Scoping Study on Conservation Agriculture in Eritrea: Opportunities and Constraints

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1. Rationale and objectives

Eritrea, an agrarian country with 70% of its population working in agriculture, is characterized by very low farm incomes and chronic food deficits with severely constrained agricultural productivity. Food security in the country is threatened by erratic episodes of drought, reduced availability of agricultural labor, localized flooding, and poor infrastructure, all of which contribute to low crop yields. Low crop yield severely affects food security. As a result, 66% of the population is under-nourished and 35% of children are underweight (World Food Program 2011).

Agriculture is the backbone of the Eritrean economy with the majority of the population depending on farming for food and livelihood security. However, farmers face serious challenges, which include small and fragmented farm holdings, rainfed agriculture on eroded and degraded soils and dealing with a severe energy crisis. There is therefore an urgent need to enhance agricultural productivity in Eritrea by sustainably intensifying and promoting conservation agriculture-based crop management practices in Eritrea.

Conservation agriculture (CA) practices that integrate a crop residue cover at the soil surface, minimal soil movement, and efficient, cost-effective crop rotations and diversification have shown promising results for intensifying cropping systems in dry areas sustainably. This includes recent success and fast adoption in West Asia (ICARDA 2010a). Compared to conventional systems, CA has been found to maintain or increase crop yields, reduce production costs and labor requirements, improve soil fertility and reduce erosion (Hobbs et al. 2008, Kassam et al. 2009). These incentives could make CA a viable alternative in Eritrea, where the system would help to address the challenges of scarce and degraded natural resources. However, unless these CA-based crop management technologies are tested and refined with farmer participation before widespread extension to farmers, the system might not be equally suitable for all locations and agro-ecosystems. Important variability and system tradeoffs could limit the expansion and adoption of these technologies in smallholdings (Giller et al. 2009; Lahmar 2010), especially if the CA-based technologies have not been adequately fine-tuned and validated in farmers' fields with active farmer participation.

The principles that underlie CA are not site specific, but CA components for crop management are. These include: cultivar selection; strategies for nutrient management; tactics for weed, disease, and pest control; crop residue management; selection of crops for rotation; and water management practices. These components must be managed and fine-tuned for each cropping situation, so that they are compatible both with the principles of CA and the requirements of farmers. There is a critical need for active farmer participation in comprehensively assessing the ecological and socio-economic conditions under which CA would be adapted for smallholder farming. This should be carried out in each target area in order to identify the most relevant and compatible crop management component technologies.

The main objectives of this paper are: (i) to briefly review previous experience of conservation agriculture in Eritrea; (ii) to examine the socio-economic, agronomic, and agro-ecological aspects of the Eritrean agricultural sector; and (iii) to identify potential entry points and target areas for introducing CA in Eritrea and means of overcoming potential obstacles.

2. The state of Eritrean agriculture

Although Eritrea is endowed with adequate land resources relative to its population, agriculture contributes only 12–15% of the national GDP. Only 3.6% of total area of the country is under cultivation, about 56% is used for grazing and 33% is considered barren (Rena 2004). The crop and livestock sector employs the vast majority of Eritrea's population and provides the basis for food security. However, domestic production remains well below consumption. Food security depends heavily on imported commodities, of which food commodities contribute nearly one quarter of the country's total imports.

In a survey conducted in Eritrea, 67% of respondents indicated that in good years, production is sufficient to satisfy household food requirements; however, 90% of respondents accepted that in bad years their farm produce covers only a quarter of food demand (Tikabo 2003). This forces the country to import commodities. The total arable area of the country is approximately two million hectares (Mha); however, only 0.4 Mha is cultivated and planted due to various socio-economic constraints, especially the community-owned land tenure system. About 1.5 Mha is suitable for rainfed agriculture, whereas the potential irrigated area is about 0.6 Mha (Rena 2004).

2.1 Land tenure systems

Five out of six regions (*zobas*) of the country are important for agriculture: Anseba, Gash Barka, Debub, Maekel and Northern Red Sea. The Southern Red Sea *zoba* is agriculturally not important as its cultivated area is limited. Land ownership in the country can be categorized into three major groups: state-owned land, known as *diesa*, village/communally-owned land and family-owned land. The most common land ownership in the highlands is the village or communal ownership, whereas in the lowlands family-owned land is not uncommon. In the communal land system in the highlands, a family or a household has land rights for a limited number of years (normally five to seven years); land is redistributed among villagers on a rotational basis after seven years (ie transferred from one family to another) (FAO 2004). This land rotation system is locally called *wareda* (ICARDA 2010b).

Rotation of land and limited land tenure rights in this system restrict farmers from making long-term investments such as improving fertility, planting perennial trees, developing ground water, terracing, leveling and fencing, for fear of losing the benefits of their investment after property rights have expired (FAO 2004). Land rotations also lead to complex problems such as land disputes, which often delay planting or fallowing. In the highlands, each family normally owns about 0.75–1.5 ha land divided into three to four fields, which can be scattered around the village. In Eritrea as a whole, the availability of cultivable land per capita is around 0.1 ha at current population levels. Nevertheless, the average land holding per family in the lowlands (Debub and Gash Barka *zobas*) can be bigger (up to 10 ha) than in highlands. The Gash Barka *zoba* has the largest area of cultivated land (0.22 Mha) and the largest amount of cultivated land per capita (0.29 ha). This is followed by the Debub *zoba* at 0.2 ha (Ministry of Agriculture 2002).

Figure 1. Map of Eritrea

2.2 Major crops and cropping systems

Eritrea has no perennial rivers or streams so agriculture is mostly rainfed; less than 2% of the cultivable area of Eritrea is irrigated. Nevertheless, in these irrigated areas, important crops such as vegetables and corn are grown and meet part of the domestic demand. These crops are usually irrigated with ground water using diesel-operated centrifugal pumps in shallow bore wells. In general, however, farmers have limited knowledge of, or capacity for, ground water development. In the highlands, some ground water is accessed for high-value crops, and in the lowlands, spate irrigation (collecting run-off from the highlands to irrigate crops) is common practice. However, spate irrigation is practiced on only 0.2 Mha and is considered to be just one-third of the potential for spate irrigation (FAO 2000).

Eritrea receives its rainfall from the south-western monsoon mainly in summer (April to October) with the heaviest rains during July and August (approximately 80%). Normally, rainfall varies from 400 mm to 700 mm in the highlands (Cummins, 2007) and 200 mm to 300 mm in the western lowlands. The rainfall patterns in most of the country are irregular both in quantity and distribution. Irregular precipitation constrains the efficient use of agricultural inputs, and farmers are forced to adopt subsistence production systems coupled with a low application of chemical fertilizers (FAO 1994).

Farmers mostly use farmyard manure as a nutrient supplement. They also tend to prefer growing low-value but also low-risk crops such as sorghum, barley, wheat, millets, teff, *hanfets* (a mixture of wheat and barley or mixture of cultivars of wheat or barley), maize and lentils (Tikabo 2003; ICARDA 2010b). Wheat, barley, and teff are grown in the highlands, whereas sorghum, millets, and chickpea feature at lower altitudes. Grass pea is also grown in the midlands and considered as a superior fodder crop.

Table 1. Area, production, and productivity of major crops in Eritrea during 2004 (a poor year) and 2007 (a normal year)

Crops	Area (000 ha)		Production (000 t)		Productivity (kg/ha)	
	2004#	2007##	2004#	2007##	2004#	2007##
Sorghum	208.9	282.9	44.6	302.5	210	1069
Maize	10.3	16.5	3.2	13.7	310	832
Wheat	23.8	24.5	5.1	20.7	210	782
Barley	51.9	44.4	25.4	39.5	210	889
Millets*	98.3	91.3	37.5	63.3	180–250	639
Lentils	0.53	0.8	0.1##	0.3	152##	409
Chickpea	17.3	6.7	3.5##	4.3	200##	646
Horse bean	3.02	NA	NA	NA	NA	NA
Grass pea	6.9	2.8	4.0##	1.7	400##	613
Sesame	33.7	24.0	5.0##	10.8	147##	453

FAO 2004, ## FAO 2004–2007 *Millets include pearl millet, finger millet, teff, hanfets

Generally, the main cropping system in Eritrea is is mono-cropping: continuous wheat or barley in the highlands and continuous sorghum in the lowlands. Sorghum, the most important crop, is cultivated on approximately 53% of the agricultural area and is followed by millets (19%), barley (10%), wheat and sesame (5% each) and maize (3%). Gash Barka (45%), Debub (35%), and Anseba (12%) are the major cereal-producing *zobas* in Eritrea.

Chickpea and grass pea are important pulse crops with an average productivity of approximately 600 kg/ha in good years. Debub, with over 90% of the total pulse area, is the main pulse-producing *zoba*. Sesame is the most important oilseed crop and is mainly cultivated in Gash Barka. The other oilseed crops are linseed and groundnut, mainly cultivated in the Anseba *zoba*.

Most farmers use their own saved seeds, as commercially available seeds are in often short supply due to drought and limited seed-processing facilities. However, the Eritrean government is trying to supply quality seeds including hybrids such as winter maize. The recommended fertilizer doses for cereals are 100 kg/ha DAP and 50 kg/ha urea; however, fertilizer availability is variable and very limited. Fertilizers are mainly supplied by the Eritrean government, but only meet 2–20% of total fertilizer demand. Moreover, erratic rainfall and droughts means that the positive effects of fertilizers on crops are not guaranteed. So although fertilizers are heavily subsidized in Eritrea, many farmers do not buy them due to limited availability, risk-prone agriculture, and poor purchasing powers.

In Eritrea, conventional tillage systems are practiced without a clear rationale except that of learned, traditional experience. Farmers till their lands repeatedly, apparently as a strategy to conserve rainwater. Farmers also plough two or three times during the fallow season, in accordance with tradition. Repeated tillage in the absence of crop residues, coupled with the rugged Eritrean topography and a highly erosive rainfall, creates severe soil erosion resulting in a considerable loss of fertile soil every year. Furthermore, insecure land rights and population growth have also contributed to the process of environmental degradation (Tikabo 2003). Overall, the total arable area of Eritrea is just over 2 Mha; however, only 0.4 Mha is cultivated due to poor profitability in farming, erratic rainfall, and various socio-economic constraints.


Figure 2. A farmer tilling his land with a traditional plough in Eritrea

2.3 Constraints in Eritrean agriculture

Eritrean agriculture suffers numerous socio-economic, political, and physical constraints. The lowlands have hot and arid climatic conditions, while the highlands are dry for a long period of time (October to June). The soils in the lowlands are marginal and sandy or loamy, whereas the highland soils are affected by erosion (Sati 2008). Agriculture is dependent on erratic rainfall and degraded soils without much use of external inputs. In addition, farmers have small and fragmented and/or rented holdings and operate individually.

Farming is mostly traditional using family labor and animal power (oxen) with limited access to mechanization and modern technologies such as improved seeds, pesticides, and fertilizers. Crop residues are treated as a commodity and are in great demand. However, using harvested crop residues as livestock feeds, combined with free grazing during the lean period, keeps the soil surface bare and prone to erosion by high intensity rain (Figures 3, 4a and 4b).

Figure 3. Well-protected and stored wheat and barley straw near Halhale

In neighboring Ethiopia, which has similar climate and soil conditions, soil erosion and declining soil quality have been reported as a serious challenge to agricultural productivity and economic growth (Mulugeta et al. 2005). Steep slopes on the Ethiopian highlands have been cultivated for many centuries and consequently suffer from extreme soil erosion leading to land degradation (Wolde et al. 2007). Soil erosion and other soil management problems have seriously affected more than 25% of the Ethiopian highlands (Kruger et al. 1996).

Figure 4a. Livestock grazing crop residues in Mandefera
Figure 4b. Bare soil left without crop residues is prone to erosion

Subsistence agriculture, with mono-cropping, low productivity and poor access to markets, leads to low profitability. When coupled with short-term land ownership, this type of farming limits most farmers from investing in agriculture. In addition, the research and extension capacity of the Eritrean national system faces severe restrictions in the availability of resources and facilities (Cummins 2007). Farming is a cumbersome occupation with low profitability. As a result, the younger generation is not motivated to take up farming but is more interested in obtaining other kinds of employment.

3. Brief overview of previous experience on conservation agriculture in Eritrea

Conservation agriculture experiments in Eritrea started in 2003 at four sites of one hectare each. The experiments formed a pilot project funded under the Technical Cooperation Program of the Food and Agriculture Organization (FAO). The project sites included the National Agriculture Research Institute (NARI) experimental station in Halhale and three farmer participatory sites at Goluge (lowland), Hazemo in the Gash Barka *zoba* (midland) and Adilago in the Debub *zoba* (highland). The project was initiated with a tractor-mounted zero till seeder imported from Brazil, and an oxen-pulled zero till seeder with a tine opener and jab seeders (Figures 5a, 5b, and 5c).

Initial results of conservation agriculture were encouraging, showing across the sites higher yields for wheat and sorghum under CA compared to conventional tillage, with lower costs of production. However, after finishing this short-term project (18 months), CA activities could not continue at Goluge and Hazemo due to budgetary constraints. Nevertheless, zero till planting of wheat continued at Adilago and at the NARI research station in Halhale with consistent positive results for the CA-based seeding systems. Conservation agriculture activities with NARI were also supported by the International Center for Agricultural Research in the Dry Areas (ICARDA) in a project to improve water productivity and cereals and food legumes in Eritrea (ICARDA, 2010b). The project evaluated the effects of different component technologies on the yield and water productivity of barley. Results of this project demonstrated that fertilizer application alone can improve crop yields from 779 kg/ha to 1728 kg/ha. Weed management trials conducted under the same project revealed that a tank mixture of the herbicides Topik and Granstar or Achieve and Granstar controlled wild oats, improved productivity of wheat from 947 kg/ha to 1600 kg/ha, and on average, improved net returns from 4011 to 9529 nakfa/ha.

The National Agricultural Research Institute is currently in the process of starting a new CA-based project funded by the European Commission which will allow procurement of CA seeders that could fit farmers' needs (Dr Ghebre Tatios, Director General, NARI, personal communication).

Figure 5a. Brazilian disk zero till seeder

Figure 5b. Oxen-drawn zero till seeder **Figure 5c. Hand jab seeder**

Some CA trials are also being conducted at the Hamelmalo College of Agriculture (HAC) at Keren in association with the Australian organizations. This project, funded by the Australian Council for International Agricultural Research (ACIAR), is exploring the potential for developing and promoting CA in Eritrea based on Australian dry land experiences (Cummins 2007). The project includes the development of suitable tractor- and animal-drawn zero till seeders (Figures 6a and 6b) in collaboration with National agro- Industries in India (Er Rajdeep Singh, personal communication.).

Figure 6a. Animal-drawn seeder developed for Eritrea
Figure 6b. Tractor-drawn seeder developed for Eritrea

4. Analysis of the major constraints to the adoption of conservation agriculture

Recent work in sub-Saharan Africa has raised some concerns about CA on smallholder farms. These include difficulties in managing weeds, and a lack of vegetation to retain water on the soil surface due to the general use of crop residues for feeding livestock (Giller et al. 2009). The transition period during the shift from conventional agriculture to CA should involve all relevant stakeholders in addressing these concerns and generating and sharing the knowledge necessary to adapt, adjust, and optimize management components related to each crop production system. The competing uses for crop residues could potentially be resolved through better integration of crop–fodder–tree–livestock systems. The dynamic functioning and evolution of these systems, and their long-term impacts on agro-ecosystems, also deserve sustained research for development (R4D) attention in the future.

In Eritrea, the constraints in agriculture revolve around soil erosion, water deficits, poor investment capacities of the farmers, weak extension systems, and weather extremes. Other challenges relate to the efficient use of limited rainwater, non-availability of resource-efficient cultivars and quality production inputs, crop and soil management technologies, farm mechanization and fodder crops. In mixed crop–livestock production systems, fodder availability depends mainly on crop residues. Except for limited fodder sorghum grown in the Northern Red Sea *zoba*, no forage crops are planted in Eritrea, which results in high demand for crop residues as animal feed (Teklehaimanota and Tritschlerb 2009). These crop residues are considered as common property of a village and are subject to common grazing. In the highlands, the village community hires a guard to ensure that crop residues are grazed on a rotational basis, thereby extending their availability as fodder. As a result, as animals feed on removed crop residues and graze the crop stubbles left in the fields, the soil, in turn, is left bare and prone to erosion.

Another main constraint in realizing optimum yields of major crops is that farmers grow local varieties with low yield potential. In years of severe droughts, farmers consume saved seeds from previous harvests. Seed availability of improved varieties is limited through public or private agencies. Likewise, availability of fertilizers and other agricultural inputs such as pesticides depends on government provision and are often under-supplied to farmers. And although fertilizers and inputs are subsidized in Eritrea, they are still too expensive for many farmers.

Pest and diseases also create considerable damage Armyworm and chafer beetles are major pests in sorghum, finger millet, maize, barley, and pearl millet in the Anseba, Gash Barka, Northern Red Sea and Maekel *zobas*. Major sorghum diseases reported in the lowlands include leaf blight (*Exserohilum turcicum*), anthracnose (*Colletotrichum graminicola)*, zonate leaf spot (*Gloeocercospora sorghi*), loose kernel smut (*Sporisorium cruentum*) and covered kernel smut (Rao et al. 2002). Similarly, the main diseases of barley have been identified as net-form net blotch, spot-form net blotch, leaf rust, and scald, whereas wheat is mainly affected by yellow rust and leaf rust (Yahyaoui et al. 2004).

Striga and wild oats are major weeds in Eritrea. Striga is widespread and causes heavy yield losses to sorghum. It has between 2% and 100% incidence and has been observed as more prevalent in the drier lowlands (Rao et al. 2002). Wild oats, however, are considered as fodder rather than weeds and are therefore not removed from wheat or barley fields. Wheat and barley fields are also commonly infested with broadleaf weeds such as thistle (*Circium spp*) and Mexican poppy (*Argimone mexicana)*. Herbicide availability is apparently limited to 2,4-D only – other herbicides are not available. Hand weeding is generally practiced as weed control but this is often ineffective during the rainy season.

To overcome the constraints posed by a lack of farm machinery, the Eritrean government recently launched a new initiative whereby, in some regions (Gash Barka and Debub), tractors are available from a government contractor at 150–200 nakfa/hr (1 USD~15 nakfa). Some private service providers also provide tractor tillage services at 250–350 nakfa/hr, but this is not affordable for many farmers. Also, dependency on tractor contractors can cause delayed planting that results in lower crop yields. This and other major production system constraints in Eritrean agriculture, together with possible solutions, are illustrated in Table 2.

The Eritrean agricultural extension system under regional governance (*zobas*) is trying to introduce new technologies to progressive farmers. This includes new improved seeds, mechanization etc. The national agriculture research and extension systems need strengthening and capacity building to serve the farmers. A recent study conducted by NARI and ICARDA revealed that training and capacity building of the national agriculture research system is essential, in the fields of water management and conservation, integrated crop livestock management, genetic enhancement and plant breeding, forage and range land management, conservation agriculture, horticulture, and women and community development (Kaffas 2011).

Table 2. Production system constraints and possible solutions in Eritrean agriculture

Production system constraints	**Potential solutions**
High production cost, soil erosion.	Conservation agriculture-based crop management. Contour bunding and planting fodder shrubs on the contour bunds.
Communal livestock grazing, fodder shortages, competition for crop residues as fodder.	Introducing fodder species as potential crops to diversify the existing rotations, and integrating fodder shrubs with annual crops. Determining the relative potential economic value of using all crop residues (removal for fodder and/or intense grazing versus retaining some rational degree of crop residue cover on the soil).
Complex land tenure system.	Targeting extension of technologies at community level rather than individual farmers, forming farmers' clubs for testing and evaluating new CA-based technologies and, as is possible, functional units for the joint management and operation of CA implements (seeders etc.).
Weed problems.	Weed management based on cropping systems, particularly focusing on potential new weed control problems that may be associated with the use of reduced/zero till seeding systems.
Risk-prone environments, run-off, and limited water availability, poor rainfall distribution.	Retention of feasible and rational levels of crop residues on the soil surface to reduce run-off and associated erosion and to reduce evaporation under reduced/zero till planting systems. Bunding for in-situ water harvesting.
Low use of chemical fertilizers.	Investigations focusing on fertilizer management (timing and placement) especially related to CA-based seeding systems with associated residue retention on the soil surface and conjunctive use of both organic and chemical fertilizers.
Labor/energy shortages.	Reduced/zero tillage seeding systems using appropriate types of both, small- and medium-scale mechanization.
Low seed replacement rate, unavailability of quality seeds.	Farmer participatory seed systems. Adaptive trials on cultivar selection.
Non-availability of machinery and inputs.	Custom service providers for farm operations and creating farmers' clubs. Promoting the development of machinery with local manufacturers.
Low public–private sector and research–extension linkages, unavailability of trained man power for CA.	Developing multi-institutional/stakeholder platforms for exchanging knowledge, networking, and capacity building of farmers and extension officials.

5. Future opportunities for developing conservation agriculture in Eritrea

Eritrean agriculture is dominated by rainfed crop and livestock farming that is low in productivity and operates at subsistence level. Beyond addressing food security, productive agriculture is equally important for livelihood security and in reducing commercial imports from other countries. Efforts are therefore needed to enhance food production, minimize soil degradation, and attain social development by reorienting agricultural research and development. Crop management based on conservation agriculture offers an opportunity to address these aims.

The introduction of CA-based technologies in the low-, mid- and highlands of Eritrea will require efficient management of rainwater, diversified crop rotations with resilient crop cultivars, and improved availability of fodder to reduce the existing high dependency on crop residues for animal feed. In similar conditions in the Ethiopian highlands, CA-based practices were found to be effective in reducing surface run-off. Here, the traditional conservation practice *terwah (*a raised-bed furrow system, compatible with animal-drawn local ploughs) can be considered as a first step towards the use of CA-based practices. However, perennial weeds are a potential problem with such CA-based technologies (Wollelo et al. 2009).

The development of sound CA-based crop management technologies has a strong potential to help improve socio-economic conditions in Eritrean agriculture. Labor availability for farming is in short supply due to low wages in agriculture (30–50 nakfa/day); young men prefer to serve in national services where salaries are twice as high as agricultural income. This large gap between the demand and the availability of farm power could be overcome by the adoption of suitable CA-based crop management practices.

Oxen, shared oxen, donkeys, and camels are the major sources of draft power. And, as noted in the previous section, in some regions, tractors are available from government contractors at 150–200 nakfa/hr. Alternatively, private contractors can provide tractor tillage services at 250–350 nakfa/hr (although this is not affordable to many farmers). In Gash Barka and Debub, the major grain-growing areas, dependency on tractors causes delays in planting, whereas CA-based practices may allow for more timely planting schedules. There are significant opportunities to improve seeding systems through techniques such as timely planting at proper depth and distributing seed uniformly, which can increase the crop yield by 20% in Eritrea (Cummins 2007).

Conservation agriculture can also help address problems caused by the large gap between the supply and demand of seeds (worse after drought years) and fertilizers. Modern CA implements can help by reducing seeding rates with precision seed metering systems, and enhancing the efficiency of fertilizer use through more accurate placement and timely planting.

CA-based practices can potentially help in reducing run-off and soil erosion. In the neighboring Ethiopian sloping highlands, replacing conventional tillage with CA-based practices reduced run-off by 51% and soil loss by 81%. Implementing CA-based practices substantially decreased requirements for oxen and straw (Nyssen et al. 2010); this means that more crop residue can be left on site to protect soil from erosion. Conservation agriculture can therefore help in overcoming major constraints relating to declining soil productivity due to erosion, unreliable rainfall, water deficiencies, and labor shortages.

In 1994, a FAO sector review noted that with appropriate incentive systems, improved technology and prudent land and water resource management, a significant increase in production and yield could be achieved in areas with low and erratic rainfall patterns. One major opportunity provided by CA is time saving, which has the potential to reduce drudgery, especially when male migration to cities and government services is common. Another major opportunity is associated with the mitigation of drought and adverse climatic situations (Ashburner et al. 2002).

It appears that the Gash Barka and Debub regions are better suited than others for initiation into the development and delivery of CA-based crop management technologies. This is because farm sizes in the two *zobas* are relatively large (5–10 ha) and have family land entitlements. Also, some of these farms are fenced which can provide suitable opportunities to test different options for managing crop residues. Moreover, the *zoba* administration rents out tractors in these regions, and some private contractors also offer tractors services. This opens up an opportunity to utilize tractor services to promote CA-based practices in sorghum-based systems. In contrast, the development of CA-based technologies for highlands subsistence agriculture area may initially be more difficult.

Potential for feeding into conservation agriculture also exists in Eritrea’s capital city, Asmara. Here, capacity for manufacturing machinery could be utilized for fabricating zero till seeders by copying imported prototypes. There already exist in Asmara at least two good mechanical workshops capable of producing simple farm machinery of this nature.

6. A roadmap for the introduction of conservation agriculture practices into smallholder farming systems

The potential adoption of CA-based crop management practices into the main crop production systems in Eritrea has many potential benefits. It can potentially reverse land degradation, and help farmers to produce more crops at reduced cost and thereby improve farm profitability and family livelihoods. Successful implementation will require the development of a knowledge base concerning the constraints associated with the main crop production systems important to farmers in Eritrea. This will enable policy makers and agriculturists to better identify and assess interventions which are compatible with the principles of CA-based crop management technologies. We need to follow a step by step process that will:

A) Assemble, evaluate, and characterize all available, relevant socio-economic and crop production information regarding the existing farmer production systems, including constraints facing farmers and associated management practices selected for improvement. The process should also determine what information is lacking and, in turn, develop questions for a rapid key informant survey to fill knowledge gaps.

B) Identify, evaluate and refine new potential CA-based technologies that combine: (i) medium- to long-term adaptive research and delivery platform trials focusing on each well-defined crop production system that is selected for improvement, with (ii) side-by-side comparison of the existing, conventional farmer practices versus the 'best bet' CA-based technologies. This will involve the following activities:

1) Adaptive research and delivery platforms and early side-by-side comparisons in farmers' fields of farmer practices with the 'best bet' CA-based technologies that will allow testing, fine-tuning and validation of appropriate CA-based technologies for extension to all farmers.
2) Evaluating, verifying, and modifying CA-based crop management practices in adaptive research and delivery platform trials.
3) Identifying and addressing major constraints to relevant crop management technologies, e.g. tillage and crop establishment, and weeds, residue and nutrient management.
4) Increasing awareness and sharing experience with local farmers and extension officials.
5) Trying out with a few progressive farmers (technology leaders) CA-based crop management in side-by-side comparisons with conventional practice.
6) Refining CA-based crop management technology to make it more appropriate for adoption in local farming conditions.
7) Promoting the integration of CA-based crop management (suitable varieties and optimal fertilizer management with non-monetary or less costly inputs such as timely planting, seed treatment with biofertilizers, and using optimum plant populations) to a larger group of farmers.

C) Generate the needed logistical support for widespread delivery of proven CA-based technologies to all farmers to ensure extensive farmer adoption. This will involve the following activities:

1) Developing and testing tractor- and animal-drawn low-cost multi-crop seeders. Introducing prototypes of simple zero till planters (two- and four-wheel tractor-operated, oxen-operated, and jab seeders).
2) Encouraging local manufacturers to copy imported prototype seeders.

3) Approaching pesticide dealers and private companies to establish the availability of herbicide options.
4) Setting up a systematic seed multiplication program with farmer participation in Gash Barka (cereals and sesame) and Debub (cereals and pulses) to improve seed availability.
5) Improving availability of fodders and forage legumes in combination with a more organized, less intensive grazing system to retain a portion of crop residues and potentially enhance crop productivity.
6) Enhance awareness and capacity of farmers for CA-based crop management through training programs, field days, videos and traveling seminars, etc.

The basic prerequisites for widespread CA-based development and farmer adoption in Eritrea are: (i) policies that permit long-term, profitable investment by farmers in adopting improved CA-based technologies and practices within integrated crop and livestock systems (land rights, grazing management, availability of inputs such as seeds, fertilizers); (ii) the creation of farmer groups to participate in the development and fine-tuning of CA-based technologies on-station and in farmer fields to better ensure the suitability of the technologies and to better facilitate the delivery/adoption of thee technologies by farmers; (iii) an enhanced role of the private sector in the supply of agricultural inputs and services; (iv) strong extension systems and public–private partnerships for the delivery and adaptation of technology and enhancing of farm mechanization; and (v) good availability of credit.

The proposed entry points and interventions for introduction of CA in Eritrea are presented below in Table 3.

Table 3. Entry points and technical interventions for conservation agriculture development in Eritrea

#	Entry points	Interventions
1.	Conserving water, halting soil degradation, and better and timelier crop establishment.	Zero-tillage, residue retention, contour/peripheral bunding and crop diversification wherever possible.
2.	Managing water.	Contour/peripheral bunding, ground water development for high value crops (diversification) and supplemental irrigation, and improving water use efficiency through agronomic management, e.g. timely seeding.
3.	Conjunctive use of organic and inorganic nutrients.	Developing effective fertilizer management (using, together with conventional farmyard manure, rational, reasonable fertilizer rates that reflect actual nutrient availability on-farm, and optimizing timing and placement to obtain high efficiency in fertilizer use). Implementing rational management of residues and

		controlled grazing.
4.	Introducing farm machinery.	Introducing reduced/zero till planters – two- and four-wheel tractor-operated (mid/lowlands) – as well as animal traction implements (highlands) and sprayers. Establishing private sector partnerships for the fabrication and repair of simple farm equipment.
5.	Enhancing crop diversification.	Intercropping and crop substitutions in some areas. Introducing fodder species, vegetables, and maize, etc. wherever possible.
6.	Improving weed management systems.	Testing new herbicides, and establishing private sector partnerships for improving the availability of herbicides. Minimizing soil disturbance, retaining residues, and implementing weed management regimes based on cropping systems.
7.	Improving seed systems.	Increasing seed availability with farmer participation, choosing appropriate cultivars, and improving seed storage.
8.	Co-learning and adopting community-based technology.	Forming CA farmers' clubs, and machinery and input hubs.
9.	Capacity building of farmers.	Enhancing the awareness and capacity of farmers' service providers and extension officials for CA.

6.1 On-farm adaptive research

The major agricultural research questions for Eritrea revolve around enhancing crop productivity and halting land degradation. These questions are: (i) will CA-based technologies be helpful in reducing costs and improving productivity of major crops while conserving natural resources?; and (ii) what is the potential trade-off in the use of crop residues – will the retention of some threshold levels of crop residues on the soil surface be more beneficial compared to removing all crop residues to feed livestock?

In Eritrea, the key agricultural constraints are soil erosion, land degradation, poor fertility of soils, water deficits, and erratic weather conditions. Other challenges are loss of rainwater due to evaporation and run-off, non-availability of resource-efficient crop varieties, and a lack of external inputs and efficient production technologies as well as the chronic energy crisis and poor farm mechanization. Furthermore, recent weather abnormalities due to the effects of climate change have increased unusual weather events such as terminal water stress and droughts that further compound the already grim situation. These constraints, coupled with poor efficiency of applied inputs due to biotic and abiotic stress, make farming uneconomical and therefore a poor investment prospect.

Concerted efforts are thus needed to achieve sustainable food production while strengthening the sustainable use of natural resources to attain socio-economic developments through the reorientation of new soil and crop management technologies for Eritrea. Technologies based on conservation agriculture hold a promise to deliver such a sustainable approach.

Introduction of CA-based technologies may offer a means of efficiently managing rainwater and implementing diversified resource-efficient agro-techniques which offset climatic aberrations. These technologies may help in improving the productivity of crops while substantially reducing production costs in ways other than simply reducing run-off and improving the fertility of soils. Indeed, initials efforts with CA in Eritrea have shown increased production at less cost. In particular, some small CA implements have been developed in Eritrea and can be used efficiently and multiplied locally to meet demands. There are small workshops in Asmara that can fabricate simple seeders if prototypes are made available to them. Recently, a two-wheel tractor-drawn multi-crop zero till seeder developed in Bangladesh and India has been identified as potentially useful in Eritrea. The seeder comes with a seed metering system (using an inclined plate) that can plant most crops, and movable tines that allow for planting at variable distances between rows. The hand-held jab seeders and simple animal-drawn zero till seeders can be locally manufactured and are easy to use.

6.2 Measurement of yield gaps

Measuring yield gaps will involve inventorying various crops and cropping systems and holding multi-location trials of different technology components in high-, mid- and lowlands to consider the production system constraints. Existing scientific and farmers' knowledge will also be inventoried and complemented in the development of appropriate CA-based technologies. Interventions and entry points will be chosen and integrated with indigenous skills and systems knowledge, with the aim of bridging yield gaps. The interventions will be tested as a part of the developed 'best bet' CA-based alternative practices versus the existing conventional farmer practices. The 'best bet' CA-based technologies will be fine-tuned as needed with the full participation of farmers to better ensure more widespread adoption.

6.3 On-farm adaptation and rollout

The research program will initiate medium- to long-term adaptive research and delivery trials for each major crop production system and region to develop and fine-tune CA-based technological interventions suitable for farmers in Eritrea. This will also be helpful in developing a strong CA-based regional knowledge base. The existing information will be utilized to develop and fine-tune technology options for wide-scale adoption. Adaptive research trials will be conducted on tillage and crop establishment, and residue management in identified potential cropping systems.

At selected sites, crop management trials on component technologies will be carried out to feed into the fine-tuning of CA-based practices to meet location-specific needs. The resulting information will also be used for training farmers and extension personnel. The available CA implements will be evaluated for different crops and potential technologies identified from the adaptive trials will be rolled out in participatory farmer trials (comparing the new CA-based practices versus conventional farmer practices), field days and traveling seminars. In addition, capacity building of the stakeholders to implement CA-based technologies will be carried out in identified regions of the country. Local machinery manufacturers will be trained and exposed to models from other countries in order to make appropriate seeders and other implements. A timeline for the adaptation and adoption of CA-based crop management is presented below in Table 4.

6.4 Formation of partnerships

A range of partnership will be needed to strengthen the development, testing and fine-tuning of CA-based technologies, in order to develop an effective delivery and adoption network. These partnerships should involve: farmers and other stakeholders; agricultural research institutes such as NARI, the Hamelmalo College of Agriculture, and the Agriculture Production Development Department; *zoba* administration (the key national extension system); and machinery manufacturers, farm input suppliers and other private sector organizations. In particular, involving the private sector, farmers' organization, cooperative and service providers, and the media will be helpful for the widespread adoption and up- and out-scaling of CA-based technologies in Eritrea.

Table 4. Possible timeline for implementing adaptive research and delivery of CA-based technologies to farmers

	Activities	**Year 1**				**Year 2**				**Year 3**				**Year 4**
		I	II	III	IV	I	II	III	IV	I	II	III	IV	I–IV
1.	Filling information gaps in the understanding of relevant socio-economic and crop production factors in existing production systems and associated management practices.	**x**												
2.	Selecting partner institutions, and prioritizing production systems and locations for the introduction and extension of suitable CA-based crop management practices.	**x**												
3.	Procuring CA implements and placement at convenient locations.		**x**	**x**			**x**				**x**			
4.	Training extension agents and farmers.		**x**	**x**			**x**				**x**			**x**

5.	Developing and fine-tuning site-specific work plans, and training farmers.		**X**				**X**				**X**			**X**
6.	Implementing, evaluating and refining new potential CA-based technologies in adaptive research platforms.			**X**	**X**			**X**	**X**			**X**	**X**	**X**
7.	On-farm side-by-side comparisons of best bet CA technology and conventional farmers practice.			**X**	**X**			**X**	**X**			**X**	**X**	**X**
8.	Component technology trials to test and refine CA implements.			**X**	**X**			**X**	**X**			**X**	**X**	
9	Farmers, local machine manufacturers, and the private sector participating in adaptive research trials for co-learning and awareness.			**X**	**X**			**X**	**X**			**X**	**X**	**X**
10	Seed multiplication for advance varieties of crops and forages.			**X**	**X**			**X**	**X**			**X**	**X**	**X**
11	Mid-season evaluation of technologies on cost of production and yield.					**X**				**X**				**X**
12	Delivering technology to a large group of farmers							**X**	**X**			**X**	**X**	**X**
13	Involving input dealers, machinery manufacturers, and policy makers for fostering widespread adoption.							**X**	**X**			**X**	**X**	**X**
14.	Technology marketing for out-scaling, traveling seminars, and field days.							**X**	**X**			**X**	**X**	**X**

7. Conclusion

Developing conservation agriculture in Eritrea requires strategies that efficiently identify, fine-tune, validate and deliver CA-based crop management technologies to farmers, with farmers' active participation in all steps of the process. Poor mechanization and low availability of tractors and other agricultural inputs, such as fertilizers and herbicides, could pose difficulties for the initial testing and development of CA in Eritrea. Large-scale, system-based adaptive research trials (for technology fine-tuning, training, economic analyses and the demonstration to and involvement of government agencies, farmers, cooperatives and the private sector in the process of CA technology adaptation and delivery) could help keep the R4D activities ongoing even after the project ends. This would increase the likelihood that CA-based crop management is adopted long term and succeeds in minimizing soil degradation and enhancing the productivity and profitability of farms in Eritrea.

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