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

Bedru Beshir, Tadesse Birhanu Atomsa, Dagne Wegary, Mulugetta Mekuria, Feyera Merga Liben, Walter Mupangwa, Adam Bekele, Moti Jaleta & Legesse Hidoto

Key points

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

Background

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

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

Importance of maize and legumes and their production challenges in Ethiopia

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

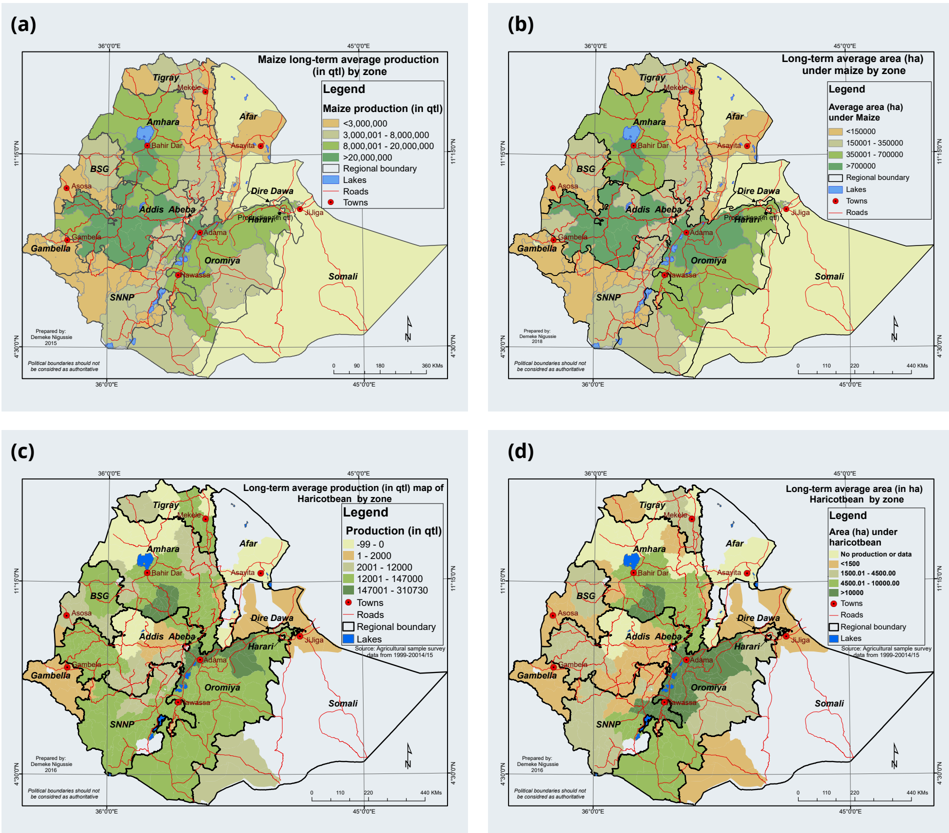

Figure 14.1 Long-term average maize production in Ethiopia by (a) weight and (b) area; long-term average common bean production in Ethiopia by (c) weight and (d) area

Note: Quintal (qt) = 100 kg

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

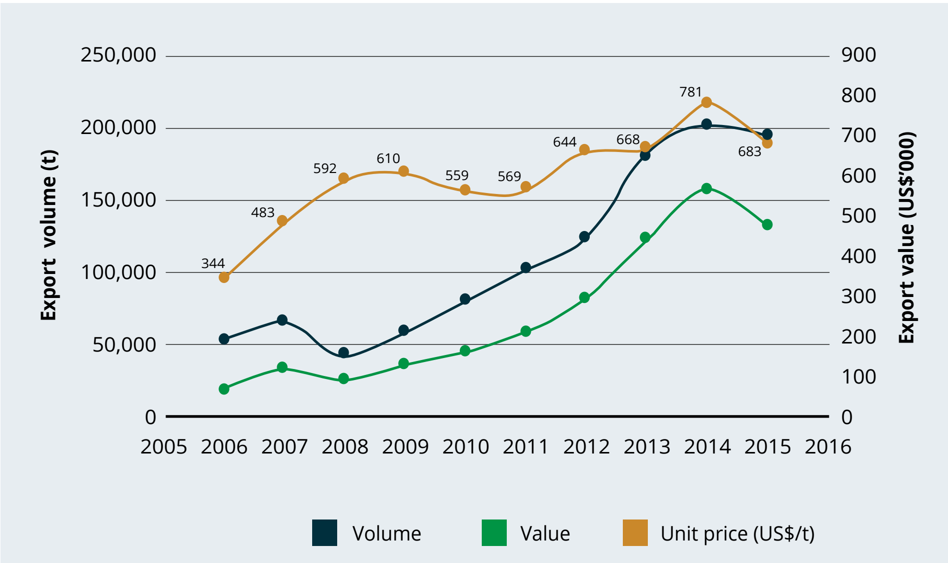

Figure 14.2 **Ethiopian common bean export volume, value and price per tonne, 2006–15**

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

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

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

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

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

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

SIMLESA program objectives in Ethiopia

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

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

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

Agroecologies

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

Research teams

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

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

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

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

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

Findings

Farming systems and household characteristics

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

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

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

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3 Kebele is the lowest administrative unit in Ethiopia.

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

Financial viability of CASI practices

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

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

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

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

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

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

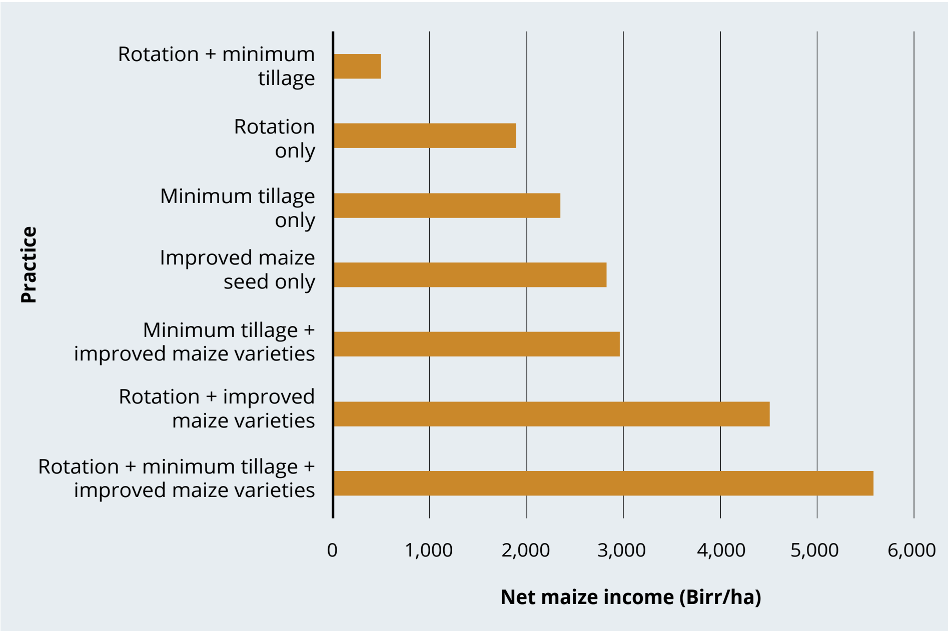

Figure 14.3 **Impact of agronomic practices on maize variety performance and net maize income in Ethiopia**

Source: Mekuria & Kassie 2014

Adoption status of sustainable intensification

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

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

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

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

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

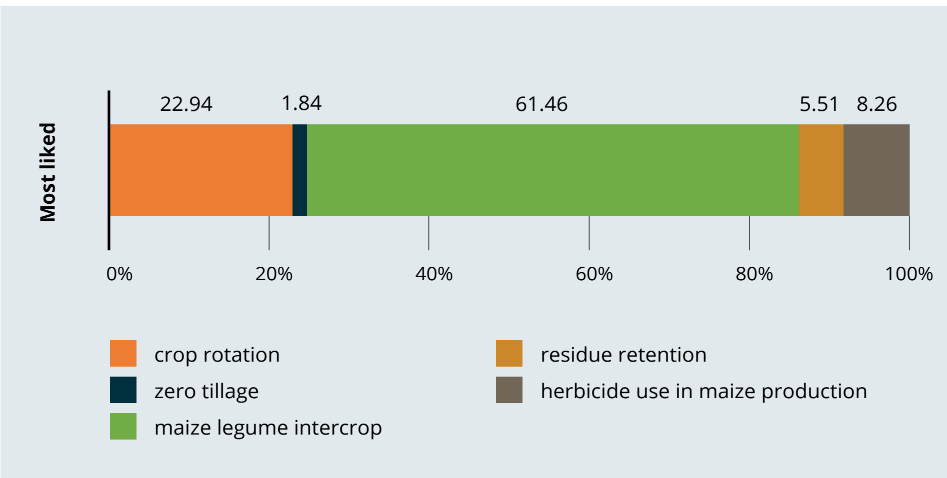

Figure 14.2 Ethiopian common bean export volume, value and price per tonne, 2006–15

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

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

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

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

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

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

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

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

Contribution of CASI practices in increasing yield and reducing downside risk

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

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

Increased rainwater productivity under CASI practices

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

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

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

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

Soil moisture and soil erosion

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

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

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

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

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

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

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

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

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

Yield and seasonal rainfall variability

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

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

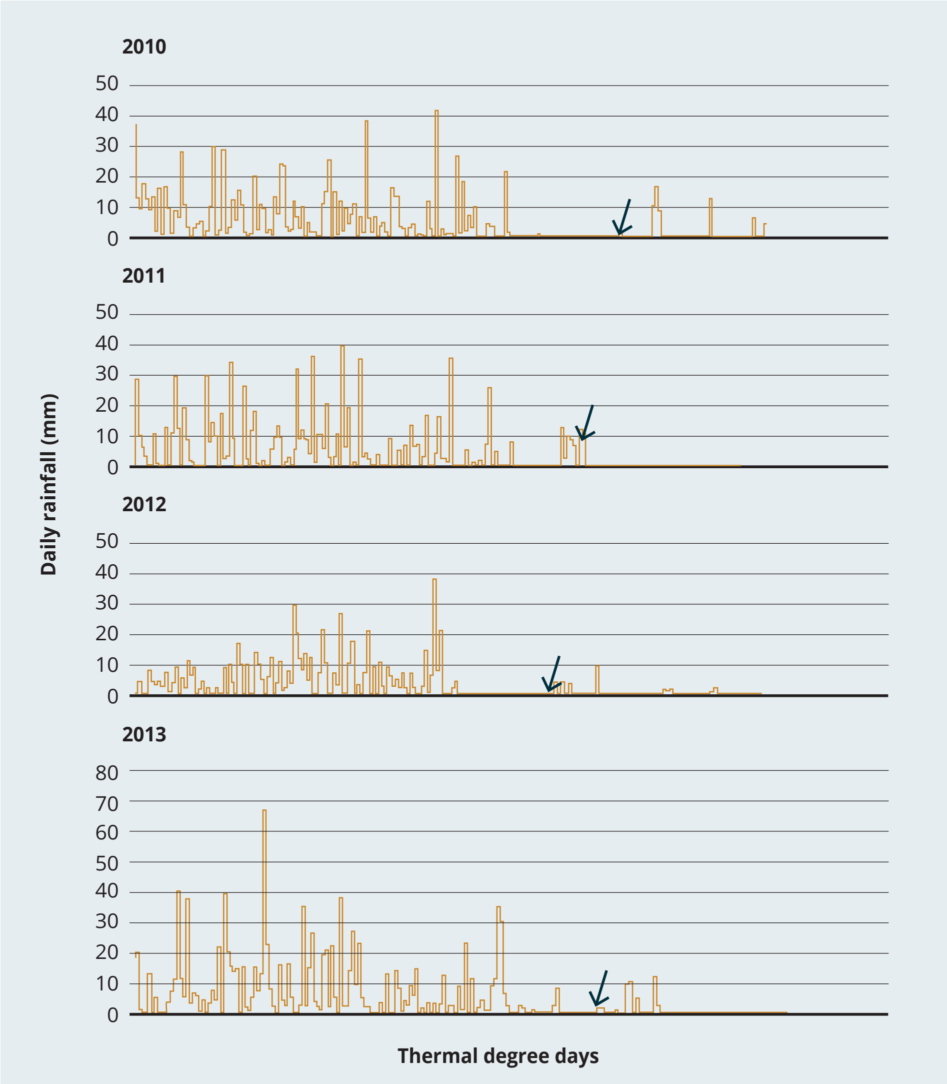

Figure 14.5 **Daily rainfall and thermal degree days during the common bean–maize cropping systems, 2010–13**

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

Grain yield, land productivity and income

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

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

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

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

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

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

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

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

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

Environmental sustainability

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

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

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

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

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

Note: CASI = conservation agriculture-based sustainable intensification

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

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

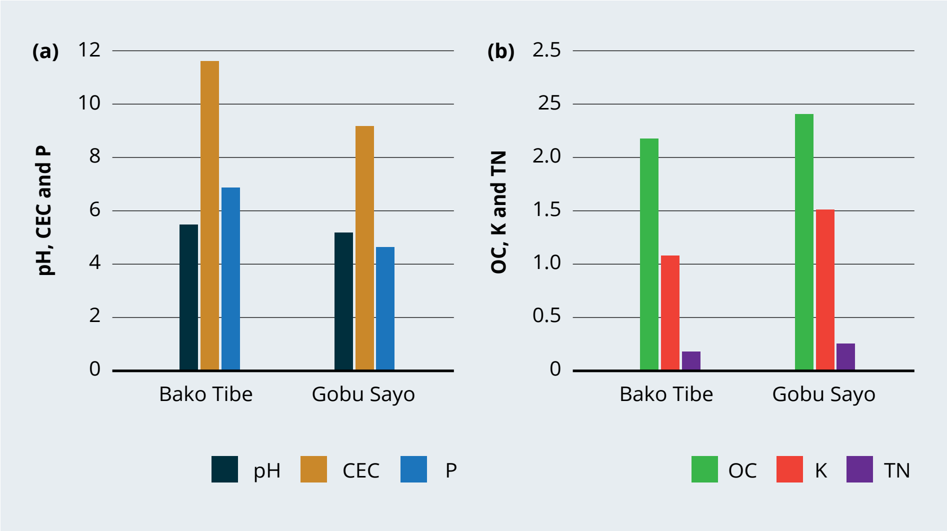

Figure 14.6 **Chemical properties of soil influenced by different cropping systems with tillage practices (across locations during 2010–12 cropping seasons)**

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

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

Maize, grain and forage legume varieties

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

Participatory variety selection of maize

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

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

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

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

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

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

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

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

Source: Elmyhun, Abate & Merene 2017

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

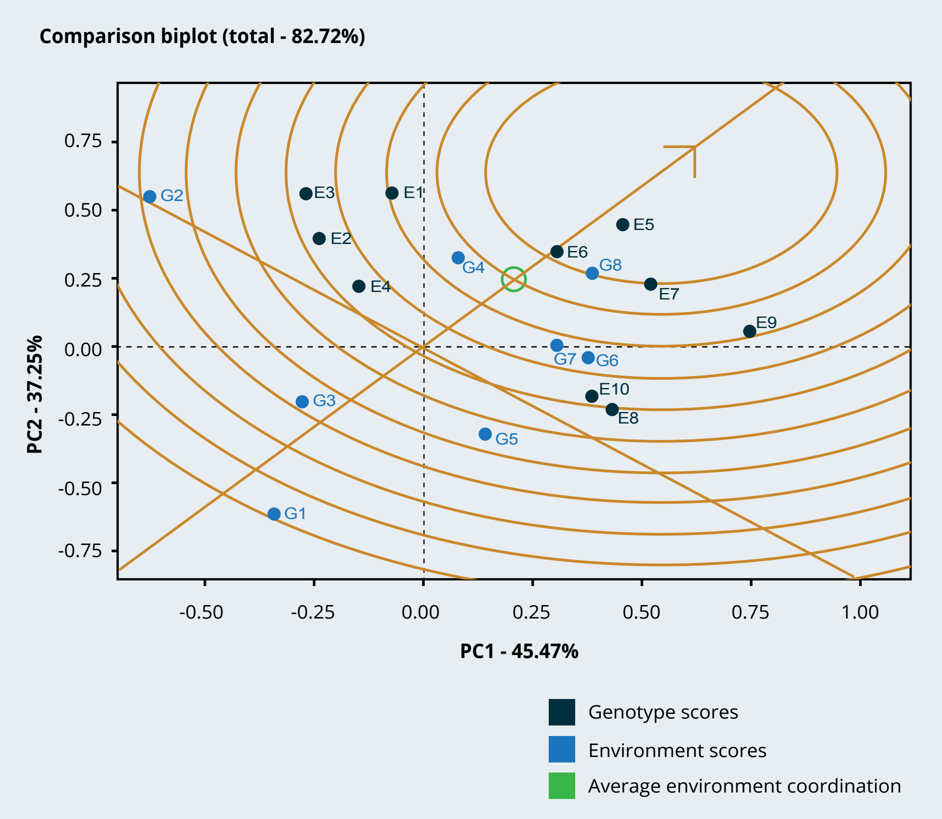

Figure 14.7 **Comparison of maize hybrids for their suitability in north-western Ethiopia**

Source: Elmyhun, Abate & Merene 2017

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

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

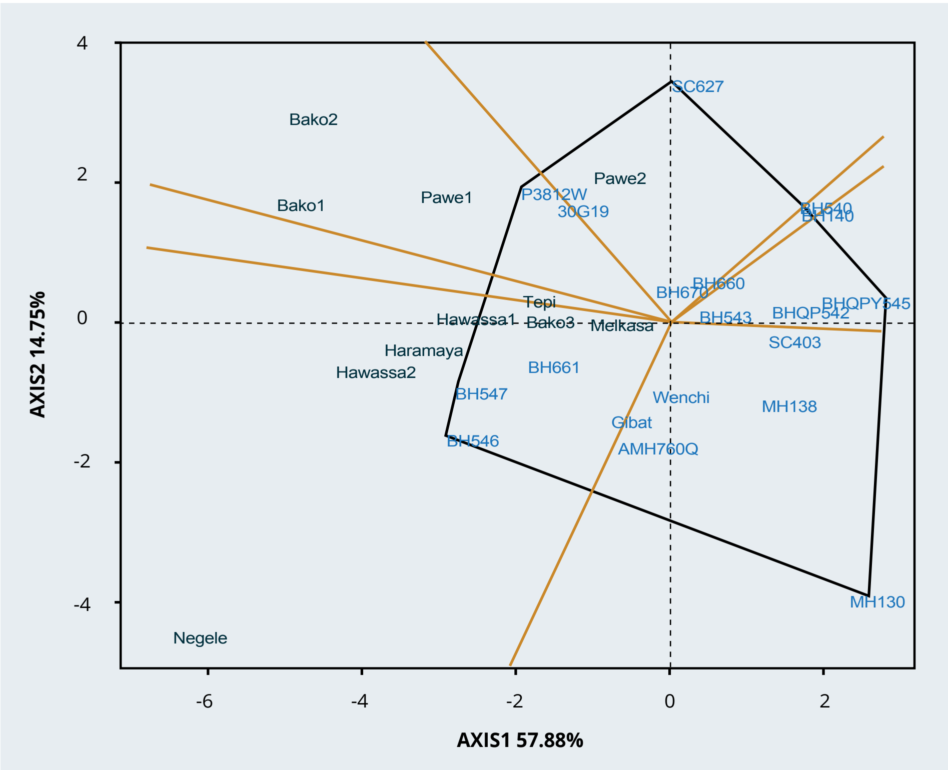

Figure 14.8 **Maize-growing mega-environments constructed using genotype plus genotype-by-environment biplot for 19 maize hybrids evaluated across 11 environments**

Source: Wolde et al. 2018

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

Participatory variety selection of grain legumes

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

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

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

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

Participatory variety selection of forage legumes

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

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

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

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

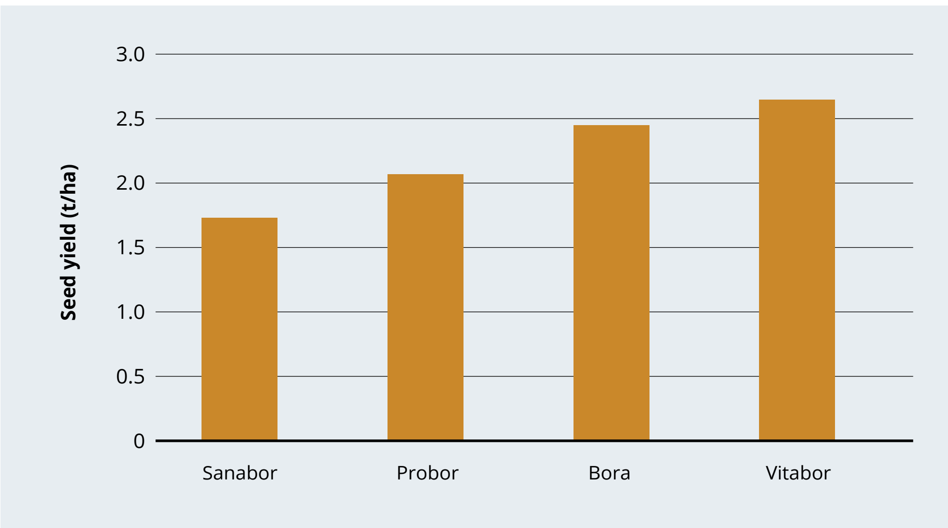

Figure 14.9 **Seed yield of sweet lupine varieties evaluated across Ethiopia**

Table 14.15 Traits of Sanabor and Vitabor sweet lupine varieties

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

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

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

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

Seed production and dissemination of selected maize and legume varieties

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

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

Taking SIMLESA output lessons to scale

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

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

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

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

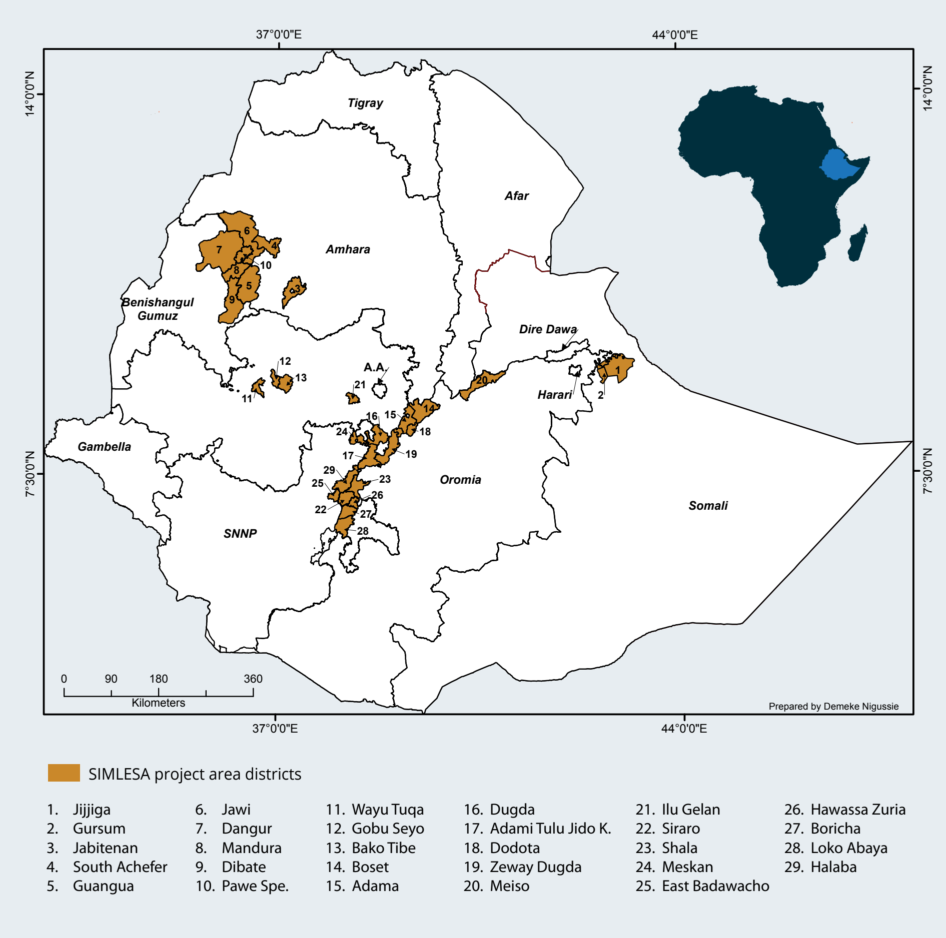

Figure 14.10 **Major districts of the SIMLESA program implementation areas in Ethiopia**

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

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

Gender roles in maize–legume production

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

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

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

Source: Own field study, April 2017

Gender roles in maize and common bean production

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

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

Conclusions

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

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

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

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

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

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

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

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