# 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.

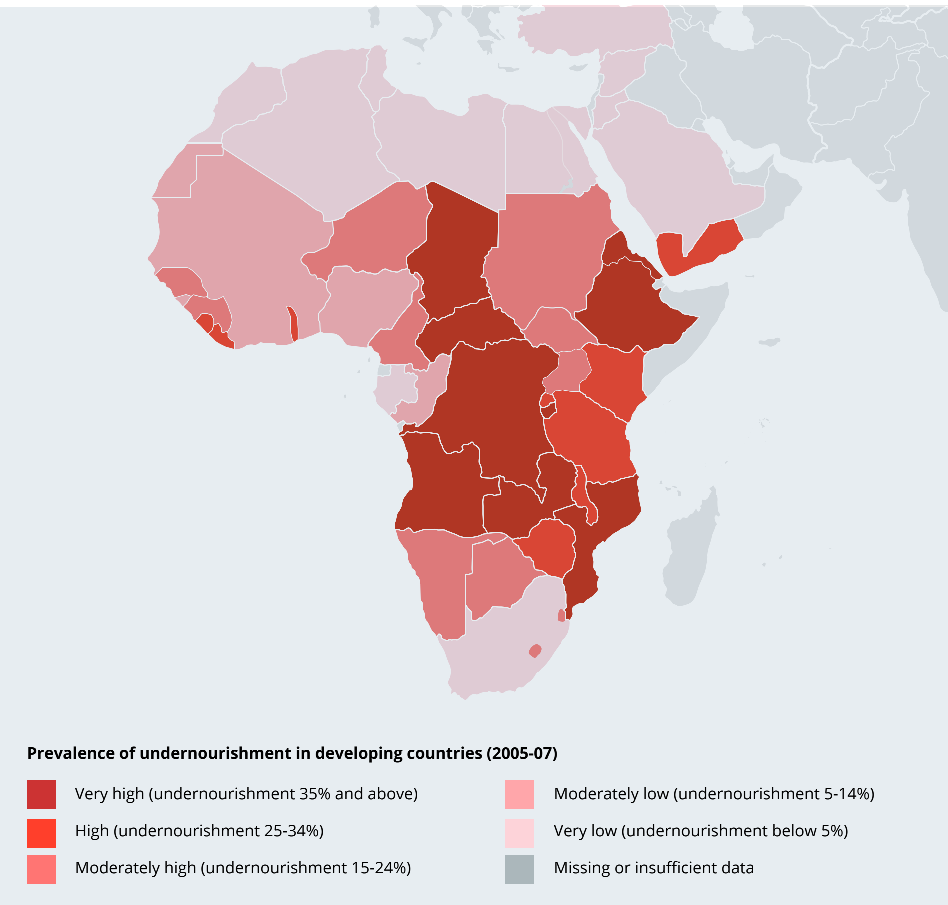


**Figure 1.1** **Hunger in eastern and southern Africa**

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.

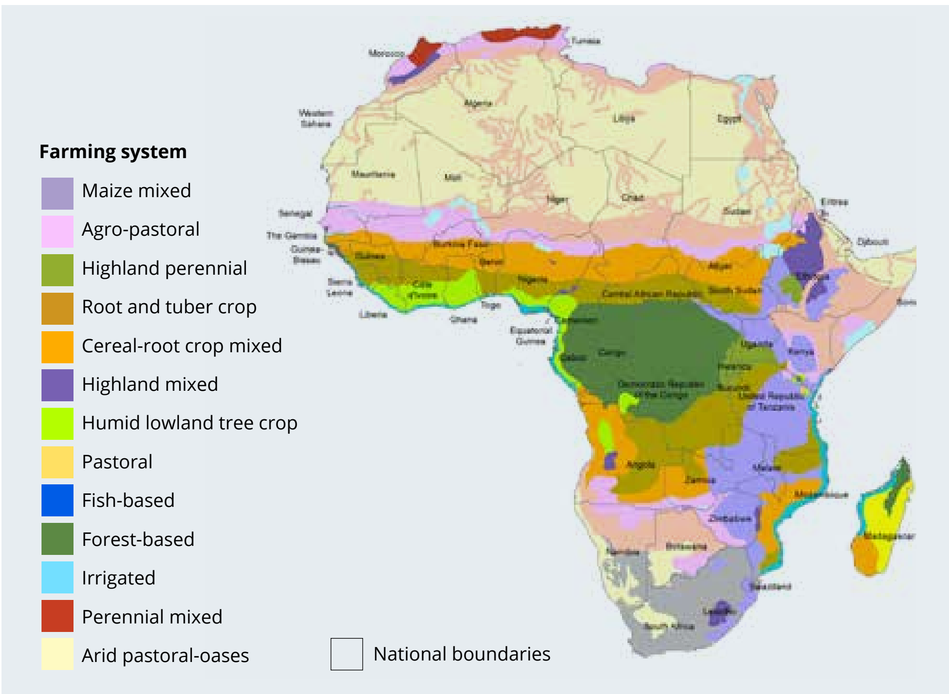


**Figure 1.2** **Principal farming systems of Africa**

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<br>• refined the site and technology characterisation and testing<br>• disaggregated farm adoption constraints, incentives and trade-offs<br>• 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<br>• expansion of on-farm evaluation of interactions among genotype, environment and management (including CASI) components of maize and legume production systems<br>• enhanced interdisciplinary monitoring<br>• fine-tuned innovations for crop–livestock farming systems<br>• 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<br>• 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<br>• 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).

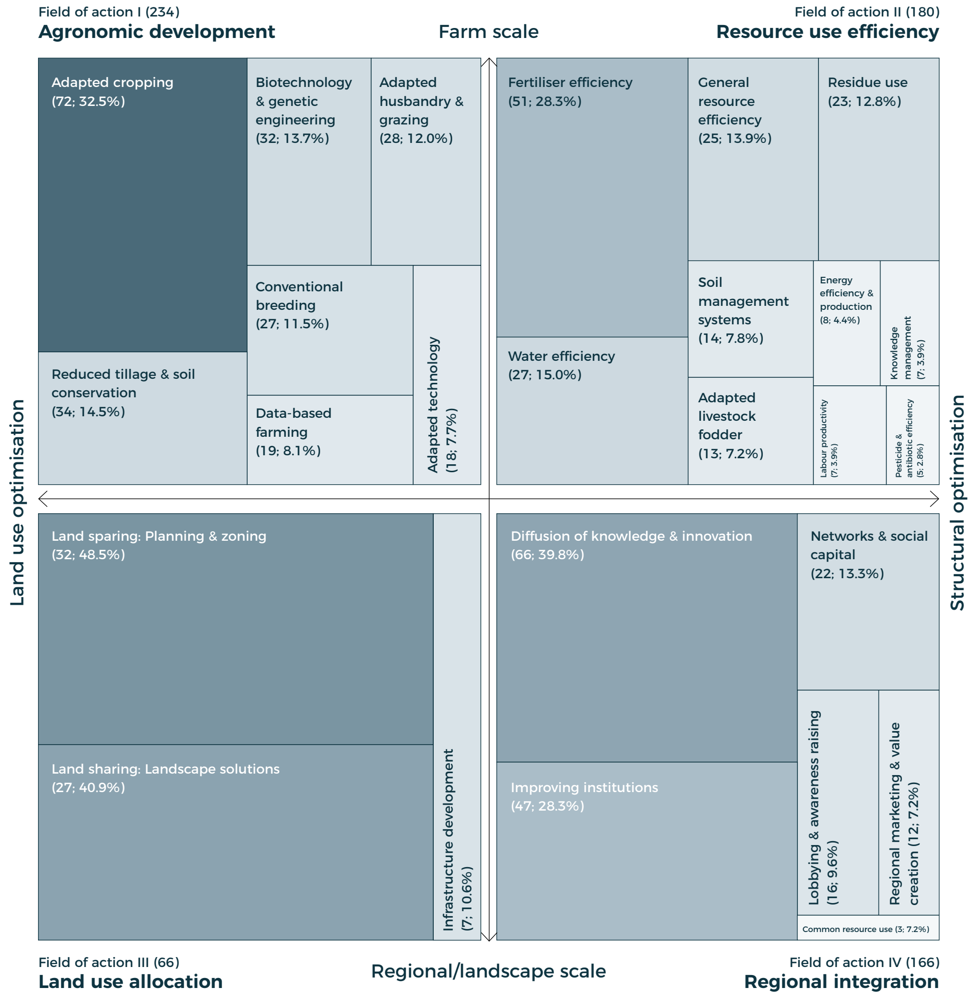


**Figure 2.1** **Prevalence of sustainable intensification application areas by scale and scope in a sample of scientific articles.**

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<br>• Pollination damage<br>• Pest damage<br>• Reduced grain fill, high moisture grain at harvest time | • Insufficient food<br>• Nitrogen loss<br>• Nutrient leaching<br>• Soil erosion | • Natural disasters<br>• 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<br>• 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<br>• Resilient tillage and plot design practices<br>• Crop insurance | • Infrastructure planning (e.g. dams)<br>• 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.

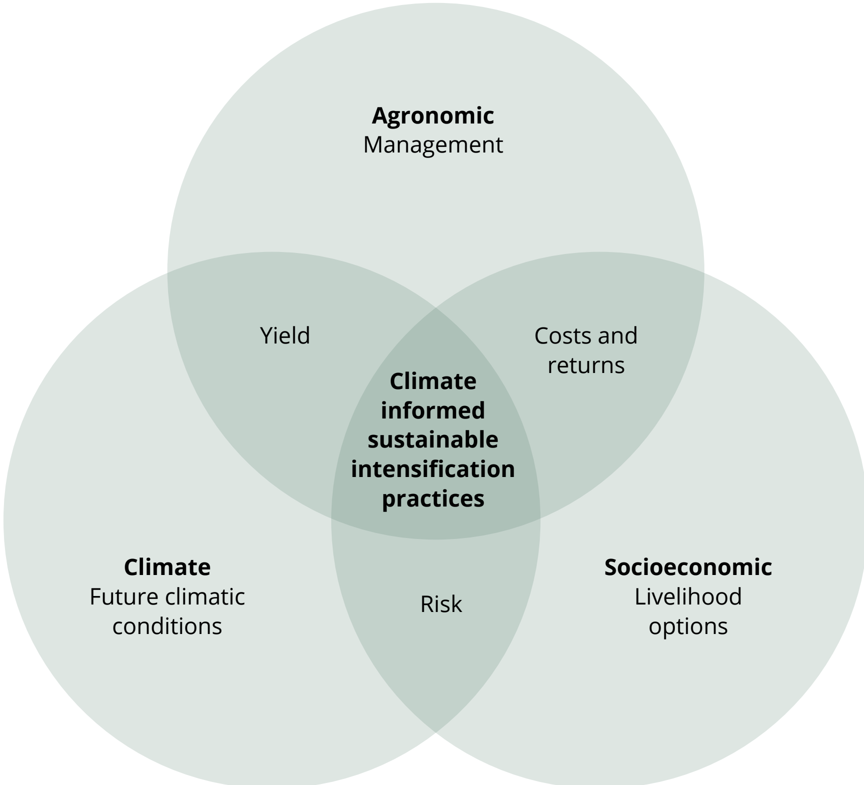


**Figure 4.1** Venn diagram of climate-informed sustainable intensification practices

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

Michael Misiko, Daniel Rodriguez, George Mburathi, Mulugetta Mekuria, John Dixon & Erin Wilkus

## 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.

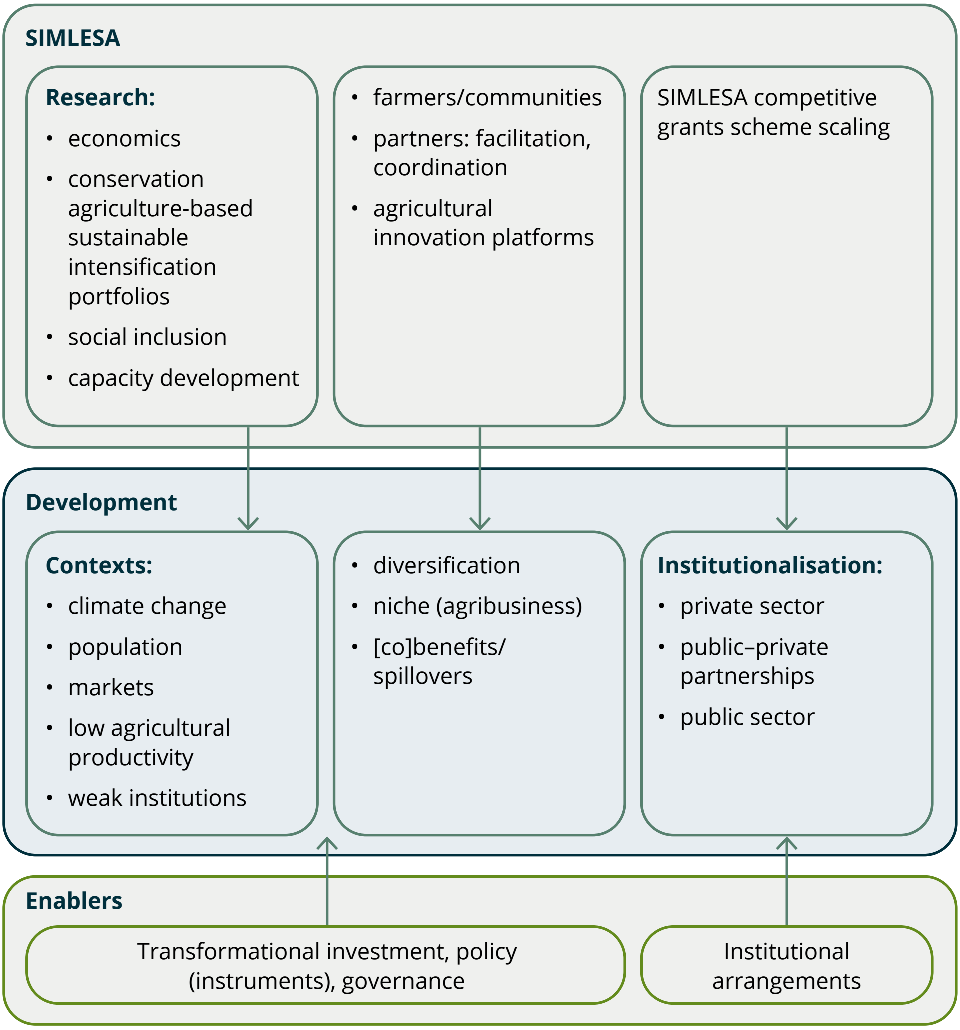


**Figure 5.1** **SIMLESA and the innovation gap (SIMLESA integrated field research, economics, capacity, social inclusion, with agricultural innovation platforms and a competitive grant scheme)**

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.

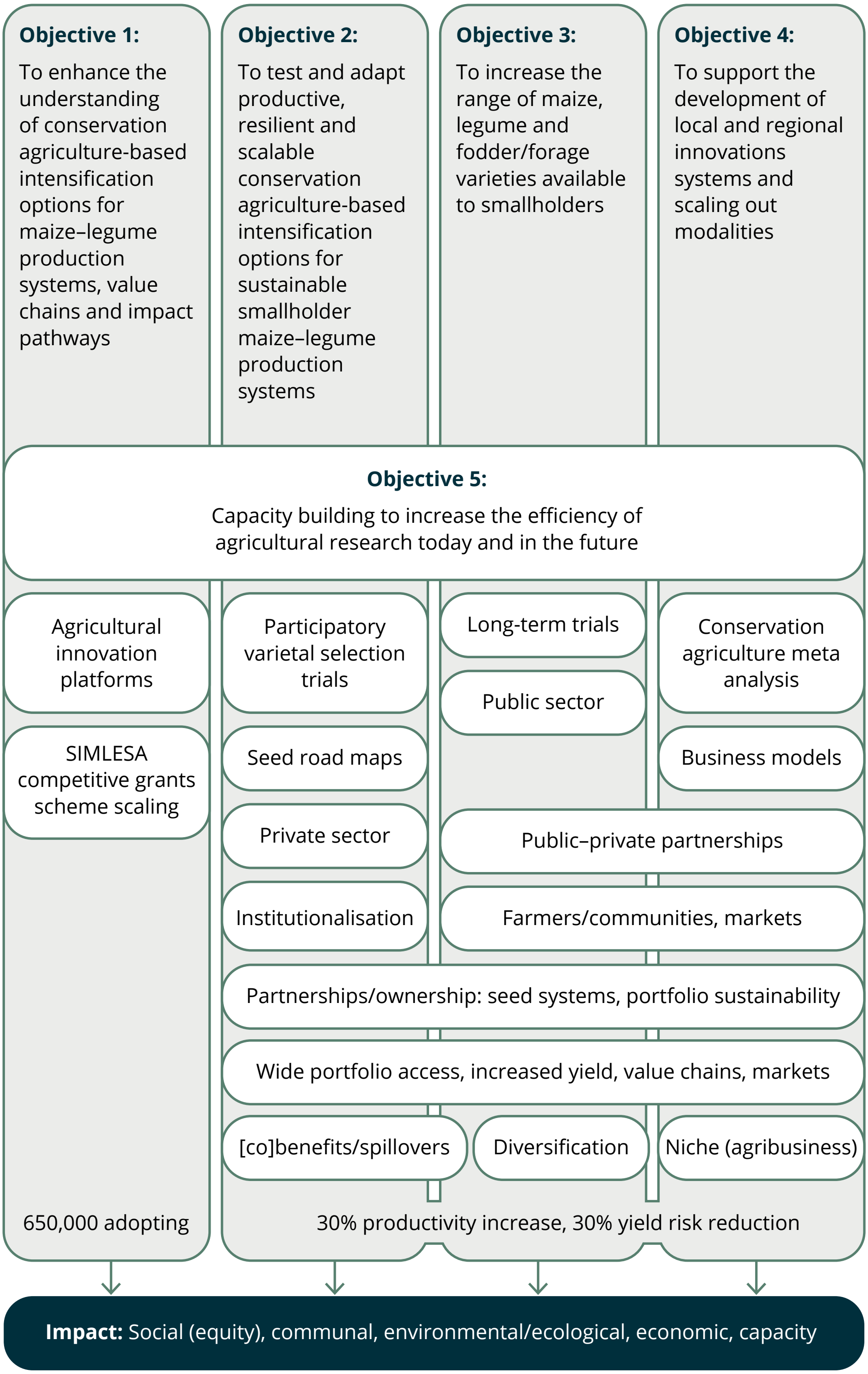


**Figure 5.2** SIMLESA transdisciplinary architecture

# 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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