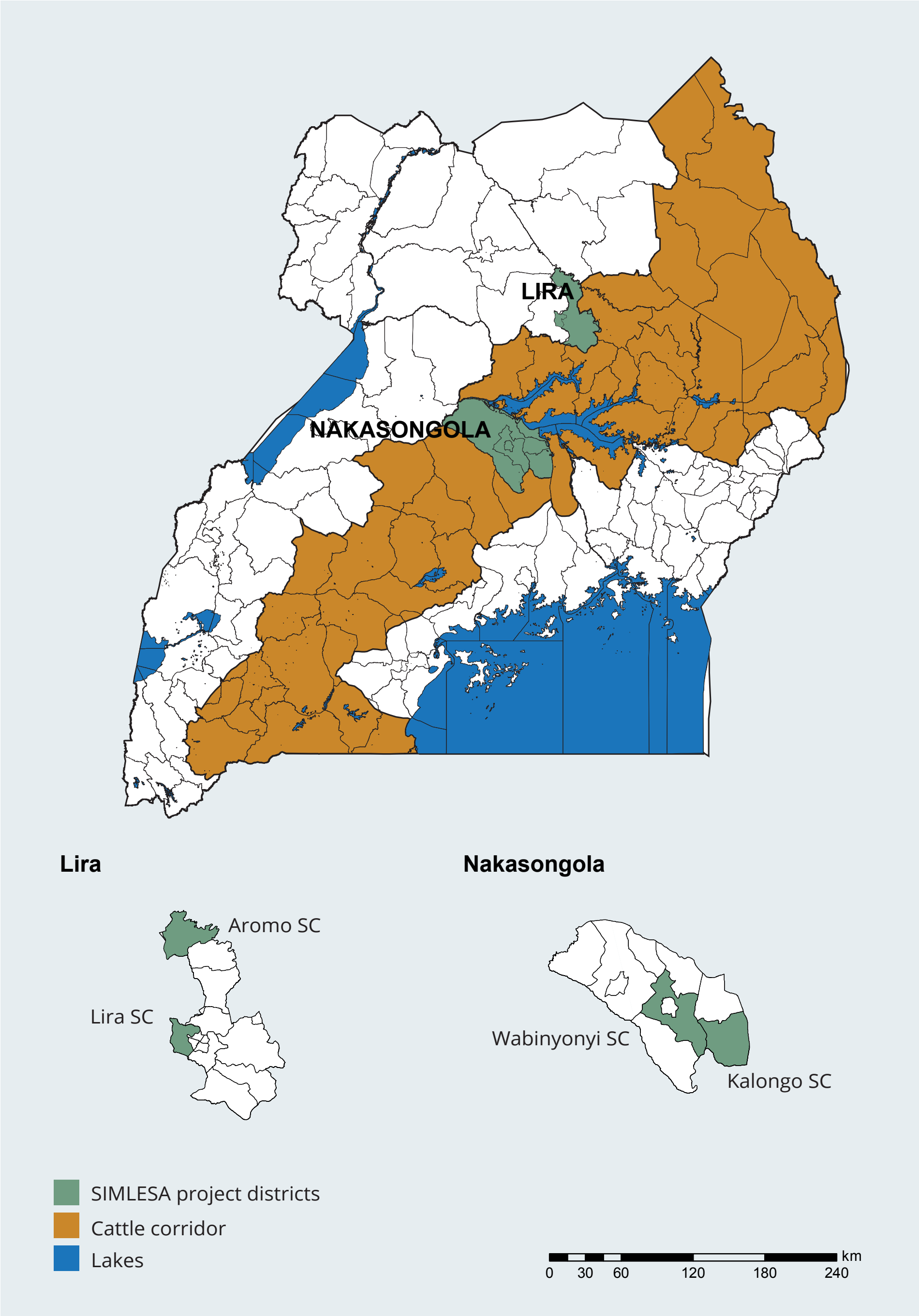

Figure 19.3 **Uganda SIMLESA program sites: Lira and Nakasongola districts and the cattle corridor**

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

Site selection

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

Assessing the biophysical state of soils

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

Intensification of sustainable production

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

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

Maize–bean intercropping patterns

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

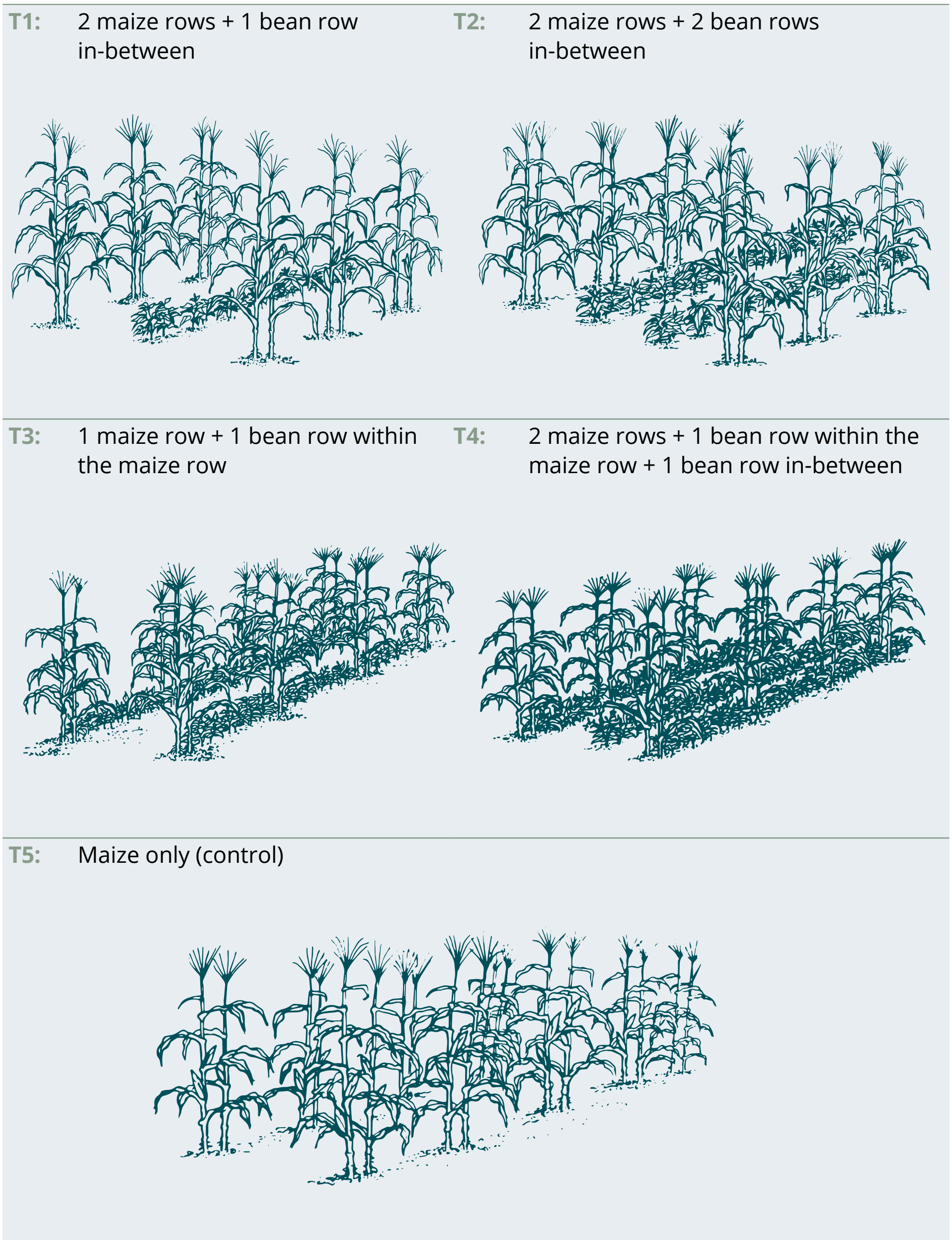

Figure 19.4 Maize–bean intercropping patterns

Maize and bean seeding rates

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

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

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

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

Comparison of tillage methods

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

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

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

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

Business model analysis

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

Impact assessment

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

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

What did we learn?

Improved understanding of socioeconomic conditions

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

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

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

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

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

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

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

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

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

The biophysical state of soils

Bare ground coverage in Nakasongola, due to extreme cases of soil compaction, was 187 km^2 (11%) of the 1,741 km^2 of arable land (Table 19.2 and Figure 19.5) (Mubiru et al. 2017).

Table 19.2 Spatial distribution of different land cover classes in Nakasongola

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

Source: Mubiru et al. 2017

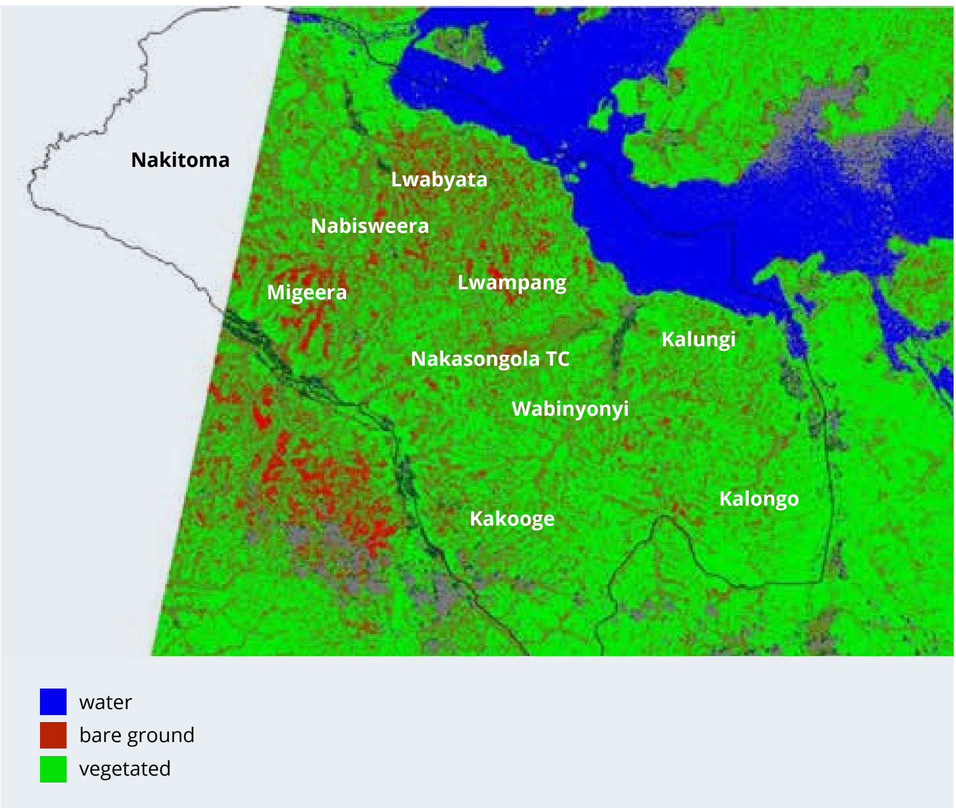

Figure 19.5 Spatial distribution of bare grounds in Nakasongola and surrounding areas

Source: Mubiru et al. 2017

Intensification of sustainable agricultural production

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

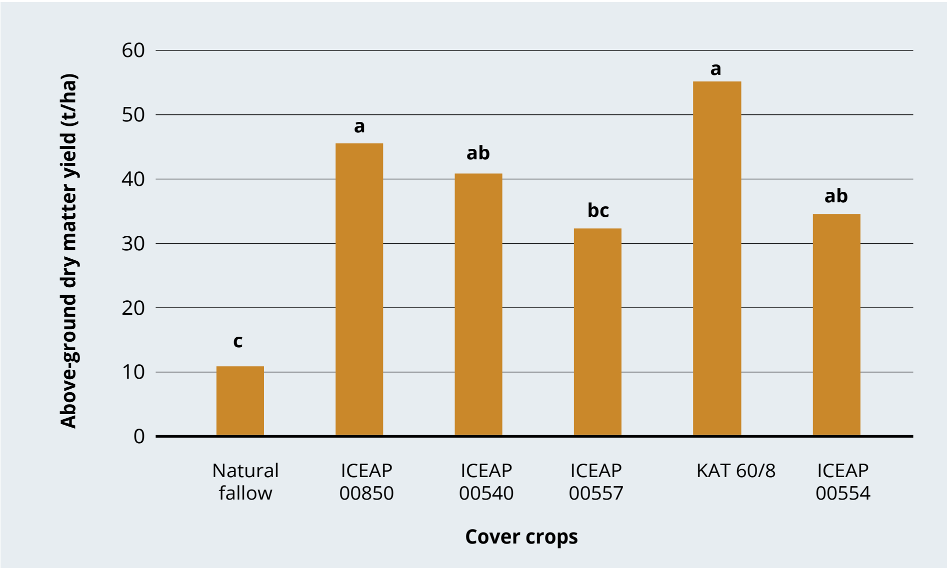

Figure 19.6 **Above-ground dry matter yield of pigeonpea elite varieties compared to natural fallow**

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

Intercropping

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

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

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

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

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

Optimum seeding rates

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

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

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

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

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

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

Bean plant population in permanent planting basins

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

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

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

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

Maize and bean seeding rate in rip lines

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

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

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

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

Comparison of tillage methods

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

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

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

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

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

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

Business models

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

What was the impact?

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

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

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

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

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

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

What should we do next?

Research

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

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

Through the agricultural innovation platforms, we expect to:

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

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

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

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

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

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

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

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

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

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

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Key points

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

Introduction

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

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

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

The study addresses the following specific objectives:

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

Methodology

Project sites

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

Table 20.1 Characteristics of SIMLESA intervention sites

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

Experiment treatments

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

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

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

Table 20.2 **Split-plot experimental design**

Tillage agriculture block	CASI block
T2	T2
T1	T1
T3	T3

Note: CASI = conservation agriculture-based sustainable intensification

Results and discussion

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

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

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

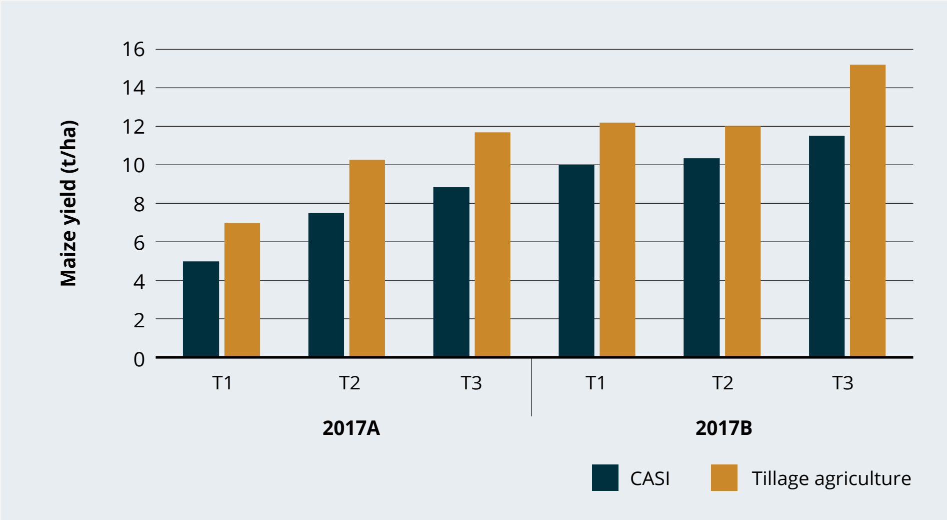

Figure 20.1 Maize yield (cobs) in Kamonyi, Runda, 2017A and 2017B

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

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

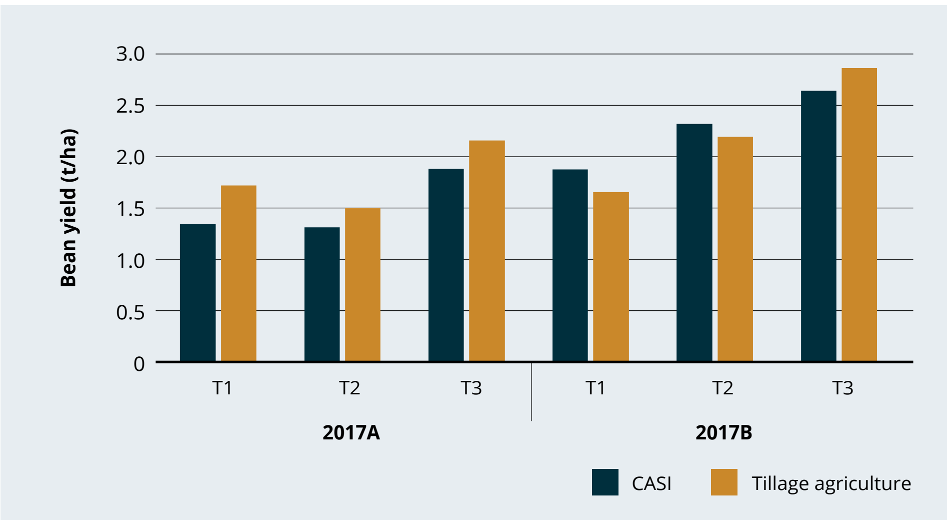

Figure 20.2 Bean yield in Kamonyi, Runda, 2017A and 2017B

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

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

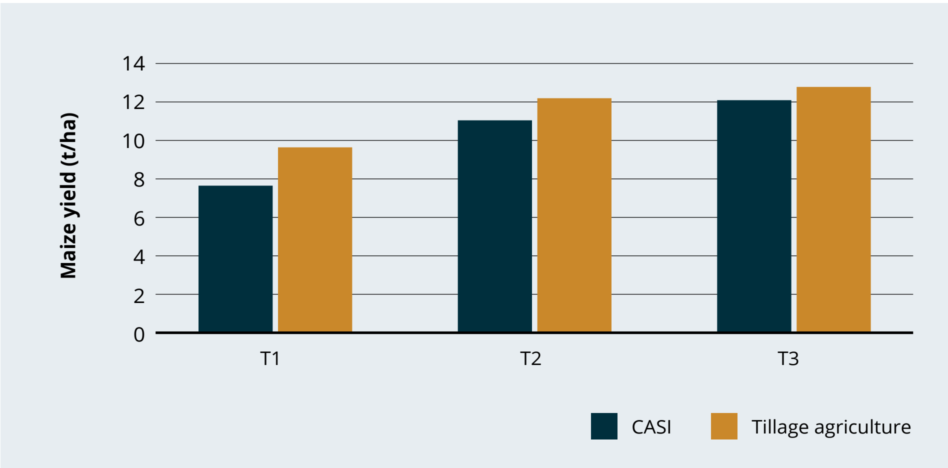

Figure 20.3 **Maize yield (cobs) in Bugesera, Gashora, 2017B**

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

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

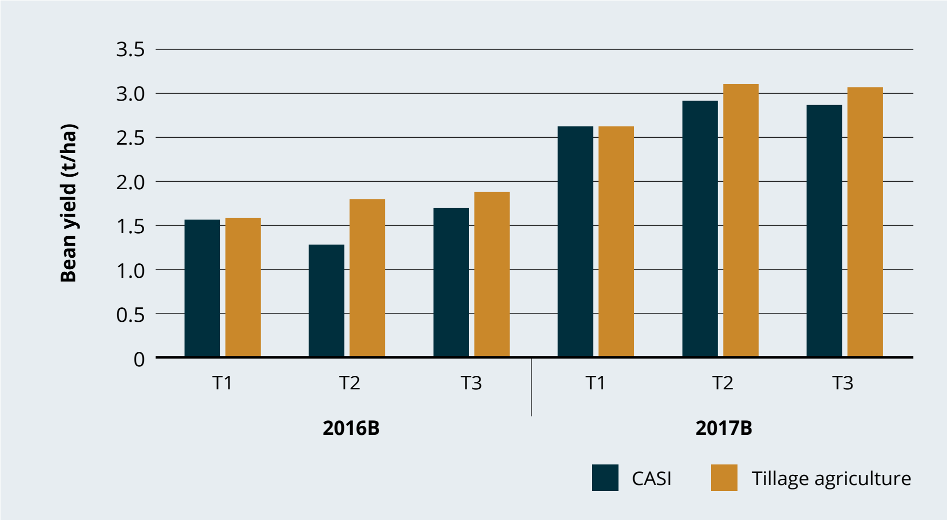

Figure 20.4 **Bean yield in Bugesera, Gashora, 2016B and 2017B**

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

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

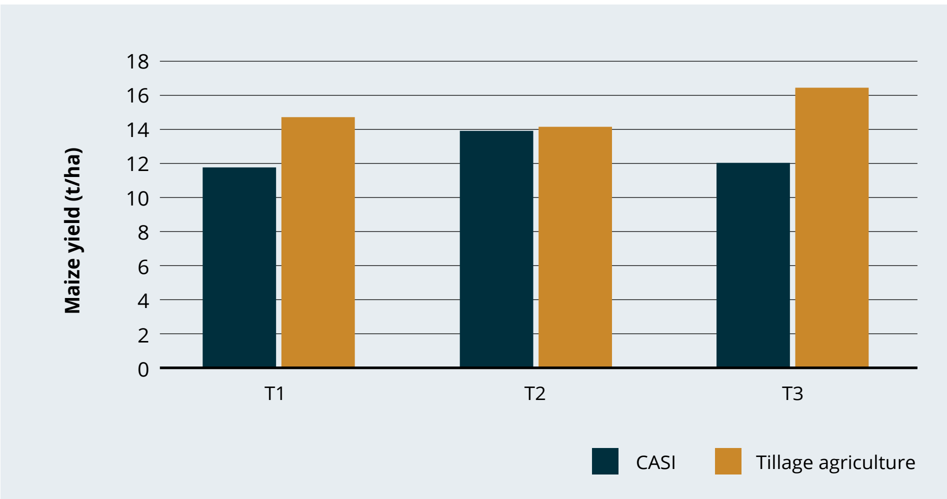

Figure 20.5 **Maize yield (cobs) in Musanze, Cyuve, 2017B**

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

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

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

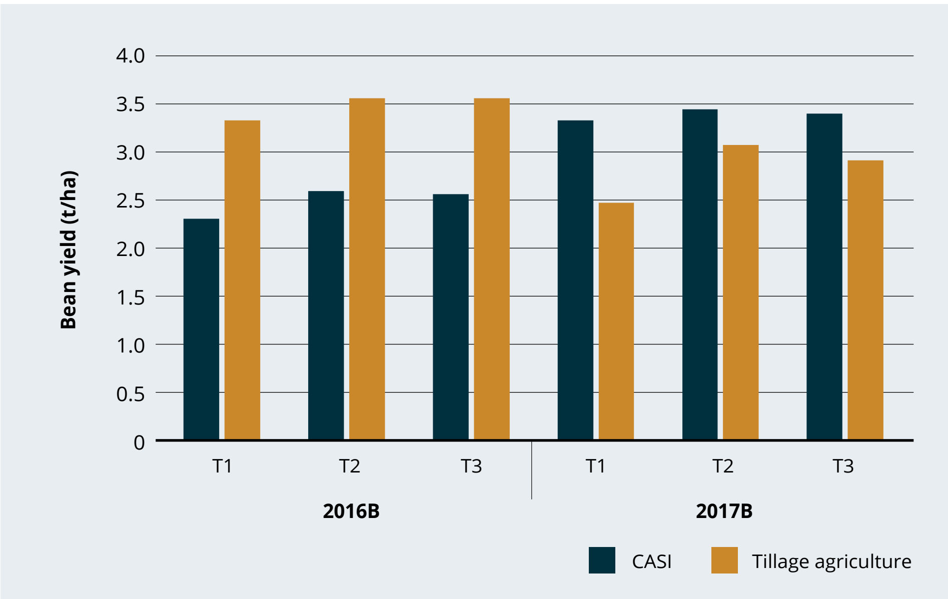

Figure 20.6 Bean yield in Musanze, Cyuve, 2016B and 2017B

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

What was the impact?

Identified and addressed knowledge gaps

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

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

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

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

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

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

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

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

Community networks that support adoption of CASI

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

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

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

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

What should we do next?

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

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

Mainstreaming CASI in Vision 2050

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

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

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

Development of an important and intensive capacity-building program

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

Promotion of CASI through its integration with agroforestry

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

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

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

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

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

Ongoing research programs

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

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

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

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

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

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

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

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

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

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21 Lessons learned from country innovations

Eric Craswell

Key points

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

Introduction

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

Table 21.1 Participating countries and institutions

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

*Spillover countries

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

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

2010-12	• **Identification of CASI options relevant to target agro-ecologies in each country** • Establishment of on-station and on-farm exploratory trials
2012	• **Initiation of innovation platforms and partnerships for scaling** • Mid term review • Realisation of the need for smart sequencing of technologies
2013-14	• **Scalable options rolled out** • Increased scaling out through IPs and partnerships • End of Phase 1 • Increased emphasis on sustainability
2015-17	• **Accelerated scaling through CGS partnerships** • Reduced emphasis on conventional research • Some efforts on crop–livestock integration and soil quality studies

Figure 21.1 Stepwise SIMLESA activities to promote CASI technologies

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

What did we learn?

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

Project design

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

Research paradigm

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

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

Component technologies

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

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

Inputs

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

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

Input and product markets

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

Innovation platforms

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

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

Table 21.2 Agricultural innovation platforms established under SIMLESA

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

Public–private partnerships

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

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

Labour inputs

Intensification involved enhanced labour productivity:

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

Constraints to production

Production was limited by a wide range of factors:

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

Extension/communications

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

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

Policy engagement

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

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

Mechanisation

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

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

Competitive grants scheme

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

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

Post-harvest

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

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

Capacity building

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

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

Australian lessons learned

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

Table 21.3 **Selected partners in each country**

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

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

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SECTION 4

INSTITUTIONS AND SCALING

22 Enabling policy and institutional environment for sustainable intensification

Michael Waithaka & Miriam Kyotalimye

Key points

- Agricultural productivity growth will remain the major driving force in the structural transformation of many countries in Sub-Saharan Africa.
- Rapid population growth and climate variability and change are the main constraints and opportunities for the sustainable intensification of agriculture.
- The adoption of conservation agriculture-based sustainable intensification practices will require concerted and coordinated efforts by all players in technology development, policy development and the private sector.
- Caution should be exercised in making blanket recommendations about which approaches to use. Since local conditions and circumstances are unique, combinations of different approaches will be required to suit specific locations.
- The potential of sustainable intensification to lessen resource constraints calls for a deliberate focus on inclusion strategies to ensure that the benefits are accrued equitably.

Introduction

Africa is facing the challenges of a rapidly increasing population and variability in weather patterns. This is prompting a rethink on the development discourse needed to minimise food insecurity. This comes in the wake of the predominance of smallholder farmers and a huge dependence on agriculture to propel economic development. Agricultural productivity growth will be a critical driving force in the structural transformation of many countries in Sub-Saharan Africa in the foreseeable future. To address these challenges, conservation agriculture-based sustainable intensification (CASI) is being proposed as a potential route to agricultural productivity growth. It is being packaged as a systemic approach to managing natural resources while enhancing agricultural productivity. Overall, the key features of the emerging agenda are:

- a systemic approach
- context adaptation
- linking farmers' and scientific knowledge.

A range of policy interventions are required to ensure that CASI is realised in practice. These interventions address three key areas:

1. incentives for private sector investment
2. de-risking agriculture
3. support the emergence of a viable rural nonfarm economy.

Involvement of the private sector is needed in, for example, market-smart input subsidy schemes. This can also contribute to improvement of the soft and hard infrastructure for marketing and trade, information and communication technology and de-risking of agriculture. Social protection through safety programs can help to ensure inclusivity. Meaningful adoption of CASI practices will require concerted and coordinated efforts by all players in technology development, policy development and the private sector.

It is projected that, by 2050, the world population will increase from 7.3 billion to 9.7 billion, with two-thirds situated in urban areas (United Nations 2014). Most of this growth will occur in Africa and 90% of these new urban dwellers will reside in Africa and Asia. In Africa, young people aged between 15 and 35 years comprise 420 million people of the total continent's population of 1.2 billion people (African Development Bank 2012). Every year about 10–12 million youth enter the labour market against a job creation capacity of only 3 million formal jobs per year. The youth face roughly double the unemployment rate of adults and about 35% of female youth and 20% of male youth are completely excluded from employment, education or training (African Development Bank 2012).

Demographic shifts notwithstanding, extreme weather events occasioned by climate change continue to cause changes in the growing seasons, inadequacy of rainfall and droughts (Intergovernmental Panel on Climate Change 2014). The 2015–16 El Niño weather caused one of the worst droughts recorded in 50 years throughout Africa, Asia and the Americas. Changing climatic conditions are creating conditions for pests and diseases to flourish in previously non-endemic areas, with devastating effects on cropping systems and livelihoods. The fall armyworm, a crop-devastating pest in Latin America, has only recently become endemic in Africa (Centre for Agriculture and Bioscience International 2017). The caterpillar has an appetite for more than 100 plant species, including maize, wheat, rice, sorghum, millet and cotton. It was first detected in Nigeria in January 2016. By January 2017, it had reached South Africa and spread to 24 countries within a year. In 2011, the maize lethal necrosis disease hit Africa and spread just as rapidly (Centre for Agriculture and Bioscience International 2017).

Variable weather, along with other drivers such as speculative investment in food markets and investments in biofuels, has led to a rise in the food price volatility index (Food Security Information Network 2017; Pingali 2015). Projections indicate that these short-term price spikes are likely to be more frequent and profound in the future, piling pressure onto a timely supply response. Populist policy responses that may appear beneficial in the short term, such as export bans, may also heighten those spikes and exacerbate food insecurity and malnutrition.

In Africa, land availability has not declined as steeply as it has in Asia. This gives scope for Africa to be a food basket in the future, if land degradation can be stemmed. However, current productivity levels will not generate enough income and employment to match the huge rate of population growth (Larson, Muraoka & Otsuka 2016). Strategies to enhance the productivity of the existing land resources are required.

Quests for increasing agricultural productivity in Africa through a focus on the smallholder sector abound. The sheer size of the sector makes it the leading pathway for any meaningful reduction in chronic poverty (OECD/FAO 2016; Larson, Muraoka & Otsuka 2010). However, given the wide heterogeneity in agroecological systems and market conditions, multiple approaches will have to be employed. These approaches include concerted efforts at developing locally adapted technologies and attendant management practices and easing of access to inputs and output markets and services. They have also involved targeted investment in research and promotion of CASI technologies.
This chapter explores the big-picture lessons of policies focused on increasing adoption of CASI practices in eastern and southern Africa.

Agricultural intensification

Efforts to promote agricultural intensification have been building on traditional techniques for the past couple of decades (The Montpellier Panel 2013). A more recent development has been the promotion of CASI as a systemic approach to sustainably manage natural resources while enhancing productivity (International Maize and Wheat Improvement Center 2014b; eds Kassie & Marenya 2015). This approach requires that enhanced productivity and resilience of agricultural production systems is achieved while conserving the natural resource base (Zeigler & Steensland 2016; The Montpellier Panel 2013; Garnett et al. 2013; International Fund for Agricultural Development 2010; Pretty, Toulmin & Williams 2011; Tilman et al. 2011). This approach includes using an agroecological perspective with more selective recourse to external inputs, striving to maximise synergies within the farm cycle and seeking adaptation to climate change.
The practices typically aim at improving soil fertility, using a combination of organic, biological and mineral resources, and using water more sparingly and efficiently. Attention to enhancing capacities for sustainable agricultural production growth is needed for smallholder farms to be viable (Jayne, Mather & Mghenyi 2010). Overall, the three key features of the emerging agenda are a systemic approach, context adaptation and linking farmers' and scientific knowledge (Zeigler & Steensland 2016; The Montpellier Panel 2013; Tilman et al. 2011). It contributes to the sustainable development goals (SDG 2) on ending hunger, achieving food security and improving nutrition and sustainable agriculture, and (SDG 12) ensuring sustainable consumption and production patterns.

Sustainable intensification has been discussed as a necessary element for raising yields to levels above current national averages. It is premised on the need to drive productivity growth and capture the dividend expected from growing demand for food and rising prices. For instance, through its crop intensification programs, Rwanda has been able to double its cereal yields since 2005. Even though no universally applicable success formula has emerged so far, Rwanda's example gives credence that substantial progress can be made in Sub-Saharan Africa. Research under SIMLESA and other projects has shown that the best outcomes in terms of income were related to simultaneous adoption of CASI practices (Kassie et al. 2015; International Maize and Wheat Improvement Center 2014b; Marenya, Kyotalimye et al. 2015; Marenya, Mentale et al. 2015).

One aspect of CASI is that it can be adapted to the different requirements and levels of assets that farmers have at their disposal. This means that many different types of farmers can adopt CASI practices and broaden their options to better capture market opportunities. While adoption of agricultural technologies in Sub-Saharan Africa during the green revolution was dismal, the situation has started to change. In 2005, adoption of high-yielding maize varieties stood at 45%, 70% for wheat, 26% for rice, 19% for cassava and 15% for sorghum (Binswanger & McCalla 2010). However, adequate incentives and risk mitigation measures are needed to enable smallholder farmers to make the shift to CASI and for impact at wider scales (Diao et al. 2007).

In the past, agricultural intensification discussions focused solely on the role of seeds and fertilisers without concomitant articulation of complementary agronomic practices. However, there is growing recognition of the need to more formally and deliberately support and promote the inclusion of agronomic and natural resource management practices as critical elements of a balanced agricultural sustainable intensification process (International Maize and Wheat Improvement Center 2014a; Kassie et al. 2015).

Does CASI deliver?

Pretty, Toulmin & Williams (2011) looked at 40 projects and programs on CASI in 20 countries in Africa over the 1990s and 2000s that benefited 10 million farmers on approximately 12 Mha. The CASI practices included crop technological improvements, agroforestry and soil conservation, conservation agriculture, integrated pest management and novel policies. They include partnerships applied on crop, horticulture, livestock, fodder crops and aquaculture commodity value chains. The average growth in yield was twofold. Those projects had the following in common:

- science and farmer inputs into development of sustainable technologies and practices
- building of social capital through use of novel social infrastructure
- capacity building and improved access to knowledge and information through use of modern information and communication technology
- engagement with the private sector for supply of goods and services
- a focus on empowering women
- linkages to financial services
- ensuring public sector support for agriculture.

Recent cross-sectional results emerging from the Adoption Pathways Project (ACIAR 2017) provide evidence of win–win–win outcomes in terms of crop income, food and nutrition security, environment and risk if implemented as composites of practices (eds Kassie & Marenya 2015; International Maize and Wheat Improvement Center 2014b). They show the large roles that information, extension and adaptive research play to improve farm management and produce evidence on where and when such benefits would occur.

Policy interventions needed to promote adoption of CASI technologies in eastern and southern Africa

In response to past development shortcomings, Africa's new strategies and development agenda are building on the successes of the Comprehensive Africa Agriculture Development Program (CAADP) of the New Partnership for Africa Development (2017a). CAADP aims in part to end hunger, double productivity, reduce post-harvest losses by half, reduce the number of people living in poverty by half and promote inclusive 6% growth by 2025. It also calls for the creation of an African Investment Bank. The Malabo Declaration of 2014 is a recommitment to the principles and values of the CAADP process and enhanced investment finance in agriculture (New Partnership for Africa Development 2017b). A refreshing departure from the past is the commitment to mutual accountability to the actions and targets of the CAADP results framework by conducting biennial agricultural reviews. This concerted commitment by many countries holds promise for the eventual transformation of agriculture in Africa.

The Science Agenda for Agriculture in Africa (Forum for Agricultural Research in Africa 2017) is an African-owned and African-led process. It articulates the science, technology, extension, innovations, policy and social learning that Africa needs to apply in order to meet its agricultural and overall development goals. The strategic thrusts of the Science Agenda for Agriculture in Africa in the short to medium term are:

- the implementation of CAADP; increase domestic public and private sector investment
- creating an enabling environment for sustainable application of science for agriculture
- to double the current level of agricultural total factor productivity by 2025 through application of science for agriculture.

In the medium- to long-term, the science agenda is to build systemic science capacity at national and regional levels, capable of addressing emerging and evolving needs arising from climate change and urbanisation.

With the right alignment, this emerging policy environment offers promise to spur wide adoption of CASI practices. This alignment needs to prioritise interventions for every unique challenge. With respect to sustainable intensification, a range of policy interventions are required to ensure that it is realised in practice. Many of these interventions build on those already identified in recent development discourse (Zeigler & Steensland 2016; Larson, Muraoka & Otsuka 2016; Feed the Future 2016; Garnett et al. 2013; International Fund for Agricultural Development 2010), those highlighted in SIMLESA's work (eds Kassie & Marenya 2015; Kassie et al. 2015; Marenya, Menale et al. 2015) and specifically those discussed during SIMLESA's high-level policy forum (Waithaka et al. 2016).

These interventions address three key areas:

1. incentives for private sector investments
2. de-risking agriculture
3. support for the emergence of a viable rural nonfarm economy.

Graphical representation of these interventions is presented in Figure 22.1.

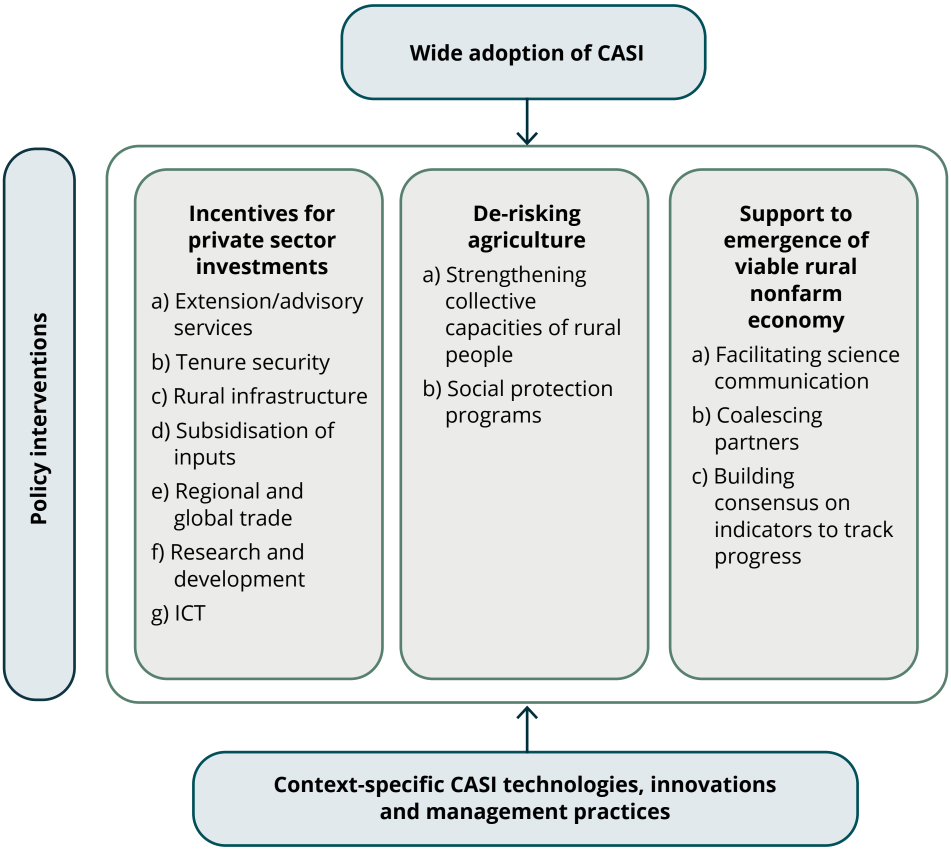

Figure 22.1 **Conceptual representation of policy interventions needed to spur wide adoption of CASI**

Notes: CASI = conservation agriculture-based sustainable intensification; ICT = information and communication technology.

Incentives for private sector investments

Private sector in this context refers to all actors who realise and utilise opportunities presented across value chains for business growth. They include farmers, business service providers, transporters, distributors and researchers. The case for private sector involvement is gaining interest (Zeigler & Steensland 2016; Feed the Future 2016; International Fund for Agricultural Development 2016).

Enhancing access to extension/agrobusiness advisory services

Empirical evidence shows that social returns to agricultural extension exceed returns to research (Pardey et al. 2016). The positive correlation between education and the adoption of CASI practices suggests that investment in rural public education may accelerate the dissemination of agricultural practices (Kassie et al. 2015). An effective and efficient agricultural extension system can enhance the agricultural productivity and production of smallholders through the delivery of innovative agro-advisory services. Several models of agricultural extension that include traditional supply- and demand-driven; participatory and pluralistic extension; private- and NGO-led or a combination have been tested. However, no model has provided a perfect fit for all farming systems, and countries practise a range of combinations (Birner et al. 2009).

Ethiopia and Rwanda have homegrown models of demand-driven, participatory and pluralistic extension service systems. The Ethiopian system includes farmer training centres. These serve as centres for information and knowledge sharing, training and demonstration of technologies and innovation close to farmers' residences. Farmers are organised into development units of 25–30 members with one model farmer leading a group of five followers. On average, there were 21 development agents for every 10,000 farmers in 2014. Although this is lower than the 33 frontline extension workers per 10,000 farmers as stipulated in SIMLESA's joint ministerial communiqué (Waithaka et al. 2016), it was still the highest extension agent to farmer ratio in Africa at the time. The government has also established 25 agricultural technical vocational education and training colleges for training extension workers and offers a full-package extension service (Ethiopian Agricultural Transformation Agency 2014).

This extension system is one of the key drivers of Ethiopia's near self-sufficiency in cereals production. It propelled Tigray region to capture the Gold Award for policies for soil conservation in 2017 (World Future Council 2017). It has been lauded as a model for Africa because of the decentralised and well-structured system, the network of agricultural technical vocational education and training colleges, proximity of the service through establishment of farmer training centres and development of farmer-led institutions. However, reviews still indicate low delivery on pluralism and demand-orientation with room for improvement. Key bottlenecks include low quality of services; a high turnover of development agents due to low resourcing; weak coordination and linkages to research, other actors and the private sector; limited integration of information and communication technology; and low attention to gender and inclusion (Ethiopian Agricultural Transformation Agency 2014).

Rwanda's Twigire Muhinzi model of agricultural extension is similar in many respects to the Ethiopia model. In 2016, the model was supported by 14,800 farmer promoters (one per village) and 2,500 trained farmer field school facilitators (Ministry of Agriculture and Animal Resources of the Republic of Rwanda and Belgian Development Agency 2016). The frontline advisers are supported by the decentralised extension service personnel made up of district and sector agronomists and the Rwanda Agriculture Board. It covers over 1 million households representing up to 50% of the rural population.

Unlike Ethiopia, Rwanda's model incorporates the use of information and communication technology. Short messaging via mobile phones is used to disseminate basic extension services to farmers at minimal cost. Farmers receive instructions from the Rwanda Agriculture Board through frontline extension agents at the beginning of the agricultural season on timing, land preparation, planting, fertiliser application, weeding, etc. The crop intensification program also relies on the farmer promoters to link the Twigire groups to agrodealers and markets and to promote the land consolidation initiative. Its main drawback is its total dependency on donor funding, which may compromise its sustainability in the future. There is a need to strengthen the linkage between local governments and the Ministry of Agriculture with regard to extension service delivery.

Tenure security

Secure land access or tenure has been shown to positively impact adoption decisions (Kassie et al. 2010). Long-term tenure security has the greatest potential to enhance adoption of CASI practices that have long gestation periods before benefits accrue (Kassie et al. 2015). Differences in capital accumulation, productivity and therefore output per worker or labour productivity are, in part, driven by differences in institutions and government policies (Dao 2017; Hall & Jones 1999). Those differences can be assessed using the World Bank's property rights and rule-based governance indicator (World Bank 2017a). This indicator is based on whether property and contract rights are reliably respected and enforced. It assesses the extent to which private economic activity is facilitated by an effective legal system and rule-based governance structure. The average rating for SIMLESA participating countries on this indicator is 3.5 from a maximum of 6. This implies low assurance of property and contract rights, which may potentially be limiting investments in CASI.

From 1997 to 2008, Ethiopia piloted a land certification program for 5 million households in four regions. This represented a shift in policy from state land ownership and frequent redistribution to a regime where farmer user rights—the ability to temporarily transfer these rights or use them as collateral in financial market—were recognised (Deininger et al. 2008). The program had impacts on land rental market participation, long-term agricultural investments, rural off-farm employment and productivity. However, those who shifted into nonfarm employment engaged in unskilled or food for work programs. This suggests that a skills and competence program was required to enable shifts into more skilled lucrative nonfarm employment. Effectiveness of tenure policy in driving productivity growth, sustainable intensification and enhancing resilience has to be backed with a complementary risk management strategy and investments in skill formation and job creation (Siba 2015).

Unlike Ethiopia, in much of Sub-Saharan Africa, access to land and investments in land are regulated within a legal pluralistic framework involving customary, statutory, and religious frameworks (Narh et al. 2016). Ownership remains largely held under customary and communal land rights systems at about 60%, with limited state ownership (Rights and Resources Initiative 2015). A pluralistic legal environment of formal and informal institutions provides an alternative form of property ownership and means of accessing land. Kenya and Ghana provide two contrasting pathways to land reforms within the context of a pluralistic legal environment for land ownership and management.

Kenya's land reform policies aim for a singularised legal framework in which all rights in land are formalised through title registration and certification (Kenya Law Reports 2012). Rights in communal land are registered and recognised as a legal tenure regime equal in status to private and public tenure. In the case of Ghana, statutory and customary property rights systems are formally acknowledged to coexist and the formalisation of rights in land is undertaken either through state-sponsored or customary sector-managed land registration, leading to a consolidation of legal pluralism (Narh et al. 2016).

Despite Kenya's singularised legal framework, citizens have continued to draw on customary institutional frameworks to legitimise their claims to land. The effect is that divergent claims may be held in formal and informal institutions. A system that legally recognises existing land rights systems, such as in Ghana, coupled with legal and business advisory support would be less costly than an entirely new land rights system that is likely to be subverted (Narh et al. 2016).

Current land reforms in both countries are still relatively new and yet to be extensively evaluated in the literature. What is emerging is that formalisation of property rights can be delivered through tenure conversion, from informal tenure to freehold title, but also by extending greater legal recognition to informal or customary tenure arrangements (Narh et al. 2016). This holds promise in enhancing investments in CASI technologies towards improved production and productivity. This analysis suggests that there is room to enhance adoption of CASI practices through improvements in long-term tenure security.

Rural and town infrastructure

Transport connectivity in particular is an essential part of the enabling environment for inclusive and sustained growth. In Africa, the vast majority of farmers are still disconnected from local, regional and global markets, contributing to a high cost of transportation. Transportation costs in Africa have impeded trade more than tariffs and other trade restrictions. The cost of transportation in Sub-Saharan Africa in 2009 ranged from US$0.06 to US$0.11/t/km, compared to US$0.04–0.05/t/km in Brazil, China, United States and western Europe. The costs have been characteristically higher for landlocked countries, including some of the SIMLESA countries (World Bank 2009) and rural communities. The cost and physical separation has denied farmers access to advanced inputs, such as fertiliser and improved seeds, or output markets to sell their produce at more competitive prices.

These challenges are expected to persist. Most of Africa's population is predicted to remain rural in absolute numbers through 2030 and beyond (OECD/FAO 2016). Relying on the public sector to deliver the huge infrastructure required is a daunting task and competes with equally important priorities such as provision of health and education services. Public–private partnerships to develop roads can open up new markets and reduce transaction costs for producers and retailers. Roads are needed to increase consumer demand and supply of inputs and outputs to stimulate development of the nonfarm economy. In Ethiopia, expansion of rural and town infrastructure has attracted firms, generating off-farm employment and benefited the rural economy at large (Shiferaw et al. 2015).

Target 9.1 of the United Nations' sustainable development goals seeks to 'Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human wellbeing, with a focus on affordable and equitable access for all'. The revised Rural Access Index was proposed in the draft indicator framework for the sustainable development goals as an indicator to inform these investments. The Rural Access Index measures the rural population that lives within 2 km of the nearest road that is considered to be in 'good condition'. Initial studies using Kenya data indicate a strong correlation between agricultural production and the Rural Access Index (World Bank 2016, 2017b). The percentage estimates of the revised Rural Access Index are available for eight pilot counties: Ethiopia (22), Kenya (56), Mozambique (20), Tanzania (25), Uganda (53) and Zambia (17) in Africa, and Bangladesh and Nepal in South Asia. In the six African countries, about 148 million people are estimated to have no access, which translates to a Rural Access Index of 32%. This indicates a significant infrastructure gap in rural access. In Tanzania, for instance, only 25% of the rural population lives within 2 km of a road in good condition (World Bank 2016, 2017b). Significant resource allocation is required to close the infrastructure gap; for instance, it is estimated that Kenya would need about US$2 billion to rehabilitate and extend its entire road network.

Regional economic communities have also embarked on a range of infrastructure projects that have the potential to connect rural communities to regional and global markets. One example is the northern road corridor running from Mombasa seaport to inland Bujumbura and serving Kenya, Uganda, Rwanda, Burundi and eastern Democratic Republic of Congo under the East African Community (East African Community 2017). Such corridors will not only link markets between the countries, but will also provide access to seaports and hence global markets for landlocked countries.

Subsidies on seeds and fertilisers

The case for input subsidies in Africa is based on the premise that, as a short-term measure, they may induce farmers to adopt the use of inputs and thereby increase agricultural productivity. On the other hand, there are reservations about their impacts, as they divert funding for long-term investments in research and infrastructure, which are also needed for increased productivity. There are also arguments that agricultural subsidies are expensive, their benefits do not reach target communities and they distort agricultural markets by encouraging farmers to overuse that which is subsidised. After widespread withdrawal of input subsidies in the 1990s under structural adjustment programs, they emerged again in earnest after Malawi's success in 2006 and 2007 (Denning et al. 2009). Malawi's example led to the increased implementation of smart subsidies estimated for some 10 African countries to be US$1 billion annually, equivalent to almost 30% of agricultural budgets (Jayne & Rashid 2013). However, there are still weaknesses in design and implementation, particularly late input delivery. Other weaknesses are the continued lack of emphasis on improving program effectiveness and efficiency, limited attention to graduation processes and inadequate attention to integration with complementary policies and programs.

SIMLESA research has shown that input subsidies have powerful effects in predicting adoption of CASI practices. Setting input subsidy expenditures at levels comparable to those recently observed in Malawi increased adoption by more than 100% in Ethiopia and Kenya, and by about 70% in Tanzania (Marenya, Menale et al. 2015b). The powerful effect of subsidies has been explained by their cost-reducing nature. Research under SIMLESA and related projects has shown that the best outcomes in terms of crop income were related to simultaneous adoption of combinations of recommended practices. It is important to consider the effects of subsidy programs on long-term development of input distribution systems, given the crowding-out effects on the still-developing private sector (eds Kassie & Marenya 2015).

Seeds

Various forms of evidence have suggested that there is great potential in the private seed sector. Besides subsidies, institutional support to develop new and improved varieties, provide quality assurance, upgrade laboratory and market infrastructure, enforce regulations and contracts and simplify procedures can provide potential opportunities that promote the seed sector. Market research on locally preferred genotypes can also support efforts by seed entrepreneurs to popularise preferred varieties and train farmers on their agronomy and post-harvest management. The capacity, human resources, skills, physical facilities and access to international genetic resources of many crops of the apex national research organisations, public universities, international centres and seed companies suggest that these institutions have potential to take charge of variety testing and development (Marenya, Kyotalimye et al. 2015).

The harmonised seed trade regulations in the Association for Strengthening Agricultural Research in Eastern and Central Africa, the Common Market for East and Southern Africa and the East African Community regions offer opportunities to speed up cross-border movement and trade in seed (Common Market for East and Southern Africa 2014). For example, member countries should take advantage of multiple releases to increase access to quality seed by farmers through the cross-border seed business. Harmonised trade agreements create opportunities to more efficiently move sustainably-produced agriculture products to markets that need them, benefiting both the environment and consumers.

There is an additional need to recognise and integrate the informal seed systems as they are gradually transformed to more formal systems. For instance, formal seed systems do not produce seeds for most of these crops. This is left to informal systems (Kimani et al. 2014). Legume crops have been important components in African farming systems. They provide a cheap source of protein and cash income to smallholder farmers and improve soil fertility through nitrogen fixation. Major legume crops include cowpea, field bean, soybean, pigeonpea and peanut. These crops are important in eastern and southern Africa, but their production is limited by low adoption of the new and more productive varieties (Zeigler & Steensland 2016). Quality-declared seed for crops that are not adequately covered under the formal system should be recognised where applicable. This can be through delegation of quality assurance among seed inspectorate agencies, seed companies, NGOs, and research or government enterprises.

Fertilisers

The empirical evidence suggests that fertilisers have potential to drastically enhance productivity. Declining soil fertility, particularly nitrogen and phosphorus, has been a major cause of low crop productivity in Sub-Saharan Africa. For example, almost 80% of African countries are confronted with nitrogen scarcity or nitrogen stress problems (Junguo et al. 2010). Research has shown high response of crops to fertiliser, especially nitrogen and phosphorus. However, the relatively high cost of fertilisers, combined with low agronomic and limited nutrient and water use efficiency, makes the use of fertilisers unprofitable in Sub-Saharan Africa (Jayne & Rashid 2013). Crop response is further affected by limited use of complementary soil and water management practices such as tied ridges, crop residues and organic manure.

The high cost of fertiliser in Africa is driven by many factors including the lack of own manufacturing, storage and blending facilities; poor rural infrastructure; a limited dealer network; small market size; over product differentiation; limited bulk procurement; high freight, port and handling charges; seasonal fluctuations in demand; bulkiness; and the high cost of finance. Forty per cent of the cost of fertiliser in eastern and southern Africa is due to transport from ports of entry to the farmers. For landlocked economies, poor port-handling infrastructure and trade barriers add to the cost of fertiliser. Additional costs to the nearest border point are estimated at US$50–100/t. Low access to credit by actors along the fertiliser value chain also affects demand and supply.

Foster capacity for regional and global agricultural trade

Over the period 1989–2007, only 13% of African exports went to Africa while 64% went to Europe and 23% went to Asia (eds Badiane, Makome & Bahiigwa 2014). Expansion of regional trade enhances the capacity of African countries to raise their competitiveness and benefit from rising demand in regional markets (Zeigler & Steensland 2016). Regional trade also provides the experience needed to break into global value chains and trade. Facilitating intra-Africa trade expansion has high potential to spur entrepreneurship in agriculture towards youth employment and value addition in the regional economy. However, a seamless flow of trade is constrained by over-regulation, high transfer costs and limited product diversification. The answers lie in better trade facilitation towards improving the soft and hard infrastructure for regional trade. This encompasses improving road infrastructure along key corridors; upgrading customs infrastructure, processes and management systems; elimination of non-tariff barriers; development and use of quality standards; and harmonisation of trade facilitating policies (Zeigler & Steensland 2016).

As tariff barriers are gradually reduced across regional economic blocs, there has been a steep rise in non-tariff barriers. The Tripartite Free Trade Area between the Common Market for Eastern and Southern Africa, the East Africa Community and the Southern Africa Development Community established an online non-tariff barriers reporting, monitoring and eliminating mechanism (www.tradebarriers.org). This is supported by a time-bound program for elimination of non-tariff barriers, national focal points and national monitoring committees who meet regularly and report to regional forums. By 2014, some 79 non-tariff barriers to the East Africa Community trade had been cumulatively resolved while 22 remained unresolved (East Africa Community 2014).

Other actions with the potential to make trade and markets function better for value-chain actors and to incentivise investments in the sector include harmonising international standards and greater transparency of sanitary/phytosanitary measures and food labels; intellectual property rights protection; creation of dispute settlement mechanisms; and expediting clearance, movement and release of goods between customs authorities (Zeigler & Steensland 2016; International Fund for Agricultural Development 2010).

Investment in agricultural research-for-development

Policies for promoting productive, sustainable agricultural growth through investments in public agricultural research, development and extension programs have been considered essential to accelerating growth in total factor productivity (Zeigler & Steensland 2016). Each $1 invested in agricultural research and development has been estimated to provide returns of up to $10 or more to the overall economy (Pardey et al. 2016). Overall, public sector expenditure on agriculture in the region still lags behind the Maputo recommendation of at least 10% of the national budget. Although this agriculture spending target was identified as the minimum required to facilitate innovation and technology generation, the average expenditure for eastern and southern African countries stood at 4.4%: 3.3% for Common Market for East and Southern Africa countries and 2.7% for Southern Africa Development Community countries in 2014 (eds Badiane, Makome & Bahiigwa 2014). Along with private sector and collaborative research, public research and development in agriculture has played an essential role in fostering agricultural innovation systems. In the spirit of the Science Agenda for Agriculture in Africa, regional agricultural research systems have catalysed collective actions that allow sharing of proven technologies and innovations as well as scarce resources such as scientist and laboratory infrastructure. National agricultural research systems can be innovation centres for local and national food security. Innovations, technologies and practices developed through publicly funded agricultural research can help producers to be competitive and adapt to climate change. Consumers of agricultural products also have potential to benefit when these efforts lower and stabilise prices and increase access to safe, nutritious food resulting from these investments. Research in this domain can contribute to these efforts by identifying reliable, site-specific and climate-relevant recommendations to minimise risks (Roxburgh 2017).

Information and communications technology for agriculture

Adoption of science-based and information technologies can help producers manage the ever-present risks in agriculture while improving sustainability and competitiveness (Zeigler & Steensland 2016; International Fund for Agricultural Development 2016). For CASI practices, information technology allows farmers to access vital information on market prices, weather, pests and soil health. Precision agriculture and data management tools help producers reduce costs and conserve scarce resources. Public policies that support the development, customisation and dissemination of these technologies to farmers of all scales and the entire value chain are essential if global agricultural output is to be doubled sustainably by 2050. Investments are also needed in market information systems, including information and communication technology, rural internet connectivity and mobile telephone options, to raise awareness on prices, trading regulations and related reforms, supply and deficit zones and stock levels.

Agriculture is considered a high-risk sector. Climate change, biotic and abiotic stresses and the lack of insurance markets and low adaptive capacity of actors heighten the situation. Investment in CASI requires enhancing the capacity of actors to cope with adverse situations, including strengthening social capital and access to social protection. In smallholder agriculture, managing these risks is an important aspect of protecting livelihoods and opening up opportunities for investment. In the context of sustainable intensification in African agricultural production systems, which feature unmitigated production risks and limited or non-existent formal social safety nets, undertaking self-protection is critical. Under these circumstances, emphasis on agricultural practices or technologies that can increase the resilience of crop production against environmental risks is a key feature in protecting livelihoods.

Strengthening the collective capabilities of rural people

Membership-based organisations have a key role to play in helping rural people reduce risk. This stems from learning new techniques and skills, management of individual and collective assets and marketing of produce (International Fund for Agricultural Development 2016). With improved skills, rural people can negotiate with the private sector or government and help hold them accountable. Based on SIMLESA's experience, structured business-focused alliances of institutional actors have represented the successful agricultural innovation platforms that enable and sustain mutual benefits (Marenya, Menale et al. 2015). Each of these actors derives clear benefits, based on their critical but unique roles: marketing, credit, investment, new agricultural technologies, reduced input costs and interaction with policy/decision makers. Many organisations have been shown to have problems of governance, management or representation. However, these organisations are usually best positioned to represent the interests of poor rural people. Capacity building efforts and opportunities to influence policy have been proposed as some of the approaches with the greatest potential to address these concerns (eds Kassie & Marenya 2015). Opportunities to build the social capital of farming communities, and formalising and supporting farmers' groups is an important opportunity to create networks of information exchange, market access and resource mobilisation (eds Kassie & Marenya 2015). Central and local governments can enhance widescale collective action from small pockets of success to empower more farmers. This would in part require retooling of extension workers to enhance their capacity to facilitate innovation platforms, mainstreaming innovation platform approach in the budgeting and planning process, strengthening the legal framework for collective action and reviewing agricultural education curriculums to build capacity in innovation platform approaches (Marenya, Kyotalimye et al. 2015).

Social protection programs

There is general consensus that implementation of agricultural input subsidies and other farm-based support boosts aggregate food production. One area of debate is the unintended consequences of bypassing the most vulnerable rural households, such as the poor and female-headed households (Jayne & Rashid 2013; eds Kassie & Marenya 2015). To address this concern, social protection programs have worked to reduce vulnerability and risk exposure of target groups including youth, women and the elderly. The risks that they try to minimise are those associated with unemployment, disability, old age and sickness. They are packaged as empowerment funding for youth and women groups, cash transfers for the elderly and people with disabilities, and food subsidies. The common challenges reportedly faced by these programs have included capacity limitations, inefficiencies arising from duplicated projects and initiatives, and poor coordination (Jayne & Rashid 2013). Improved targeting is needed to help them improve their risk management (Jayne et al. 2016).

Unconditional cash transfer programs are a popular instrument for poverty reduction and social protection programs. They are implemented by 40 out of 48 countries in Sub-Saharan Africa. Hagen-Zanker et al. (2016) presented an evaluation of cash transfer programs from 165 studies, covering 56 programs in low- and middle-income countries. The programs have shown significant impacts on expenditure on food and other household items, access to schooling or use of health services. The study also found positive impacts on investments in agricultural inputs in Sub-Saharan Africa. This study suggests that cash transfers and other social protection programs can be effective instruments in reducing poverty and spreading of economic autonomy and self-sufficiency.

Support for the emergence of a viable rural nonfarm economy

Agriculture remains a key driver of nonfarm economic development, with each $1 of additional value added in agriculture generating $0.30–0.38 cents in second-round income gains elsewhere in the economy (International Fund for Agricultural Development 2010). A viable rural nonfarm economy requires an environment where people can find greater opportunities and face fewer risks, and where rural youth can build a future. Devolved governance structures in most countries are making this a reality, although most are still in infancy and need to evolve and grow. Greater investment and attention are needed in infrastructure and utilities, particularly roads, electricity, water supply and renewable energy. Also important are rural services, including education, health care, financial services, communication and information and communication technology services, particularly the diffusion of mobile phone coverage in rural areas. Good governance is also critical to the success of all efforts to promote rural growth and reduce poverty, including developing a more sustainable approach to agricultural intensification.

Strengthening the capabilities of rural people to take advantage of opportunities in the rural nonfarm economy has also been central to these efforts (Jayne et al. 2010). Education and skills are particularly important, because they enable rural youth and adults to access employment opportunities and enhance their capacity to start and run their own businesses. Technical and vocational skills development in particular needs to be expanded, strengthened and better tailored to the current needs of rural people. These include microentrepreneurs, workers who wish to remain in their areas of origin and those who may seek to migrate. Strengthening capabilities on all these fronts requires various, often innovative, forms of collaboration, in which governments play effective roles as facilitators, catalysers and mediators and the private sector, non-government organisations and donors are significantly engaged.

There is also a need to demystify CASI, which requires actions in at least three areas:

1. Facilitating science communication experts to simplify CASI into an everyday term for policymakers and the public, like other terms that are now taken for granted (e.g. climate change and food security).
2. Supporting the coalescing of experts and think tanks across the public, private and non-state sectors. Teams should work on the key policy actions for bringing CASI into holistic, interdisciplinary networks or communities of practice. They should build synergistic effects, avoid duplication and ensure learning and the emergence of best practice. A starting point would be to bring together key players to develop action plans as happened in the SIMLESA high-level policy forum.
3. Developing and building consensus on succinct indicators for tracking progress in CASI that are aligned to the sustainable development goals and continental and national frameworks and push for their mainstreaming in national planning and policy documents.

Extracts from the joint communiqué of the high-level policy forum on SIMLESA, Entebbe, Uganda, 28 October 2015

A synthesis of the presentations and discussions made led to the production of a joint communiqué, which was signed by representatives of the ministries responsible for agriculture in Kenya, Mozambique, Rwanda, Tanzania and Uganda. The presentations made at the forum were based on seven policy briefs.

The communiqué was informed by research evidence showing that:

- application of resource conservation practices, crop diversification and livestock integration can increase productivity
- farmers belonging to groups are more likely to diversify cropping patterns, build their resilience by trying out new farming practices, use improved varieties and adopt soil and water conservation practices
- farmers who are close to markets have better access to farm inputs, can readily sell their farm produce and are more likely to adopt maize and legume intercrops and rotations, improved varieties and other CASI management practices.

The communiqué recommended follow-up policy actions to governments and concerted actions from a range of stakeholders in eastern and southern Africa. Examples of actions aimed at promoting CASI through enhanced input access included:

- Governments and development partners working through agricultural extension service agencies should increase frontline extension workers to at least 33 per 10,000 farmers for an effective extension system and other homegrown approaches (e.g. mobile short message services).
- Extension organisations and advisory service providers should train farmers in CASI practices validated under SIMLESA and other players to enhance soil health including the use of organic matter, mineral fertilisers and planting of legume crops like cowpea, soybean and pigeonpea.
- Researchers should establish fertiliser recommendations supported by soil testing by crop and agroecological zones and increase efficiency at farm level by promoting production technologies and practices that enhance nutrient and water use efficiency, to increase returns to fertiliser use.

The full text of the communiqué is available at https://simlesa.cimmyt.org.

Conclusion

Agricultural productivity growth will remain a major driving force in the structural transformation of many countries in Sub-Saharan Africa in the foreseeable future. Unfortunately, this situation will be shrouded by increasing challenges from rapid population growth and climate change and variability.

CASI is a potential route to agricultural productivity growth and enhanced food security into the future. However, meaningful adoption of CASI practices will require concerted and coordinated efforts by all players in technology development, policy development and the private sector.

Multipronged approaches from extension to social protection are needed. Caution should be exercised in making blanket recommendations on which approaches to use. Since local conditions and circumstances are unique, combinations of the approaches will be required to suit specific locations.

CASI's potential to lessen resource constraints calls for a deliberate focus on inclusion strategies to ensure that the benefits accrued are equitable. Robust monitoring and evaluation frameworks are also required to remove the ambiguities related to the measurement of CASI and its impacts, including the relevance and effectiveness of policy actions.

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23 Benefits and trade-offs from alternative adoption pathways

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Key points

- Various pathways towards widespread conservation agriculture-based sustainable intensification (CASI) can be effective, including subsistence-based, market-oriented and policy-driven pathways.
- Both the subsistence-led and the market-led pathways can be enabled by investing in agricultural advisory systems such as increasing the extension agent to farmer ratio and encouraging other complimentary providers of services.
- Although CASI practices include sets of practices with demonstrable cost advantages and productivity dividends, the widely known enablers of agricultural technology adoption also remain relevant.
- Policy attention in support of CASI should remain focused on better access to markets, solid information delivery through strong agricultural extension and policy and infrastructure investments to produce favourable input and output price ratios.

Introduction

The need for conservation agriculture-based sustainable intensification (CASI) at this juncture is well established. The most promising options for increasing food production and achieving household food security involve some form of intensification—either intensify on available land, maintain or produce more food using limited amounts of family labour, or both. CASI includes the notion that smallholder agriculture can be a steward of the natural resource base while also sustaining productivity. However, this requires that these practices, technologies or interventions are more productive than current ones, address farmers' needs and are compatible with their circumstance. Even when these criteria are met, farmers have typically accepted certain trade-offs in the process of adopting CASI practices.

The literature on this issue, including that from the SIMLESA program, shows that resource scarcities (or more specifically, high opportunity costs of cash, land, labour and the like), have discouraged adoption and diffusion of the most promising CASI practices. Resources used to purchase inputs and labour for CASI practices may be alternatively directed towards more immediate needs. Delayed returns on investment have similarly posed a major challenge for CASI adoption.

Trade-offs have often resulted from agricultural market conditions. Markets that provide incentives for investment in CASI require information, grading facilities and other market infrastructure. However, these markets may exclude certain groups, including some of the most at-risk members of the smallholder population. Environmentally benign production methods have not always guaranteed high production or profits. For example, building soil carbon stocks and soil fertility may require several seasons of new practices before crop yields improve. Strategies, or adoption pathways, that help farmers bear (not avoid) these costs, including early incentives (e.g. labour savings), can help ensure that farmers benefit from CASI. Policies that subsidise inputs in the short term may also crowd out investments in private fertiliser distribution.

This chapter demonstrates the plurality of pathways that can lead households to rapidly and sustainably intensify. We identify three key pathways that smallholder agriculture can follow when adopting CASI practices:

1. subsistence and food security
2. markets and incentives
3. institutions and policies.

The first pathway involves securing sustainable household food security from diversified and household-level production. Household-level production for food security has been recognised as a strategy in market-constrained and relatively land-abundant situations. The second route involves greater participation in input and output markets. The promise of higher incomes from vibrant food markets can provide strong incentives for technology adoption and CASI. New market outlets can make the sale of staple crops such as maize and legumes a viable source of income for those who have access to these well-functioning markets. The third pathway involves an enabling policy and institutional environment including finance and information. The macro-economic conditions in which farmers operate will determine whether they have access to inputs and services that support adoption of CASI practices.

The three pathways above are not mutually exclusive (Figure 23.1). The predominant pathway used by individual farmers or communities of farmers in a country or region will depend on the needs and circumstances of the community. A number of steps can be taken to reduce trade-offs, or the potential losses that often accompany the different CASI pathways. These include building better information systems, developing contract-based value chains and grading and post-harvest processes.

First, we describe the data collected by the SIMLESA program, which are used in this analysis. This is followed by three main sections that outline and explain each of the pathways and their trade-offs. The concluding section outlines the key lessons that have been learned from the body of evidence generated in SIMLESA and similar literature.

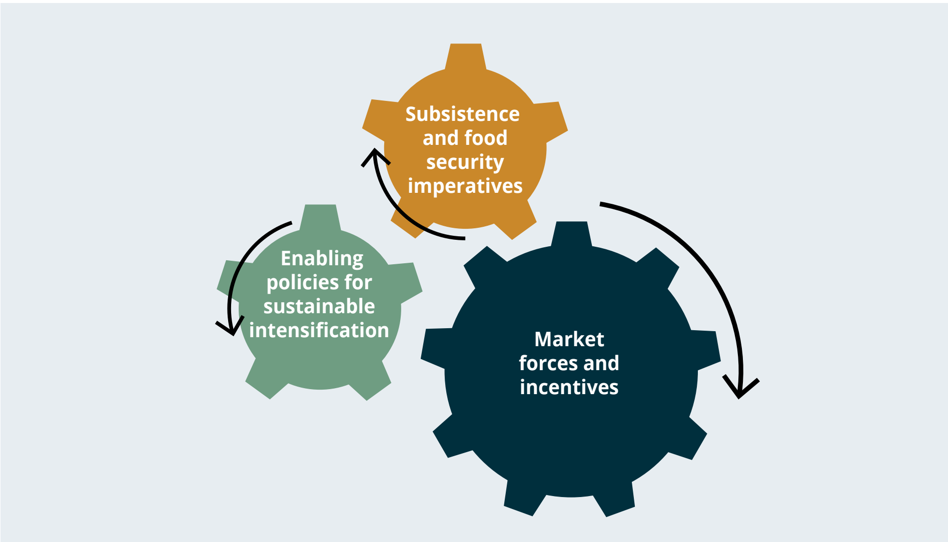

Figure 23.1 Three related pathways to sustainable intensification

Data used in this chapter

Broadly, the research results reported in this chapter are based on household and plot-level data gathered under the SIMLESA program, as well as a collaborative project named the Adoption Pathways Project[20]. The data were collected to understand drivers and enabling environments for the adoption of CASI practices and their impacts on farmers' livelihoods. The broad aim of these data was to generate information on farmers' resource conditions, community characteristics, gender relations, value chains and policies. This information was then used to support farmers, extension agencies, non-governmental organisations and public agencies including ministries of agriculture and agribusinesses along the value chains to inform investment in CASI technologies.

20 The Adoption Pathways Project, formally known as Identifying socioeconomic constraints to, and incentives for, faster technology adoption: Pathways to sustainable intensification in eastern and southern Africa, was meant to complement the work of the SIMLESA program and focus on generating information to support researchers, decisionmakers, farmers and development partners in making high-quality decisions that improve food security by providing appropriate panel datasets, knowledge base, tools and methods that can be used for better targeting of technologies, accelerating adoption and to understand the dynamics of socioeconomic development because of technology and policy interventions within maize farming systems in eastern and southern Africa. The project ended in June 2016. The data from this project are now available in Open Access at http://data.cimmyt.org/dvn/dv/cimmytdatadvn/faces/StudyListingPage.xhtml?mode=1&collectionId=119.

Subsistence and food security

Own-farm production has offered one of the most important strategies for ensuring food security in rural areas. Empirical studies associating food security with intensity of adoption of improved varieties have demonstrated the relationship between household production levels and food security (Kassie, Jaleta & Matei 2014). Food security and nutrition depended on household-level production and crop diversification among SIMLESA households. Kassie et al. (2016) further demonstrated a link between the mix of crops under production and household diets. They showed increases of 27%, 29%, 50% and 7% in kcal, protein, iron and diet diversity, respectively, when crop diversification was adopted jointly with improved maize varieties (Kassie et al. 2016) (Figure 23.2). Dietary diversity also increased when modern seeds and maize–legume diversification occurred simultaneously (Hailemariam et al. 2013). This suggests that, for many rural households, access to agricultural and labour markets is not the primary means of procuring food, especially when households have limited access to food markets. The results demonstrate the benefits of smallholder diversification in the face of subsistence production and weak markets. Households that rely on their own farms for food and nutrition security can reduce the risk of crop failure by sustainably intensifying production. Production of a diversified crop portfolio should be encouraged under these conditions, given the limited opportunities for specialisation and constrained access to diversified diets through local food markets. The requirements of this pathway towards CASI should, therefore, be critical information for agricultural extension and the development of other policies.

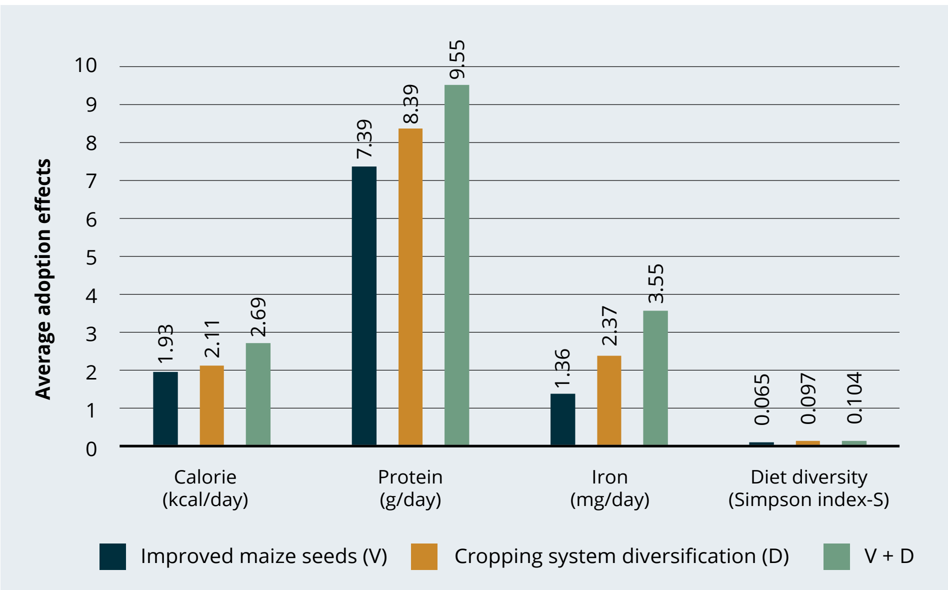

Figure 23.2 **Impacts of CASI practices on nutrition**

Source: Kassie et al. 2016

When farm production generates sufficient food and profits for an adequate food supply, the opportunity cost of investing labour towards own food production can be low, depending on food prices in local markets. However, the cost increases when labour is in high demand. Peak labour-demand periods for farmers can coincide with household food shortages and create a trade-off between immediate needs and medium- to long-term investment on their own farms. Most of the costs of production must be incurred up-front, from savings, credit or other non-crop income. The decision to outsource labour can minimise costs when the value of a household members' labour is high, food stocks from previous harvests have been drawn down and labour investments are immediately necessary to maintain on-farm operations.

Labour markets had a mixed effect on adoption of CASI practices among SIMLESA households. Households with salaried off-farm incomes had a higher probability of adopting soil and water conservation practices in Kenya. Yet the probability of manure use was lower in households with a salary earner, suggesting that, in some cases, the comparative advantage of off-farm income outweighed on-farm agricultural investment (Kassie et al. 2015). Similarly, Marenya, Menale et al. (2017) found that farmers who had off-farm wages or income or off-farm self-employment were less likely to adopt minimum tillage and mulching practices in Ethiopia. Yet in Tanzania, those who were self-employed off-farm were less likely to practise minimum tillage. Marenya, Menale et al. (2017) concluded that the negative correlation between access to nonfarm income and adoption of CASI practices may suggest 'high opportunity cost of labour' used on-farm. This means that farmers are better off in some cases allocating their labour to economic activities outside their farm. To offset this, Marenya, Menale et al. (2017) suggested that significant increases in on-farm crop yields and incomes are needed to attract more family labour to their own-farm production activities.

The high discount rate occasioned by short-term survival needs is the most cited cost of CASI (Diagana 1999). Rural households faced a trade-off between immediate survival and long-term benefits of CASI (e.g. soil quality) when households used the entirety of existing labour and financial tools to support immediate needs or when market failures were common. Most SIMLESA farmers who had an immediate and urgent need for food production did not invest in CASI technologies. Households did not reallocate resources that supported these strategies towards investment in intensification. Rather, they tended to use other short-term livelihood strategies to fulfil immediate needs.

Scholars have suggested that these costs and trade-offs have hampered and explained low CASI technology adoption levels, even when the benefits of adoption were significant (Marenya, Smith & Nkonya 2012; Reardon et al. 2001). One way to enable farmers to adopt CASI practices is to support immediate needs (decrease discount rates) and reduce financial hurdles. For example, Schmidt et al. (2017) showed that investments in own-farm soil erosion control in Ethiopia would largely be unprofitable given the prevailing shadow wages (i.e. alternative wage opportunities) and subsistence needs to sell labour for wage income. They suggest that sustainable land management investments must be paired with other input and infrastructure investments, as well as subsidies for initial labour costs, in order to incentivise adoption and long-term sustainable land management maintenance.

Markets and incentives

In areas with good infrastructure and inclusive market access, opportunities for the commercialisation of food crops can be high. Diversification into relatively high-value, nutrient-dense legumes can support high returns on production and incentivise CASI. However, the agricultural output markets assessed under SIMLESA operated with multiple market failures. Despite recent trends towards structured, quality-driven staple food grain markets in Africa (Vandeplas & Minten 2015), data collected under SIMLESA show that, in Ethiopia and Kenya, maize and legume grain markets were mostly informal with little or no integration, and no access to financial or insurance markets (Marenya, Bekele & Odendo 2016). Moreover, these markets were localised, and most transactions are made at or within the vicinity of the local village. In Ethiopia and Kenya, the local village or town was the primary area of operation for 94% and 72% of maize traders (Table 23.1).

Table 23.1 The main location of maize traders' operations and sales

	Operations and sales (%)	
Location	**Ethiopia**	**Kenya**
Local market, village and town	94	72.1
District/woreda	5.8	–
Zone	0.2	–
Division	–	10.9
Subcountry	–	9.3
Country	–	7.8

Source: Marenya, Bekele & Odendo 2016

Further, there were few transactions based on contracts in either country. Nearly all traders had no contract-based purchases from farmers in Ethiopia (99.6%) and 91% in Kenya (Table 23.2). Commitment failure is common in the absence of contracts (Palaskas & Harriss-White 1993; Gebre-Madhin 2001). These commitment failures may be explained by missing market information, inadequate regulation and lack of legal framework for contract enforcement. In other words, these markets are largely informal, rather than structured institutions with the capacity to facilitate anonymous exchange (Gebre-Madhin 2001, Kydd & Doward 2004). Kydd & Doward (2004) concluded that these qualities can hinder the development of modern value chains and the benefits of sustainable intensification.

Table 23.2 Prevalence of contracts in purchase or sale transactions by traders

	Ethiopia (%)	Kenya (%)
Do you have supply contracts with farmers?		
No contract	99.6	90.6
Have supply contract	0.4	9.4
Do you have buyer contracts to purchase from you?		
No contract	96.0	87.7
Have buyer contract	4.0	12.3

Source: Marenya, Bekele & Odendo 2016

The trade-off between costs of market access (e.g. transportation costs) and market revenues can determine the benefits of this agricultural intensification pathway and drive adoption of CASI practices. Some evidence has shown that SIMLESA households who were located close to markets were more likely to be net sellers of maize (Marenya, Kassie et al. 2017). CASI adoption patterns have been explained by household proximity to peri-urban markets, where farmers were more likely to implement CASI practices such as maize–legume diversification. For example, Kassie et al. (2015) found that households located closer to markets had a higher chance of adopting maize–legume crop mixes and manure in Ethiopia, improved varieties in Malawi and minimum tillage in Tanzania. As household distance from main markets increased, the chances that they implemented practices like minimum tillage, soil conservation and fertilisers decreased (Marenya, Menale et al. 2017).

Marenya, Bekele & Odendo (2016) suggested that expanding market access beyond local spot markets has potential to substantially increase financial incentives for CASI. Second, availability of support services such as transportation, post-harvest handling and grading will likely increase value addition along the value chain, opening up greater income enhancement opportunities beyond primary production. Third, price information systems based on widely accepted quality definitions can also substantially increase financial incentives for CASI. These can provide incentive signals for quality-based pricing and therefore production and value capture by farmers, providing financial incentives for CASI.

Institutions and policies

The potential benefits of CASI are clearly apparent, but also depend on the policy environment. Major policy reorientation across much of eastern and southern Africa has been necessary for the benefits of CASI practices to outweigh certain costs. In rural settings, where own production tends to be the major source of food, subsistence needs form an important consideration. Specific policies that support CASI can address constraints to food security. Policies can help address the high costs of investments in natural resources by supporting rural financial services. Policies that prioritise adaptive and on-farm research or fund adaptive research and agricultural extension can also help farmers to bear some of the adaptive and information gathering costs of CASI. Policies that promote investment in agricultural input and output value chains also have potential to greatly enhance rural livelihoods. In this section, we report results from a policy simulation exercise that sheds light on some principles to guide extension and programs that support investment in agricultural inputs and enhance market access. The policies that were simulated include investments in agricultural extension, input subsidies, credit provision and rural infrastructure. They can function to offset initial investment costs, since consumption smoothing through credit has been important in determining adoption outcomes.

Extension institutions

In the agricultural economies of eastern and southern Africa, extension services remain one of the most critical public investments and rural services. Recent interest in reforming agricultural extension services has given new impetus to revamping these services, which suffered neglect during the years of the structural adjustment programs of the 1980s (Rivera & Alex 2004; Pye-Smith 2012).

These declines were partly due to unsustainable expansion during the 1980s decade and the need for public sector contraction as part of the structural adjustment reforms. At the peak of investments in extension in the pre-adjustment years, the developing country average of the extension agent to farmer ratio was 1:300 and that declined to 1:1,500–3,000 by 2012 (Pye-Smith 2012).

Reflecting the new impetus for extension, the Ethiopian government has recently been investing considerably in agricultural extension, specifically the number of frontline extension staff. Davis et al. (2010) showed that, in Ethiopia, these efforts contributed to one of the most favourable extension agent to farmer ratios of 16:10,000 (at the time of publishing). This is certainly impressive, compared to 4:10,000 in Tanzania, 3:10,000 in Nigeria, 6:10,000 in Indonesia and 2:10,000 in India (Davis et al. 2010). Compare this with the recommendation in Pye-Smith (2012), that a good ratio concentration of extension agents would be about one extension agent for every 300 farmers, or 33 agents per 10,000 farmers, suggesting that Ethiopia was halfway towards this target.

Input subsidies

The return of fertiliser subsidies in eastern and southern Africa in recent years comes after a period of their absence in the wake of the structural adjustment programs of the 1980s and 1990s. At their peak in the 1960s and 1970s, the main reasoning for subsidies was based on evidence from the Asian green revolution showing that subsidies were crucial in supporting the widespread adoption of improved seeds and fertilisers. The evidence showed that carefully targeted subsidies can allow liquidity-constrained households to overcome short-term financing gaps that trap many farmers in vicious cycles of low productivity. By lowering the overall costs of inputs, farmers may be able to afford fertiliser and other CASI practices. Subsidies could relieve financial, liquidity, profitability or infrastructure-induced cost constraints.

Consequently, public expenditures on subsidies has been considerable in countries that chose to implement them. For example, Malawi spent about 72% of its agricultural budget in 2008–09 on agricultural input subsidies (Dorward & Chirwa 2010). Such a policy of increasing government investment on subsidies has frequently led to a number of challenges, including high fiscal costs and crowding out investment in other areas of agricultural development. The effect of subsidy policies will depend on a number of conditions being met, which ensure that market-smart programs do not undermine the private agribusiness sector (Smale, Byerlee & Jayne 2011).

There has been noticeable progress in market access and agribusiness activity in eastern and southern Africa since the end of the 1990s (Jayne, Chapoto & Shiferaw 2011). Nevertheless, outstanding issues remain that prevent these sectors from attaining their full potential. Some of these are inadequate infrastructure and weak input (output) supply chains leading to effectively high (low) and prices for inputs (outputs). These impediments have hampered technology adoption because they made otherwise beneficial technologies (e.g. hybrid–fertiliser combinations, herbicide-based conservation methods) inaccessible or expensive (Marenya, Mentale et al. 2017). Poor infrastructure leads to market isolation and lack of integration with national or regional markets, implying that any increased production can easily lower producer prices (due to the limited market horizons), erode profitability and undermine technology use. Due to poor infrastructure, fertiliser/grain price ratios in Sub-Saharan Africa have been found to be two times those found in Latin America or Asia (Yamano & Arai 2010).

Policy simulation exercise

In this section, we report on a policy simulation exercise to illustrate the possible policy pathways towards the adoption of CASI practices. We use minimum tillage combined with mulching as two important conservation agriculture-based practices that were researched under SIMLESA. The simulations are carried out based on the regression and simulation procedures reported in Marenya, Menale et al. (2017). We simulated two main policy aspects involving extension and fertiliser subsidies (Table 23.3). These were combined with indicators of market access and fertiliser–maize price ratios.

Table 23.3 **Policy simulation variables**

	Ethiopia	Kenya	Malawi	Tanzania	Average
Extension personnel per 10,000 farmers	**16.0**	**10.0**	**6.2**	**4.0**	**9.0**
Years	2010	2012	2008	2010	
Source	Davis et al. (2010)	Government of Kenya (2012)	Pablo et al. (2008)	Davis et al. (2010)	Authors' computations from indicated sources
Input subsidy expenditure as a percentage of public agriculture spending (%)	**10.4**	**19.0**	**58.9**	**46.0**	**33.6**
Years	2009–11	2009–11	2009-11	2009–11	
Source	Jayne & Rashid (2013)	Jayne & Rashid (2013)	Jayne & Rashid (2013)	Jayne & Rashid (2013)	Authors' computations from indicated sources
Farm gate maize prices (US$/kg)	**0.158**	**0.230**	**0.170**	**0.189**	**0.187**
Year	2010	2010	2010	2010	
Source	Authors' computations	Authors' computations	Authors' computations	Authors' computations	Authors' computations
Farm gate fertiliser prices (US$/kg)	**0.455**	**0.807**	**0.392**	**0.344**	**0.500**
Year	2010	2010	2010	2010	
Source	Authors' computations	Authors' computations	Authors' computations	Authors' computations	Authors' computations
Fertiliser–maize price ratios	**2.9**	**3.5**	**2.3**	**1.8**	**2.7**
Year	2010	2010	2010	2010	
Source	Authors' computations	Authors' computations	Authors' computations	Authors' computations	Authors' computations

Extension simulations

The extension agent to farmer ratio had a significant impact on the predicted probability of adopting minimum tillage combined with mulch as one element of conservation agriculture-based sustainable intensification (CASI) across all countries (Table 23.4). In Kenya, the probability of adoption increased from 3.9% to 6.5% by increasing the extension agent to 10,000 farmers ratio from 10 to 16. Similarly, the probability of adoption increased from about 34% to about 50% in Malawi and from 10% to 21% in Tanzania when the extension agent to 10,000 farmers ratio increased from 6 to 16 in Malawi and from 4 to 16 in Tanzania.

Subsidy expenditures had a significant impact on the probability of adoption when the extension agent to farmer ratio was reduced (by setting it at the lowest level, observed in Tanzania) and the input subsidy expenditure as a percentage of public agriculture spending was increased to Malawi's level of 58.9%. Despite the 75% reduction in the extension agent to farmer ratio in Ethiopia, the probability of adoption increased by about 4% (from 26% to 30%), due to the increase in subsidy expenditure. Increasing the extension agent to farmer ratio to compensate for reductions in subsidy expenditure led to a marginal increase in the probability of adoption in Kenya. For Tanzania and Malawi, the probability of adoption declined by between 2% (Tanzania) and 14% (Malawi).

Table 23.4 Extension simulations: predicted probability of CASI adoption by sample

Panel I:	**Effect of increasing EFR: for each country set EFR at Ethiopian level**				
EFR level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
At respective country means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Ethiopian mean (C)	0.214*** (0.019)	N/A	0.065*** (0.013)	0.498*** (0.067)	0.214*** (0.057)
Chi-square tests					
A = B	NA	8.60**	7.09**	6.0**	4.61**
A = C	5.47***	N/A	4.47**	5.91**	4.10**
Panel II:	**Effect of low EFR and high SER: For each country set EFR at Tanzania's level and SER at Malawi's level**				
EFR/SER level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective country means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Tanzania's EFR and Malawi's SER (B)	0.213*** (0.023)	0.301*** (0.037)	0.092*** (0.029)	0.308*** (0.014)	0.142*** (0.019)
Chi-square tests					
A = B	3.85*	1.31	3.60*	6.50*	5.62*

Note: CASI = conservation agriculture-based sustainable intensification

Table 23.4 Extension simulations: predicted probability of CASI adoption by sample (continued)

Panel III: Effect of high EFR with low SER: For each country set EFR and SER at Ethiopia's level					
EFR/SER level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective country means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Ethiopia's EFR and Ethiopia's SER (B)	0.129*** (0.015)	N/A	0.048*** (0.006)	0.201*** (0.047)	0.080*** (0.015)
Chi-square tests					
A = B	7.22**	1.31	3.61*	7.89*	2.35
Panel IV: Effect of high extension with complete absence of credit: for each country set credit constraint at 1 and EFR at Ethiopia's level					
EFR/Credit constraint level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective country means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
No credit available and EFR at Ethiopia's level (B)	0.192*** (0.019)	0.179*** (0.022)	0.056*** (0.011)	0.469*** (0.067)	0.184*** (0.051)
Chi-square tests					
A = B	1.75	12.16***	2.33	4.04*	2.73*
Observations	11,188	3,861	2,851	2,937	1,539

Notes: EFR = extension agent to farmer ratio; SER = input subsidy expenditure as a percentage of public agriculture spending; CASI = conservation agriculture-based sustainable intensification; *, ** and *** indicates statistical significance at 1.5 and 10% levels respectively.

The compensatory effect of a high extension ratio and lack of credit is demonstrated when the extension agent to farmer ratio was increased but credit was assumed to be unavailable. This was achieved by setting the extension agent to farmer ratio at the highest level (Ethiopia), and making the credit constraint binding for all farmers. The results show that in all cases (except Ethiopia), the magnitudes of increase ranged from 16% in Kenya, 13% in Malawi and 8% in Tanzania. The probability of adoption in Ethiopia fell from 26% to 18% when 100% of household credit was constrained (from 56%) and the extension agent to farmer ratio was unchanged.

Subsidy simulations

Setting subsidy expenditure as a ratio of all agricultural expenditure at the Malawian level (which was observed as the highest) increased the probability of adoption by more than 100% in Ethiopia and Kenya and about 40% in Tanzania (Table 23.5). Lowering subsidy expenditure and increasing credit (by treating every household as if they all had credit) lowered the probability of adoption in all cases (including the pooled sample) except in Ethiopia. Eliminating credit availability and increasing and setting subsidy expenditure at its highest (Malawian) level increased adoption across all countries except in Malawi, where elimination of credit had no corresponding subsidy expenditure increase.

Table 23.5 **Subsidy simulations: predicted probability of CASI adoption by sample**

Panel I: Effect of increasing SER: for each country set SER at Malawi's level					
SER level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
At respective sample means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At whole sample mean (B)	N/A	0.401*** (0.060)	0.065*** (0.013)	0.197*** (0.045)	0.067*** (0.013)
At Malawian mean (C)	0.319*** (0.67)	0.572*** (0.126)	0.140*** (0.057)	NA	0.143** (0.019)
Chi-square tests					
A = B	N/A	5.90**	4.80**	9.27***	9.91***
A = C	5.12**	6.38**	3.11*	NA	5.62**
Elasticities of adoption with SER					
A to B	NA	0.248	0.868	0.971	1.199
A to C	1.194	0.261	1.233	NA	1.585
Panel II: Effect of low subsidy with full credit availability: for each country set SER at Ethiopia's level and credit constraint at 0					
SER/credit constraint level	**Pooled**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective sample means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Ethiopia's SER and no credit constraint (B)	0.109*** (0.024)	0.285*** (0.010)	0.033*** (0.006)	0.119*** (0.062)	0.031*** (0.017)
Chi-square tests					
A = B	6.15**	19.3***	2.54	11.83***	17.93***
Panel III: Effect of high subsidy with no credit available: for each country set credit constraint at 1 and SER =at Malawi's level					
SER/credit constraint level	**Pooled**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective sample means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Malawi's SER and no credit available (B)	0.292*** (0.064)	0.547*** (0.126)	0.124*** (0.052)	0.312*** (0.010)	0.120*** (0.017)
Chi-square tests					
A = B	3.80*	5.34*	2.61	20.96***	1.63
Observations	11,188	3,861	2,851	2,937	1,539

Notes: EFR = extension agent to farmer ratio; SER = input subsidy expenditure as a percentage of public agriculture spending; CASI = conservation agriculture-based sustainable intensification; *, ** and *** indicates statistical significance at 1.5 and 10% levels respectively.

Fertiliser–maize price ratio simulations

A high fertiliser–maize price ratio can indicate either that fertiliser prices are too high relative to maize or that maize prices are too low relative to fertiliser. When fertiliser is seen as a critical component for conservation agriculture success, an increase in the fertiliser–maize price ratio resulting from high fertiliser prices can decrease the probability of adoption (Table 23.6). The profitability of fertiliser and maize production can decrease when the ratio is high (because of very low maize prices relative to those of fertiliser, all else equal), and undermine the rationale for CASI. Lowering the fertiliser–maize price ratio increased the probability of adoption in all cases. When the fertiliser–maize price ratio was set at the whole sample mean, increasing the values for Malawi and Tanzania, then the probability of adoption reduced in both cases from 34% and 10% to 32% and 8%, respectively.

Table 23.6 **Fertiliser–maize price ratio simulations: predicted probability of CASI adoption by sample**

Panel I:	**Effect of increasing FMPR: for each country set FMPR at Tanzania's level**				
FMPR level	**Whole sample**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
At respective sample means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At whole sample mean (B)	NA	0.268*** (0.010)	0.051*** (0.007)	0.315*** (0.015)	0.076*** (0.009)
At Tanzanian mean (C)	0.207** (0.021)	0.316*** (0.031)	0.067*** (0.016)	0.367*** (0.016)	NA
Chi-square tests					
A = B	NA	4.04**	3.54*	4.28**	4.38*
A = C	3.65*	3.76**	2.89*	4.04**	NA
Elasticities of adoption with FMPR					
A to B	NA	–0.562	–1.346	–0.391	–0.465
A to C	–0.696	–0.593	–1.478	–0.395	NA
Panel II:	**Effect of high FMPR with high EFR: for each country set FMPR at Kenya's level and EFR at Ethiopia's level**				
FMPR/EFR level	**Pooled**	**Ethiopia**	**Kenya**	**Malawi**	**Tanzania**
SER and EFR set at respective sample means (A)	0.168*** (0.004)	0.258*** (0.008)	0.039*** (0.004)	0.338*** (0.009)	0.099*** (0.008)
At Kenya's FMPR and Ethiopia's EFR (B)	0.181*** (0.029)	0.171*** (0.017)	0.065*** (0.013)	0.424*** (0.091)	0.145*** (0.063)
Chi-square tests					
A = B	0.21	22.94***	4.47*	0.93	0.51

Notes: EFR = extension agent to farmer ratio; FMPR = fertiliser–maize price ratio; CASI = conservation agriculture-based sustainable intensification; *, ** and *** indicates statistical significance at 1.5 and 10% levels respectively.

Conclusion

Constraints arising from limited markets and weak policy support have amounted to a number of trade-offs associated with adoption of CASI practices. Many agrarian households in the developing world have navigated decisions between immediate survival needs and long-term sustainability and productivity. The implications of the policy simulation results are threefold.

First, the power of input subsidies in predicting adoption suggests that lowering costs of inputs is central in encouraging adoption of CASI practices. Since the cost of investment can be a major barrier to adoption, diverse options for lowering input/output price ratios should be put on the policy table, including subsidies that effectively reduce the prices of inputs.

Second, investing in agricultural extension systems by increasing the number of personnel (increasing the extension agent to farmer ratio) and expanding the reach of publicly funded extension systems among complementary providers is a crucial element for successful CASI and would support both the subsistence-led and market-led pathways.

Third, although sustainable intensification practices include sets of practices that are resource-conserving with demonstrable cost advantages and CASI dividends, the same factors known to facilitate or impede agricultural technologies generally will remain relevant for CASI practices as well. Policy attention in support of CASI should remain focused on better access to markets, solid information delivery through strong agricultural extension and creating policy and physical infrastructure to produce favourable input and output price ratios.

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24 The role of digital knowledge sharing for scaling

Ângela Manjichi

Key points

- The participatory development of SIMLESA text messaging allowed the SIMLESA team to develop information that was relevant and actionable by poorly resourced farmers.
- The use of mobile phones was an efficient and effective tool for scaling the SIMLESA project information beyond the areas where the project was actively interacting with farmers.
- Both male and female farmers benefited from the information they received over their mobile phones.
- Due to the impact of the SIMLESA approach, there are now institutions willing to cover the cost of maintaining, expanding and delivering the service.
- Capacity building on the Internet of Things and information and communication technology within the national system should be considered a government priority.

Introduction

The SIMLESA project developed and disseminated agricultural technologies with the aim of adoption by 500,000 farmers in 10 years. Achieving this goal required strategies that extended beyond traditional diffusion methods and utilised novel information and communication technologies. The use of information and communication technology, particularly mobile phones, was piloted in Mozambique in 2013. In 2015, this was spread to other SIMLESA countries. In this chapter, we discuss the process, impacts, lessons and the successful use of information and communication technology to foster adoption under SIMLESA.

Access to information is a key determinant of agriculture technology adoption in developing countries. This is widely recognised, based on evidence that timely access to agriculture and market information enables farmers to make better decisions and improves farming practices, access to markets and financial services (Anderson 2008) and opportunities to participate in the markets (Anderson 2008; Akera, Gosh & Burrell 2016). Extension and advisory services are considered principal mechanisms of establishing links with farmers and providing them with information to support knowledge acquisition and technology transfer and adoption (Maffioli et al. 2013). SIMLESA developed partnerships with major local agricultural and rural development organisations through innovation platforms. However, these services did not have the capacity to reach SIMLESA targets because they were understaffed and had limited funds. With extension agent to farmer ratios of 1:18,000 to 1:25,000, the publicly funded agriculture extension and advisory services in SIMLESA countries were limited in their effectiveness, relevance and coverage. Therefore, the SIMLESA scaling out and diffusion framework required an innovative approach that would go beyond traditional models and include opportunities to disseminate the technologies to a large number of farmers.

Given that more than half of Africa's 1 billion population were using mobile phones, the potential of the African mobile network for the delivery of actionable agricultural information was great. The use of mobile phones was already being implemented in India and western Africa (World Bank 2017). To better assess the potential of mobile phones as a tool for transferring agriculture information, a pilot study was conducted in Mozambique. The initial results confirmed the opportunity to use mobile phones as pathways for information delivery, but also to offer the kind of information farmers valued most, making the system relevant and timely and giving it greater reach. Therefore, mobile phones were treated as a critical tool for sending farmers relevant information under SIMLESA.

Pilot survey and model development

In 2013, a short survey was implemented in Mozambique to better understand mobile phone use and what kind of information farmers would like to receive. The survey also showed increasing mobile phone subscriptions in rural areas, with an increase of almost 49% since the 2010 baseline study. Moreover, the telecommunication companies were expanding their services to the rural areas, increasing the likelihood that more people would access mobile phones. These trends in Mozambique were similar to those of other SIMLESA countries.

The study also identified the main type of information that farmers were willing to receive and the frequency that would produce the intended outcome. Farmers wanted to receive information about weather, markets, availability and price of inputs, agronomic practices and networking events in their region. Based on the farmers' needs, we developed a model for information acquisition and quality management in consultation with farmers and stakeholders (Figure 24.1).

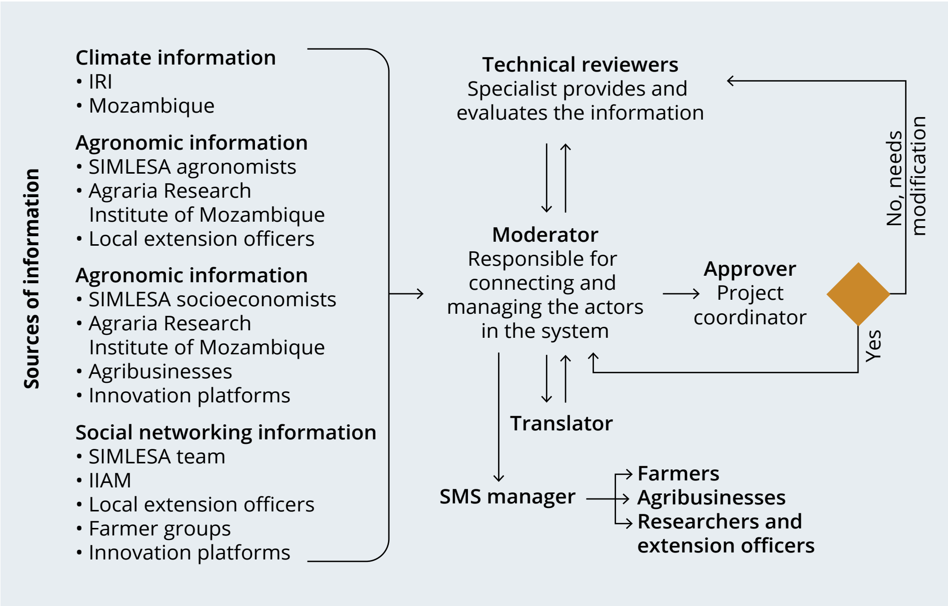

Figure 24.1 **Model for the delivery of information to farmers and agribusinesses by mobile phone**

Notes: IRI=International Research Institute for Climate and Society; IIAM = Instituto de Investigação Agronómica de Moçambique.

The model has five main components:

1. Source of information—organisation, people and systems that provide information that is relevant and useful for farmers.
2. Moderator—person who transforms the information to a format that is easily understood by farmers.
3. Technical reviewer—specialist in the areas, usually objective leaders who had the role of evaluating the scientific and technical content of the message, providing corrections where necessary.
4. Approver—usually the project coordinator, who would approval the messages to be disseminated through the cropping season.
5. SMS manager—responsible for managing the web-based platform and sending the information to the stakeholders.

It was necessary to ensure the quality of the data, particularly the weather and market information, in order to build trust and reliance in the system, and also to make the system specific to each location. This required a mechanism for collecting information in each location.

Content development

A two-day workshop was conducted with the farmers, agrodealers, traders, extension agents and agriculture development organisations working in the target regions. The objective of the workshop was to discuss the relevance of the approach, the model to be implemented, the roles of each actor, the type of information and a timeline for message delivery. A key aspect was the participatory approach of content development. This process included farmers, extension agents and agrodealers, who discussed the type of information and the content they needed. This allowed for the development of message content that was relevant to each of the actors, and ensured adoption of the system. During these content development workshops, it became clear that that many of the actors in the chain required the same information (Table 24.1).

Extension agents also required the same information, but needed it before it was sent to the farmers. This would support them during their meetings with farmers. When farmers face problems, the first person they reach out to is their extension agent, who would therefore need the same information as the farmer.

The output of the participatory content development workshop was a spreadsheet with the SMS content, the period when it was to be sent and the frequency of messaging. This was introduced in the web-based platform.

Table 24.1 Type of information required by users

Information	Farmers	Agrodealers	Traders
Price of inputs	Yes One month before the planting period	Yes	No
Amount of inputs	Yes One month before the planting	Yes At least three months before the cropping season	No
Price of produce	Yes Before planting	No	Yes After harvesting
Amount of produce available/needed	Yes	No	Yes Before harvesting

Implementation of mobile phone system

Farmers' entry

The implementation of mobile phone in SIMLESA countries was phased. In 2013, it was implemented in Mozambique. It was spread to other countries in the second phase of SIMLESA. The implementation started with the establishment of a farmer database in the web platform.

The data collection tool collected information on farmers such as region and village and, whenever possible, this was georeferenced to support the monitoring and evaluation process. However, during implementation, it became clear that other information, such as gender, age, farm area and main crops, would also be relevant. This could be used for monitoring and also to estimate production in each region, which would provide accurate product information for traders.

Systems management

Systems management involved two components: hardware (technical aspects) and software (managerial aspect) of the system. The SMS platform was a web-based system with a server domain outside the SIMLESA countries. Two issues were raised:

1. one-way information flow
2. capacity to reach all mobile phone companies in the SIMLESA countries.

Through the systems, farmer could receive information but were not able to provide feedback or ask for clarification or additional information. This was a great limitation because it was difficult to track farmers' responses in real time. To overcome this, some countries put in place a mobile phone line where farmers could send messages. The answer to the question was afterwards sent to all farmers in the system. Moreover, some major mobile companies were not reached through the server, making it difficult to reach all the farmers in the database.

Each country identified different stakeholders to engage in the system and modes of operations that best suited the country capacity. For example, in Mozambique, the system was managed by an information technology specialist and a moderator. Only they could add farmers to the database and send messages. In Tanzania, the system was open to all systems operators, who could all send messages. These models each had advantages and disadvantages. In Mozambique, it relied only on two operators, making it easier to ensure quality assurance but putting pressure on the operators. When all operators had access to the system, it was more difficult to ensure quality and there was increased risk of losing control of the messages being delivered, but there were more people to share the workload.

Stakeholder engagement

The model adopted by the project enabled each country to adapt and adjust it to meet their needs. In each country, a different model of engagement and different roles for each stakeholder were established (Table 24.2).

Table 24.2 Stakeholder engagement

Role	Ethiopia	Kenya	Malawi	Mozambique	Tanzania
Source of information				NARS SIMLESA team	
Moderator	NARS	NARS		Scaling partner	Scaling partner
Technical reviewer		Objective leader	Objective leader	Objective leader	Objective Leaders
Approver	SIMLESA country leader	SIMLESA country leader	SIMLESA country leader	SIMLESA country leader	SIMLESA country leader
SMS administrator	NARS	NARS		Scaling partner	SIMLESA

Note: NARS = national agricultural research systems

Each country adjusted to a model that best fit its own needs and ensured reliability and sustainability of the system. The role of scaling partners varied in each country.

One of the main challenges was the engagement of traders to effectively establish market linkages and enable market access. Although traders recognised that the system could help them to plan and establish trustworthy relationships with farmers, they also understood that revealing prices in advance reduced their negotiation power with farmers. The system gave traders an estimate of products available and their main location, but farmers did not have access to the price the trader is willing to pay. Farmers only had access to the average price in the region. They could use this information to negotiate with traders.

Impacts

The system reached 1,071 farmers in Tanzania and 6,035 farmers in Mozambique. The farmers received a variety of information throughout the cropping season and used this to enhance their production systems. In 2014, farmers in Mozambique showed that the mobile phone played an important role in providing agriculture information. Of 100 farmers interviewed, 49% had a mobile phone and 63% of farmers who received a message with agriculture information shared that with people in their network, sending an average of 89 messages throughout the cropping season.

The system also improved the relationships in the chain and provided information to all stakeholders, increasing access to inputs and linkages to traders. However, market relations were still weak and needed further improvement as traders were still not willing to share their prices.

Figure 24.2 shows how sources of information have changed in Mozambique and provides evidence that mobile phones and information and communication technology can support existing extension services. Since the start of mobile phone usage, the ways of sending and sharing information changed. Mobile phones played an increasing role in individual decision-making but were also being used in social networks, strengthening and supporting more people.

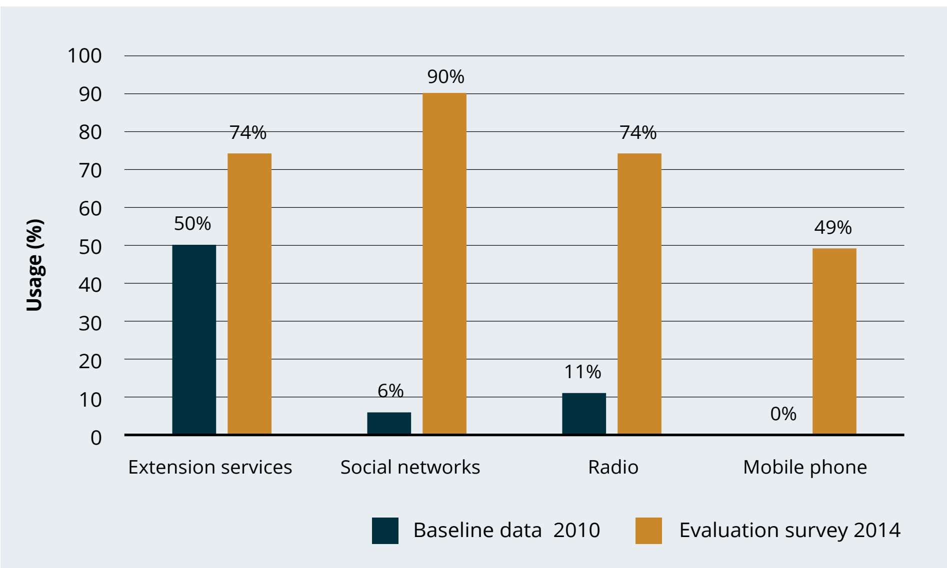

Figure 24.2 Main sources of information among participating farmers

Lessons learned

The use of mobile phones was a breakthrough for information dissemination in the different regions. The system enabled information to be sent to a more diverse and spread out population, making it possible to reach thousands of farmers in a very short period of time. The system supported existing extension services, reached more people, provided opportunities to get timely feedback from farmers and significantly reduced the cost of extension services in the target regions. However, to be effective, farmers needed to be able to use the system to increase their market opportunities. This was only possible if traders were willing to be more transparent and share timely information with farmers.

At the moment, all the costs to host the servers are supported by the project, but due to its effectiveness institutions are willing to pay for the service. In Mozambique, the SMS administrator has established contracts to deliver information for programs working in agricultural development. To further strengthen the system and increase its sustainability, administrators and moderators need to provide information to farmers, traders and policymakers and encourage them to use the system on a daily basis.

The success of the system is also linked to the fact that it was very flexible and simple to manage, and allowed for interaction and participation by the main stakeholders in the chain. It was also necessary to engage telecommunications companies in each of the countries and jointly develop a platform so that the dependence on international server hosts was reduced and the systems could be entirely managed by the countries.

As the role of the mobile phone is increasingly being recognised in these countries, more organisations are using similar tools. This creates the risk of conflicting or duplicated information being sent to farmers.

Future plans

The success of the mobile phone system shows that there is a potential to continue using it, but also to develop more systems. Research and development institutions face the challenges of getting accurate data.

The experience of the project shows that there is potential to develop interactive mobile phone applications that features information on weather, fertiliser recommendations, weeding and pest management recommendations and market information, among others. These features would include the capacity to take pictures in the field and send them in, triggering a response to the problem faced by the farmer.

Using mobile phones, farmers could collect georeference data and upload it, using the same model as the Open Data Kit but with a simpler method of data collection. The system could also be used to develop educational videos in local languages, upload them and provide a link to farmers.

Additionally, this experience showed that it is necessary to continually engage stakeholders and policymakers to increase the usage of the system. A promising strategy for ongoing engagement is the development of a national Knowledge Management System Framework for Agriculture Development.

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25 Linking sectors for impact: the science of scaling out

Michael Misiko, Gérard Bruno, George Mburathi, John Dixon & Mulugetta Mekuria

Key points

- Effective scaling of research results to substantial numbers of benefiting farm households is essential to generate value for money, or national return to investment in agricultural research.
- Three approaches to scaling were incorporated in the SIMLESA program: initial scaling around research hubs during Phase 1, systematic testing of selected scaling models and pathways during Phase 2, and strengthening of regional spillovers to three countries in the region through both phases.
- The impacts from SIMLESA scaling included quantitative benefits to adopting farm households and qualitative benefits to national capacity and the institutional and policy environment along pathways to impact.
- Agricultural innovation platforms based on research hubs linked the field and local levels with the policy level and added to the effectiveness of public extension and private sector input and service delivery for conservation agriculture-based sustainable intensification (CASI).
- The effectiveness of linking agriculture-related sectors and refocusing public and private organisations and investment on CASI has been demonstrated by SIMLESA in selected countries in the region.

Introduction

The objective of this chapter is to illustrate quantitative and qualitative nature of scaling by analysing results of a competitive grant scheme and agricultural innovation platforms. By focusing on the SIMLESA project, we illustrate why science is critical in achieving efficiency in scaling conservation agriculture-based sustainable intensification (CASI) portfolios. Quantitative expansion in the SIMLESA competitive grant scheme included a catalytic budget of A$700,000, partnerships of more than 90 organisations in more than 60 districts of five countries, reaching over 2 million households, targeting to influence adoption among more than 400,000 households. This expansion also included the furtherance of 58 agricultural innovation platforms, which are a unique impact pathway. With the right niche focus, policy, transformational investments, national coordination and mentoring, agricultural innovation platforms generated equitable spillovers, co-benefits and impact at scale. Underlying these numeric gains was qualitative expansion, in skills, coordination leadership, communication, strategic partnerships, policy processes, institutionalisation and innovation. Innovation and cost reduction resulted from research-led investments and resourceful partnerships guided by higher goals, such as the United Nations Sustainable Development Goals and national policies.

The word ‘scaling’ is often used in combination with ‘up’ or ‘out’ to signify covering many beneficiaries by some ‘package’ of interventions (IIRR 2000; Uvin & Miller 1994; Proctor 2003). It mostly refers to increasing the numbers. In this chapter, it means achieving wide agricultural impact at affordable cost. It is a process with several stages. Some of the stages can be measured during a single agricultural project. However, the totality of ‘scale’ cannot be demarcated within a few years. Holistic scale (which is key for increased impact) is a function of the exposure of a population, combination of several initiatives’ effectiveness (quality of implementation and efficacy of interventions employed), efficiency (cost per beneficiary), sustainability (benefits, continuity, ownership), and equity (equitably reaching the hardest to reach, usually the poor, women and youth). A large project such as SIMLESA can act as a catalytic component, especially among many partnering initiatives. Improved coverage under a single initiative can cause impact to increase. However, impact is a function of many variables such as program quality (including innovation), affordability (efficiency) and quantity. Impact is moderated by social, economic, temporal, ecological or physical variability. True impact at scale is therefore more possible through a network of programs with multiple agricultural research and development interventions that are socially inclusive, and that respond to a broad range of societal, spatial, communal, historical and individual needs.

Scaling in SIMLESA

The SIMLESA project was implemented mainly in Ethiopia, Kenya, Malawi, Mozambique and Tanzania. Between 2010 and 2014, SIMLESA Phase I undertook participatory testing, agronomic and economic evaluation and validation of several CASI options in numerous sites. During this phase, tens of agricultural innovation platforms were established, with the underlying aim of catalysing equitable impact. In 2014, a scaling phase was launched to strengthen the agricultural innovation platforms' achievements, and aid SIMLESA's overall adoption target of 650,000 households by 2023. A competitive grant scheme was designed to bring on board new partnerships for broader capacity in scaling. The SIMLESA competitive grant scheme had three main objectives:

1. scale SIMLESA research portfolios through producer-oriented programs
2. pilot an innovation-based knowledge value chain, based on demand–supply partnerships among international, private and public research and development institutions
3. draw lessons from the experience of funded projects that reduce the margins of technology transfer in SIMLESA countries.

SIMLESA and the science of scaling

Scientific research principles and evidence are essential in shaping scaling (World Bank 2012). Scaling science is critical in planning for and guiding program impact (Waddington 1993). As illustrated in Figure 25.1, SIMLESA innovatively applied essentials of scaling science to guide impact at scale.

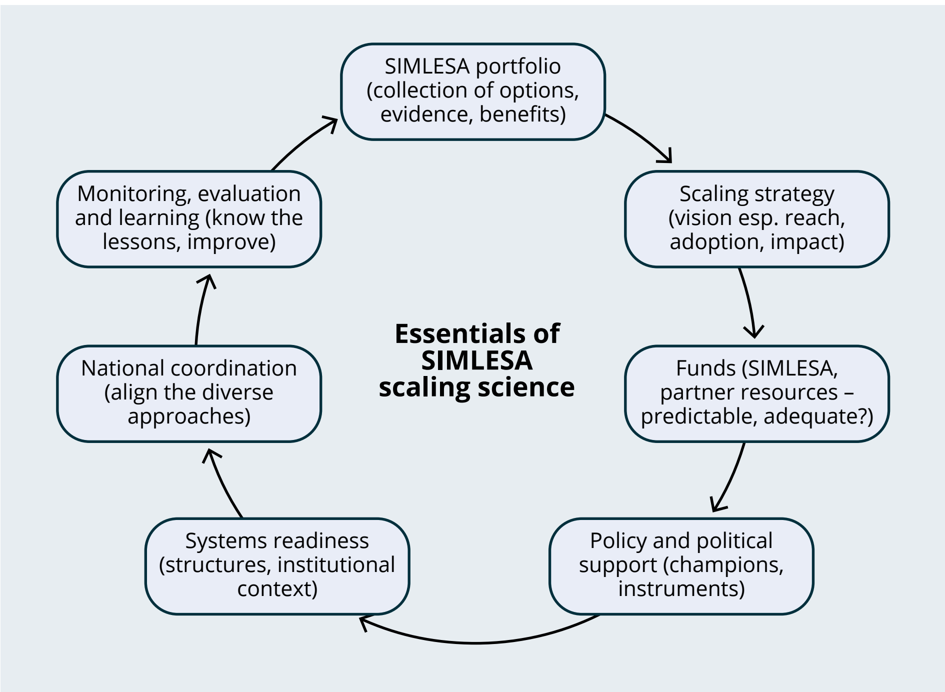

Figure 25.1 Components of SIMLESA scaling science

The success theory of SIMLESA was that, supported by scaling science, the program would catalyse wider reach and stimulate multiple benefits for equitable impact at scale. Beside planning and guiding impact, scaling science was critical in the measurement of results, outcomes and impact. SIMLESA measured these in terms of both quantitative and qualitative expansion.

Quantitative expansion

Quantitative scaling denotes quantities—inputs and achievements that can be measured and written down numerically (Table 25.1). 'Number of farmers reached' is the most sought target.

Table 25.1 **Partner estimates of reach vs application (or tryouts by end 2018)**

Country	Partners	Partner estimations			No. of districts	No. of partners	No. of portfo-lios
		No. reached	No. applying	%			
Ethiopia (Public extension at Zonal level)	East Shewa Zone	72,660	21,798	30	3	4	4
	East Wollega Zone	74,180	22,254	30	3	4	4
	West Shewa Zone	53,690	16,107	30	3	4	4
	Hadiya Zone	53,140	15,942	30	3	4	4
	West Arsi Zone	73,150	21,945	30	3	4	4
	Sidama Zone	48,980	14,694	30	3	4	4
	West Gojjam Zone	48,840	14,652	30	3	4	4
Kenya	University (Egerton)	30,000	7,500	25	4	7	4
	Seed company (Freshco)	30,000	24,000	80	4	4	4
	Faith-based (NCCK)	30,000	9,000	30	4	7	4
	Television (Mediae)	2,000,000	300,000	15	>20	5	4
Malawi	Radio (Farm Radio Trust)	100,000	15,000	15	3	4	4
	Seed company (MUSECO)	10,000	5,000	50	-	-	4
	Farmers organisation (NASFAM)	30,000	7,500	25	4	7	4
Mozam-bique	Business non-government organisation (Agrimerc ODS)	50,000	15,000	30	5	7	4
	Information and communication technology-based (ISPM)	100,000	15,000	15	>10	4	4
	Farmers organisation (UCAMA)	30,000	9,000	30	4	5	4
Tanzania	Farmers organisation (MVIWATA)	50,961	15,288	30	4	7	4
	Non-government organisation (RECODA)	24,000	12,000	50	3	6	4
	Seed company (SATEC)	30,000	24,000	80	3	5	4
Totals		**2,939,601**	**585,680**	**34**			

Notes: Reach = farmers being covered and verifiably receiving SIMLESA portfolios. This is different to diffusion (Walker & Alwang 2015). Applying (also referred to as tryouts) = farmers using the options scaled out. Adoption and impact will be fully measured in 2023 (see definitions in Walker et al. 2014). However, outcomes can be reported in 2019. NCCK = National Council of Churches Kenya; MUSECO = Multi-Seed Company Limited; NASFAM = The National Smallholder Farmers' Association of Malawi; ISPM - Instituto Superior Politécnico de Manica; ODS = Sustainable development goals; UCAMA = União Províncal de Camponeses de Manica; MVIWATA = Mtandao wa Vikundi vya Wakulima Tanzania; RECODA = Research, Community and Organisational Development Organisation; SATEC = Suba Agro Trading and Engineering Co.Ltd.

A comprehensive set of criteria and indicators of quantitative expansion are given in Table 25.2.

Table 25.2 **Criteria and indicators for quantitative expansion (directly attributable to SIMLESA)**

	Criteria	Indicator
Short term	Reach	Number of women and men beneficiaries verifiably receiving research portfolios, sites covered
	Try outs (application)	Number of women and men beneficiaries verifiably utilising, taking up or trying information
	Innovation management	Proportion of contracted projects (% of total applicants)
		Number of projects terminated after start of competitive grant scheme
		Per cent of projects that have achieved target goals
		Rate of realised against planned time for project execution
Medium term	Value for dollar	Total cost of SIMLESA competitive grant scheme initiative relative to number of beneficiaries, number and value of benefits
	Institutional change	Partnership ventures during the period of the competitive grant scheme
		Matching funds allocated to SIMLESA competitive grant scheme initiative
		Capacity changes related to competitive grant scheme initiative
Long term	Additionality and sustainability of resources	Increase of partner scaling budget in over a defined period—because of fundraising SIMLESA competitive grant scheme success
	Impact or effectiveness attributed to scaling initiative financed by the SIMLESA competitive grant scheme	Factor productivity (crop yields, labour productivity)
		Rate of adoption of SIMLESA research options
		Incomes and social benefits derived—absolute and relative rates

Source: Misiko 2017—unpublished (also see International Service for National Agricultural Research 1998)

Table 25.2 illustrates that quantitative expansion means holistic measures of values (including counts or occurrences) expressed as figures. Numeric variables, including ‘how many’, ‘how much’ and ‘how often’, are necessary in measuring scaling. Quantitative expansion means more or new gains, in terms of absolute number and rate of households reached and adopting, and more and better diversity of incomes/benefits derived. Efficiency in scaling includes early successes such as reaching more people more rapidly, achieving a higher ratio of adoption per reach population, extending portfolios that are well tested, and applying partnerships that integrate complementary concepts that are necessary for inclusivity. In short, realising value for money with less investment.

Value for money

The ultimate value for the SIMLESA competitive grant scheme will be known after related International Maize and Wheat Improvement Center and partner administrative and staff costs are known, when adoption is established and benefits are valued. Among those benefits will be how many women and youth are increasing (the diversification of) their incomes and social welfare (e.g. reduced labour, time or energy use) as a direct result.

Initial value for money is seen to emanate from sheer reach and tryouts (i.e. initial farmer application of options) resulting from the SIMLESA competitive grant scheme. Partner scaling plans have 2,939,601 farmers being targeted with CASI options (Table 25.3). However, projections show only an average of 34% (585,680) are likely to try out one or different combinations of the sustainable intensification portfolios, with an estimated 15% (440,940) sustaining by 2023. This is based on known adoption rates among exposed farmers (Simtowe 2011; International Maize and Wheat Improvement Center 2014, 1993). Besides end users, partners are capacitating a network of 4,115 professionals including extension officers, agricultural innovation platform actors and farmer group officials.

The total SIMLESA competitive grant scheme was 2% of the entire SIMLESA budget and it ran for 18% of SIMLESA's duration. From a project perspective, the SIMLESA competitive grant scheme will be hugely successful if it contributes over 50% of SIMLESA's target of 650,000 adoptions of (single or different combinations of) its research options.

Qualitative expansion

By qualitative expansion, we refer to aspects of SIMLESA benefits that are non-numerical, and that will sustain quantitative benefits over time and across locations. Indicators of qualitative expansion include various forms of knowledge or benefits. One example is women having influential leadership in SIMLESA-supported agricultural innovation platforms, rather than merely increasing membership numbers. Other qualitative aspects are skills from program training in marketing and resulting agribusiness innovation. Identification and pursuit of innovation opportunities was a critical pathway to scaling CASI co-benefits, and a sustainable way to target spillovers and co-benefits. SIMLESA achieved enhanced excellence of institutional capacities (a collective mix of mutually supportive skill sets and coordinated leadership), especially through mentoring for national capacity in evidence-based scaling. It also achieved adaptive communication (including interactive feedback), strategic partnerships and policy processes. These are incremental aspects of the development process that can be treated as inputs, variables and outcomes that explain, enable and shape the quantitative impact of SIMLESA. They were essential for innovation in scaling for impact.

Innovation in SIMLESA-led scaling for impact

Innovation in SIMLESA came from the diversity of scaling approaches and partners. For instance, AgriMerc in Mozambique worked with marketing, SMS, radio, seed companies and other private sector actors to link farmers to better markets despite the poor road network. Although innovation was often a by-product, this was not accidental. SIMLESA had a carefully developed strategy and defining guiding principles that were applied by partners to facilitate innovation. Table 25.3 shows how selected partners applied these principles based on their scaling concepts.

Table 25.3 Summary of SIMLESA competitive grant scheme guiding principles as applied by selected partners

Guiding principle	Mediae	AgriMerc	Recoda	Farm Radio	ISPM	Egerton	NASFAM
Main scaling approach	iShamba, Shamba Shape Up	Agrodealer system, lead farmer, mobile platform	RIPAT recoda-tanzania.org/ripat	Participatory radio farmradiomw.org	SMS, radio, video	Participatory, farmer group networks, radio, print media	Club model, lead farmers
Motivation	TV info deals	Smallholder business	Participatory service	Radio/ information and communication technology information deals, intermediaries		Data and policy drive	Farmer welfare, value chain
Policy linkages	Medium	High	Low	Low	High	High	High
Main capacity	Message delivery	Brokerage	Participatory	Message organisation	Content development	Testing and delivery	Delivery and advocacy
Scaling pathway	Via field, TV and mobile	Piloting, testing and replicating	Piloting, testing and replicating	Via field, radio and mobile	Via information and communication technology (SMS), radio and video	Participatory, media and local farmer networks	National network of farmer groups
Partnership nature	Transitory, based on knowledge needs and funding source	Wide, depend on national agricultural research systems and international knowledge market	Wide, depend on national agricultural research systems and international knowledge market	Transitory, based on knowledge needs and funding source	Long-term, stable and less dependent on external funding	Long-term, stable, national and external funding	Wide, stable, national agricultural research systems, national and international knowledge market
Key monitoring, evaluation and learning mechanism	Unique, designed for TV and information and communication technology feedback	Performance of agribusiness	Partner feedback systems	Learning by doing, radio feedback mechanism	Standard monitoring, evaluation and learning methodologies	Extension methodologies, standard monitoring, evaluation and learning	Farmer network evaluation
Orientation for purpose	Partnerships with knowledge partners	Market-related work	Partnership, especially with research	Depends on partners with knowledge portfolios	Collect and/or organise content	Research, participatory extension	Training a critical component

Source: Misiko 2017

Table 25.3 shows how innovation was catalysed (Hall, Mytelka & Oyeyinka 2006). It illustrates the need to organise partnerships based on converging interests. SIMLESA needs were well aligned with the visions of selected partners. Table 25.3 explains the SIMLESA handover of CASI portfolios from research to sustainable ownership (FAO 2002).

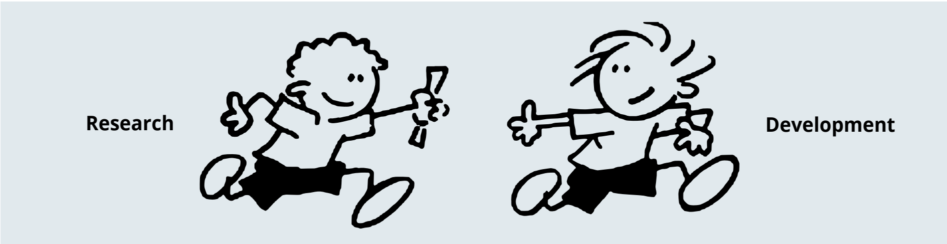

Figure 25.2 Research and development is a relay

Handover is a transition. Research organisations pass bundles of research portfolios to the next users, who deliver the products of the research to beneficiaries (Figure 25.2). This is a qualitative process.

SIMLESA competitive grant scheme

The full range of SIMLESA competitive grant scheme merits will not be wholly discerned in the short term. However, a program review revealed emerging merits and demerits of the current competitive grant scheme (Table 25.4).

Table 25.4 Merits and demerits of SIMLESA competitive grant scheme

Merits	Demerits
Role of research and science entrenched	Limited funding, pilot, not wider scaling
Efficacy through competition and cofinancing	Good proposals did not necessarily mean good opportunities for better scaling
Enhanced capacity among scaling partners	Short-term, limited documentation for fuller lessons
Simplification of research products for sharing	No institutionalisation of competitive grant scheme, lack of mentoring program
Target-oriented and demand-driven system, seamless relay of research options	Demanding and costly transactions, less time for scaling research
New type of research-scaling partnerships	Legal, financial, administrative and technical complications
Diversification of ideas = innovation, new scaling concepts such as iShamba	Competition means large organisations dwarfed less-known local actors, no equity
Scaling strategy key to guide basic institutional arrangements	Seed partners need to be purposively rather than competitively selected
SIMLESA competitive grant scheme was an arranged market concept based on merit/objectivity	Depends more on knowledge market rather than needs oriented
New research opportunities have emerged	Prone to delays. Limited grants, small scaling teams, exit of a team member disruptive
Suitable for targeting diversity of needs at national level	

Source: Misiko 2017

Principles of SIMLESA's scaling partnerships

Scale and higher goals

Table 25.3 shows partnerships based on diversity and complementarity. In Kenya for instance, scaling partnerships comprised media (Mediae Ltd, FM radio), seed producers (Freshco Seed Ltd), farmer networks (Egerton University), participatory extension (National Council of Churches of Kenya), public extension (county governments) and newspapers (Egerton), among others. The integration of diverse approaches ensured that CASI portfolios reached, and were utilised by marginalised men, disadvantaged women and low-resourced youth. These contributed to higher goals, United Nations Sustainable Development Goals and other national policy priorities. SIMLESA partnerships considered how to best achieve national scale and social inclusion.

Local ownership, equity and sustainability

SIMLESA investments in capacity mentoring resulted in agricultural innovation platforms that catalysed multiple benefits (Table 25.5).

Table 25.5 Number of agricultural innovation platforms established under SIMLESA

Country	Sites	Agricultural innovation platforms	Levels of agricultural innovation platform
Ethiopia	7	19	Woreda (District)/Community
Kenya	5	13	District/Community
Tanzania	5	10	District/Community
Malawi	6	6	District/Community
Mozambique	4	4	District/Community
Rwanda	4	4	Sector
Uganda	2	2	District
Total	**33**	**58**	

Case studies were conducted for six of the 58 agricultural innovation platforms. Findings show agricultural innovation platforms were ideal for generating spillovers and co-benefits, and in addressing equity.

Agricultural innovation platforms

Agricultural innovation platforms are an alliance of stakeholders formed to diagnose constraints, explore opportunities, analyse solutions and complement efforts along a value chain to generate mutual benefits.

Case studies show successful agricultural innovation platforms under SIMLESA or elsewhere benefited from research and were initiated by donor projects. Once established, members were taught techniques to identify business opportunities and trained in business management skills.

Once registered, members made regular contributions. Key milestones in the conservation agriculture-based sustainable agricultural innovation platforms were inclusivity and investments (especially direct support) from governments and donors, for example, in machinery, storage and transport. Inclusivity was directly related to how benefits were generated and equitably shared. Agricultural innovation platforms at Level 5 of progression (Figure 25.3) were not mere conservation agriculture-focused assistance-receiving committees, but rather service-oriented entities that resulted in multiple benefits and spillovers beyond their membership.

There were four key fundamentals that separated failure and success:

1. Policy instruments. In Rwanda, successful cooperative-based agricultural innovation platforms received a 40% price reduction on capital equipment.
2. Development investments. Beyond research, transformations were enabled through development investments. These were directly catalysed by policy instruments, and were specifically targeted to agribusiness/diversification.
3. Agricultural innovation platforms. Agribusiness was directly related to CASI. Agricultural innovation platforms that diversified—beyond field activities—generated more benefits, and evolved beyond 2–5 years of project support.
4. Coordination. All these factors were operationalised by appropriate coordination. SIMLESA invested heavily in mentoring for national capacity to coordinate.

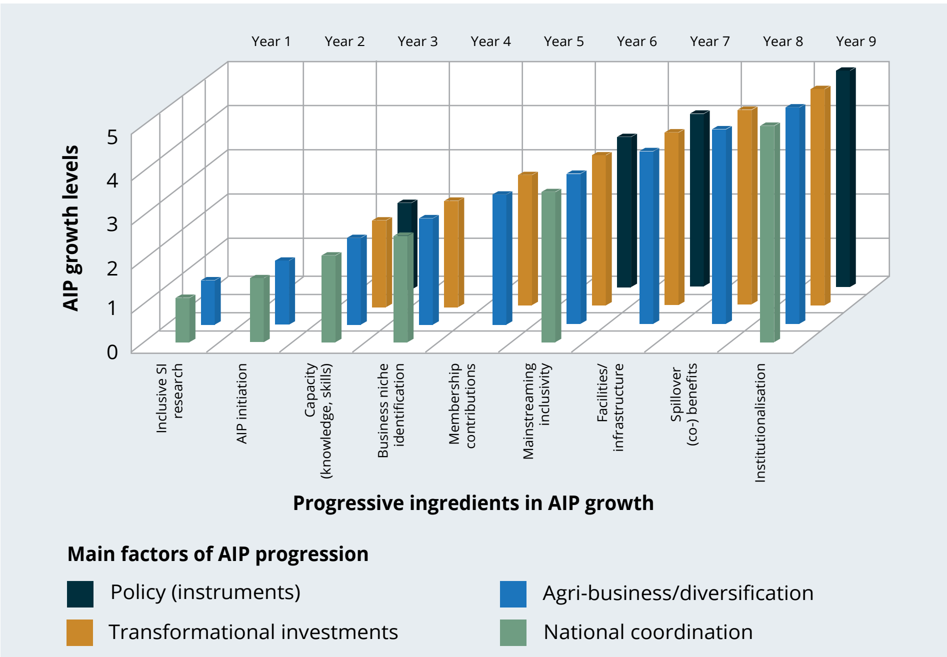

Figure 25.3 **Factors of agricultural innovation platform maturation and their ingredients of growth, along with extrapolated illustration of time and growth stages**

Notes: AIP = agricultural innovation platform; SI= sustainable intensification
Level 1: Foundation; group integration with project activities
Level 2: Committee; for scaling out, trainings
Level 3: Niche integration; project funding supplemented by aspects of agribusiness
Level 4: Growth; business, asset, etc.
Level 5: Maturity; diversification, transformational investments—focus on long-term benefits, co-benefits, spillovers

Figure 25.3 illustrates that over time, successful agricultural innovation platforms generate spillover co-benefits that provided evidence for institutionalisation. Conversely, institutionalisation ensured the sustainability of agricultural innovation platform concepts and their benefits. This is illustrated by SIMLESA case research in Rwanda (Misiko et al. 2016). Findings show that the Mudende Innovation Platform and the Cassava Innovation Platform had a combined network of 700 men and women. About seven years after being established through research funding, their core activities evolved into processing cassava (KIAI) and milk, and producing seed potato (and potato seed, Mudende). They evolved from research-supported agricultural innovation platforms by integrating community-based organisation, self-help and (mostly) cooperative principles. In 2016, the combined direct service (and infrastructure) network reach of KIAI and Mudende was more than 7,500 non-member households.

Mudende and KIAI avoided the pitfalls of typical cooperatives by integrating the agricultural innovation platform principles of wider partnerships, benefits equity, niche diversification and diverse membership. They:

- increased market access, mitigated transaction costs and leveraged better and stable (input and produce products) prices for marginalised smallholders
- improved nutrition among the vulnerable
- attracted infrastructure development (e.g. Mudende feeder road)
- attracted banking facilities and services
- provided affordable and secure produce transport
- facilitated equitable sharing of proceeds and influence/leadership
- aided responsible management of common pool natural resources, including land, water and new germplasm.

In Kenya, the Kieni agricultural innovation platform attracted insurance and poultry investments that benefited thousands more than the 35 members. The Rhotia agricultural innovation platform in Tanzania created a new international market channel for pigeonpea smallholders, lowered transaction costs and helped to commercialise an otherwise subsistence pattern of production.

Conclusion

Figure 25.4 illustrates how scaling in SIMLESA sought to be holistic and integrative.

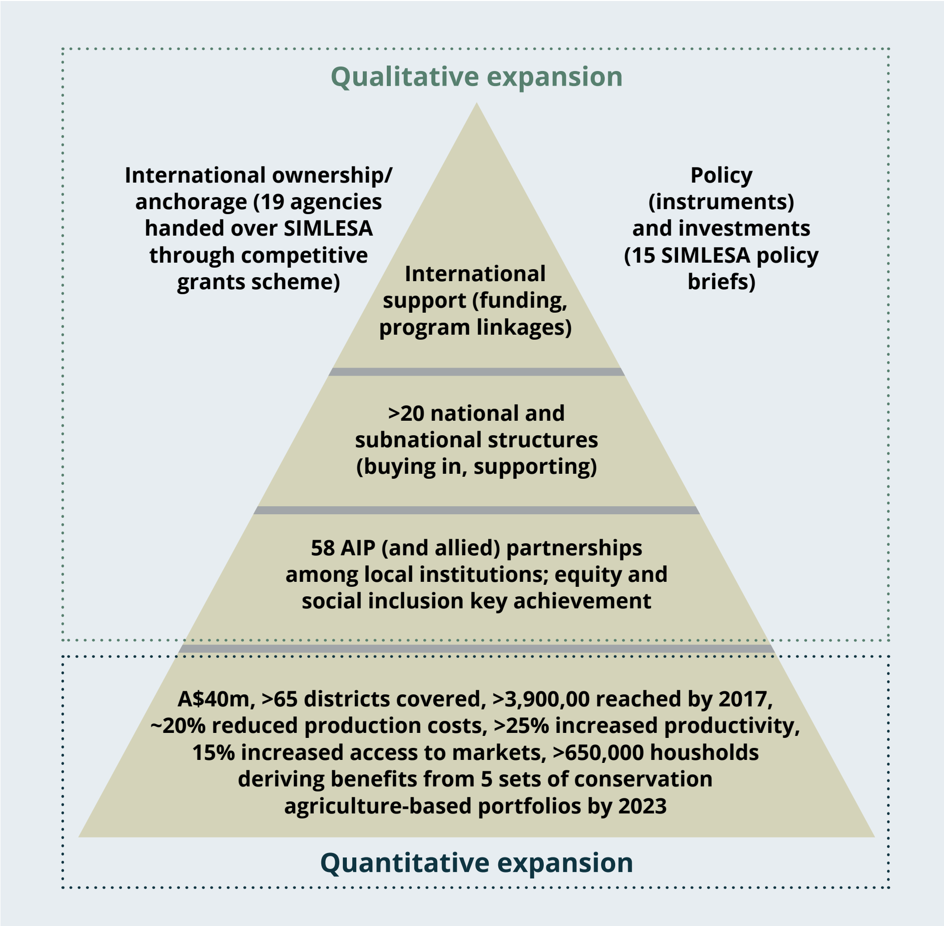

Figure 25.4 **Summary of SIMLESA scaling**

Figure 25.4 illustrates qualitative and quantitative expansion. These are necessary for generating impact. However, immense investments in scaling are necessary for impact at scale. Although recent debates show public–private partnerships are key, the role of governments in Ethiopia, Rwanda and Mozambique, along with donor support in agriculture (extension, research and reforms) have played greater roles in transformation. SIMLESA scaling focused on integrating marketing and value additions, which had better technical economies of scale compared to those arising from the indivisibility of agricultural inputs (e.g. draft animals, machinery, farm management skills) (Binswanger & Deininger 1993). Scaling was not merely about ensuring reach, but rather organising farmers (especially through agricultural innovation platforms) to have access to the necessary inputs, machinery and infrastructure to operate efficiently (Deininger et al. 2011).

The wisdom of SIMLESA was that it ensured that smallholders generated their own means to enhance farming through income diversification. In other words, scaling the means to impact was more transformational than mere scaling of research technologies. The focus on partnerships in competitive grant schemes and agricultural innovation platforms was informed by the African smallholder heterogeneity that complicates the wider use of research products. Impact among smallholders resulted from diversification of incomes.

The fuller impact of SIMLESA will be realised with increased direct investments that contribute to the fundamental transformation of the agriculture sector. Governments must play a critical role to ensure policy (instruments) enhances the ability of smallholders to adapt to the changing structure of the modern food and agriculture sector, while reducing the risk of social exclusion. The SIMLESA competitive grant scheme has generated ground for a new sort of policy instrument for information chain development, such as a national agricultural scaling innovation facility.

SIMLESA shows the need to focus on three areas:

1. improve access to capital, inputs, and markets through membership in cooperative-led agricultural innovation platforms (Von Pischke & Rouse 2004)
2. participate in collective livelihood schemes like export agro-processing, increase negotiation capacity and reduce agro-related transaction costs
3. tune rural farming to align with off-farm economic services and entrepreneurship.

These must be supported by investment in strategic skills in management and technology adaptation. With strategic skills and organisation, farmers can take advantage of cheap land leases to circumvent usual constraints, including small farms and lack of capital. Both the competitive grant scheme and agricultural innovation platform analyses show rural transformation is possible when skills gaps are closed. Without this, any research, development or other investments lead to a lack of spare capacity to utilise transformational investments.

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SECTION 5

BUILDING ON SIMLESA

26 SIMLESA: Outputs, outcomes, impacts and way forward

John Dixon & Mulugetta Mekuria

Looking at #SIMLESA's evidence, we can say that #conservation agriculture works for our farmers.

Josefa Leonel Correia Sacko, Commissioner, Rural Economy and Agriculture of the African Union, https://t.co/iLHhnp0K19

Key points

- The SIMLESA program established the confidence of agricultural leaders across eastern and southern Africa in conservation agriculture-based sustainable intensification (CASI) as a pathway to food security and rural development, and influenced the design of a number of major research-for-development initiatives.
- The program demonstrated improved productivity, resilience and resource management through CASI in more than 30 research hubs with relevance across southern and central Queensland and the maize mixed farming systems of eight eastern and southern Africa countries.
- The livelihoods and food and nutrition security of more than 480,000 farm households spanning low- and high-potential environments of eight eastern and southern Africa countries improved with the adoption of CASI methods.
- Impact-oriented integrated innovative interdisciplinary systems approaches to soil health, field agronomy, market access, computer modelling and policy engagement provided effective research results.
- More than 50 innovation platforms, designed to complement the interdisciplinary research sites, coordinated farm, research, extension, value chain and other business activities and generated co-learning, feedback to research and evidence for local scaling of CASI practices.
- Scaling grants targeted selected public and private organisations and scaled up adoption and impact processes manyfold, from tens of thousands to hundreds of thousands of adopting households.
- The SIMLESA program contributed to widespread capacity building of farming women and men, small- and medium-seed enterprises and the National Agricultural Research and Extension Services.
- Effective pathways to impact were identified and scaling models tested to enable the National Agricultural Research and Extension Services to scale out and scale up CASI innovations and expand climate-smart agricultural research-for-development across eastern and southern Africa.

Introduction

The previous chapters of this book offer a rich set of highlights of the activities and results of a unique regional—indeed interregional—program of research and capacity building centred on agricultural transformation through conservation agriculture-based sustainable intensification (CASI). The contents of the book indicate the breadth and diversity of the research outputs[21] generated by the SIMLESA program in relation to the intensification, diversification and resilience of the maize mixed farming system. This system is the future ‘engine of growth’ in Africa, which has a farm population of 107 million, cultivated area of 40 Mha and a livestock population of 36 million tropical livestock units in 2015 (eds Dixon et al. 2019), and dominates farming, food production and rural development across eastern and southern Africa. The SIMLESA program design recognised that rainfed mixed crop–livestock farming is common in both Australia and eastern and southern Africa, and that both continents confront many similar agricultural challenges, for example, infertile soils, land degradation, variable rainfall and long distances to markets. (ACIAR has supported 30 years of agricultural research partnerships in the region.) SIMLESA was focused on CASI, a relatively new theme for African research, to ensure environmental sustainability along with intensification and build on Australian experience with conservation agriculture. It is no surprise that the strengthening of the agricultural science bridge between Africa and Australia is a major outcome of SIMLESA, building on the program research partnerships, study tours and graduate scholarships.

Research by the National Agricultural Research System in five African countries (Ethiopia, Kenya, Tanzania, Malawi and Mozambique) and Australia constituted the backbone of SIMLESA. This five-country core was supplemented by the managed spillovers of SIMLESA research results to three other countries (Uganda, Rwanda and Botswana). In addition, there were two-way science exchanges on CASI with Zimbabwe (in particular, on appropriate mechanisation and crop–livestock integration). Training activities were initiated in South Sudan but circumstances did not permit their continuation. Inspired by SIMLESA, USAID established a similar CASI program in Zambia.

Soon after SIMLESA commenced, ACIAR launched complementary research in the region on appropriate mechanisation for CASI, crop–livestock integration, water management, agroforestry and socioeconomic constraints to adoption of CASI innovations. The Bill and Melinda Gates Foundation considered investing directly in SIMLESA, but ultimately the N4Africa program was established on legume development, which complemented SIMLESA. USAID also drew upon the SIMLESA program design and experience for the formulation of the Africa Rising program. The SIMLESA design and experience informed the formulation by ACIAR of the Sustainable and Resilient Farming Systems Intensification project in South Asia and the Sustainable Intensification and Diversification project in Cambodia. Thus, another outcome of SIMLESA was the improved design of CASI research-for-development initiatives in Africa, South Asia and South-East Asia.

21 The conventional project and program definitions of outputs, outcomes (effects of output use by next users, for example increased competency and organisational effectiveness after training) and impacts (effects on final target beneficiaries, ecosystems or social groups).

Highlights of SIMLESA outputs are described in the book and organised in five parts:

- **Section 1:** setting the scene (rationale, sustainable intensification and agricultural transformation, development diversity, climate variability and uncertainty and agricultural innovation)
- **Section 2:** regional research-for-development (CASI, climate-informed management, mechanisation, gender, crop varieties, livestock, markets and value chains and South African–supported training)
- **Section 3:** country research-for-development (highlights of research from nine countries, co-learning between Africa and Australia, and synthesis of lessons from countries)
- **Section 4:** scaling (adoption pathways, capacity building, policies and institutions, intersectoral linkages)
- **Section 5:** future vision (key outcomes and way forward).

While the outline might appear comprehensive, readers should be aware that the 88 authors of these 26 chapters have described only a small proportion of the knowledge outputs and development outcomes generated by the SIMLESA program across nine countries of the region and Australia. This impressive sampling of research outputs does not completely represent the SIMLESA legacy, but points the way to potential future outcomes and impacts from the program. Some of these are foreshadowed in this chapter.

Paradigm shifts

When SIMLESA began, improved food security was the priority of a majority of research leaders in the region and research efforts tended to be dominated by commodity-based approaches associated with improved varieties, inorganic fertiliser and improved markets. As noted in the introduction to this book, food crop yields were stagnant, annual variability was high and rural hunger was prevalent. SIMLESA has contributed to a paradigm shift towards a systems approach to sustainable intensification based on conservation agriculture, with the triple-bottom-line of increased productivity and incomes, strengthened resilience (and reduced risk or variability) and reduced soil degradation. This paradigm shift was fostered by effective ownership of SIMLESA by participating countries, which ensured that research was focused on national priorities. Given their seniority, national members of the program steering committee were often active advocates of the promising field research results. The annual national and regional program meetings exposed policymakers to the adaptations and performance of CASI in SIMLESA countries. As a consequence, national SIMLESA teams received the necessary support for their research. Moreover, CASI offered effective triple-bottom-line outcomes of increased productivity, system resilience and sustainable resource management, which had been noticeably missing from earlier research efforts.

After four years of operation, the performance of SIMLESA was widely recognised in the region. At a high-level forum in October 2015, organised by the Association for Strengthening Agricultural Research in Eastern and Central Africa, five ministers of agriculture signed a communiqué endorsing CASI in agriculture and committing to supporting the adoption of SIMLESA research results.

This policy-level recognition led to an invitation to present SIMLESA results at the Africa-wide CAADP platform meeting in Gabon in April 2018. During SIMLESA's concluding year of operations, high-level policy support for its role and results was reaffirmed in May 2019 at a high-level ministerial forum organised by ASARECA-SIMLESA, at which a ministerial joint communiqué on CASI to support and scale up CASI was endorsed by 14 ministers of agriculture from eastern and southern Africa (see Appendix). Few research initiatives achieve such policy influence and outcomes so quickly.

By reaching out and influencing other projects, national agencies, private companies and regional platforms, SIMLESA demonstrated noteworthy responsibility and maturity. The program stepped beyond a project mindset, and focused on activities and outputs towards a responsible program approach, demonstrating and networking on the effectiveness of farming systems research and CASI as viable alternatives to the commodity and disciplinary approaches that were the norm a decade before.

The paradigm shift towards systems-oriented CASI was reinforced by specific policy analyses of the SIMLESA regionwide household survey panel database, which generated a series of critical findings. For example, the synergy between different technological components of CASI was clearly demonstrated, which has major significance for extension policy. Policy simulations estimated the impact of changes in public investment in extension or subsidies on the adoption of CASI. The open-access 5,000-household survey database from three panel rounds in 508 villages in five countries is a major and unique resource for the region and enables further outcomes in the form of valuable policy analyses to examine other policy and institutional options (Nyagumbo et al. 2020).

Policymakers can also draw lessons from the operational effectiveness of and outcomes from 58 innovation platforms. These evolved into multistakeholder forums for co-learning and adaptation of CASI innovations by farmers, extension, research, local business and civil society, as well as coordinating local demonstrations, input supply and marketing. Such social capital can also underpin local scaling of the SIMLESA results, and provide insights for investment in impact pathways and the planning of wider scaling efforts.

Putting knowledge to work

Some SIMLESA contributions to science are highlighted in this book, and more are comprehensively reported in about 100 reports, publications and program syntheses, organised by country and research theme, including more than 50 journal articles on CASI (29% of articles), technology adoption (24%) and research methods (20%) (Keating 2017). The focus on one broad farming system type in the region (maize mixed farming system) facilitated the interpretation of on-station and on-farm trial results and allowed for meaningful cross-country comparisons. These were enhanced by the systematic location of 33 maize–legume cropping system research sites in contrasting agroecological environments in each African country. Spatial analyses identified a number of agroecological and climate analogues between the main five SIMLESA countries in eastern and southern Africa and Australia (specifically Queensland). The productive partnership between Australian universities, African national agricultural research systems and the Consortium of International Agricultural Research Centers contributed greatly to research productivity, as did the national ownership and investments, and the capacity building activities.

A fundamental research outcome is the confidence in CASI established by the triple-bottom-line benefits (productivity, resilience, improved soils) in the maize mixed farming system, as Keating, Gahakwa & Rukuni (2018) observed, 'under farmer's circumstances at a scale previously never achieved—that is over 5,000 treatment observations developed across five countries and multiple agroecologies within country'. SIMLESA complemented the on-farm research trials with on-station experiments in all countries and agroecologies. The combination of the basic principles of conservation agriculture (minimum soil disturbance, residue retention and rotation) with complementary sustainable intensification practices (e.g. appropriate varieties, modest fertiliser applications and improved weed management) increased average maize yields by 5–38% and legume yields by 5–15% (SIMLESA 2019). Because of savings in labour requirements for ground preparation and weeding, labour productivity approximately doubled with significant savings for farming women.

The program has shown that positive environmental outcomes are possible with a multidisciplinary approach to better agronomic and natural resource management practices in a context of appropriate socioeconomic incentives and institutions. With these, African farming systems can truly enter a sustainable intensification pathway. CASI significantly improved soil health (for example, reduced bulk density and indications of increased soil carbon even in the short term). Also, maize–legume intercrops under CASI increased cropping system ecoefficiencies in Mozambique and Ethiopia, including increased water use efficiency and 34–65% reduction in soil erosion. Significantly, household surveys showed that the use of CASI practices doubled the probability of adoption of crop diversification and soil and water conservation practices. Therefore, CASI could be viewed as an entry point to wider farm and landscape developments.

In 2012, early SIMLESA experience led the program to adopt a flexible and stepwise approach to CASI smart sequences, with the intensity and sequence of practices dependent on the agroecological and socioeconomic circumstances of the farm. For example, the high ratio of livestock numbers to crop area in Ethiopia favoured zero tillage (for savings of labour and draught animals) and rotation (for soil health, human nutrition and crop sales), but farmers preferred feeding crop residues to livestock over leaving them on the soil surface. Conversely, the low population density in Malawi and lower demand for animal feed favoured the retention of crop residues in the field. The flexibility of CASI, as applied by SIMLESA, embraced agroforestry in Rwanda and improved forage production and livestock feeding in Ethiopia and Tanzania.

The program has established the complementarity of conservation agriculture principles and selected sustainable intensification practices, including improved varieties and modest inorganic fertiliser use. The on-farm evaluation and release and promotion of 40 improved maize cultivars and 64 legume varieties with significant yield potential is a major CASI-based contribution. Some of the germplasm entered the breeding program in Queensland but has not progressed to the release stage. An accompanying outcome is the increased effectiveness of coordinated germplasm improvement and seed multiplication and distribution by farmers, breeders, seed companies and farmer groups working in concert. Farming systems modelling was essential to estimate synergies between enterprises (for example, maize and legumes) and trade-offs between practices (for example, crop residue retention on the soil surface vs feeding to cattle). These activities built an understanding of the power of modelling in farming systems analysis. Efforts to build capacity on APSIM have been initiated and a number of postgraduate students have used the model for their research.

System resilience has a number of implications for sustainable rural development, not least the household food security and transient poverty arising from climate and market volatility and uncertainty. Farm household system resilience, household aversion to risk and the riskiness of technologies interact and influence the propensity of smallholder adoption. In recent years these issues have been largely ignored by most African national agricultural research systems. The program generated valuable new knowledge on risk premiums of CASI practices through econometric analysis of the household survey data and crop model simulation, which can be utilised by weather-indexed insurance programs, agricultural finance programs and agricultural extension programs. In fact, simulations based on 30-year weather series were critical for estimating the nature and level of risk stemming from climate variability. These analyses generated a greater awareness of the importance of risk and resilience for smallholders and are central to considerations of climate-smart agriculture.

Scaling and rural development

The above outputs have already led to significant farm-level economic, environmental and social impacts that indicate the potential for transformation of agricultural and rural development in eastern and southern Africa. A primary outcome of SIMLESA activities is the ability of more than half a million farmers to manage CASI practices in a way that augments crop production and income and conserves soil. By 2019, an estimated 484,000 farmers had adopted and benefited from CASI practices (SIMLESA 2019), compared with a program target of at least 650,000 farmers by 2023. The impact of adoption on household livelihoods is impressive. Based on household surveys in Ethiopia, net maize incomes expanded by 6–35% from the adoption of conservation agriculture practices and 26–137% from the adoption of the richer set of CASI practices.

Increased social capital is another farm household-level outcome, achieved through program formation of 58 operational innovation platforms. There are encouraging indications of additional household impacts arising from the innovation platforms. In due course, SIMLESA established the knowledge base, social capital and agricultural institutions to improve access to inputs, services and markets, gender empowerment, co-learning between farmers and other groups and possibly greater willingness to take risks associated with intensification, diversification and commercialisation.

The scaling activities were incorporated in SIMLESA for two reasons:

- to provide feedback to research on second-generation research issues as technologies are adopted by farmers
- to research the best scaling models for CASI under various African institutional and policy environments.

The innovation platforms are a key component of adoption and impact pathways, complementing the field operations of agricultural extension, agribusinesses and non-government organisations. SIMLESA has emphasised the importance of research, extension, agribusiness and policymakers working together to formulate practical scaling strategies for CASI. In the process of testing alternative scaling models, SIMLESA managed a competitive grant scheme to test the contributions of business, non-government organisations and media to scaling. The assessment of these alternatives is critical information for informing policymakers on optional mechanisms for scaling, which has the potential to boost scaling effectiveness and smallholder impacts.

Capacity for sustainable rural development

Strengthened capacity in eastern and southern Africa (of individuals, organisations and institutions) for CASI and diversification of agriculture is one of the major outputs of the program. This is touched on throughout this book and emphasised in the midterm and interim final reviews of the program.

From its inception, SIMLESA prioritised research competency building through on-the-job training, informal mentoring and graduate education. Training, predominantly postgraduate, was one of the planks of the Africa–Australia bridge. In fact, the program supported or arranged for 65 fellowships for masters or PhD degrees in Australia or Africa, which represents a major boost to agricultural science capacity in eastern and southern Africa. In order to ensure high-quality standardised field research, the program provided substantial short-course training of National Agricultural Research System agronomists in relation to CASI and on-farm research procedures. ACIAR, the Crawford Fund and CSIRO provided short-course training on impact pathways, innovation platforms, leadership and research report writing. The Republic of South Africa also provided a range of scholarships for masters degrees and introduced new concepts and skills through short courses on innovation systems and gender analysis. National researchers were mentored in a wide range of skills, and observers often remarked on the growth of confidence, analytical insights and presentation skills of the national program scientists. Many thousands of research-hub farmers also learned a tremendous amount about soils, inputs, CASI and marketing through interactions with scientists and the other farmers. Sister research projects also built complementary skill sets in economic analysis, mechanisation and business development. The strengthened competencies have increased the quality and efficiency of the national agricultural research systems and, to some degree, agricultural policymakers, development agencies and agribusinesses, and improved the prospects for the fine-tuning and adoption of CASI.

Building on strengthened competencies of staff, SIMLESA contributed further to the operational capacity of eight national agricultural research systems, many public agricultural development organisations and at least 40 agribusinesses. National agricultural research systems were empowered to find solutions to multidisciplinary problems in the development of CASI, especially in complex contexts such as soil health, crop–livestock integration and climate change. Similarly, the capacity of commercial firms to build and support input/output supply chains was strengthened, notably in relation to improved seed multiplication and sale. This was augmented by the business development services of a sister project on mechanisation. Thus, policymakers and governments will be better equipped to create enabling environments for the adoption and adaptation of CASI innovations by smallholder farmers.

There is a third level of capacity building related to social capital and agricultural institutions (in the sense of the ‘rules of the game’, which influence individual and organisational cooperative or competitive behaviour). There is a growing understanding of the ways in which social capital and institutions influence incentives and behaviour. By pioneering 58 innovation platforms in the African program countries, SIMLESA has demonstrated the power of social capital in relation to actor cooperation, co-learning, ongoing innovation and community monitoring of environmental and social outcomes that can be replicated by other farmers’ groups, women’s groups or cooperatives.

By way of a synthesis, Table 26.1 aggregates SIMLESA outputs into broad clusters and summarises likely outcomes from the application of the outputs until 2024 (five years after the end of the program) and anticipates probable impacts approaching 2030 (up to 10 years after the end of the program). The outcomes depend on continued commitment and follow-up investment by national governments.

Table 26.1 Selected SIMLESA output clusters, likely outcomes and probable impacts by theme

Program themes	Output clusters generated during the program	Likely outcomes from use of outputs (up to 2024)	Anticipated impacts (up to 2030)
Agricultural development paradigms	Influence on systems and CASI-oriented content of other programs and projects in Africa and Asia	Growing recognition of the relevance and effectiveness of systems and CASI approaches to agricultural development	More effective regional and national agricultural and rural development programs
Farming systems research methods (including agronomy, crop improvement, livestock forage, socioeconomics)	Demonstrated multidisciplinary team management in eight countries, demonstrated crop modelling, major open-access databases and analyses, notably the 5,000 household panel surveys and agronomy trial data	Strengthened multi- and interdisciplinary research in national agricultural research systems, wider use of crop modelling, further analysis of SIMLESA agronomy and economic data, integrated analysis of crop management, mechanisation and livestock feed management results	More effective and adoptable innovations for farming systems intensification and resilience, through routine use of farming systems research multidisciplinary teams and farming systems modelling, a knowledge base on maize mixed farming system informing eastern and southern Africa research priorities and policymaking
CASI	Proven CASI-based maize–legume practices supported by soil health, mechanisation and value chains in high/low potential agroecologies in 5+ countries, pilot adopted by 480,000+ farmers	Regional policy support and national investment in CASI smart sequences for sustainable rural development, significant farmer adaptation and innovation of CASI practices	Sustainable intensification trajectories for major eastern and southern Africa farming systems through application of CASI smart sequences, enriched with legumes, livestock, agroforestry and mechanisation
Resilience/risk reduction	Demonstrated estimates of risk premiums by practices from surveys and crop climate simulations	Greater awareness of risk management in sustainable intensification, promotion of crop and livestock insurance	Improved risk management options available to smallholders, routine risk assessment, most likely by farming system simulations
Innovation platforms	58 operational innovation platforms linking local actors, fostering co-learning and innovation, and strengthening market access	Awareness of the role of social capital and multistakeholder forums, support for the existing innovation platforms, and replication	Increased smallholder benefits from access to and adaptation of CASI innovations and markets, improved storage
Capacity building	Increased competencies of farmers, research, extension and businesspersons, and postgraduate training for 65 researchers	Improved research and scaling quality and efficiency, and more productive and adoptable innovations	Improved smallholder livelihoods and environmental benefits from the increased research capacity of national agricultural research systems
Scaling and spillovers of CASI and related innovations	Cross-border spillovers to three countries, identified impact pathways, scaling strategies and pilot scaling leading to adoption of CASI by 480,000+ smallholders in five countries	National and agribusiness investment in adoption and impact pathways for CASI, adoption by more than 650,000 smallholders, continued exchanges across regional platform	Widespread adoption and sustainable economic, environmental and social benefits contributing to the United Nations Sustainable Development Goals

Note: CASI = conservation agriculture-based sustainable intensification

Of course, SIMLESA could not embrace all aspects of farming systems in its first decade. However, the program linked directly to complementary research projects on critical themes such as adoption pathways, mechanisation and crop–livestock integration; and communicated with other projects in Africa on relevant research on agroforestry and sustainable intensification (e.g. the USAID-supported Africa Rising) and in Asia on sustainable and resilient farming systems intensification.

Ways forward and building on SIMLESA outputs

The immediate opportunity, even an expectation, is that national governments will invest in scaling CASI-smart sequences, building on the results and capacity generated by SIMLESA, in line with the intent and spirit of the communiqué endorsed by eight ministers of agriculture from the region in May 2019. The immediate target would be the adoption of CASI by at least 650,000 smallholders by 2023. Naturally, there are opportunities to strengthen institutions piloted by SIMLESA, such as the innovation platforms and working links with agribusiness seed, machinery and media companies and non-government organisations. It would be advantageous to monitor adoption and farmer adaptation of CASI and extend the lessons to national agricultural research systems and national policymakers.

The relevance, strength and magnitude of SIMLESA outputs and outcomes for CASI in eastern and southern Africa countries is obvious, and opens many opportunities for research and development in the short term and in the medium to long term. There would be good pay-offs from pursuing a deeper analysis of the existing socioeconomic and agronomy databases. Research on the integration of mechanisation, perennials and livestock into selected program research hubs and/or innovation platforms would be valuable. While CASI clearly benefits farming women, additional research on adapting and scaling CASI in the context of gender empowerment would be very useful.

Climate change has become a top policy and research priority for countries of eastern and southern Africa. Agricultural leaders focus on the adaptation to climate change, especially the increased variability of precipitation. In the medium term, changes in annual precipitation, shifts in seasonal rainfall patterns and increases in temperature are common concerns. It will be important to identify win–win solutions for adaptation to climate change and mitigation of emissions of greenhouse gases. In Africa, a large proportion of the continental emissions are agriculture-related, and the conversion of land to cultivation continues (see Kenya's Climate Smart Agriculture Strategy 2017–2026, Tanzania's Climate Smart Agriculture Program 2015–2026, and Africa Climate Smart Alliance convened by The New Partnership for Africa's Development and the Common Market for Eastern and Southern Africa). However, it is important to recognise that non-climate-related constraints to smallholder intensification and diversification and food and nutrition security have not evaporated; in fact, they interact with and compound the climate change challenges.

Because SIMLESA focused on risk reduction (in the context of variable climate) alongside CASI (across a spectrum of agroecologies), the CASI results are directly relevant to the challenge of climate variability and climate change. Moreover, the augmented capacity built by SIMLESA in research, development and businesses for multidisciplinary research and scaling development is a huge advantage for tackling 'wicked' (complex and uncertain) problems such as climate change and its interactions with other agricultural constraints. The goals of intensification, food and nutrition security and climate-smart agriculture (including climate change adaptation and mitigation) are intimately intertwined with those of CASI (Figure 26.1).

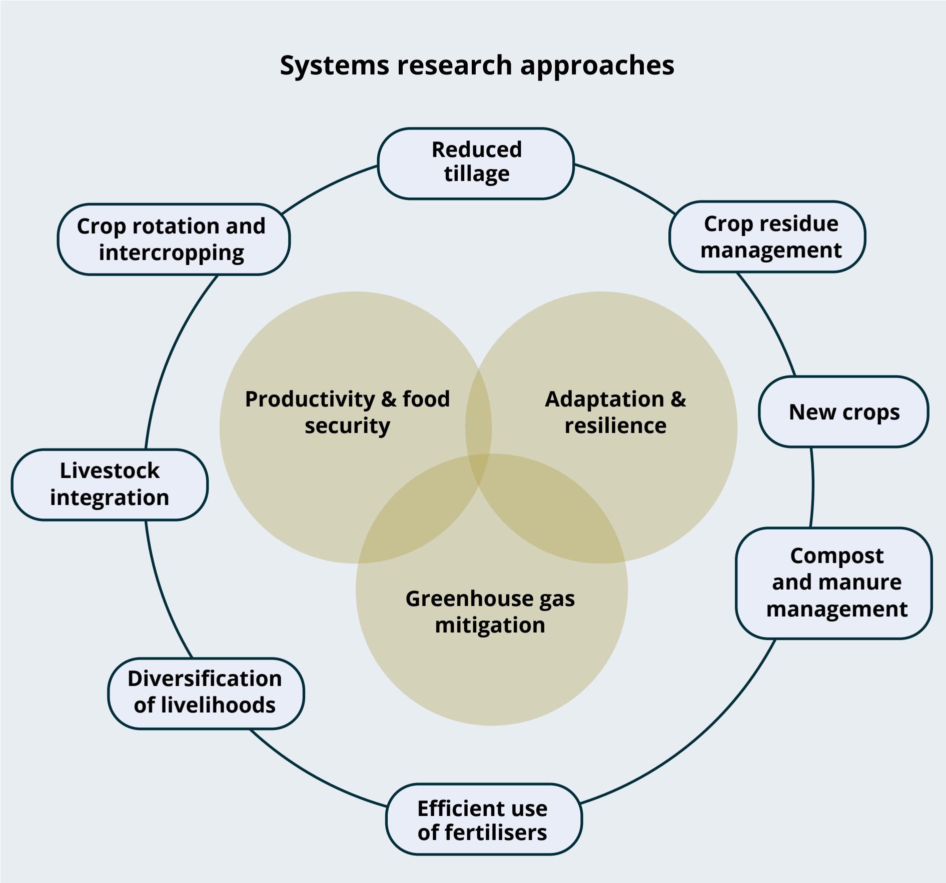

Figure 26.1 **Key CASI focus areas mapped to three climate-smart agriculture pillars**

Source: Adapted from Keating 2018

The complementarity between climate-smart agriculture and CASI is clear. Climate-smart agriculture is viewed as an approach towards the goals of agricultural productivity/food security, adaptation/resilience and mitigation, rather than a recipe of technologies. Generally, climate-smart agriculture practices are not novel. Rather, they are well researched soil, water, nutrient, crop and residue, tree and livestock practices, often with newer complementary institutional or insurance mechanisms. All of the issues of concern to researchers and policymakers looking into CASI pathways are in scope in a climate-smart agriculture approach. However, climate-smart agriculture is highly context dependent (as with systems-oriented CASI). Thus, the Climate Smart Village approach seeks to place climate-smart agriculture in a community-based participatory learning context, focused on local co-learning about feasible options rather than spilling-in technologies from outside (there are similarities with SIMLESA's innovation platforms). Trade-offs and synergies across climate-smart agriculture are common—a single practice or portfolio of practices/services will generate a mix of costs and benefits that could contribute to the three climate-smart agriculture goals. The evidence is mounting that markets and institutions in the broadest sense are critical obstacles to progress (as with CASI goals).

Addressing the climate change challenge requires integrative and transformative farming systems research. Given the richness of the knowledge bases on resource management, agronomy, livestock and socioeconomic aspects of farm households, it has been argued that transformation requires an emphasis on the benefits and trade-offs of alternative policy and institutional innovations (in particular, social capital contexts) for the climate-smart sustainable intensification of agriculture. It is important to focus policy and institutional options on integrated farming systems (for example, crop–livestock farming systems, interfaces of production systems with local institutions and markets, and coordinated provision of agricultural services and inputs) towards CASI to boost livelihoods and resilience while navigating the complex challenges of climate change. Farming system modelling and policy simulation will be useful tools, especially if differentiated by types of farming systems and households. It is essential to clarify pathways to impact and scaling strategies for any technological or institutional innovation prior to major investments in research. Naturally, there would be advantages in building on some of the scientific relationships established between eastern and southern African countries and Australia.

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Appendix

Joint Communique: ASARECA COUNCIL OF PATRON MINISTERS SUMMIT: Repositioning ASARECA for Accelerated African Agricultural Transformation, May 2019

CIMMYT International Maize and Wheat Improvement Center

Australian Government
Australian Centre for International Agricultural Research

ASARECA Transforming Agriculture for Improved Livelihoods

Joint Communiqué

Joint communiqué by Ministers of Agriculture of The Republic of Burundi, The Republic of the Congo, The Democratic Republic of Congo, The State of Eritrea, The Federal Democratic Republic of Ethiopia, The Republic of Kenya, The Republic of Madagascar, The Republic of Rwanda, The Republic of South Sudan, The Republic of the Sudan, The United Republic of Tanzania, The Republic of Uganda, The Republic if Malawi and The Republic of Mozambique of the high level Ministerial Panel on Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) implemented by CIMMYT and national partners in Uganda, Ethiopia, Kenya, Malawi, Mozambique, Rwanda and Tanzania at the ASARECA Council of Patron Ministers Summit.

We, the Ministers responsible for Agricultural Research from the aforementioned countries gathered in Kampala, Uganda, on this 3rd day of May 2019;

Aware

- **that** in Eastern, Central and Southern Africa, the challenge of feeding a growing population projected to double by 2050 has to be met,

- **that** despite a degrading resource base coupled with global climatic and economic changes, where smallholder agriculture remains the centerpiece of our countries' economies,

- **that** confronting this challenge while protecting the natural resource base involves finding innovative and sustainable ways to produce more food with less resources.

Cognizant of the need to use our land resources in ways that will ensure its health and sustainable access to future generations, **Here note that:**

- conservation agriculture-based sustainable intensification (CASI) practices, including practicing minimum tillage, maintaining permanent soil cover and mulches and implementation of crop diversification practices (such as cereal legume intercropping and rotations), as tested through the sustainable intensification of maize-legume cropping systems in eastern and southern Africa (SIMLESA) program and similar multidisciplinary research efforts show promise in boosting and stabilizing productivity and safeguarding the resource base in the face of climate change.

- Mainstreaming CASI calls for institutionalization efforts that support scaling and networking, integration into agricultural research and extension systems and fostering value chains development. CASI also benefits from appropriate mechanization which would reduce drudgery especially for women farmers and laborers; as well as attracting youth talent into agriculture.

Do therefore recommend the following policy actions to our Governments and call for concerted action from a range of multiple stakeholders in Africa including: multi-disciplinary researchers, Think Tanks, extension agencies, National and Regional Parliaments and Local Governments, private businesses, non-governmental organisations, regulatory agencies, farmers and their community organisations, trade organisations and others:

Mainstream and Institutionalize Conservation Agriculture-based Sustainable Intensification (CASI) farming practices through:

Enhanced investments in scaling priority technologies through

- *Advisory and extension institutions.* Ministries of Agriculture should facilitate re-skilling extension personnel in CASI and the operations of farmer innovation platforms and collective institutions

- *Broad-based Farmer Education through CASI demonstration and learning sites.* By mobilising public and private partnerships to fund national networks of long term CASI learning sites.

Regional CASI networks of

- *Ongoing adaptive and multi-disciplinary research, training at multiple levels and knowledge systems.* This should be done in collaboration with other relevant ministries and agencies (such as Education, Science and Technology, Environment and Natural resources) as well as sub-regional research organisations such as ASARECA, CCARDESA and CORAF.

Enable rural market development by:

Encouraging innovations that improve rural value chains and enable adoption of CASI.

- Supporting agribusinesses willing to invest in rural innovation and market development as part of their business model, e.g. through funds that enable such innovators to access start-up capital where needed.

- Promoting collective institutions to enable farmer integration into markets

Support the development of smallholder machinery value chains through:

Collaborative efforts for networks of machinery development, testing and adaptation

- Local-level training for entrepreneurs in decentralized custom hire businesses and service centers

- Support market innovations that enable low-cost farmer learning and experimentation

To conclude, **we re-affirm** that with multi-sector support, smallholder farmers can trial, select and adopt CASI practices suited to their varying conditions to build resilient farms needed to feed the growing populations in Africa. Using CASI as a framework, it is possible to instigate critical paradigm shifts in smallholder farming systems and underlying agronomy, encourage institutional and market innovations to support farmers adopt CASI.

The potential of CASI to conserve soils, improve yields and have positive environmental impacts can enhance farm resilience to the effects of climate change. Therefore, CASI should be promoted as a regional initiative and as a major contributor to achieving the Malabo Commitment on resilience of farming systems in Africa.

We also affirm that political and material support at both national and regional levels are required to build strong partnerships in regional AR4D flagship programs for scaling of agricultural technologies and innovations. These regional collective actions are critical opportunities to create the free flow of new ideas, research results, technologies and innovations to generate the much needed spillovers across institutions and countries. Such positive spillovers are central to achieving impact of agricultural innovations faster and at national and regional scale.

IN AGREEMENT HEREOF, the undersigned representatives being duly authorized by their respective Governments have signed the present Joint Communique

DONE AT KAMPALA, this___**3rd**___ day of __**May**__Year __**2019**_____

FOR:

THE REPUBLIC OF BURUNDI

....

MINISTER OF ENVIRONMENT, AGRICULTURE AND LIVESTOCK

REPUBLIC OF THE CONGO

....

MINISTER OF SCIENTIFIC RESEARCH AND TECHNOLOGICAL INNOVATIONS