Using Science Knowledge and Expert Feedback to Accelerate Local Adoption

*Climate Smart Technologies and Practices Meet ICT Tools*

*Selian Agricultural Research Institute (SARI) – Arusha, Tanzania*
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Correct citation:
1 Executive summary

Background, objectives and goals

Population growth and dietary change will drive global food demand to unprecedented levels in the coming decades. The region of East Africa, in particular, has a high demand for improved agricultural productivity, as almost 70 percent of its 211 million populace is agricultural rural population practicing and depending on small-scale agriculture, (FAO 2013). In Sub-Saharan African countries for example, rural poverty accounts for as much as 90 percent of total poverty, (Dixon et al. 2001). Smallholder farmers and local decision makers, such as national agriculture research institutes and extension officers, need concrete frameworks and pathways to respond to global climate change through adaptation and mitigation practices.

This project and its activities, specifically undertaken in Northern Tanzania, focused on the CCAFS (CGIAR Research Program on Climate Change, Agriculture and Food Security) site of Lushoto (link to CCAFS site Atlas), and is closely linked to climate-change and land management activities within the region. Located in Northeastern Tanzania, the Lushoto district forms part of the Eastern Arc Mountains of East Africa, and despite its small area it is considered a global hotspot for biodiversity due to its numerous micro eco-zones. It is a mixed crop-livestock area, with intensive farming systems found at higher elevations and agro-pastoral systems at lower elevations.

“Climate-smart agriculture (CSA) is agriculture that sustainably increases productivity, enhances adaptive capacity, and reduces or removes greenhouse gas emissions where possible”.

“About Climate-Smart Agricultural Practices”, CCAFS

CSA helps farmers at the local level build adaptive capacity and resilience to climate variability and change, and at the national level it helps decision
makers to deliver food security and development goals, while reducing emissions.

Using the strength and knowledge of scientists across multiple disciplines and at different levels together with the methods developed in this project, researchers aimed to accelerate the rate of adoption of climate smart agricultural (CSA) practices and technologies within East Africa, and to help farmers adapt to and mitigate the effects of climate change.

The overall goals of this project were to combine highly relevant CSA research outputs with practical knowledge on the ground, use modern information and communication technology (ICT) to support the interaction between actors and to accelerate the delivery of information from experts to implementers, and feedback from implementers to scientific experts.

Researchers developed and implemented integrative climate adaptation platform that builds on an interdisciplinary environmental, agricultural and socio-economic framework, together with inputs from national and international partners.

Specific objectives:

1. Identify the most promising CSA practices for Northern Tanzania.
2. Conduct spatially explicit monitoring and modeling of land health and agronomic suitability.
3. Assess modeled agronomic and environmental benefits for the CSA practices at the local level.
4. Validate benefits of CSA with local agriculture experts through an interactive platform.
Researchers successfully:

- Tested a participatory prioritization of CSA packages methodology, which included local farmers, technicians from the local agricultural district office and experts from different areas of Northern Tanzanian.

- Conducted biophysical impact of climate change through integrated modeling: the Decision Support System for Agrotechnology Transfer (DSSAT) model, a climate data set of meteorological daily data for a historic period of 27 years, soil data from the Land Degradation Surveillance Framework (LDSF) as well as selected agronomic management methods from survey data of a previous baseline project of the Climate Change, Agriculture and Food Security program (CCAFS).

- Developed an interactive platform for monitoring and feedback loops of participants on CSA practice implementation, and adapted an existing platform-framework for collaborative problem solving within the citizen’s spatial context (Geocitizen) for the Spatial Data Infrastructure (SDI).

- Developed the project’s activities as a continuation of previous CCAFS projects in the region and prepared outputs for further use in other project activities in Lushoto and within the East African context, including the further use of ICT tools and interactive platform for the monitoring of demo plot activities in other ongoing CIAT led projects.
2 Methods and Tools

Prioritization of CSA practices

Climate-Smart Agriculture Prioritization Framework, the CCAFS approach, was used to identify and characterize promising CSA practices and technologies for Lushoto. The approach, though designed to be used at the national level, was adjusted to be used on the local scale, in this case for selecting CSA practices for the Lushoto area.

The flowchart in Figure 2 shows the different steps taken during the project.

An “Assessment of CSA practices” was conducted. Here, a literature review was carried out to filter an initial long list of practices from the Scientific & Grey Literature in terms of geographical area, challenges to be addressed and desired outcomes.

The top CSA options were identified along with local stakeholders in order to create a shortlist of CSA options for Lushoto. To do this, two separate stakeholder “Participatory Workshops” were conducted, one with farmers and the other with national and local agriculture and development experts. The overall objectives of the workshops were to gather information on the barriers and constraints for climate smart agricultural practices in Lushoto from various stakeholders, and to ask stakeholders to select and place practices into CSA packages they would like to see demonstrated in the region. Specific objectives from both workshops were:

1. To identify the different agro-ecological zones around Lushoto CCAFS Villages and describe their characteristics.
2. To assimilate information, opinions, and/or concerns regarding CSA practices from farmers and experts.
3. To develop a prioritized list of CSA practices and/or packages for each agro-ecological zone.

These workshops built upon previous efforts, including the CCAFS Baseline Household and Village Surveys, IMPACTLite Surveys, Land and Soil Health Biophysical Surveys, Playing out transformative adaptation in East Africa, as well as previous initiatives to identify current CSA practices.
Modeling the biophysical impact

For the assessment of the biophysical impact expected through climate change, the Decision Support System for Agrotechnology Transfer (DSSAT) was used. DSSAT is a software application program that comprises crop simulations models which simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. DSSAT incorporates about 16 crops, of which maize and beans are included, (ICASA 2007, Jones et al. 2003).

![Image](image-url)

**Figure 3: Input and output in the Decision Support System for Agrotechnology Transfer (DSSAT).**

The methodology showed in Figure 3 used different combinations of inputs to simulate yields in kg/ha of dry beans and maize so as to achieve results as output.

**Soil data**

The Land Degradation Surveillance Framework (LDSF) is a spatially stratified, randomized sampling design, developed to provide a biophysical baseline at landscape level, and a monitoring and evaluation framework for assessing processes of land degradation and effectiveness of rehabilitation measures over time. Measured variables include: erosion prevalence, land cover, tree and shrub densities, root depth restrictions and infiltration capacity. In LDSF, the soil sampling was done using areas of 100 Km² (10 * 10 Km); each area was divided in 16 clusters and each cluster into 10 plots, see Figure 4. Soil samples were taken in two depth ranges, 0 – 20 cm and 20 – 50 cm. These samples were analyzed to establish their texture, organic carbon content, pH, basic cations, and size particle distribution, among others (Vågen et al. 2013). These variables were used as input in DSSAT however, some parameters were estimated: including field capacity (SLLL), permanent wilting point (SDUL), soil saturation (SAT) and apparent density, (Minasny & Hartemink 2011, Tomasella & Hodnett 2004, Gijsman et al. 2007, Benites et al. 2007).
Climate data

A data set of meteorological daily data for the historic period 1979 to 2005 was used. This data is based in the reanalysis of NCEP-NCAR (NNR) of West and East Africa at 0.1 degrees resolution (approximately 10 km), (Sheffield & Wood 2006). Researchers performed a data conversion of units of solar radiation, precipitation and of maximum and minimum temperature, DSSAT (2010).

Agronomic management

Based on DSSAT (2010) requirements, different variables were grouped to accurately perform the simulation of the crop growth, including varieties, planting date, plant density, application technique, fertilizer (inorganic and organic) and the amount.

The bean variety, Phaseolus vulgaris L., was selected using principal component analysis (PCA), (Borcar & Legendre 2011). As a point of reference, researchers used cultivars recently grown in East Africa and compared it to 28 other varieties currently found in DSSAT 4.5. The varieties of maize were selected using a study conducted by The International Food Policy Research Institute (IFPRI), where DSSAT 4.5 was used to simulate the growth and development of different maize cultivars in 0.5-degree worldwide grids, using multiple agricultural technologies such as irrigation, and different fertilization plans, (Rosegrant et al. 2014).

The data for planting date, plant density, type of fertilizer and amounts was extracted from the Baseline CCAFS Benchmark Sites (Laderach et al. 2014), the AgTrials platform (CCAFS 2015), and case studies (Lekasi et al. 2001). The objective was to capture the most used techniques of smallholders in their fields and to transfer them to DSSAT in order to make the simulations as close to field production as possible.

The data used as input for the model were:

- Soil measurements taken from 16 places in Lushoto, Tanzania, LDSF (Vågen et al. 2013).
- Minimum and maximum temperature, precipitation and solar radiation in Lushoto, Tanzania, Princeton University, (Sheffield et al. 2006).
- Bean cultivar B0014, Canadian Wonder, and maize cultivar, IB0064 H. Obregon, (Rosegrant et al. 2014).
- Two planting dates: bean in March-April and October-November; Maize in March-April and August-September, with a 45 day time window to ensure the best humid conditions of soils in order to have optimal germination.
- Organic fertilizer with manure (2 t/ha), mulch (1.5 ton/ha). Inorganic fertilizer to beans with 125 kg/ha of DAP (16-46-0) at planting time and 50 kg/ha of DAP to maize; 45 days after, researchers simulated the application of 50 kg/ha of urea for both crops, and also the control, a blank treatment without fertilizer.

ICT tools and interactive platform

The interactive adaptation platform supports the idea of farmers being actively involved in the test and evaluation of cultivars and practices as citizen scientists, (Van Etten 2011). For the technological platform, researchers adapted an existing platform-framework for collaborative problem solving within the citizen’s spatial context, Geocitizen (Resl et al. 2013, Atzmanstorfer et al. 2014). For this project, the framework was complemented by adding a feedback tool for the demonstration process of
selected CSA practices through project implementers.

Main purposes of ICT tools:

1. Easy and simple (data collection)
2. Spatial data relation
3. Flexible survey building
4. Monitor plot activities

To test and develop tools with local agricultural experts and farmers, researchers visited the field twice and carried out capacity building and field testing sessions together with the local partners. The trainings also served to capture barriers in using the ICT technology and were used to improve some features of the second version of the technology.

Local agricultural experts were trained on the use of ICT tools and its application for their daily work communicating with farmers. Barriers to participation for farmers exists on such a platform, as such local agriculture experts acted as knowledge workers to close this communication gap.

The CSA Implementer platform is a crowdsourcing tool used to collect relevant data for monitoring a project implementation in a structured way. It offers easy information access in the field and offers to the user, a tool to share feedback with the experts. The platform can be used for the monitoring of ongoing field implementations of CSA practices and for sharing of lessons learned during the implementation process, including its spatial context of the implementation site.

Data Infrastructure for CSA Implementer

A data infrastructure for structuring all the data collected through the interactive platform in a Postgresql database was built. Figure 5 shows a schematic Entity Relation Model (ERM) of the tables built.

![Figure 5: Schematic ERM of main tables in the database.]

Mobile application

While developing the pilot application for an android operating system, researchers took into account that:

1. Most low cost mobile devices run on an android based operating system,
2. Installing and updating can be done easily without going through an online distribution system, and
3. There is a high availability of online support.

The finished application consists of several modules which are explained in more detail in the following sections.

Data collection module

The data collection module consists of two main features:
1. The registration of new farmers in the database, and
2. The collection of spatial related information, points with GPS coordinates and related information as attributes, in fields visited.

See in Figure 6 an example of the state/activity diagram in Unified Modeling Language (UML) for the “Register farmer” feature.

![Figure 6: The activity UML diagram shows how to register a farmer in the database through the mobile application.](image)

The collection of spatial related information can be done in the map viewer. The map viewer provides basic functions for zooming on the map, adding additional map layers, and recovering information. Information can be collected as observation in the field, or researcher relating the information to a registered farmer, (see manual in annex 1 for more details).

**Survey module**

Surveys can be created directly in the database. Questions are generated independently and can be assigned to several surveys. Surveys created can be assigned to individual farmers and will appear as pending if they are not carried out by the field worker.

![Figure 7: Shows the map view of the mobile application.](image)
Implementation monitoring module

Currently, the International Center for Tropical Agriculture (CIAT) together with the Selian Agriculture Research Institute (SARI) are carrying out learning demonstrations on farm plots for implementing CSA practices. The basic idea of the interactive platform is to support their ongoing activities through a simple field activities monitoring and feedback tool.

The local project Implementer of CSA practices can use the mobile application to access relevant information on a specific CSA practice while they are meeting with farmers in learning sessions. The information on each CSA practices needs to be uploaded before going to these sessions into the database. The local implementer can then access the information through their android devices. To do this they would go through the following steps (blue box):

**Main steps for starting a demonstration plot:**

1. Collect new observation point on the map (or use existing marker point).
2. Open related information by clicking on the point.
3. “Start demo” converts this point maker into a demonstration plot.
4. Assign relevant information for demonstration plot:
   - Plot name
   - Start date
   - Responsible Farmer
   - CSA practices for demo
5. Submit information to database and start demonstration plot.

Once the demonstration has started the marker symbol on the map changes to a different color and the map site can now be used for reporting ongoing activities on this plot. Figure 9 shows the use/case UML diagram for monitoring the demonstration plots. Local Implementer together with participating farmers can access and view relevant information - handbooks, videos, photos, descriptions - on a specific CSA practice on the mobile application. For every work session on a specific demo plot site, field workers can submit a short progress report on the mobile application: main activities, number of participating farmers, photos. On their next demo plot session, they can view the previous activity reports. If farmers have questions which the local Implementers cannot respond, they can submit questions related to a CSA practice through the mobile application to the database. Once the question has been responded to by a CSA Expert through the web platform, the answer can be seen by farmers and local implementer on the mobile application in the next training session...
3 Carried out activities and achieved results

Assessment of CSA practices for Lushoto

Richard Gledhill et al (2012) paper entitled “CSA Project Identification and Feasibility Guide: Climate Smart Agriculture in Sub Saharan Africa Project” presents several guidelines for the implementation of climate smart agriculture at different phases of a CSA project. Based on his work, research questions were identified and developed that uncovered critical information about land and soil health along with other environmental conditions for the area, existing socio-cultural conditions, land use and land history, farming systems and household types. From the information obtained, researchers were able to identify social, natural and human barriers that exist in Lushoto for the adaptation of climate smart agriculture.

The guidelines provided by Richard Gledhill et al (2012) were further supplemented by successful stories of climate smart agriculture presented by Michael Hailu & Bruce Campbell (2013). The authors wrote extensively on the impact of agriculture on the climate, particularly through the production of methane and nitrous oxide—potent greenhouse gases. From their work, researcher identified the main sources of GHG emission by the agriculture sector, and also identify CSA practices with multiple benefits that would offer adaptation, production and mitigation benefits. With the information obtained from the literature review, researchers were better able to select those practices that addressed (for the most part) the existing conditions in Lushoto.

In Lushoto, CSA practices should:

- Aid in the retention and enhancement of soil nutrients and fertility, and improve soil moisture. Interventions should focus on practices that stabilize or increase soil organic carbon (SOC) in
order to increase the capacity of the farming systems, Leigh Winowiecki et al (2014).

• Build resilience to pests, diseases & weeds.
• Build resilience to heat stress, droughts and erratic rainfall.
• Take into account socio-economic challenges and constraints.
• Include policies and programs that support adaptation methods. In order to overcome barriers to CSA and achieve adaptation of CSA at a meaningful scale, activities need to be implemented at a project and/or even program level, Richard Gledhill et Al (2012).

• Create new spaces for men and women to collaborate and make decisions together.
• Take into account labor and input requirements and costs of establishment.
• Take into account potential risks and uncertainties.
• Take into account time lag until realization of benefits.
• Increase production of marketable agricultural and agroforestry products. Select crops that have short term and long term maturity. This is a more sustainable approach to livelihood and food security.
• Improve capacity to access market information.
• Mobilize farmers into farmer based organization.

Preselected long-list of Climate-Smart Agriculture Practices & Programs: the case of Lushoto

1. **Crop rotation**

Crop rotation is the alternation of different crops with different characteristics cultivated on the same field to avoid exhausting the soil nutrients and to control weeds, pests, and diseases, (FAO 2014).

Potential Benefits: Increases soil organic matter and by extension enhances water and nutrient retention, and decreases synthetic fertilizer requirements. Improves soil structure, reduces soil degradation, and can result in higher yields and greater farm profitability in the long-term. Controls weeds and diseases, and limit insect and other pest infestations and as a result significantly reduce pesticide use. (IFOAM EU et al 2012).

2. **Inter-cropping**

Planting of two different, though complementary, crops on the same plot of land, either in a mixed row or strip intercropping system, Stephen Machado 2009.

Potential Benefits: Production diversification, reduces risks of total crop failure, reduces pest and or diseases.

3. **Rotational grazing**

Livestock are strategically moved to fresh paddocks or partitioned pasture areas to allow vegetation in previously grazed pastures to regenerate, Dan Undersander et al 2002).

Potential Benefits: Reduces soil erosion and soil compaction, which encourages root growth and reduces weeds from resting periods. It lengthens the grazing season because of a shorter forage recovery period when rotating paddocks. More efficient use of forage, healthier livestock and improved animal productivity, improved income.

4. **Cut and carry with improved forages**

Establishing livestock fodder such as *Napier* grass that is cut green and then fed to animals contained in feeding pens, rather than allowing free grazing or pasture grazing, Caitlin A. Peterson et al, 2014).

Potential Benefits: Reduces land degradation and soil compaction from overgrazing and animal trampling. It provides additional income from the sale of livestock products, The land is utilized more efficiently and centralization of animal waste production, J. Jeff Palmer et al.

5. **Seasonally adapted planting time (early planting)**

Planting seeds before the onset of the rains to compensate for rainfall variability and shortened growing season, Caitlin A. Peterson et al, 2014.
**6. Terracing**

Construction of earthen, bench-like structures along the contours of planting of annual crops. The structures are stabilized by planting erosion-resistant fodder grasses and/or agroforestry tress, Caitlin A. Peterson et al, 2014.

**Potential Benefits:** Reduces weed infestations, compensates for climate variability and shortened growing seasons. It reduces the risk of crop failure.

**7. Irrigation: water harvesting and storage**

System to transport and supply water to crops, either on a large-scale such as a canal/pump system, or as a smaller micro-irrigation scheme, Caitlin A. Peterson et al, 2014.

**Potential Benefits:** Increases soil-water availability reduces soil erosion and land degradation, increases agricultural productivity.

**8. Mulching**

Covering the soil surface with a layer of organic residues (leaves, straws stems, cut grasses) and allowing for eventual decomposition.

**Potential Benefits:** It reduces soil temperatures, increases soil moisture retention to compensate for drought or reduced rainfall. Stifles weed growth and reduced GHG emissions from exposed soil surface.

**9. Organic fertilizer (composting)**

Collection and heaping of organic waste materials such as food scraps, crop residues or livestock manure in a pit, pile or other structure to allow for decomposition and later application to cropland soil. Caitlin A. Peterson et al, 2014.

**Potential Benefits:** Reduces emissions associated with production. It reduces use of inorganic fertilizers, improves soil fertility and agricultural productivity.

**10. Optimal use of inorganic fertilizer**

A substance of synthetic origin that is applied to the soil to supply one or more key nutrients essential to the growth of the plants, Mercy S, Mubsira Banu S, Jenifer, 2014.

**Potential Benefits:** Compensates for declining soil fertility.

**11. Minimal tillage**

Tillage refers to all methods used to prepare soil for planting, especially the loosening and breaking up of topsoil by the use of a hoe, plough or similar tilling implement. Specifically, minimum tillage can refer to tied ridging, digging, planting, preparing pits with a hand hoe, in contrast to conventional deep tillage. Crop residues are often left on the soil surface or incorporated into the soil rather than removed, Caitlin A. Peterson et al, 2014.

**Potential Benefits:** Reduces soil compaction from over tillage, prevents soil degradation. Reduces GHG emissions compared to deep tillage or conventional ploughing, improves agricultural productivity.

**12. Contour (I) ploughing (II) bunding**

Contour ploughing: The practice of ploughing and/or planting across a slope following its elevation contour lines. These contour lines create a water break which reduces the formation of rills and gullies during times of heavy water run-off, Caitlin A. Peterson et al, 2014).

Contour-bundling: This practice consists of making a comparatively narrow-based embankment at intervals across the slope of the land on a level that is along the contour, Caitlin A. Peterson et al, 2014).

**Potential Benefits:** Reduces soil compaction from over tillage, prevents soil degradation. Reduces GHG emissions compared to deep tillage or conventional ploughing, improves agricultural productivity.
13. **Strip cropping**

Growing crops in a systematic arrangement of strips across a field, i.e., planting strips several meters wide of alternating grasses, hedge rows, or shrubs and annual crops. Types of strip cropping include contour, field or buffer, Dennis Carman, 1997.

**Potential Benefits:** Creates favorable microclimates, improves water quality control, increases soil carbon sequestration, and reduces soil erosion from water and wind.

14. **Silvopastoral system**

Silvopastoral systems are characterized by integrating trees or shrubs within forage and livestock production systems in the same acreage to utilize space and growing season limitations, Stephanie & Temidayo 2014.

**Potential Benefits:** Improves soil condition with the incorporation of trees, improves nutrient cycling with the deeper tree roots or use of nitrogen-fixing trees, reduces soil erosion, and provides shade for animals, reduces wind velocity, improves soil moisture retention and increases production.

15. **Weather index insurance/ micro-lending**

(SACCOS) Savings and credit cooperatives- local organizations offering micro loans and savings opportunities for members in exchange for a membership fee, Caitlin A. Peterson et al, 2014.

**Potential Benefits:** Reduces risks associated with crop loss or extreme weather events, provides additional financial resources to purchase food and other products.

Many of these practices already exist in Lushoto. However upon presenting these practices to the stakeholders during the participatory workshops, we hoped to get a better understanding of either the failure or successful of each, and the way forward.

### Participatory workshops

The farmer participatory workshop was attended by thirty men and women farmers from the seven CCAFS Lushoto baseline villages. Workshops provided insights into farmers’ perceptions of locally appropriate CSA practices in the region.

Fifty-three percent of the attendees were between 21-35 years old, 34% were between 36-50 years old, and 13% were above 50 years of age, see Figure 11. The majority of the participants (84%) had primary level of education, while 16% had secondary level of education, see Figure 11. Of the five farmers who obtained secondary education, three were females and two males. Head of households were male dominated. Household members ranged from 3 to 11 people.

Figure 11: Age distribution and education level of workshop participants.

![Figure 11: Age distribution and education level of workshop participants.](image)

Figure 12: Women group discussing CSA practices in farmer participatory workshop.

**Farmer characterization of agro-ecological zones in the Lushoto District**

An important consideration for developing locally appropriate CSA practices is acknowledging the different biophysical environments, including the
varying agro-ecologies and climates. While Lushoto is one of CCAFS sites, it has diverse topography and climate. Researchers gathered information on farmers’ perceptions of the ecological and climate diversity, which ultimately reflected their crop selection as well as farm management practices. Also, participatory mapping of the different agro-ecological zones revealed specific characteristics for each zone.

**Zone one: Highland**

The highland region includes altitudes of 1700m and higher. It includes Mamba, Milungi, Gare, Yamba and Masange villages. The area, defined by extremely steep slopes and forest, contribute to the cool and temperate climate. Of all the villages, Milungi was described as the coldest. Farmers in Zone 1 benefit from three rainy seasons: the long rains, the short rains and intermediate rains. Farmers produce cash crops such as coffee, tea, chili peppers and different varieties of maize. Milungi village specializes in vegetables, potatoes and chili peppers. Crops are planted seasonally, for example maize is planted only during the long rainy season. Among the challenges to production are soil erosion and over grazing. To combat these challenges, farmers practice terracing and agroforestry related practices, such as strip-cropping. Farmers in this region engage in a mixed crop-livestock production system.

**Zone two: Upper midland**

Upper midland includes Kwang’wenda. Similar to the Highland areas, Zone 2 is heavily forested and has cool and temperate climate. Farmers cultivate different varieties of maize and vegetables. Crops in Kwang’wenda, similar to those in Zone 1, depend entirely on rains. Vegetables are planted during the long rainy season, and maize is planted during the long and short rains. Terracing along with strip cropping are two dominant agricultural practices in this area. Farmers engage in mixed crop-livestock production systems.

**Zone three: Lower midland**

Zone 3 includes the village of Mbuizi. Here, farmers experience a warmer climate compared to Zones 1 and 2. There are two seasons for planting, the short and long rains. Maize, which is both a food and cash crop, was reported to yield better in terms of quantity and quality, during the long rainy season, compared to the short rainy season. Traditional irrigation is practiced here, as well as minimal tillage.

**Zone four: Lowland**

Zone 4 includes the village of Boheloi. In Boheloi, the climate is warm and farmers experience two rainy seasons, the long rains and short rains. During the long rains, farmers plant cash crops such as vegetables and French beans, and food crops such as maize and French beans. Farmers reported that maize matures early due to the warm climate. Irrigation and tillage are widely practiced in this area. Farmers harvest rainwater in drums and practice traditional irrigation.

**Farmer Prioritization of CSA Practices**

The fifteen pre-selected CSA practices were presented diagrammatically and descriptively to farmers. That is, each practice was drawn on a card and participants working in groups identified each and gave an explanation of their benefits, see Figure 12. From the pre-selected list, farmers identified the practices that have been and are currently being used in the area, and created packages of CSA practices they would like to see demonstrated for the different agro-ecological zones.

Participating farmers were divided into four groups, based on gender and agro-ecological zones:

- Lowland women: (mainly Zone 3 and 4)
- Lowland men: (mainly Zone 3 and 4)
- Highland women: (mainly Zone 1 and 2)
- Highland men: (mainly Zone 1 and 2)
Comments of farmers from group work

Lowland’ women in Zones 3 and 4 stated that early planting occurs between February and March for the long rainy season. Whilst for the Highland’ farmers, Zones 1 and 2, early planting is in November during the short rainy season.

Lowland’ women, Zones 3 and 4, stated that mulching was not practiced due to unavailability of materials, and the lack of knowhow. For this reason the use of manure was preferred. In contrast, Lowland’ men in Zones 3 and 4 stated that mulching was good for vegetable growers, but not on the sloping areas of the highlands. Highland’ men in Zones 1 and 2 stated that mulching was used but for ‘special crops’ such as tomatoes and vegetables.

All four groups stated that due to lack of knowhow contour ploughing and contour bunding were among the least commonly practiced. However, Lowland’ men in Zone 3 and 4 said that a few farmers had started practicing contour ploughing. Lowland men and women stated that an obstacle to contour bunding was the lack of stones. Despite this, highland men were enthusiastic to learn about contour bunding through a demonstration plot.

Collectively, farmers believed that terracing required advance knowledge and specialized skills. This practice, notwithstanding its benefits, is perceived as having high input and labor costs, with a long time lapse before benefits are realized, thus making the practice unattractive to farmers. Lowland farmers noted that terracing was less relevant to them on flatter land.

Rotational grazing was discussed by Lowland men and Highland women as unsuitable due to land scarcity, but that zero grazing and cut and carry were more appropriate to their farming systems.

The application of fertilizer was favored by Highland men, but concerns were expressed regarding correct application. Highland women also used this practice to make up for the depletion of soil nutrients.

Highland men practiced crop rotation to reduce the risk of pests e.g., White Fly.

Highland men intercropped crops such as maize and beans. For these farmers, having several crops was advantageous because if one crop failed they could rely on the second crop. Farmers noted however that intercropping requires technical knowledge and it is a rain-dependent practice.

Farmers from the Lowland men’s group also expressed concerns regarding youth participation in agriculture or lack thereof. According to farmers, youths have lost interest in agriculture. Reasons included too much work and low return and low income. Other challenges in agriculture included pests and diseases and the lack of pesticide protection equipment.

Creation of CSA packages for potential implementation, as identified by farmers groups

Table 1: CSA packages created by lowland women group.

<table>
<thead>
<tr>
<th>CSA Practice</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter cropping</td>
<td>Sustainable income and maximizes land use</td>
<td>Shading effect from trees does not allow other crops to grow well. Crops demand much attention-labor intensive</td>
</tr>
<tr>
<td>Optimal use of inorganic fertilizer and animal manure</td>
<td>Increases yield and improve soil fertility</td>
<td>Does not work well in dry season, farmers are unsure of the rate of application to crop and high price of fertilizer</td>
</tr>
<tr>
<td>Silvopastoral system</td>
<td>Efficient use of land, manages soil erosion, source of timber, charcoal, fodder for livestock, fodder adds nutrients to soil and maintain soil fertility, sustainable means of income</td>
<td>Limited land</td>
</tr>
<tr>
<td>Strip cropping</td>
<td>Efficient use of land, manages soil erosion, sustainable means of income, fodder adds nutrients to soil and maintains soil fertility</td>
<td>Shading effects from trees do not allow other crops to grow well. Some trees are toxic, which can poison animals</td>
</tr>
<tr>
<td>Zero grazing / Cut and Carry</td>
<td>Healthy livestock and by extension better quality meat and high production of milk. Provides manure</td>
<td>Labor intensive and time consuming</td>
</tr>
</tbody>
</table>

Table 2: CSA packages created by lowland men group.

<table>
<thead>
<tr>
<th>CSA Practice</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early planting</td>
<td>Increased yield</td>
<td>Rainfall is not reliable</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>Increases yield and improve soil fertility</td>
<td>Inputs are very expensive, subsides from government are needed</td>
</tr>
<tr>
<td>Compost</td>
<td>Improves soil fertility</td>
<td></td>
</tr>
<tr>
<td>Rotation</td>
<td>Improves soil fertility and reduces runoff</td>
<td></td>
</tr>
<tr>
<td>Intercropping</td>
<td>Provides more income, reduces risks to crop failure and improves soil fertility</td>
<td></td>
</tr>
</tbody>
</table>
Table 3: CSA packages created by highland women group

<table>
<thead>
<tr>
<th>CSA practice</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop rotation</td>
<td>Improves soil fertility</td>
<td>Limited land</td>
</tr>
<tr>
<td>Early planting</td>
<td>Higher yields</td>
<td>Unreliable rainfall</td>
</tr>
<tr>
<td>Inter cropping</td>
<td>Sustainable income, efficient land use and</td>
<td>Low yields due to overshadowing e.g.</td>
</tr>
<tr>
<td></td>
<td>improves soil fertility</td>
<td>beans &amp; maize.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Poor spacing due to limited land</td>
</tr>
<tr>
<td>Optimal inorganic</td>
<td>High yields</td>
<td>Expensive</td>
</tr>
<tr>
<td>fertilizer use</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mulching</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 4: CSA packages created by highland men group

<table>
<thead>
<tr>
<th>CSA practice</th>
<th>Benefits</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composting</td>
<td>Inexpensive and requires limited labour</td>
<td></td>
</tr>
<tr>
<td>Contour ploughing</td>
<td>Conserves water and controls soil erosion</td>
<td>Loss of fertiliser during heavy rains and high start-up cost</td>
</tr>
<tr>
<td>Inter cropping</td>
<td>High yields Maximizes land use. Cost of labor is minimized</td>
<td>Soil fertility could decrease</td>
</tr>
<tr>
<td>Mulching</td>
<td>Conserves soil moisture and controls soil erosion</td>
<td>If there is prolonged drought, fields can be set on fire</td>
</tr>
<tr>
<td>Contour bunding</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Participatory experts workshop

The general objective of the participatory experts’ workshop was to obtain a general overview on experts’ opinion with regards to CSA practices.

Participants came from Dar es Salaam, Tanga, Arusha, Kilosa and Lushoto and were part of the following institutions:

- Ministry of Agriculture (Food Security and Co-operatives)
- Mlingano Agricultural Research Institute
- Selian Agriculture Research Institute
- Lushoto District Council (Dept. of Agriculture and Livestock Development)
- Ilonga Agricultural Research Institute
- Ardhi University
- Selian Agriculture Research Institute
- Rural Resources Centre (RRC)
- Ministry of Agriculture

Key points from expert discussion on the pre-selected CSA list

Variety selection:

Variety selection was the key to all other processes. It is important to firstly think about appropriate varieties in a climate smart manner before considering practices.

Planting date and weather forecasting:

One major challenge for smallholders in Lushoto is early and unpredictable onset of rains. As a possible solution, experts stated that that benchmark dates should be set for planting, and proposed renaming early planting to ‘timely planting.’

Crop Rotation:

Crop rotation, although practiced by some smallholders in GARE Zone 4, is not a practice with which farmers would not be keen to implement, because farmers like to maintain the crops they are accustomed to growing. However, experts noted that crop rotation could work on larger farms where there is space to experiment. Experts considered the idea of ‘differentiated fields’ instead for smaller farms, but concluded that intercropping would be a more suitable practice.

Optimal use of inorganic fertilizer:

A baseline survey showed that in Lushoto, organic manure is more commonly used, as most smallholders cannot afford inorganic fertilizer. There had also been problems with Rock Phosphate fertilizer in Lushoto, making it unattractive an option for many farmers.

Contour bunding:
Contour bunding is labor intensive, without available help, farmers would not be inclined to adopt it.

Rotational grazing:

Land scarcity may be a barrier to adoption. Post-harvest:

Experts discussed the importance of a collection center to ensure security and stability of food supply. Collection centers can also evolved into a market place, as is the case of Mtega center in the Uluguru Mountains. Experts proposed having a collection center in Lushoto to support CSA practices and policies.

Outputs of biophysical modeling

In the tropics where weather is highly variable, and can be affected easily by air movements with high or low precipitations, the weather has great influence over crop development. For this reason, climate directly affects the production of basic grains, which are very important for food supply and the preservation of smallholders’ livelihood in Lushoto.

The climatic analysis for Lushoto focused mainly on the evaluation of the frequency of monthly dry and rainy periods. Figure 15, Figure 16, Figure 17 and Figure 18 show the monthly climatic variability of temperatures (maximum and minimum), and solar radiation and precipitation since 1979 to 2005. From June to September there are temperatures from 11°C to 21°C. Solar radiation and temperature have a directly proportional relation; changes in temperature are similar to the changes in solar radiation. In precipitation, there is more variability showing nonfunctional and disperse behavior. This is especially true during high precipitation periods, February to March, first rainy season of the year.
El Niño Southern Oscillation (ENSO) phenomenon implies big heat interchanges between the ocean and the atmosphere that affects the medium world temperature and cause extreme events in the hydrological cycle, such as storms and droughts. Between 1979 and 2005, the effects of El Niño were evident in Lushoto. There were warmer seasons where the ocean surface temperature was higher, impacting temperature and rain regimes in the continent, see Figure 19.

The production of beans and maize in Lushoto is directly affected by weather conditions and inter-annual climate variation. There are two planting seasons; the first planting season, March-April, and the second, August-October. Planting seasons reflect the variability in precipitation patterns; however outside these seasons, farmers would plant if the land has enough water to sustain the germination of the plants.

In order to replicate this practice, two different planting dates were entered in the DSSAT so as to obtain the yield differences along the years, and to see how the meteorological phenomena affects bean and maize. In Figure 20 and Figure 21, DSSAT is simulating better yields for the first season, this is probably due to higher precipitation in the first quarter of the year; and its decreasing behavior for the remainder of the year, could indicate that that period presents better conditions for crop growth and development.
The second planting date showed some periods of time where there is an increase in yield; generally this occurs in years when weather behavior is normal, mainly in 1982, 1997 and 2004 to 2005. The greatest yield losses were in 1983 and 1987, when El Niño Phenomena was evident. Long periods of drought diminished crop growth. In the case of maize, in 2000 La Niña phenomenon caused a decrease in the yield, which indicated that maize is susceptible to high precipitations.

Soils and the type of fertilizer used also affect crop yield. In this study, 16 soil points in 100 Km² and three different types of fertilizer, organic and inorganic, were used to evaluate the impact these variables have on the plants. For the beans, there is no great variation with respect to the different types of fertilizer used (Figure 22, Figure 23), this may be because DSSAT only takes into account the percentage of Nitrogen, excluding the contents of phosphorus and potassium, that has more influence on this particular crop. Because bean is a legume, it fixes nitrogen atmospheric into the soil, so the importance of nitrogen intake is less relevant than the possible effect of other elements. However, the crop yields show an increase when the beans are fertilized with manure and inorganic sources; although it is not a statistically significant difference, it gives an idea of how the crop behave when fertilized.

For maize, different types of fertilizer impact yields (Figure 24, Figure 25); generally, inorganic fertilizer present better results followed by manure. However, in the case of soil 15, the control treatment exceeds the results with fertilizer, this may have occurred due to the fact that soil contents had high levels of organic matter that favored crop growth.
Soil samples 7 and 15, classified as Clay Loam and Loam, have better soil conditions, as they have high levels of organic material and good soil structure. On the other hand, soil samples 5, 8 and 16 have lower yields especially for bean, these soil have high content of clays, high pH and low contents of organic matter that affect the crop development.

Field testing of ICT platform

**Transect walks to test ICT tools and to identify potential demonstration plots**

Transect walks were done throughout the Lushoto district to identify and observe food and cash crops planted on individual farmer and community demonstration plots. Thirteen demonstration plots were visited. Different management approaches were observed on demo plots visited; additionally the diverse landscape, soil types and farming systems gave researchers a better understanding of the possible challenges, limitations and barriers for the implementation of CSA practice, and for the monitoring and management of demonstration plots.

**Training on the use of ICT tools with the local technicians from Lushoto District Council Office**

Together with our project partner SARI, two separate training sessions were conducted with
local technicians from the Agricultural District Office of Lushoto. The first session was done after finishing the first prototype of the mobile application.

Figure 30: Technician taking a picture of farmer, registering her in the database.

We provided three low cost tablets to our partner and technicians and registered test user in the system. Technicians used the tablets during the transect walks and documented observations of agricultural practices in the field by taking a photos, categorizing the information and registering the observations to geographical coordinates. Further tests were conducted to register farmers in our database and to carry out a survey.

During the June field visits, about 70 GPS points were collected and approximately 30 farmers were registered.

After the field day, discussions were held with technicians to get a clear understanding of the experience of the user and to note suggestions for improving the application.

Figure 31: Technician conducting survey with woman farmer.

After the project team left Lushoto, the technicians were instructed to use the tablets and application to register farmers in other villages, and to complete the demographic baseline survey..

Six month later, the project team returned to Lushoto for a second training session and for the completion of data collection. During this session, the facilitator explained the following features and tasks:

- CSA implementer uninstallation and update of apk File.
- Application launch and login.
- Language selection and farmer registration.
- CSA baseline survey filling.
- Visualizing CSA practices.
- Mapping Sites.
- Registering demo sites.
- Demo site reporting.
- Farmers’ demo site feedback (questions and answers).

After both training sessions, the technicians registered more than 920 farmers in the database, collected more than 720 baseline surveys, and geo-referenced more than 670 field observations.

See some examples of baseline survey results in Figure 32, Figure 33, Figure 34, Figure 35 and Figure 36.
4 Lessons learned

Food security and biophysical impacts of climate change

Beans and maize are important to the smallholder livelihoods in Lushoto. As previously noted, these crops could be more frequently affected by future climate variability, especially in years presenting El Niño and La Niña phenomenon. Therefore, farmers should increase their resilience against climate risks in agricultural production to be prepared.

Inorganic fertilizer has a positive influence on the yield of the studied crops, however the farmer has to assume financial cost and manure could be an alternative due to its low cost. However, a combination of the right amount of inorganic...
fertilizer and manure could represent a viable option for farmers to increase yields.

Soils with higher contents of organic matter have better characteristics for crop development and higher yields. The incorporation of organic matter to these soils could improve yields and soils itself.

In general, biophysical analyses are a good way to demonstrate potential impacts of climate change on current crop production systems. Even though there are many uncertainties related to climate change impact modeling, like the uncertainty of scientific models or, the uncertainty of political scenarios. Farmers and Expert decision makers have to make decisions for adaptation and mitigation now, and under these uncertainties. However, biophysical impact analyses are a first step to estimate the potential impact and to select first strategies. Finally, CSA strategies must always be evaluated and approved by local experts and farmers before the final implementation process is starting.

More importantly, biophysical impact models can deliver input data for more detailed trade off analysis to weight out negative side effects of practices and underpin the CSA practice selection by a solid cost and benefit analysis.

Selection of the right CSA packages must be site-specific

The selection of the right CSA practices for a farmer is a very complex task and there are many internal and external factors influencing the success of implementation. Figure 37 is showing the complex causal loop systems diagram of our designed CSA implementation framework using the support of an interactive platform and developed applications.

First of all, it is very important that all actors participate in the CSA practice selection process. CSA Scientists, Agricultural experts having the expertise on a specific practice and local knowledge transfer and supporting experts for working with farmers on the ground and on demonstration plots.

A selected CSA practice by a national program not taking into account the local site specific socio-
ecological conditions might probably fail. It is therefore very important to use participatory methods for the selection and prioritization of practices on a local scale. Selected practices can be analyzed before implementation using trade off analysis and biophysical modeling.

The use of ICT tools can help to be more effective and to deliver information

Information and communication technologies (ICT) are valuable tools to support the implementation process of CSA practices. They can build a communication bridge from experts to farmers and stimulate question and answer sessions between them. Further they are very well suited for simple evaluation of the implementation success and can be used for monitoring ongoing activities on demonstration plots and the process of up taking CSA practices by farmers.

The usage of ICT tools must be carefully integrated in the participatory process. Local knowledge broker, like agriculture experts and technicians, must be trained well and manuals should be provided to them.

End user of ICT applications, like local agriculture experts working with farmers, should be included in prototype testing. They can provide very useful feedback for improvement of usability and future success of developed application.

However, ICT tools are not the new panacea for agricultural extension services and they can only be used to improve the communication process and delivering beforehand site-specific targeted information easier and faster to the ones being on the ground implementing CSA practices. They can only be used being integrated together with participatory methods and must be used carefully for the development process. The spatial context (see point cloud on Figure 38) of implementation can be very useful for building contextual research and wide scale adoption of successful practices on climate- and landscape similar sites.

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References


Hailu, M. and Campbell, B. Climate Smart Agriculture Success Stories From Farming Communities Around the World, (2012)


