ENHANCING AGRICULTURAL RESILIENCE AND SUSTAINABILITY IN EASTERN AND SOUTHERN AFRICA

Key Findings and Recommendations for Rwanda

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RAB
RWANDA
AGRICULTURE AND ANIMAL RESOURCES DEVELOPMENT BOARD

CIMMYT

SIMLESA
Sustainable Intensification of Maize and Legume Systems for Food Security in Eastern and Southern Africa

Australian Government
Australian Centre for International Agricultural Research

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List of Acronyms

ACIAR	Australian Centre for International Agricultural Research
AIP(s)	agricultural innovation platform(s)
CASI	conservation agriculture-based sustainable intensification
CIAT	nternational Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
FAO	Food and Agriculture Organization of the United Nations
GDP	gross domestic product
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
ILRI	International Livestock Research Institute
NGOs	nongovernmental organizations
QAAFI	Queensland Alliance for Agriculture and Food Innovation, University of Queensland, (Australia)
RAB	Rwanda Agricultural Board
SIMLESA	Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa

AGRICULTURE IN RWANDA

A NISR study [1] estimates that Rwanda's agricultural sector employs 72 percent of the population and contributes 33 percent of the country's gross domestic product (GDP). The mismatch between the high proportion of the population engaged in agriculture and its low contribution to GDP is indicative of an unproductive sector (despite its intended role as an engine of economic development) and a lack of serious alternative economic activities. As a result, the majority of the population is under-utilized.

The dual concerns of low productivity and food insecurity stem from frequent crop failure due to semi-humid conditions and very low crop yields due to acidic soils — both of which affect 45 percent of the country's arable land [2]. The low productivity of Rwandan agriculture is basically attributable to inherently poor soil parent materials, such as granite, gneiss and schists, which create soils with low concentrations of basic cations (calcium, magnesium, phosphorous and sodium) and very low cation exchange capacity. Soil infertility is exacerbated by soil nutrient depletion. This, in turn, arises from soil water erosion due to intensive cultivation (two seasons per year) and steep slopes (up to 60 percent or more).

Another considerable constraint relating to soil quality is declining soil organic matter due to high population density (400 inhabitants per square kilometer) and intensive land use. Farmers' low purchasing power is also a considerable constraint to the adoption of sustainable intensification technologies, such as the application of lime, manure and fertilizer [2]. Finally, Rwandan agriculture is highly vulnerable to climate change because rainfed agriculture dominates due to the unfavorable topography. Moreover, the high risks associated with climate change create disincentives for farmers to invest their limited resources in improving soil fertility.

Almost all farmers in Rwanda are smallholders, cultivating less than two hectares. Yet most of the country's farm households (60 percent) cultivate plots of less than 0.7 hectares [1]. Despite efforts by the Rwandan government in the past decade, more than 4.4 million people remain in poverty [3]. Almost 38 percent of children under five years of age are chronically malnourished, with stunting levels of more than 40 percent [4]. A survey by the World Food Programme [5] showed that the high shares of households with unacceptably low food consumption levels were located in the western and southern provinces, alongside the Congo-Nile Crest. Soils are acidic in these areas, and 70 percent of the households located there face food insecurity.

In the past, farmers adapted to climate change by intercropping combinations of maize, beans, and cassava, or by planting drought-tolerant crops, such as sorghum and sweet potatoes [2, 6]. Extensive land use has made these approaches obsolete because the resulting productivity is too low. In response to this situation the government of Rwanda promoted the rotation of the staples maize and beans as priority crops [7]. As a result, the production of maize rose sharply, from 167,000 metric tons (mt) in 2008 to 668,000 mt in 2013; it subsequently declined, however, to 370,000 mt in 2017 [8]. While Rwanda's biophysical environment would seem only marginally suitable to producing maize, the country's potential market for maize is large, with a total consumption of 550,000 mt in 2012 [9]. Beans are the country's major source of protein and calories [10]. Climbing beans are cultivated in the wet highlands (more than 1,800 meters above sea level), whereas bush beans are cultivated in the humid middle and semi-humid lowlands (1,800–2,300 meters above sea level). Therefore, the sustainable intensification of maize and bean production in Rwanda appears to be justified.

A New Approach to Agriculture

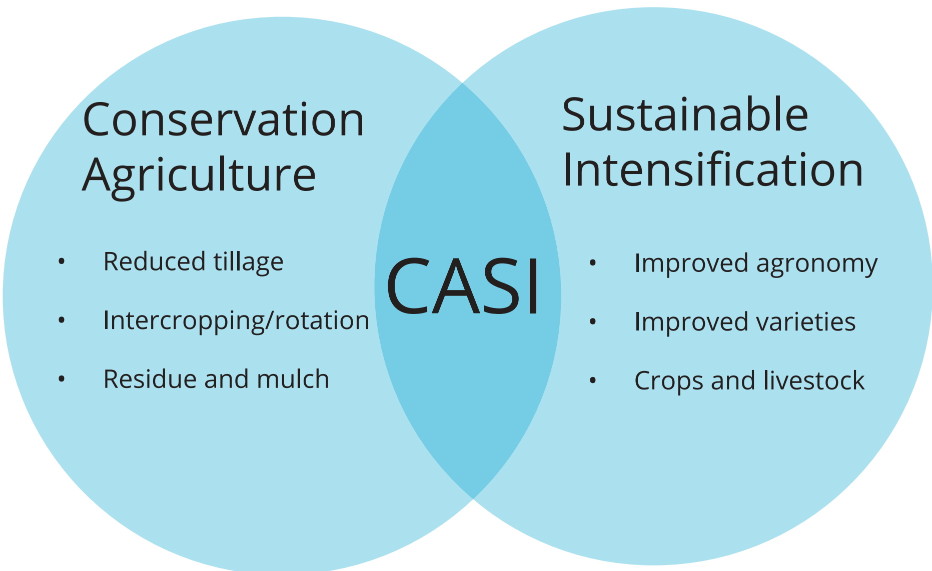
Sustainable Intensification of Maize-Legume Cropping Systems for Food Security in Eastern and Southern Africa (SIMLESA) was a project implemented between 2010 and 2018 in five African countries (Ethiopia, Kenya, Malawi, Mozambique and Tanzania) and two spillover countries (Rwanda and Uganda). The project's goal was to increase African smallholders' food security, productivity and income levels by integrating sustainable intensification practices to increase productivity, while simultaneously protecting the natural resource base. The particular mix of technologies developed by SIMLESA are known as "conservation agriculture-based sustainable intensification," or CASI (Fig. 1). By utilizing these technologies, SIMLESA sought the dual outcomes of sustainably raising yields by 30 percent, while decreasing the risk of crop failure by 30 percent. In short, SIMLESA focused on and promoted maize and legume cropping systems to improve food and income security and resilience to climate change on African farms.

The project — financed by the Australian Centre for International Agricultural Research (ACIAR) — was led by the International Maize and Wheat Improvement Center (CIMMYT) in collaboration with numerous partners, including national agricultural research institutes (NARIs), in this case, Rwanda Agricultural Board (RAB); CGIAR centers, such as the International Center for Tropical Agriculture (CIAT), the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), and the International Livestock Research Institute (ILRI); and the Queensland Alliance for Agriculture and Food Innovation (QAAFI) of the University of Queensland, Australia.

Project Overview

SIMLESA undertook onfarm research in different agro-ecological zones to assess the benefits of conservation agriculture-based sustainable intensification and to develop appropriate technology packages for smallholder farmers. The project succeeded in increasing the range of maize, legume and fodder/forage varieties available, and involved farmers in seed-selection trials so they could identify their preferences. SIMLESA helped establish agricultural innovation platforms (AIPs) to progress members — including farmers, seed producers, agro-input dealers, nongovernmental organizations (NGOs) and extension workers — along the value chain. The platforms serve farming communities, help mobilize resources, and support up- and out-scaling. SIMLESA also provided training and capacity strengthening for national agricultural research systems and worked with government, business and civil society organizations to provide an enabling environment for the benefits of the newly introduced technologies to be realized by farmers.

Figure 1. Conservation agriculture based on sustainable intensification



Source: SIMLESA-Rwanda
Note: Improved agronomy includes the use of fertilizer and herbicide; crops and livestock include fodder and forage.

SIMLESA-Rwanda

The overall objective of the interventions promoted by SIMLESA-Rwanda was to evaluate conservation agriculture approaches and demonstrate and promote the best performing options to farmers, field technicians, scientists and policy-makers. If yields under conservation and tillage agriculture do not differ statistically at the beginning of two to three first growing seasons, it is assumed that conservation agriculture should be considered based on its associated environmental and labor saving benefits. In addition, crop yields are expected to rise overtime as soil properties — such as soil carbon and nitrogen — improve under conservation agriculture, as opposed to continuing to deteriorate under tillage agriculture. The specific objectives were (1) to demonstrate the comparative effects of conservation agriculture and tillage agriculture practices on maize and bean yields in rotation within each site, (2) to compare the effects of different soil fertility inputs on maize and bean yields, and (3) to identify the adoption drivers of conservation agriculture in three agroecological zones.

Strategic Approach

The SIMLESA-Rwanda approach was unique in that, rather than having different farmers applying either conservation agriculture or tillage agriculture approaches, it allowed individual farmers to experiment with both kinds of practices side-by-side on plots, providing them with first-hand experience of the differences over time. Statistical comparisons of the results by scientists remained viable, but the comparative approach facilitated easy and rapid learning on the part of the farmers. Another strategy involved conducting a minimum of one farmer field day during the growing season so farmers could compare differences between the two kinds of treatments. The goal was to form cooperatives of farmers practicing conservation agriculture, ultimately leading to the development of AIPs around conservation agriculture technologies.

Project Sites

SIMLESA-Rwanda implemented activities in three agroecological zones based on altitude, rainfall levels, topography and soil fertility (Tab. 1). The experiment fields acted as an "adoption desk," tangibly demonstrating the feasibility and benefits of conservation agriculture practices both to farmers and to reluctant scientists. Each plot was subdivided to receive one of three treatments: manure; manure and fertilizer; or manure, fertilizer and biofertilizer. The trial plot was of five by five meters (25 square meters). Treatments were applied uniformly in the split plots using conservation agriculture and tillage agriculture. The project worked with 30 farmers: 12 located in Nyaruguru, 12 located in Runda and 6 located in cyuve. The resulting area totaled 750 square meters (30 x 25 square meters).

Table 1. SIMLESA-Rwanda intervention sites

Site	Agroecological zone	District	Altitude (m)	Rainfall (mm/year)	Site topography	Soil fertility
Gashora	Semi-humid lands of Bugesera	Bugesera	1,000–1,400	900	Flat	Very good
Runda	Central plateau	Kamonyi	1,400–1,800	1,200	Hilly	Good
Cyuve	Volcanic lands of Birunga	Musanze	>2,000	>2,000	Flat	Excellent

Source: SIMLESA-Rwanda

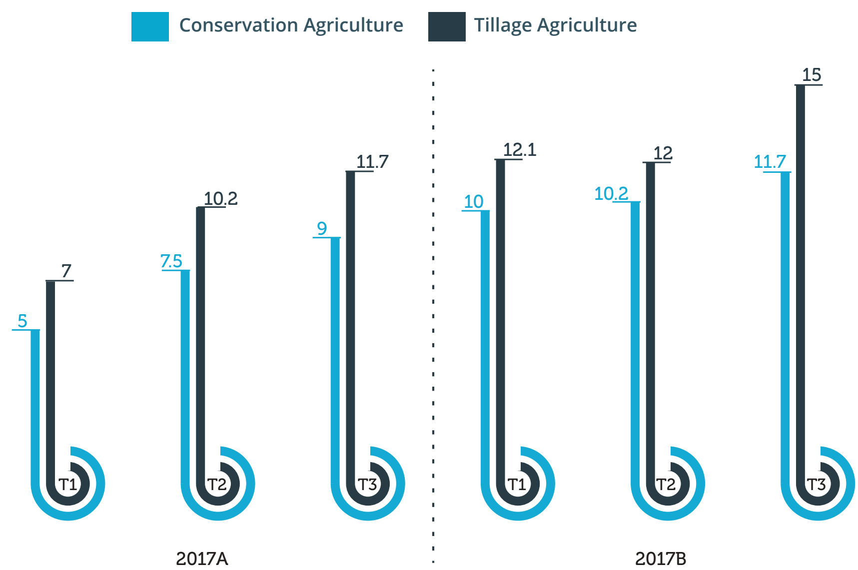
KEY FINDINGS

Results in Runda

In the first season of 2017, tillage agriculture in Runda yielded statistically higher results across all treatments compared with conservation agriculture (Fig. 2). The second season of 2017, however, yielded no observable differences between conservation agriculture and tillage agriculture. These results may indicate a learning curve, whereby the newer practices were inefficiently implemented, or that the soil was still lacking organic matter and nitrogen. The difference between two kinds of approaches was smaller in the second growing season. More appropriate application of the techniques by farmers and subsequent improvement in the soil properties under conservation agriculture could explain the reduced performance margin in the first season. During the second season, the differences between Treatments 1, 2 and 3 were not significant, but yields under tillage agriculture were significantly higher under Treatment 3. In all cases, however, Treatment 3 outperformed Treatment 2, and Treatment 2 outperformed Treatment 1.

Bean yields under conservation agriculture and tillage agriculture were not significantly different in Runda over two consecutive growing seasons, but significant differences were observed between seasons and treatments (Fig. 3). The benefits of conservation agriculture were apparent in the second season based on the use of mulch in the first season and farmers' familiarity with the new techniques (such as mulching and timely weed control).

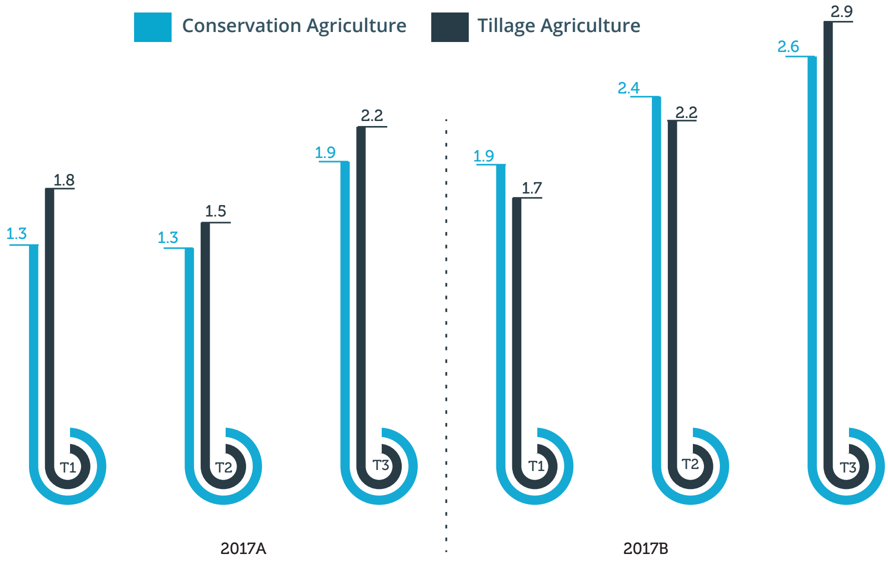
Figure 2. Maize yields in Kamonyi, 2017



Source: SIMLESA-Rwanda.

Notes: Yield is measured as cobs and grain. Treatment 1 (T1) = manure only; Treatment 2 (T2) = manure and fertilizer; and Treatment 3 (T3) = manure, fertilizer, and biofertilizer. 2017A indicates the first growing season for the year, and 2017B indicates the second.

Figure 3. Bean yields in Kamonyi, 2017



Source: SIMLESA-Rwanda

Notes: Yield is measures as grain. T1 = manure only; T2 = manure and fertilizer; T3 = manure, fertilizer, and biofertilizer.

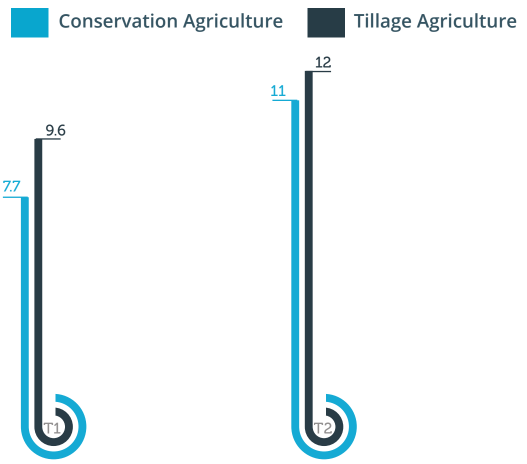
Results in Bugesera

Looking at maize yields in Bugesera, no significant difference was observed between the two kinds of agricultural practices in one season in 2017 (Fig. 4). Treatment T1 was, however, less effective than Treatments 2 and 3, which prompted the inclusion of soil fertility management as the fourth principle of conservation agriculture [11]. The significant improvement in yields with the application of fertilizer can be attributed to depleted soils in Bugesera, which required amendment for maize production. The effect of biofertilizer was not statically significant, however.

Production in Bugesera in the first season of 2017 was a total failure due to drought, irrespective of the farming practices used.

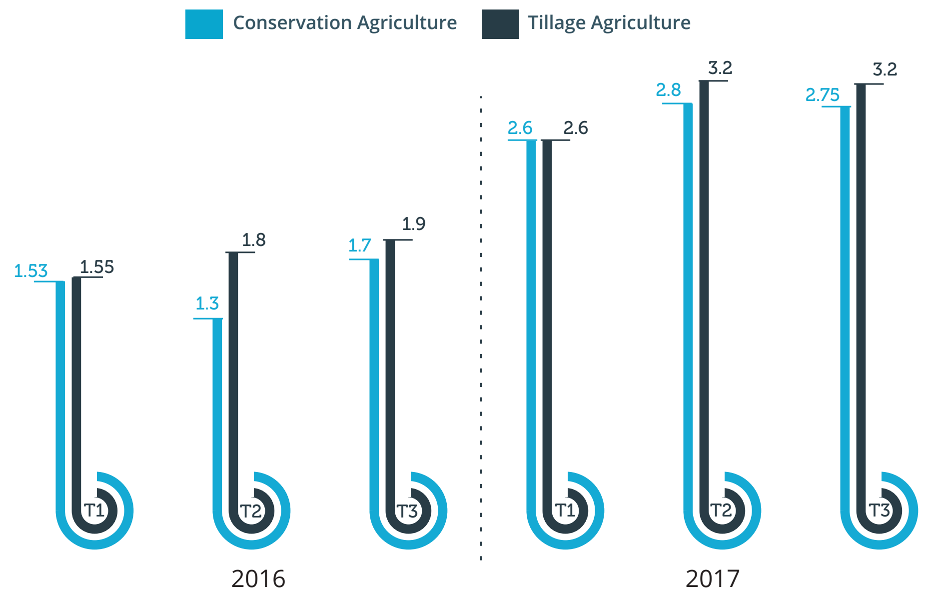
Bean yields for the second growing seasons of 2016 and 2017 in Bugesera were not significantly different either in terms of the method of farming practices or the treatments used (Fig. 5). Bean production might have been less sensitive to inputs than maize because beans require fewer soil nutrients. In addition, the soils in Bugesera were more fertile than those in Runda.

Figure 4. Maize yields in Bugesera, 2017



Source: SIMLESA-Rwanda.
Notes: Yield is measured as cobs and grain. T1 = manure only; T2 = manure and fertilizer; T3 = manure, fertilizer, and biofertilizer.

Figure 5. Bean yields in Bugesera, 2016 and 2017



Source: SIMLESA-Rwanda.

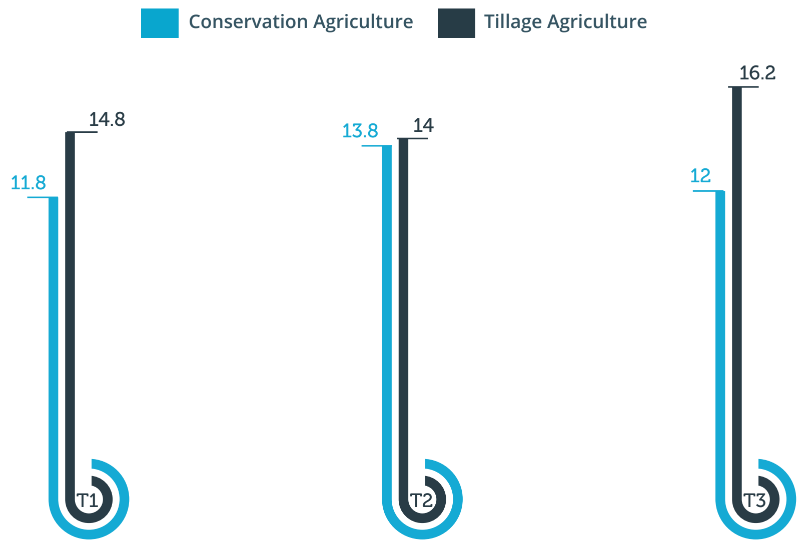
Notes: Yield is measured as grain. T1 = manure only; T2 = manure and fertilizer; T3 = manure, fertilizer, and biofertilizer.

Results in Cyuve

In Cyuve, in the second season of 2017, the combination of conservation agriculture with manure was the most productive (Fig. 6). Once again, little difference was observed between the two kinds of farming practices and the three kinds of input treatments. This may be because the rich volcanic soils provided adequate nutrients to support maize production.

In the second growing season of 2016, maize yields under tillage agriculture were significantly higher than under conservation agriculture (Fig. 7). One possible explanation is that farmers were not yet used to conservation agriculture techniques (mainly mulching and weeding). Differences among the three treatments were not significant because of the region's rich quality. This is consistent with a study that found that Rwanda's fertile soils (pH > 6.0) can produce good yields with the application of manure only [12]. The most productive option for this season was tillage agriculture with manure only; interestingly, the most productive option in the second season of 2017 was conservation agriculture with manure only. Yields under conservation agriculture in the second season of 2017 were consistently higher, and the difference was significant when combined with the application of manure. This is consistent with studies indicating that the benefits of conservation agriculture increase overtime as soil conditions improve, whereas they decline over time under tillage agriculture as soil quality deteriorates [13]. Nevertheless, the benefits of applying manure can be minor under conservation agriculture if the soil's organic carbon content is sufficient for optimum crop production. This is consistent with a study indicating that 2 percent organic carbon is sufficient in Rwandan soils for optimum crop production if other factors are provided [2].

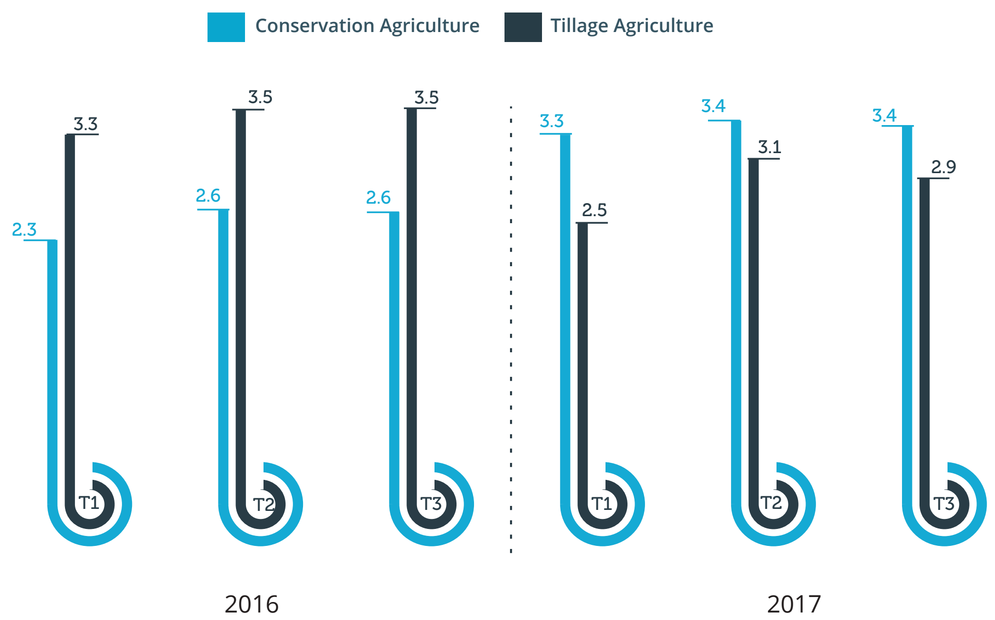
Figure 6. Maize yields in Cyuve, 2017



Source: SIMLESA-Rwanda.

Notes: Yield is measured as cobs and grain. T1 = manure only; T2 = manure and fertilizer; T3 = manure, fertilizer, and biofertilizer.

Figure 7. Bean yields in Musanze, 2016 and 2017



Source: SIMLESA-Rwanda.

Notes: Yield is measured as grain. T1 = manure only; T2 = manure and fertilizer; T3 = manure, fertilizer, and biofertilizer.

Knowledge Gaps Identified and Addressed

Conservation agriculture has only been introduced in Rwanda through research stations [14]. SIMLESA-Rwanda's onfarm experiments are among the few known examples where the practices were directly introduced to smallholder farmers. SIMLESA-Rwanda's short-term results indicate that conservation agriculture and tillage agriculture perform similarly, yet the reduced requirement for labor — at least long term — makes conservation agriculture more advantageous for smallholders (Figs. 2–7). Under fertile soil conditions, yields were higher under tillage agriculture in the first growing season, but yields were higher under conservation agriculture in the second season (Fig. 7). This suggests that conservation agriculture is more effective and takes effect more quickly when soils are fertile (Cyuve being more fertile than Bugesera, and Bugesera more fertile than Runda) [15].

The benefits of conservation agriculture also depend on the effectiveness of farmers' field management. The more engaged and informed the farmer, the better the results. In general, without the use of herbicides, the effectiveness of conservation agriculture increased in the third growing season. In field trials, farmers had become proficient in the use of the new techniques by this stage, so the effects of mulching on soil properties were significant, and weed control had become manageable. As a result, the benefits of tillage agriculture were completely eliminated (Fig. 8).

These encouraging results support the scaling of conservation agriculture, but additional efforts are needed to promote adoption. Outreach and extension will help inform farmers on the new principles and practices, which were unclear to many participants of this study. Farmers had many questions, concerns and reservations when first introduced to the new practices. These included whether it was possible to grow crops without cultivation, how weeds could be managed, and where to obtain mulch. In addition to farmers, extension agents, policy-makers and scientists were also skeptical about the new practices in the absence of empirical evidence, training, and implementation.

The first two principles of conservation agriculture — minimum soil disturbance (no tillage) and permanent soil cover — were the most challenging to newcomers. Minimum soil disturbance is a fundamental principal on Rwanda's degraded lands, where farmers have historically practiced deep tillage (30–50 centimeters) to uproot weeds. In addition, most weeding in Rwanda is done by hoe or hand, so weed management depends on the availability of labor, especially at increasing production scales. Mulching also raises issues because crop residues in Rwanda are an important source of fuel and fodder. The problem of what to use as mulch under conservation agriculture poses a common problem in the highly populated regions of Africa [13]. The solution is integrating conservation agriculture with agroforestry, whereby mulching materials and fodder are produced in contour lines (Fig. 9).

Figure 8. A field under conservation agriculture after bean harvest in Cyuve

Photo credit: SIMLESA-Rwanda.

Notes: The beans were planted in the second season of 2017 after maize was harvested in the first season. This field is ready to be sown without tillage, but with the addition of water and mulch.

Figure 9. A conservation agriculture system integrated with agroforestry hedgerows along contour lines as a permanent source of mulch

Photo credit: SIMLESA-Rwanda.

Note: The biomass of the hedge provides mulch, freeing crop residues for their traditional uses as fuel and fodder. This is an efficient system for controlling soil erosion, improving soil fertility and sustainably increasing crop yields.

Community Networks that Support the Adoption of Conservation Agriculture

SIMLESA-Rwanda was able to initiate three community networks from which large-scale extension can develop. The networks comprised farmers who collaborated with SIMLESA-Rwanda during fields trials and converted their land for large-scale conservation agriculture practices. These farmers were also enthusiastic and active in encouraging their neighbors to adopt conservation agriculture. The neighbors' interest was peeked by their firsthand exposure to the new practices. Their surprise at seeing vigorous crops under production was evidence that labor-intensive tillage practices were unnecessary (Figs. 10–11). Within this framework, SIMLESA-Rwanda generated interest in the conservation agriculture, and demand for related inputs in Runda, Bugesera and Cyuve. Moreover, because SIMLESA-Rwanda's technicians had themselves become convinced of the efficacy of conservation agriculture practices, they accepted adoption in the Gatsibo District, in Rwanda's extreme east, and in the Huye, Nyanza, Nyaruguru and Nyamagabe districts, in southern Rwanda.

Figure 10. Climbing beans in Cyuve, 2017

Photo credit: SIMLESA-Rwanda.

Note: The field is planted with plots using both conservation agriculture and tillage agriculture (left and right, respectively).

Figure 11. A field of bush beans under conservation agriculture in Runda, 2017

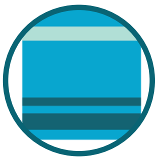
Photo credit: SIMLESA-Rwanda.

Notes: The field was planted in the first season of 2017 after a preceding season of maize in 2016. Notice the use of mulch.

FINDINGS FROM SCALING OUT SIMLESA-RWANDA'S ACTIVITIES

The following priorities were identified for the future large-scale promotion of conservation agriculture in Rwanda:

Allocate a budget for the implementation of CASI practices given that conservation agriculture has already been incorporated into strategic planning documents



Develop and disseminate user guidelines as a manual for implementing conservation agriculture, specifically adapted for Rwanda

Develop and implement a capacity building program

Promote the integration of conservation agriculture with agroforestry as a main component

Promote appropriate use of other inputs, such as manure and fertilizer

Use AIPs to promote large-scale adoption

Initiate more in-depth research to provide quantitative data on the positive longer term effects of conservation agriculture on soil nutrients, pest management and crop yields

Figure 12a. Water logging associated with tillage agriculture has negative effects on crop growth

Figure 12b. The use of soil ridges to promote drainage

Figure 12c. The positive effect of conservation agriculture on soil drainage, water infiltration and crop health

Photo credit: SIMLESA-Rwanda.

Factors Driving Adoption

Initial efforts at introducing conservation agriculture to Rwanda have yielded numerous benefits across various fields of science. Such benefits could constitute drivers of adoption, as is described below.

Erosion control, water infiltration and water-use efficiency. In flat volcanic areas, tillage agriculture is problematic due to water logging, which negatively affects the growth of crops (Fig. 12a). Farmers usually manage this problem by constructing soil ridges to induce intensive erosion (Fig. 12b). Conservation agriculture has been effective in increasing soil drainage and infiltration, controlling soil erosion and promoting efficient water use (Fig. 12c).

Carbon sequestration and improved microbial activity in soils. As was indicated by the presence of chickens and the health of crops in plots utilizing conservation agriculture as opposed to tillage agriculture (Fig. 13), conservation agriculture is likely to have increased the organic carbon levels in the soil, thereby increasing beneficial insects and microbes (bacteria, fungi and protozoa).

Crop health. Maize crops under tillage agriculture were severely attacked by fall army worm, but the incidence was minimal in plots utilizing conservation agriculture in the same fields (Figs. 14a and 14b). A recent study of maize in East Africa reported the positive effects of ecologically based approaches on the same insect [16].

Figure 13. Chicken in maize plots under conservation agriculture indicate positive soil microbial activity in Cyuve

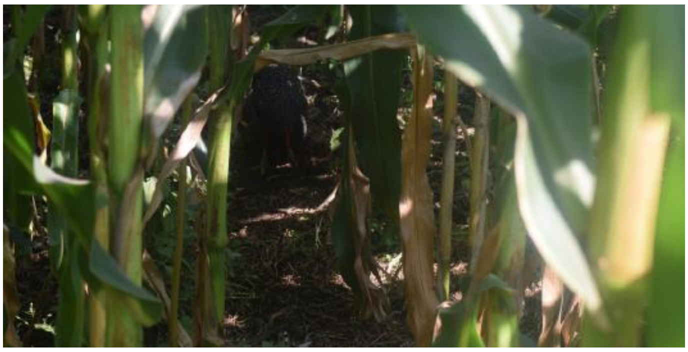


Figure 14a. Reduced damage to maize from fall armyworms under conservation agriculture

Figure 14b. Severe damage to maize from fall armyworms under tillage agriculture

Photo credit: SIMLESA-Rwanda.

Barriers to Adoption

The following factors, while not insurmountable, can be considered barriers to the adoption of conservation agriculture in Rwanda.

The mindset of scientists. Scientists who have been trained in the practice of tillage agriculture can be reluctant to promote conservation agriculture. They require a clear understanding of the practice and benefits of conservation agriculture in order to change their mindset and support the problem-solving innovations conservation agriculture offers.

The mindset of farmers. Farmers taught tillage agriculture by extension agents across generations can also have difficulty opening their minds to new approaches. Efforts are needed to demonstrate the benefits of innovations under conservation agriculture to support farmers in shifting their mindset.

Lack of mulching materials. The availability of mulch constitutes a serious constraint to the adoption of conservation agriculture in Rwanda because crop residues are either used as fuel for fires or as feed for livestock under a zero grazing system.

The drudgery of manual weeding. Introducing conservation agriculture requires considerable commitment in terms of manual labor in the form of weeding — at least the two first seasons — for those without access to machinery. This can present a significant disincentive to adopting the new practices.

Insufficient knowledge of conservation agriculture. Conservation agriculture has yet to be properly introduced in Rwanda's agricultural teaching curricula. Moreover, detailed manuals and user-guides on the subject are needed.

FUTURE PLANS FOR SCALING CONSERVATION AGRICULTURE

It is recommended that CASI practices be scaled out across Rwanda's major agricultural regions:

1. In the low altitude region (900–1,600 meters), technologies would spread from the Gashora and Gabiro demonstration fields in the respective districts of Bugesera and Gatsibo in eastern Rwanda. In these areas, the new technologies could cover also at least 20 percent of the crop land by 2023.
2. In the medium altitude region (1,600–1,800 meters), technologies would expand from the sites of Runda, Kinyogoto, Nyakagezi and Nyabyunyu in the respective districts of Kamonyi, Nyanza, Huye and Nyaruguru in central and southern Rwanda. In these areas, the new technologies could cover at least 10 percent of arable land by 2023.
3. In the high altitude region (1,800–2,300 meters), technologies would be scaled out from the Cyuve demonstration fields in the district of Musanze in northern Rwanda. In this area, the technologies could cover at least 20 percent of the arable land area by 2023.

SIMLESA-Rwanda's maize-bean rotation is the recommended foundation for scaling out the new technologies, combined with minimum tillage, mulching and the correct use of inputs. In Rwanda these practices are integrated with agroforestry in the use hedgerows along contour lines that serve both as erosion control and as a vital source of mulch. Hedgerows of legumes (such as Calliandra Callothyrsus) and nonlegumes (such as Alnus Acuminata) also serve as fodder where conservation agriculture is integrated with livestock.

In both the volcanic highland regions and nonvolcanic lowland regions — where the soil quality is good (that is, a pH of 6.0) — practices would focus on reducing intensive fertilizer use, which is costly. Different fertilizer levels would be tested to determine optimum levels. In these regions, the control treatment (manure only) usually yields acceptable results [2, 12]. In the nonvolcanic highland and medium altitude regions, where soils are highly acidic and soil nutrients depleted, the new technologies would also be integrated with agroforestry, but a liming program using locally available liming stones would also be incorporated. Here also, lime and fertilizer levels would be tested to determine optimum levels. Despite its local availability, lime constitutes a high investment for farmers because of its associated transportation costs. Yet lime is another vital input in the successful production of cereals and legumes in Rwanda [17] (Fig. 15).

Across all regions, outscaling would incorporate the use of adapted crop varieties, including the establishment of a seed production system, together with the integration of livestock. Cost-benefit analyses and environment impact assessments are also recommended, along with determinations of the number of farmers benefited, and the impacts on their livelihoods/wealth levels. Transforming Rwandan agriculture requires a significant investment on the part of farmers. Agroforestry seedlings used to introduce much-needed soil organic matter in all Rwandan soils represent a high investment for farmers. Similarly, seed and fertilizer are also costly, but without them, other investments are rendered ineffective.

Figure 15. The effect of lime, manure and fertilizer on maize yields in the Nyaruguru District

Photo credit: SIMLESA-Rwanda.

Notes: The control treatment (that is, zero inputs) is shown in the middle of the photo. The plots on either side were treated with lime, manure and fertilizer.

CONCLUSION

SIMLESA-Rwanda was unique in providing smallholder farmers with first-hand experience of the differences between conservation agriculture and tillage agriculture, utilizing split plots in their own fields. The new practices focused on maize-bean rotations using zero/minimum tillage and mulching; soil fertility improvement where needed, such as liming and the application of manure; and the supply of additional plant nutrients as needed though the application of inorganic fertilizer. Given the country's topography, agroforestry interventions, in the form of hedgerows along contour lines, were integrated with the new approaches to reduce soil erosion and provide a much-needed source of mulch.

In addition to the sustainability of these practices, farmers benefited from the reduced requirement for labor in the medium to long term, overcoming a key constraint to scaling production. Rwanda was also able to initiate three community networks from which large-scale extension can develop. A number of barriers to adoption remain to be overcome, mainly through effective education and information dissemination, not only of farmers, but also of scientists, extensions agents, and policy-makers.

REFERENCES AND FURTHER READINGS

1. NISR (National Institute of Statistics Rwanda). (2012) "EICV Poverty Analysis for Rwanda's Economic." Available at: http://www.rwandapedia.rw/cmis/views/workspace. (Accessed: month day, year).

2. Rushemuka, N.P., L. Bock, and J.G. Mowo. (2014) "Soil science and agricultural development in Rwanda: The state of the art." *Biotechnology, Agronomy, Society and Environment* 18(1): p142–154.

3. IFAD (International Fund for Agricultural Development). (2018) Investing in rural people in Rwanda. https://www.ifad.org/web/knowledge/publications/asset/39319916. (Accessed: November 15, 2018).

4. UNICEF (United Nations International Children's Emergency Fund). (2013) Improving Child Nutrition: The achievable imperative for global progress. Available at: https://www.unicef.org/publications/index_68661.html. (Accessed: November 15, 2018).

5. WFP (World Food Programme). (2014) Rwanda: Food and Nutrition Security Monitoring System. Round 9. Available at: wfp.org/stellent/groups/public/documents/ena/wfp284404.pdf. (Accessed: November 15, 2018).

6. Clay, D.C., and L.A. Lewis. (1990) "Land use, soil loss, and sustainable agriculture in Rwanda." *Human Ecology* 18(2), p147–161.

7. MAAR (Ministry of Agriculture and Animal Resources). (No date) "Crop intensification program (CIP)." Available at: http://www.minagri.gov.rw/index.php?id=31. (Accessed: November 15, 2018).

8. IndexMundi. (2018) "Rwanda corn production by year." http://www.indexmundi.com/agriculture/?country=rw&commodity=corn&graph=production. (Accessed: November 15, 2018).

9. MAAR (Ministry of Agriculture and Animal Resources). (No date) Replacement reference needed for link that is not working: http://www.minagri.gov.rw/fileadmin/user_upload/documents/INVESTORS_GUIDE/Maize. (Accessed: month day, year).

10. Fortune of Africa. (No date) "Bean farming." http://fortuneofafrica.com/rwanda/bean-farming/. (Accessed: November 15, 2018).

11. Vanlauwe B., Wendt J., Giller K.E et al (2014). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa: The appropriate use of fertilizer to enhance crop productivity. Field Crops Research. 155, 10-13.

12. Rutunga, V., and H. Neel. (2006) "Yield trends in the long-term crop rotation with organic and inorganic fertilisers on Alisols in Mata (Rwanda)." *Biotechnology, Agronomy, Society and Environment* 10(3), p217–228.

13. Rodriguez, D., P. de Voil, M.C. Rufino, M. Odendo, and M.T. van Wijk. (2017) "To mulch or to munch? Big modelling of big data." *Agricultural Systems* 153, p32–42.

14. Kabiligi, M., F.K. Ngetich, K.K. Mwetu, P. Rushemuka, et al. (2017) "Implications of tillage practices, management of soil surface and fertilizer application on sustainable dryland agriculture: A case study of Eastern Rwanda." *African Journal of Agricultural Research* 12 (31), p2524–2532.

15. Birasa, E.C., I. Bizimana, W. Boucaert, A. Deflandre, J. Chapelle, A. Gallez, G. Maesschalck, and J. Vercruysse. (1990) Carte pedologique du Rwanda. Kigali, Rwanda: MINAGRI.

16. Midega C. A.O;.Pittchar J. O; Pickett J. A. et al (2018). A climate-adapted push-pull system effectively controls fall armyworm, Spodoptera frugiperda (J E Smith), in maize in East Africa. Crop Protection. 105, 10-15.

17. Rushemuka N. P. and Bock L. (2016). Tailoring soil fertility management inputs to specific soil types: case study of a pot experiment in Rwanda. Nature & Fauna Journal, a flagship publication of FAO Regional Office for Africa: Nature & Faune: 30,1, In Press. Theme: Sustainable soil management: an indispensable need for environmentally sound food security in Africa.

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