Biophysical and Socioeconomic Results of CLIMATE-SMART AGRICULTURE TECHNOLOGIES in Machinga District of Malawi

Project Report

Edited by Peter Setimela

USDA

CIMMYT
International Maize and Wheat Improvement Center

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Abstract

The USAID/Malawi-funded Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project was designed as the flagship implementation vehicle for the Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) partnership between the United States Government (USG) and the Government of Malawi (GoM), and as a core component of environment programming under USAID/Malawi's Development Objective Assistance Agreement with the GoM. The main goal for PERFORM's five-year engagement was to make a lasting improvement in Malawian quality of life. To do that, PERFORM aligned with Malawi's Growth and Development Strategy to promote forest conservation and green growth. At the site-level PERFORM activities were designed and implemented to address drivers of deforestation and forest degradation, and included a mix of forestry, agriculture/livelihoods and energy focused activities. In Machinga District, adjacent to the Liwonde Forest Reserve, this include a mix of CSA activities designed to improve near-term food security, and build resilience in the longer-term.

The CIMMYT contribution to the project focusses on assessing the merits of a selected range of Climate-Smart Agriculture (CSA) technologies implemented by PERFORM. Specifically, the goal of this project is to improve understanding and application of CSA practices for improved agricultural productivity in Machinga district of Malawi. The project seeks to quantify the benefits and costs of different CSA practices promoted by the PERFORM project and measure the various sustainable intensification indicators as assessments of the climate smartness of key CSA technologies implemented in the district, namely CA, pigeonpea and the Mbeya crop fertilization strategy.

In addition to the biophysical measurements, the studies undertake community-wide focus group discussions (FGDs) and one FGD each with male and female respondents, to understand community livelihood trends, land use patterns, CSA adoption trends, distribution of cost and benefits of CSA practices among household members, market and social dynamics influencing CSA technology uptake choices.

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Acknowledgements

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Acronyms

CGIAR	Consultative Group for International Agriculture Research
CIMMYT	International Maize and Wheat Improvement Center
DAES	Department of Agricultural Extension Services
DARS	Department of Agricultural Research Services
DoLR	Department of Land Resources
CA	conservation agriculture
CSA	climate-smart agriculture
DT	drought tolerant
EC-LEDS	Enhancing Capacity for Low Emission Development Strategies
FtF MISST	Feed the Future Malawi Improved Seed Systems and Technologies Project
FGD	focus group discussions
KIIs	Key Informant Interviews
MADD	Machinga Agricultural Development Division
PERFORM	Protecting Ecosystems and Restoring Forests in Malawi
PRA	participatory rural appraisal
TLC	Total Land Care
USDA	United States Department of Agriculture
USAID	United States Agency for International Development

Foreword

This publication is one of the outputs of the project titled "Protecting Ecosystems and Restoring Forests in Malawi (PERFORM)" funded by USAID and managed by TETRA-Tech, focused on Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) as a part of an agreement between the governments of the United States of America and Malawi, from 2014 to 2019.

The project's purpose was to support communities to manage their forest and soil resources more efficiently, equitably, and sustainably. The project focused on climate-smart agricultural interventions in Malawi including agroforestry or fertilizer tree systems, conservation agriculture, drought tolerant improved maize germplasm, permanent tree intercropping, sequential tree fallow, and biomass transfer aimed at increasing the productivity of smallholder farming systems.

CIMMYT analysed the data arising from biophysical and socioeconomic interventions being implemented by PERFORM in five communities surrounding the Liwonde forest reserve in Machinga district of Malawi. This area covered two agro-ecological zones to determine the potential of climate-smart agronomic practices to build climate change resilience, and to assess the farmers' perceptions of their impact.

The results showed that three specific climate-smart agricultural technologies (conservation agriculture versus conventional farmers' practices; MBEYA fertilization strategy involving a combination of organic manures and conventional mineral inorganic NPK and urea fertilizers and intercrop systems) positively impacted on climate resilience in different respects. With respect to productivity, conservation agriculture (51%) and the MBEYA strategy (19%) resulted in higher maize yields and contributed to improved food security and livelihoods of the smallholders. Combinations of conservation agriculture, drought tolerant improved maize varieties (developed by CIMMYT), and pigeon pea intercropping gave the highest yields and net incomes.

In addition to the biophysical studies, the socio-economic studies revealed that through the awareness created through this project, the farming communities understood better the linkages between climate change, forest ecosystem services and improved seed and agronomic practices.

Without such adaptation measures, Malawian agriculture and the livelihoods of smallholders will be negatively affected by the climatic risks and increasing climate variability. We sincerely hope that this report will provide valuable information to the climate-smart agriculture practitioners as well as policy makers in Malawi.

Prasanna Boddupalli
Director, Global Maize Program, CIMMYT & CGIAR Research Program MAIZE

Chapter 1

Quantification of climate-smart agriculture technologies in Malawi

Isaiah Nyagumbo, Munyaradzi Mutenje, Blessings Mwale and Peter Setimela

1. Introduction

Climate-smart agriculture (CSA) relates to agricultural practices and approaches hinged on three overlapping pillars or components i.e. improved productivity, adaptation and mitigation of climate change (Figure 1). CSA (https://ccafs.cgiar.org/climate-smart-agriculture-0#.WJ_L4E27ocM) is defined as an integrative approach that addresses the interlinked challenges of food security and climate change, and explicitly aim at the three objectives:

1. sustainably increasing agricultural productivity, to support equitable increases in farm incomes, food security and development;
2. adapting and building resilience of agricultural and food security systems to climate change at multiple levels; and
3. reducing greenhouse gas emissions from agriculture (including crops, livestock and fisheries).

A wide range of crop and livestock practices can contribute to these three CSA pillars and include practices or technologies such as such as agroforestry or fertilizer tree systems, conservation agriculture,

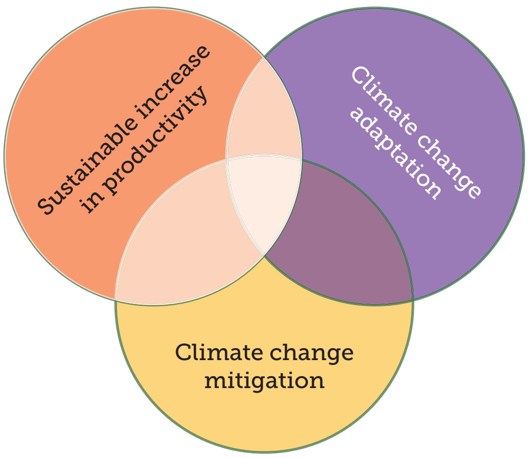

Figure 1. Climate-Smart Agriculture components

drought tolerant germplasm, intercropping, tree fallows, water harvesting and irrigation technologies. These practices all aim at increasing productivity and incomes of smallholder farming systems and address the adaptation and mitigation components to varying extents (Descheemaeker et al., 2016; Steward et al., 2018). Conservation Agriculture (Kassam et al., 2009), is one such practice that has received considerable research attention as a climate smart technology in Malawi in the last two decades. However, many other practices such as Farmer Managed Natural Regeneration that seek to reverse the widespread vegetation degradation have also been recently the focus of research. Agroforestry has been one of the common CSA practices in Malawi. The high cost of mineral fertilizers in cropping systems have also necessitated the widespread use of nitrogen fixing legumes and organic manures (composts) as strategies for alleviating nutrient deficits in cropping systems. Using agroforestry technologies can help to maintain soil cover, improve nutrient levels, increase soil organic matter, water infiltration, and provides a secondary source of food, fodder, fibre and fuel.

The Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project was designed as the flagship implementation vehicle for the Enhancing Capacity for Low Emission Development Strategies (EC-LEDS) partnership between the United States Government (USG) and the Government of Malawi (GoM), and as a core component of environment programming under USAID/Malawi's Development Objective Assistance Agreement with the GoM. The main goal for PERFORM's five-year engagement was to make a lasting improvement in Malawian quality of life. To do that, PERFORM aligned with Malawi's Growth and Development Strategy to promote forest conservation and green growth

In line with this purpose, prioritized intervention activities in Machinga district and in communities around Liwonde included forest restoration, Climate-Smart Agriculture, Intensification (more output per unit area), low-cost irrigation systems where applicable and soil fertility-enhancing measures, diversified farming systems, and improved access to quality planting material and seeds. These technologies implemented as pilot activities, were also envisaged to contribute towards national efforts for reducing emissions from deforestation and degradation (REDD+) readiness under the United Nations Framework Convention on Climate Change.

CIMMYT, and many other partners have been implementing CA as one of CSA practices in Malawi for many years. Most of these studies however assessed the performance of CA technologies when implemented as trials or field experiments and not when farmers implemented these technologies on their own. Under the PERFORM project, farmers were recommended to try out new improved drought and heat stress tolerant maize varieties as part of the suite of CSA technologies. The high cost of mineral fertilizers also necessitated the use of a local fertilizer innovation involving the combination of organic manures and conventional mineral inorganic NPK and Urea fertilizers to produce a popular fertilizer known as "MBEYA". This "MBEYA" fertilizer was considered by farmers as a very useful fertilizer enabling more efficient use of limited quantities of mineral fertilizers. Not much is available from literature on this technology despite its popularity.

The use of pigeonpea as an intercrop in maize systems is also increasingly seen as an important climate smart and food security strategy. This arises from the fact that pigeonpea, being a deep rooted and high biomass producing legume, can generate significant soil cover levels during the cropping season after the maize has senesced and can relay well in maize systems and fix substantial amounts of nitrogen during the period (April-June) when the rainfall season is tailing off. Pigeonpea therefore makes a highly compatible intercrop in maize systems. Pigeonpea has also been promoted as an important cash crop that could potentially be used to generate income for the smallholders and improve their market participation. However, the pigeonpea export market in India collapsed in the last two years thereby leaving many farmers who produced this pulse crop somehow stranded with unsold grain stocks and no market. Yet the maize-pigeonpea intercrop system answers well to the CSA pillars as it could improve productivity and incomes, enhance adaptation and resilience through diversification and through high biomass production and it could contribute to the mitigation component. Following a reconnaissance visit to Machinga Agricultural Development Division (ADD) in September 2018 the CIMMYT team in collaboration with key stakeholders in the PERFORM project identified CA, pigeonpea intercropping and the MBEYA fertilization strategy as the most widely used CSA rainfed cropping technologies in communities around the Liwonde Forest Reserve.

To assess climate smartness, relevant key indicators are often used to evaluate the contribution of such technologies to the three CSA pillars. For example, yield income and food security can be used as proxies for sustainable productivity while a range of soil quality indicators such as microbial activity, soil organic carbon, water infiltration, soil loss, nitrogen content, pH and other soil chemical properties are used to assess resilience attributes of the CSA practice. For mitigation, measures such as the greenhouse gases emissions (CO_2, CH_4 fluxes), above ground biomass, total soil carbon (t/ha) and fuelwood consumption are often used.

Measurement of biomass inputs in cropping systems for example, is important for the purpose of understanding annual carbon injection and thus a good indice for above ground biomass production. In CA systems, provision of residue cover usually derived from crop biomass inputs, is important and one of the three key principles of CA. FAO recommends that farmers have at least 30% residue cover at the time of seeding but most farmers in Southern Africa hardly meet this limit due to competing uses of the residues as livestock feed, fuel and other uses (Valbuena et al., 2012). Residue cover also plays an important role in reducing rainfall erosivity as the energy of rain drops is attenuated by the presence of residues on the surface. Residue cover and water infiltration rate related parameters could thus be used as indicators for resilience of CSA systems.

The objective of this study was therefore to quantify the costs and benefits of three CSA cropping practices in Machinga district with respect to productivity, adaptation and mitigation indicators among farmers voluntarily employing these technologies. Specifically, the study evaluated the following attributes as CSA performance indicators:

- Assess the annual biomass, residue cover and water infiltration capacities as proxies for mitigation and resilience
- Assess soil quality changes with respect to soil physical and chemical properties of fields under CSA practices
- Assess the yield merits of implemented CSA practices relative to conventional farmer practices as proxies for productivity assessments
- Establish if the measured soil quality and yield merits are influenced by household socioconomic characteristics of targeted households.

1 Mbeya manure constitute a mixture of 10 kg of inorganic fertilizer and 20 kg of livestock manure (goat or chicken pass-on or cattle manure)+ 5 kg of ash (well sieved) + 15 kg of maize bran locally known as madeya. After thoroughly mixing these constituents, approximately 20 litres of water is sprayed to the mixture using a watering can. The wet mixture is then wrapped in plastic for decomposition and matures within 3 weeks.

2. Materials and Methods

2.1. Sampled communities

Five communities in which the PERFORM project had been implemented since 2014, were selected for in-depth studies on biophysical parameters. The five communities were Lower Ntubwi, Mbonechera, Upper Ntubwi, Domasi and Nsanama. It is noteworthy that Nsanama was only sampled for the yield assessments. Farmers using CA, pigeon pea intercrops and the MBEYA fertilization strategy were selected for in-depth studies with the help of local field officers and lead farmers. On every farm, a field with the targeted technology was identified for sampling while another control field without the technology was also identified within the same farm (Table 1). Special considerations were given to allow for equal sampling of fields in the high and low rainfall communities. Due to its widespread use, more farmers using CA were identified for sampling compared to those sampled for pigeonpea and MBEYA fertilization technologies. Other factors considered in sampling the study fields, were duration of implementing the technologies (2 years or less, or a longer period) and soil texture (light and heavy textured soils).

2.2. Annual biomass inputs residue cover and water infiltration assessments

2.2.1. Biomass Assessments

Measurement of biomass input in cropping systems is important for the purpose of understanding annual carbon injection as a measure or proxy of climate change mitigation. The amount of biomass available for incorporation into the soil or left on the soil surface as cover at the end of the dry winter season in southern Africa's cropping systems can be a good proxy to how much carbon is returned to the soil system annually leading to carbon sequestration (Govaerts et al., 2009; Kell, 2011; Lal, 2004; Palm et al., 2014). However, measuring biomass inputs may be a tedious exercise, therefore visual estimates of percentages of residue cover are often used in CA systems.

In this study, annual biomass inputs after the dry winter season were made by randomly placing a 0.70m*0.70m quadrant made of wood or wire on the ground and collecting all biomass at the surface into a khaki bag and weighing it using a precision scale. In each plot measurements were made three times thereby giving a total of six observations on each farm: 3 in the CSA technology and 3 in the conventional non-CSA technology. The dry residues were weighed and the type of residues available on the surface were also recorded. Because measurements were done after a prolonged hot and dry period, we assumed the residues were air dry.

2.2.2. Residue cover percentages

Similarly residue cover estimates were also made through visual observations in each plot and data recorded on a datasheet for each farm using the photo comparison method (Shelton et al., 1995) to estimate residue cover. By visually observing the ground and comparing it to the photos, percentage of residue cover for each quadrant was estimated.

2.2.3. Time to pond infiltration measurements

The time to pond technique is a quick and rapid but reliable technique for comparing water infiltration characteristics on cropping systems managed in different ways. With this technique differences in water infiltration patterns are evaluated by measuring the time taken for sprinkled water to flow out of a ring of about 50cm diameter. The device has a provision for measuring volume of water infiltrated and the time it takes for the applied infiltrating water to start flowing laterally and hit the ring. The amount of time this takes depends on how well water infiltrates into the soil. The longer this takes, the better. This technique was recently improved by agronomists at CIMMYT-Harare to reduce subjectivity of results caused by different water pouring intensities when different individuals use the technique. With the improved technique, water drops from a funnel which is a fixed distance from the ground across all measurements. In this study all measurements were conducted with the water delivery funnel set at 45 cm above ground and three runs were conducted per plot.

Table 1. Sampling of farmers for CA, pigeonpea and Mbeya fertilization CSA technologies in Machinga district, Malawi.

Community name	Lower Ntubwi	Mbonechera	Upper Ntubwi	Domasi	Total farms or farmers	Total samples or points
Agro-ecology	*Low rainfall*	*Low rainfall*	*High rainfall*	*High rainfall*		
1. CA systems	**16**	**16**	**16**	**16**	**64**	128
2. Pigeonpea systems	**6**	**6**	**6**	**6**	**24**	48
3. Mbeya strategy	**6**	**6**	**6**	**6**	**24**	48
Total farms					**112 farms**	
Total samples or points						224

Some simple household data from each farm including soil type and household size, were collected for each of the three focal technologies: CA, pigeon pea and the Mbeya Fertilization technology.

2.3. Soil Quality assessments for CSA resilience

Composite soil samples were collected from the top 20 cm of each of the two fields on each farm. Samples were randomly collected with a shovel on at least 10 random but evenly distributed positions on each field and then mixed up to make one composite sample per cropping system on each farm. Collected samples were air dried and then sent to Bvumbwe Agricultural Research Station laboratory for analysis. Standard laboratory procedures were used to analyse for soil physical properties such as texture. Similarly, standard procedures were used for the analysis of soil chemical properties such as pH, N, P, K, %OC, %SOC, POMP and others.

2.4. Assessing maize productivity of CSA practices in Machinga

Yield assessments were carried out at the end of the 2018/19 season including some on farms where previous data was collected on water infiltration and for which laboratory soil analysis had been carried out in Oct and Nov 2018. Maize yields were physically measured on farmers' fields where CA, MBEYA and Pigeonpea technologies had been employed and measurements were made on both the CSA and the control non-CSA technology fields within the same farm. A total of 64 farmers (Table 2) were sampled for the yield assessments despite the initial target of 80 as some of the farmers harvested their fields before arrival of the yield assessment team. A list of farmers from the initial soil sampling was used for the selections in each of the five communities. For each farm and in each of the two fields on each farm, 4 checkplots (5m*4 rows) for crop cuts were randomly chosen in the CSA intervention plot and on the non-CSA intervention plots close by and within the same farm (Figure 2).

2.5. Statistical analysis

Annual biomass, residue cover and water infiltration data (time to pond and water intake) were assembled for each of the farmers and analysed using t-tests for comparison of means comparing CSA and the corresponding control non-CSA technology for the CA, pigeonpea intercrops and Mbeya fertilization strategy. To analyse the contribution of factors such as agro-ecology, soil texture and associated basic socioeconomic attributes for each farm, a Linear Model in R-stats was applied since the distribution of these factors was unbalanced for each community. Similarly soil chemical and yield data were subjected to analyses using the same models as above. Since there was no measured rainfall data for the sites, gridded rainfall data from NASA (https://power.larc.nasa.gov/data) were used for sites that had GPS coordinates for a 30 year period up to 2018/19. Cumulative seasonal rainfall data for the 30 years were used to compute a normal rainfall mean for the area. Using this mean a t-test comparing the season 2018/19 total rainfall from the known 30 yr. mean was used to establish if the last season 2018/19 had significantly deviated from the mean. Finally, the analysis combined socioeconomic attributes to yield attributes to test if there are any socioeconomic variables that were associated with the observed yields and their differences relative to the conventional farmer practices

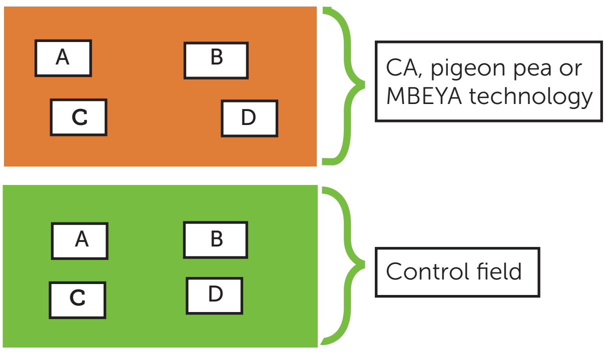

Figure 2. **Schematic diagram of a typical layout of harvesting checkplots (ABCD) in a technology treated and a control field on a farm.**

Table 2. **Farms sampled for yield assessments disaggregated by technology and site in Machinga district, Malawi in April 2019.**

Community Name	Lower Ntubwi	Mbonechera	Upper Ntubwi	Domasi/ Mposa	Nsanama	Total farms or farmers
Agro-ecology	*Low rainfall*		*High rainfall*			
Sampled CA farmers	7	12	10	7		36
Sampled pigeonpea intercrop farms	4	4	2	4		14
Mbeya strategy farms	1	3	5	4		19
Total farms						**64 farms**

3. Results

3.1. Annual biomass inputs, residue cover and infiltration characteristics

Results from the studies show that the average annual biomass inputs from the CSA cropping systems amounted to 3,400, 2,900 and 3,800 kg/ha for CA, MBEYA fertilization strategy and pigeonpea intercrops, respectively (Figure 3.1 a). There were no significant differences between the annual biomass inputs in the CA and MBEYA systems compared to conventional practices. However, the pigeonpea intercrops showed significantly higher biomasses and better infiltration (higher *time-to-pond*) compared to conventional monocrop systems (Figure 3.1 b). Although positive, differences between CSA and non-CSA technologies in residue cover, and water intake were mostly not significant.

The results therefore suggest that the pigeonpea systems which had high biomass inputs also contributed to the better water infiltration as reflected in the higher time to pond (Figure 3.1. b).

3.2. Soil quality characteristics

T-test results analysing the different soil quality attributes are presented in Table 3.1. CA showed relatively better and statistically significant ($P<0.05$) soil quality attributes except for soil pH. In comparison to the conventional cropping systems, the increases varied between 39 and 201% (Table 3.1). Thus both easily degradable and protected particulate organic matter (POMR and POMP) were much higher in CA compared to conventional farmer practices and increased by 195 and 201%, respectively. Consequently, the soil organic carbon measured in the top 20cm of the soil averaged 0.71% for conventional practices compared to 1.06% under CA giving a net increase of 48%. With respect to compaction and bulk density, CA also portrayed more positive attributes with significantly higher ($P<0.0001$) compaction and bulk density being measured on conventional farmer practices compared to CA. Thus, CA had lower bulk densities of 1,280 compared to 1,330kg/m^3 under the conventional practices. No significant differences were however observed in soil pH.

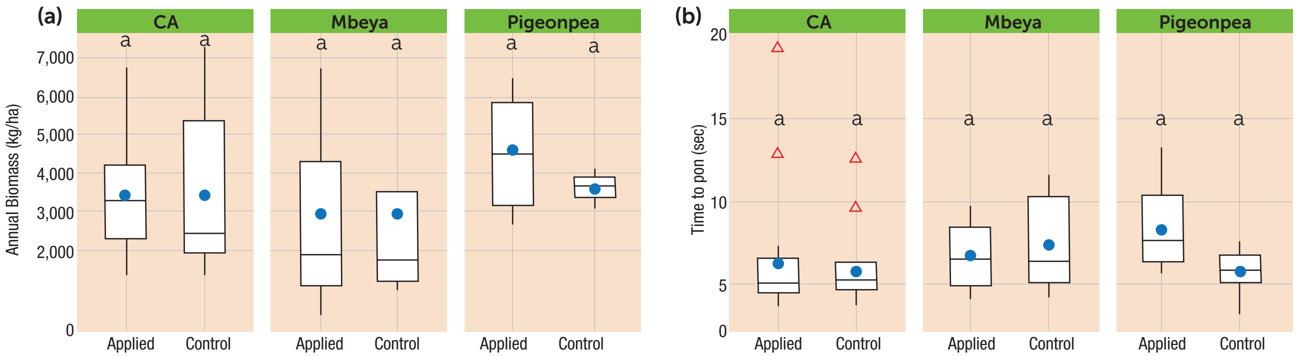

Figure 3.1. (a) Annual biomass inputs and (b) Time to pond (sec) measured across three CSA practices (CA, MBEYA and Pigeonpea intercrops) in Machinga district, October 2018.

N. B. Blue circles inside boxes represent means; Black horizontal bar in the middle of each box represents the median. Upper and lower ends of each box represent 75% of the upper and lower quartiles. For each CSA system different letters above bars indicate significant differences between respective cropping systems at P<0.05.

Table 3.1. Means of various soil quality attributes measured from farmer-managed systems under conventional ridge/furrow farmer practice and CA in Machinga district, Malawi, October 2018.

	N	Conventional	CA	Relative CA Advantage (%)	p-value from t-test	Sig.
pH	25	5.91	5.91	0	0.988	n.s
POMR (g/kg)	25	51.15	150.65	195	0.015	**
POMP (g/kg)	25	31.95	96.31	201	0.003	***
Mg (cmol/kg)	25	0.15	0.26	70	0.014	***
Ca (cmol/kg)	25	1.97	4.24	115	0.014	**
K (cmol/kg)	25	0.06	0.09	39	0.026	*
P (ppm)	25	42.41	59.21	40	0.090	.
N (%)	25	0.06	0.09	44	0.010	**
OC (%)	25	0.71	1.06	48	0.001	***
OM (%)	25	1.23	1.82	48	0.059	.
Compaction (kg/cm^2)	25	2.70	1.84	-32	0.000	***
Bulk Density (g/cm^3)	25	1.44	1.34	-7	0.000	***

Note: CA= conservation agriculture; POMR= Easily degradable particulate organic matter content (%); POMP= Particulate Organic Matter protected by soil aggregates (%)

Similarly, the MBEYA fertilization strategy also had positive and better soil quality characteristics than conventional till with organic carbon increasing from 1.07% to 1.58% (Table 3.2). The highest relative advantages were noted under the POMR (141%) and POMP (164%) The MBEYA fertilization strategy thus contributed to improved soil organic carbon status and better soil nutrient characteristics. The strategy was thus contributing to improved soil fertility despite the challenges of preparing this organic fertilizer. Differences in soil pH were also not significant as for the CA systems.

Pigeonpea systems also had significant positive increases on organic carbon (OC) (42%), Particulate organic matter POMR (167%), POMP (120%), Magnesium (54%), Ca (98%), Potassium (74%), Phosphorus (49%) and Nitrogen (26%) compared to conventional monocrops while differences in soil pH were not apparent (Table 3.3). Thus, in general the pigeonpea intercrop systems brought about significant improvements in soil quality attributes.

With respect to the pigeonpea systems, soil pH remained insignificant when comparing mono and intercropped systems. However, all other soil attributes for pigeonpea intercrops were more positive than for maize monocropping as most of the differences were positive and significant ($p<0.05$). Bulk density differences were also not significant but there was significantly less compaction in the pigeonpea intercrop fields compared to the mono-cropped ones. Thus in general the pigeonpea intercrop system brought about significant improvements in soil quality attributes.

Table 3.2. Means of various soil quality attributes measured from farmer managed systems under normal conventional fertility management and the MBEYA fertilization strategy in Machinga district Malawi, October 2018.

	N	Mbeya		Relative CA advantage (%)	p-value from t-test	Sig.
		Non-Mbeya	Mbeya			
pH	14	6.12	6.10	0	0.767	n.s
POMR (g/kg)	14	59.0	141.9	141	0.001	***
POMP (g/kg)	14	37.6	99.1	164	0.003	***
Mg (cmol/kg)	14	0.20	0.33	65	0.004	***
Ca (cmol/kg)	14	2.87	5.21	82	0.031	**
K (cmol/kg)	14	0.08	0.13	63	0.001	***
P (ppm)	14	45.55	58.86	29	0.020	**
N (%)	14	0.10	0.13	30	0.059	*
OC (%)	14	1.07	1.58	48	0.016	**
OM (%)	14	1.85	2.73	48	0.016	**
Compaction (kg/cm^2)	14	2.33	1.83	-21	0.001	***
Bulk Density (g/cm^3)	14	1.33	1.28	-4	0.299	n.s

Note: MBEYA = a locally developed organic and inorganic fertilizer formulation used as basal fertilizer; POMR = Easily degradable particulate organic matter content (g/kg) POMP= Particulate Organic Matter protected by soil aggregates (g/kg).

Table 3.3. Means of various soil quality attributes measured from farmer managed systems under normal conventional mono-cropped maize versus maize intercropped with pigeonpeas in Machinga district Malawi, October 2018.

	N	Maize-pigeonpea systems		Relative intercrop Advantage (%)	p-value from t-test	Sig.
		Maize Monocrop	Pigeonpea Intercrop			
pH	14	6.03	6.09	1	0.253	n. s
POMR (g/kg)	14	55.96	149.40	167	0.023	**
POMP (g/kg)	14	37.64	82.73	120	0.002	***
Mg (cmol/kg)	14	0.18	0.27	54	0.006	***
Ca (cmol/kg)	14	2.06	4.08	98	0.001	***
K (cmol/kg)	14	0.06	0.11	74	0.000	***
P (ppm)	14	30.35	45.13	49	0.001	***
N (%)	14	0.08	0.11	26	0.046	*
OC (%)	14	0.93	1.32	42	0.001	***
OM (%)	14	1.60	2.27	41	0.001	***
Compaction (kg/cm^2)	14	2.36	1.62	-31	0.003	***
Bulk Density (g/cm^3)	14	1.38	1.37	-1	0.868	n.s

Note: POMR= Easily degradable particulate organic matter content (g/kg) POMP= Particulate Organic Matter protected by soil aggregates (g/kg).

Overall, across all the practices (CA, Mbeya and pigeon pea) soil pH was the same and didn't show an improvement as their relative advantages were not significant at P< 0.05. The most significant relative advantages were observed under POMR and POMP across all the systems. Most of the soil chemical attributes proved to better under the climate-smart agriculture practice as compared to the conventional practice. Overall the results suggest the three CSA systems contribute 4.2, 6.0 and 5.3 tC/ha from the CA, MBEYA and pigeonpea intercrops systems, respectively (Table 3.4).

3.3. Rainfall Analysis and maize yield responses to CSA interventions in 2018/19

The average 30-year total annual rainfall for the five communities amounted to 1,160 mm versus 1,593 mm received in the 2018/19 season in which yields were assessed (Figure 4). Statistical analyses suggested the 2018/19 season was significantly wetter than the normal average for the area. Out of this the rainfall analysis suggested that the in-crop rainfall total (Nov.-April) amounted to 1,076 mm versus 1,522 mm received in 2018/19. The major differences arose from the floods brought about by Cyclone Idai during which some 470mm were received in March. Thus the season did not suffer from any serious moisture deficits for crops since there was excessive rainfall compared to the normal. By comparing the season onset to the reported dates of planting by the farmers, no delays in planting dates were apparent and hence farmers efficiently utilized the first opportunity availed by the rains to plant their crops.

The three CSA systems combined, significantly improved maize yields as shown in the box plots (Figure 5.1, p.8) compared to the conventional farmer practices. Climate-smart agriculture technologies had average maize grain yields of 3,834 kg/ha as compared to the conventional practice with a mean of 2,916 kg/ha. When compared across agro-ecologies (high and low rainfall areas), results showed the same general pattern with CSA performing better than conventional.

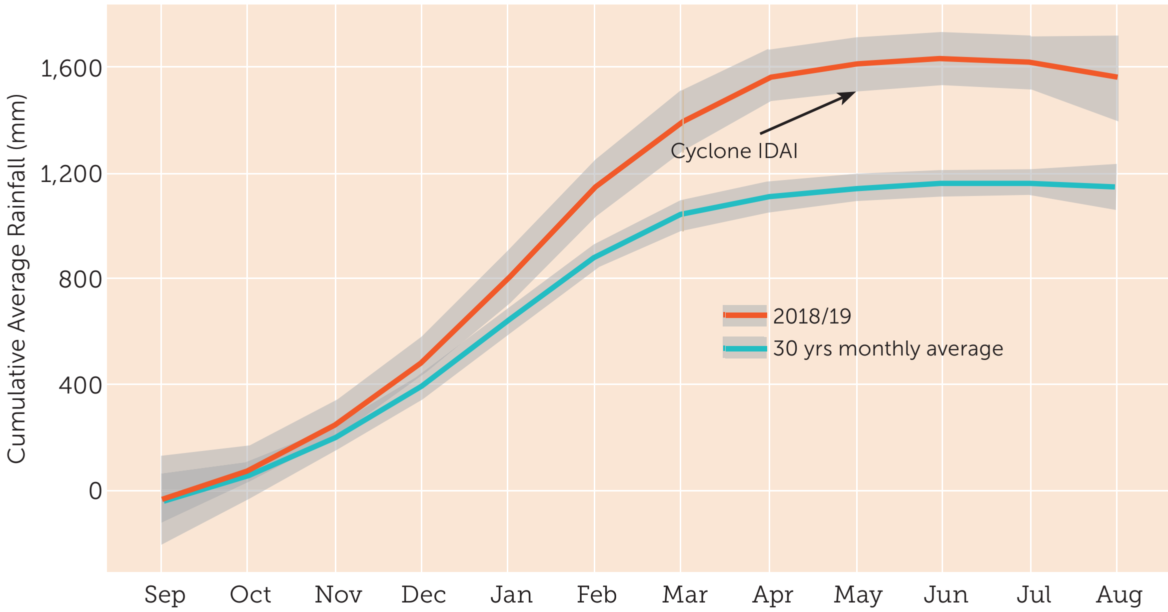

Figure 4. Mean cumulative seasonal rainfall distribution over a 30yr period for PERFORM sites in Machinga district in comparison to season 2018/19.

Note: shaded areas denote +/- 95% confidence intervals for the 30yr period and for the2018/19 season, respectively.

Table 3.4. Soil organic carbon in the studied CSA systems and the potential organic carbon contribution.

Cropping Systems	CSA *g C/kg*	Control *g C/kg*	Increase *g C/kg*	CSA *tC/kg*	Control *tC/kg*	Increase *tC/kg*	Average annual biomass input *kg/ha/annum*
CA	10.6	7.6	3.0	15.2	10.9	**4.2**	3,400.0
Mbeya fertilization	15.8	10.7	5.1	20.2	14.2	**6.0**	2,900.0
Pigeonpea intercrops	13.2	9.3	3.9	18.1	12.8	**5.3**	3,800.0

The CSA systems had a mean of 3,965 compared to 3,049 kg/ha under conventional in high rainfall areas while in the low rainfall areas CSA had a mean of 3,595 kg/ha compared to 2,675 kg/ha in low rainfall areas. The results provided solid evidence that CSA increased yields compared to the conventional system (farmer practice) at least in the 2018/19 season, a result that echoes well with sentiments expressed by farmers.

On separating and analysing the three CSA systems (CA, MBEYA and pigeonpea intercrops), the yield responses under the three practices i.e. CA, Mbeya and pigeonpea intercrops are shown in Figure 5.2. From this, the CA practice performed significantly better (P=0.016) with a mean maize yield of 4,106 kg/ha compared to the conventional with a mean of 2,713 kg/ha equivalent to 51% increase. Similarly, the Mbeya fertilization strategy also increased mean maize yields by 19% compared to the normal conventional fertilization (non-Mbeya) at 4,535 compared to 3,793 kg/ha, respectively but the differences were statistically not significant (p=0.571). Maize yields in the pigeonpea intercrop system were insignificantly higher than that from the monocrop maize (p=0.735) at a mean of 3,047 versus 2,802 kg/ha, respectively, a 9% increase. The positive yield responses from CA are attributed to the improved soil quality characteristics observed under CA which included better organic carbon, higher nutrient content (N, P, K) and lower bulk densities.

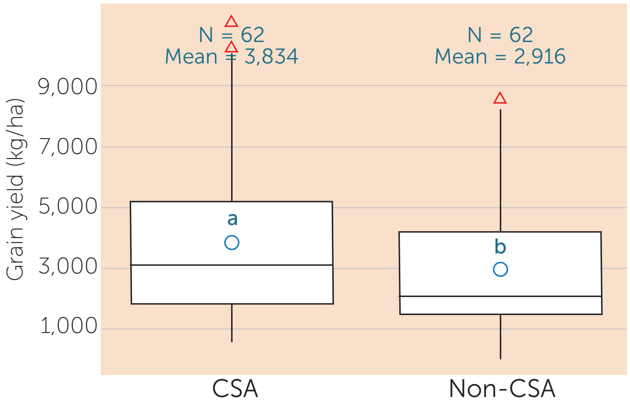

Figure 5.1. **Maize yield responses to CSA and Conventional cropping systems as practised by farmers in 2018/19 in five communities of Machinga district. Note: Minimum Significant Difference: 406 kg/ha.**

N. B. Blue circles inside boxes represent means; Black horizontal bar in the middle of each box represents the median. Upper and lower ends of each box represent 75% of the upper and lower quartiles. For each CSA system different letters above bars indicate significant differences between respective cropping systems at P<0.05.

3.4. Agronomic practices: varieties, residue application, planting density and weeding effects.

Across the three CSA systems, key agronomic factors that significantly ($p<0.05$) influenced yield included residue application (Figure 5.3.), plant population (Figure 5.3.) and number of weeding (Figure 5.4.) carried out per season. Plant population had a significant and positive linear regression effect on maize yield ($P<0.0000$); $R^2=0.144$ with peak yields at about 44,000 plants per ha (Figure 5.3). Low yields were mostly associated with low plant populations.

Weeding was an important and significant factor influencing yields in CA systems where the number of weeding cycles per season significantly correlated to maize grain yield. Yield penalties were evident from not weeding at all while weeding two or three times, resulted in improved yields. The majority of farmers weeded their crop twice per season. On average under CA, returns to weeding amounted to 1,098 kg/ha/weeding run thereby suggesting that investments in weeding by farmers could give them labor investments returns of at least 1 tonne of grain for every weeding run (Figure 5.4).

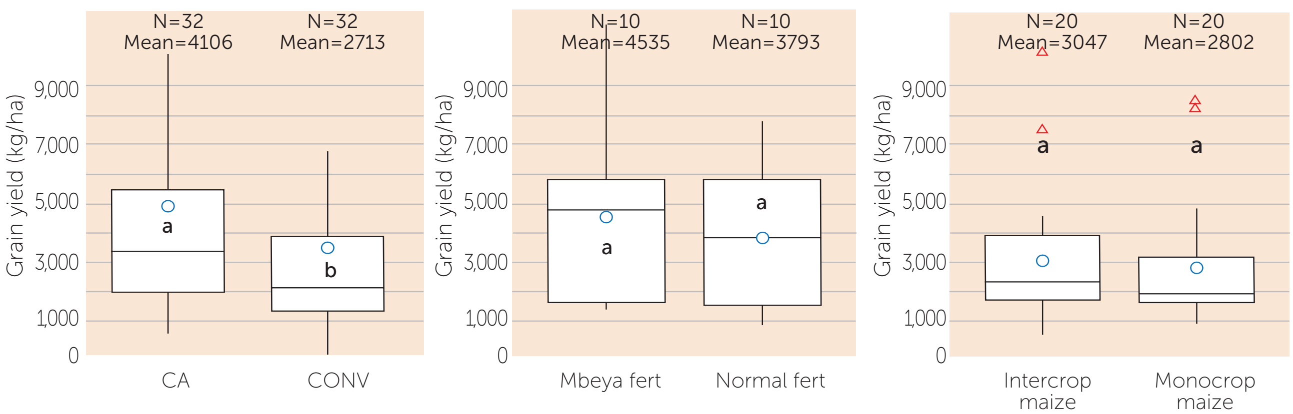

Figure 5.2. **Maize yield responses to CA, Mbeya fertilization and pigeonpea intercrop systems as practised by farmers in 2018/19 in five communities of Machinga district.**

Note: Blue circles inside boxes represent means; Black horizontal bar in the middle of each box represents the median. Upper and lower ends of each box represent 75% of the upper and lower quartiles. For each CSA system different letters above bars indicate significant differences between respective cropping systems at P<0.05; LSD (0.05)CA= 1,122 kg/ha LSD(0.05) Mbeya=2,701 kg/ha; LSD (0.05) Intercrop= 1,451 kg/ha.

Farmers were found to be growing varieties from more than 20 different seed companies. These varieties included drought tolerant and non-drought tolerant ones (Figure 5.5). The most widely grown varieties were DKC8033, MH33 and SC627 from three different companies. Figure 5.5 shows that newly released variety like Peacock-10, ZM523, MH26 are slowly penetrating the market compared to DKC 8033 which has been on the market for more than 10 years. PERFORM in collaboration with the USAID-funded MISST project had for the past 3 seasons demonstrated these different DTM varieties and it is pleasing to see a number of farmers now taking up these varieties. It is important for farmers to replace old varieties with new improved ones which are more tolerant to diseases and climate change.

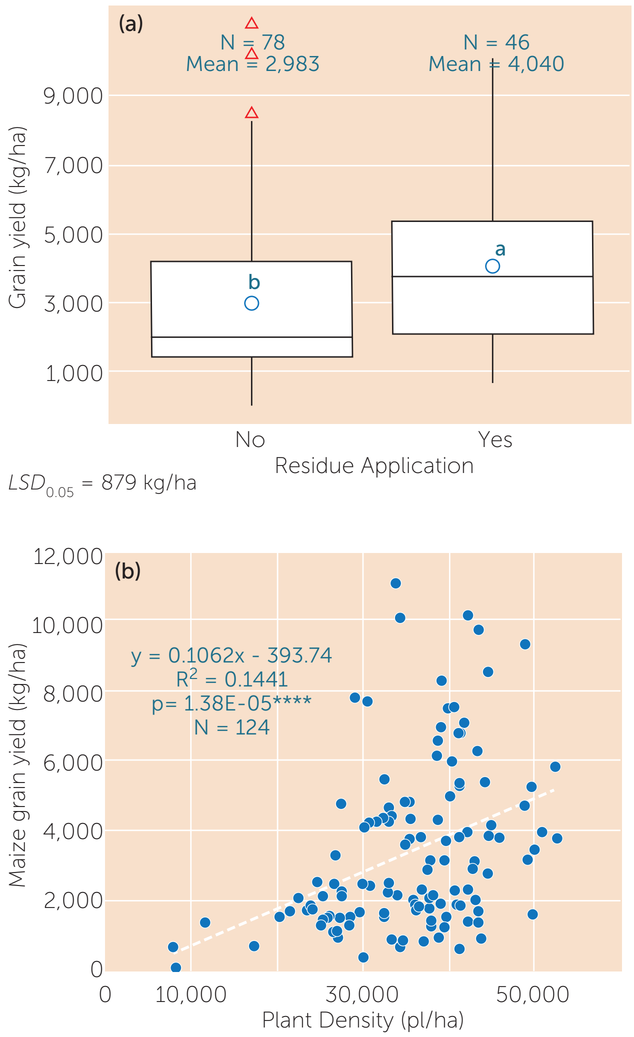

Figure 5.3. Effect of (a) residue application and (b) planting density on subsequent maize yields in CSA cropping systems in Machinga district, Malawi, in the 2018/19 season.

N. B. Blue circles inside boxes represent means; Black horizontal bar in the middle of each box represents the median. Upper and lower ends of each box represent 75% of the upper and lower quartiles. Different letters above bars indicate significant differences between respective practices at P<0.05.

3.5. Contribution of socioeconomic factors

Yield performance was also evaluated based on sex of the household head. Results generally suggested male-headed households had higher yields compared to female-headed ones. Chi-square analysis also suggested a significant positive association between resource endowment and maturity of CSA implementation (p=0.013). Experience in CA was categorised into two major groups namely, junior and

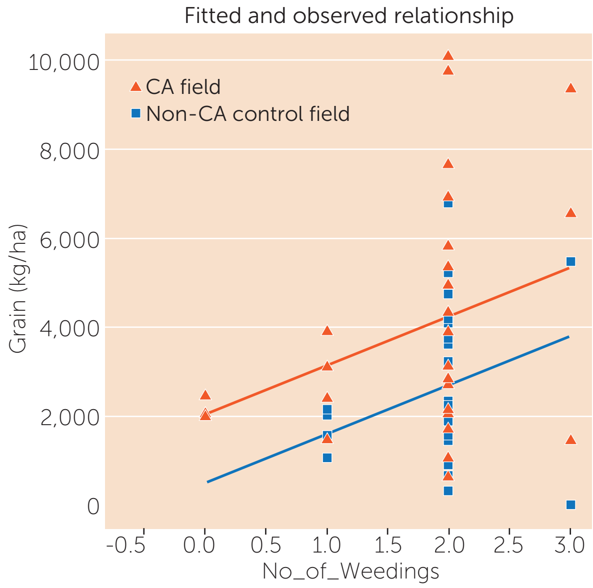

Figure 5.4. Maize yield responses to number of weeding per season under CA and conventional cropping systems in Machinga district in 2018/19 season.

Note: Linear regression significant at p=0.013; Yield (CA)= 2063+1098x; Yield (Conv)= 513+1098x where x= no of weeding; Variance accounted for (R2) =15.8% (0.158); r= 0.4

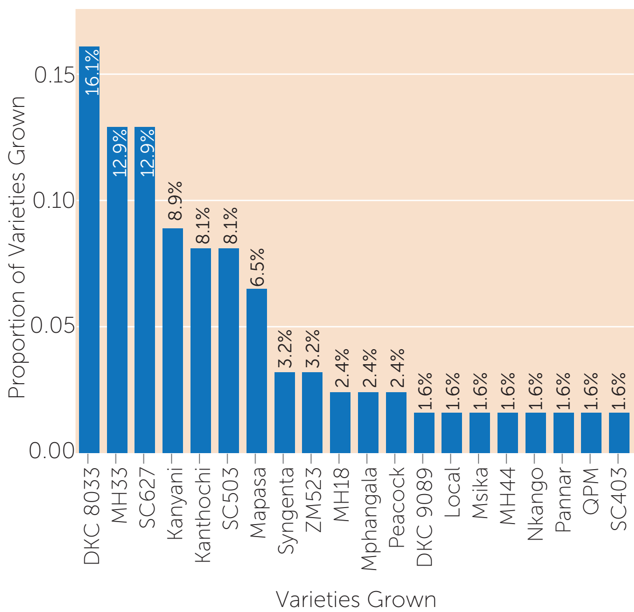

Figure 5.5. Proportion of different maize varieties grown by farmers in Machinga district in 2018/19.

mature. Most of the farmers (out of a total of 19) who were mature in practicing CA technologies, were also relatively wealthy while the junior CA implementers were mostly resource constrained (Table 3.5). However, results also showed no special correlations or associations between annual biomass inputs, time to pond and water intake characteristics and resource endowment or wealth status of households.

Table 3.5. Chi-square association between Experience in CA and wealth status of a subset of sampled households.

Experience in CA	Endowed	Medium	Constrained	Total
Junior (0-2 yrs.)	**2** *(11%)*	**2** *(11%)*	**10** *(53%)*	**14** *(74%)*
Mature (3yrs +++)	**4** *(21%)*	**1** *(5%)*	**0** *(0%)*	**5** *(26%)*
Total	**6** *(32%)*	**3** *(16%)*	**10** *(53%)*	**19** *(100%)*
Chi-squared = 8.6857, df = 2, p-value = 0.013				

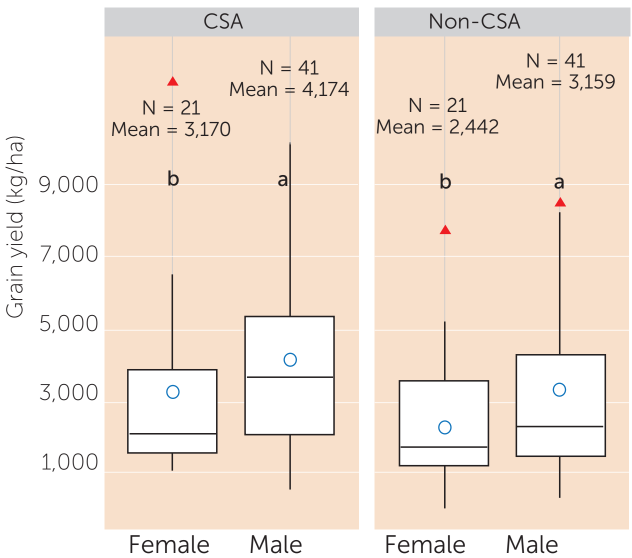

Figure 5.6. Maize grain yields from CSA and non-CSA technologies by sex of household head in Machida district in 2018/19 season.

N. B. Blue circles inside boxes represent means; Black horizontal bar in the middle of each box represents the median. Upper and lower ends of each box represent 75% of the upper and lower quartiles. For each CSA system different letters above bars indicate significant differences between respective cropping systems at P<0.05.

4. General Discussion

The findings of this study align well with other previous studies on CSA which have shown that such technologies make significant contributions to productivity and resilience pillars of CSA (Steward et al., 2018). For example, studies in the Southern Africa region have shown that technologies such as CSA result in yield increments of up to 50% (Nyagumbo, et al., 2016). In this study where farmers implemented the technologies on their own and not as trials or experiments, the results give a close reflection of practical realities of possible achievements when farmers implement these technologies on their own. The conclusively positive soil quality benefits suggest that these CSA technologies have long term impacts on resilience and hence yield outcomes (Michler, 2015; Pittelkow et al., 2015). Some of the sampled farmers had implemented CSA technologies for more than six years and hence the positive soil health attributes measured. Yet the technologies don't seem to have any apparent effects on pH (Bayala et al., 2012; Bai et al., 2018).

The yield increases observed from CA systems in this study amounted to 51% compared to conventional farmer practices and clearly show the extent to which CA practices can potentially help to address food security challenges and resilience of farmers. The newly introduced local MBEYA fertilization innovation resulted in 19% yield increases but due to a small sample size (14 farms) the differences were not significant statistically. This suggests there is need to look more elaborately into this technology and properly evaluate its potential crop yield benefits. Not much information was available from literature on this technology. The modest yield increases (9%) from the intercrop systems also generally agree with many other findings on intercropped maize in the region which show that maize yield tends to get depressed in intercropped systems ((Bahareh et al., 2009; Ngwira et al., 2012; Rusinamhodzi et al., 2017, 2012; Nyagumbo et al., 2016). However, the combined benefit of this intercropping practice lies in the additional legume output that also enables farmers to diversify food and income sources and so the total output from this system is usually much higher than the monocrops. Furthermore, the measured enhanced annual biomass inputs, increased water infiltration characteristics and soil carbon and nutrient contents observed, all point towards a more sustainable, resilient and productive cropping system. However, a shortcoming of this study is that it only evaluated the performance of the CSA technologies with respect to their maize yield merits and did not measure legume yields from pigeonpea for example. Consequently, the full productivity benefits, particularly the diversification benefits, were not fully assessed in this maize yield assessment.

The results also suggest the need to address gender in-equalities as female-headed households were found to be less productive compared to the male-headed households across both CSA and non-CSA technologies while those with mature CA also turned out to be more resource endowed. We however could not establish the cause-effect relationship of this significant association to conclusively ascertain if use of the CSA technologies studied was singly responsible for the better resource endowment of those households.

5. Conclusion

The three CSA technologies evaluated in this study positively addressed the CSA pillars in different respects. With respect to productivity, CA (51%) and the MBEYA strategy (19%) resulted in higher maize yields and this could help to contribute to improved food security and livelihoods. Although pigeonpea intercrops did not improve maize yields compared to the monocrops, the total output from this system (maize + legume) would give the farmers higher benefits compared to the monocrop systems thereby leading to improved diversification of food sources for the households.

With respect to resilience and adaptation, the CSA technologies also resulted in better yields even in a season whose rainfall was way above the normal for this area. CSA systems thus helped farmers overcome the extreme weather conditions characterized by floods experienced in the 2018/19 season.
Results from the studies confirmed higher annual biomass inputs and improved water infiltration from the pigeonpea intercrops. Particulate organic matter, soil organic carbon, Ca, Mg, K, N and P, all significantly improved under the three CSA systems while the soil was also more friable under CSA as evidenced by the measured lower bulk densities on CSA systems.
With regards to climate change mitigation, the results obtained in this study suggest the CSA systems could lead to better sequestration of carbon as there was more organic carbon found in soils under CSA, let alone the higher biomass inputs annually from the pigeonpea systems.

6. Policy implications

Given that the CSA technologies assessed in this study were managed by farmers on their own without any external input resources, the results clearly show the superiority of CSA technologies in terms of improving the productivity of cropping systems towards enhanced food security by smallholders in a highly variable climate induced by climate change. Results show that crop fields using CA, MBEYA fertilization and pigeonpea intercrops were more productive and thus food secure than those under conventional tillage systems within the same households. The benefits of such CSA technology investments would naturally be synergized whenever farmers integrated different CSA component technologies into their systems. For example, use of CA, intercrops and MBEYA fertilization along with drought tolerant maize varieties could go a long way in enhancing productivity as compared to when these are applied in isolation.

Improved soil quality from CSA systems could also contribute to improved resilience and sustainability in the long run. The higher soil organic carbon in the CSA systems also suggests these systems have scope for mitigating against greenhouse gas emissions since more carbon in the system suggests a higher potential for carbon sequestration and hence improved mitigation.

The results from this study therefore suggest that the tested CSA practices effectively address two of the CSA pillars (productivity, resilience/adaptation) and to an unquantified extent, they also contribute to mitigation. Supportive policy environments are therefore required to incentivize smallholder farmers to take up and apply these CSA practices on a relatively larger scale for improved climate smartness. However further studies are required to establish the practical economic feasibility of these CSA innovations so as to further provide evidence-based recommendations on perceived macro-scale benefits of their use.

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Chapter 2

Assessment of climate-smart agricultural technologies in Machinga District of Malawi using PRA

Munyaradzi Mutenje, Peter Setimela, Isaiah Nyagumbo, Blessings Mwale

1. Introduction

Climate change and variability is increasingly constraining the ability of forest ecosystem services to sustain agricultural production and improve food security and incomes of smallholder farmers in Malawi (WFP, 2016; Kreft et al., 2016; Tesfaye et al., 2017). Smallholder farmers are the most vulnerable because of their high dependence on forest ecosystem services and their limited capacity to adapt to a changing climate (FAO, 2010; WFP, 2016; Tesfaye et al., 2017). Climate change and variability is one of the contemporary threats to the livelihoods of the forest fringe communities and its impacts will deepen food insecurity and poverty. Forest ecosystem services are of great importance in the landscapes and climate context, through regulating services such as biophysical processes that control climate, floods, diseases, air and water quality, and erosion; sustaining agriculture through nutrient cycling, providing energy resources and cultural, such as spiritual and recreational benefits. Empirical evidence elsewhere shows that poverty reduction, improved food security and health efforts may be unsustainable if most of the ecosystem services on which smallholders rely on continue to be degraded. IHDP emphasizes that continuous forest ecosystems system service degradation increases smallholder farmers' vulnerability to climate, economic and natural shocks. Moreover, preserved forest ecosystems contribute to climate resilience of agri-food systems (IHDP, 2005). Thus there is an increasing need to understand the link between climate change, forest ecosystem services and livelihoods of forest fringe communities. It is important to assess the vulnerability of forest ecosystem and smallholder farming systems to climate change variability as well as identify suites of adaptation options.

PERFORM Malawi has long recognized these problems and has been promoting an integrated technology package to communities around Liwonde forest reserve in Machinga district, southern Malawi. In 2014, PERFORM, with funding from USAID implemented a project to address key drivers of deforestation of the targeted pilot sites of Liwonde Forest Reserve, Ntchisi Forest and Reserve and Perekezi Forest Reserve through a range of interventions in three focal areas: a) Forest sector b) Rural energy and c) Agriculture. Among the interventions promoted included use of improved cook stoves (ICS); afforestation, natural regeneration of trees, village and individual managed woodlots and various agriculture intensification pathways, such as use Mbeya manure, conservation agriculture, promoting drought tolerant crops (different maize varieties, Orange Fleshed Sweet Potato (OFSP), Irish potato), irrigation with treadle pumps or river diversion, chicken pass-on scheme, and Village Savings and Loan (VSL) clubs. A greater part of the work was also to look at how to improve governance of the targeted forest reserve. All this aimed at preserving the forest ecosystem services of the targeted forest reserves. This project funded by USDA is a collaborative effort of PERFORM and CIMMYT to understand the vulnerabilities of these Liwonde forest fringe communities to climate change and assess the efficacy of suites of adaptation options promoted. The undertaking was also designed to understand the local institutions, market forces and policies driving Liwonde forest ecosystem services preservation.

The research hypothesis is that an integrated approach which enhances livelihoods and ecosystem resilience and strengthens forest governance, is practical option to address Liwonde forest deforestation.

1.1. Conceptual framework

The link between climate change, forest ecosystems and smallholder farming systems is complex and multifaceted, therefore can be most effectively examined by an integrated socio-ecological approach. This approach provides a holistic methodology to look at reducing vulnerability and increasing adaptation to climate change. Such an approach explicitly promotes multiple objectives linked to vulnerability reduction, sustainable forest ecosystem management, and strengthening livelihood strategies (Brooks et al. 2005). The three principles underlying this study are understanding a) the vulnerability of forest ecosystem services to climate and non-climate stresses, b) the vulnerability of the farming system due to the loss of forest ecosystem services they depend on and, c) the adaptive capacity of the socio-ecological system as a whole (Figure 1). Existing understanding of the link between climate change, forest ecosystem services and smallholder farming system remain weak (Carpenter et al. 2009). It limits our knowledge on how to enhance synergies and minimize trade-offs among forest ecosystem services and farming systems of forest-dependent communities (Bennett et al. 2009). This limitation has also driven researchers, development practitioners and policy makers to focus more on the safety net role of forest ecosystems. This safety net role represents a reactive measure to climate change and vulnerability for forest-dependent communities. This have led to an increase in investments, polices and institutions for tangible forest goods and services such as food, timber and fiber. As a result, the proactive role of forest ecosystems to climate change such as atmospheric carbon sequestration flood control, water regulation, combating desertification, and genetic resource preservation has taken a secondary role. These functions represent major adaptation assets in responding to climate change (Bennett et al. 2009). Another key aspect that this framework focuses on is how governance mechanisms influence the adaptive capacity of vulnerable forest-dependent farmers and communities.

In the context of climate change, vulnerability is a function of the character, magnitude and rate of climate variation to which smallholder farming systems and forest ecological systems are exposed, people's sensitivity and their adaptive capacity. Vulnerability is defined as "the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes" (IPCC, 2014; Parry et al. 2004). Vulnerability to climatic shocks is a multi-dimensional concept, encompassing bio-geophysical, economic, institutional and socio-cultural factors. Vulnerability is usually considered to be a function of a system's ability to cope with stress and shock. The assessment of vulnerability then includes a measure of exposure to the risk factors and sensitivity to these factors, together comprising the potential impact of such risks, and the capacity to manage and respond to those risks.

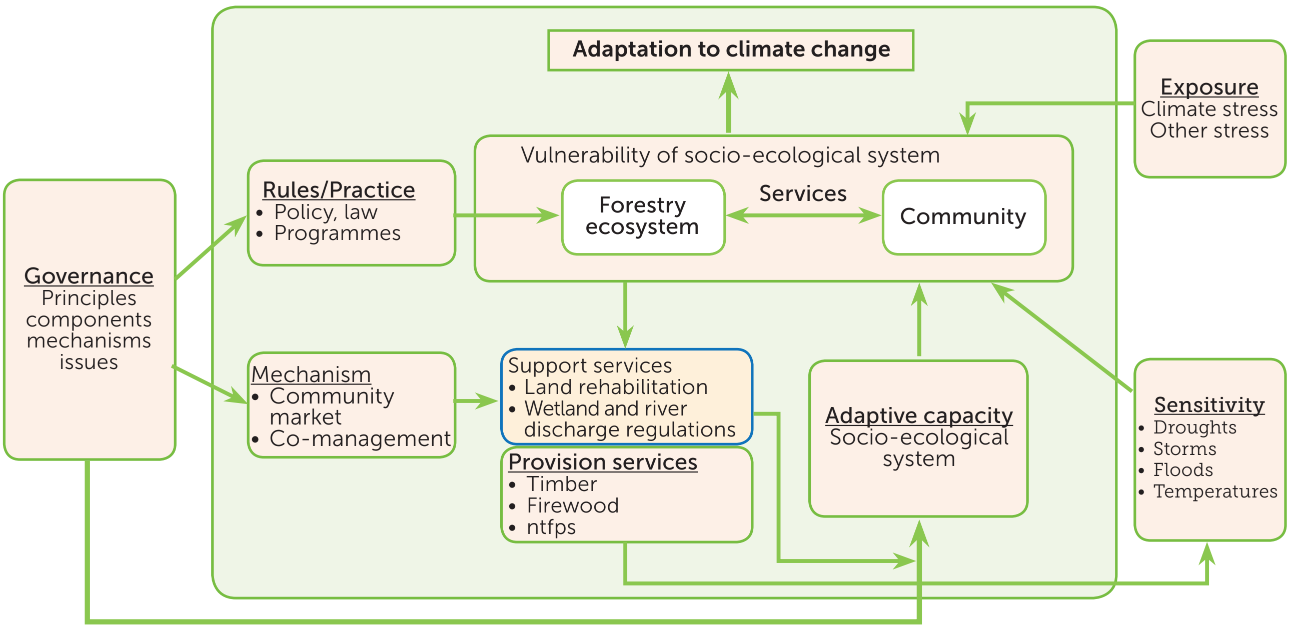

Figure 1. shows that the risks posed by climate change and extreme weather events are dependent on the interaction of climate-related hazards and sensitivity of both human and natural systems as well as their ability to adapt (Field et al., 2014).

2. Methodology

2.1. Study Site and data collection

This study draws from PRAs and semi-structured interviews conducted in October 2018 in four EPAs (Mbonechera, Ntubwi, Nsanama, and Domasi), surrounding Liwonde Forest Reserve in Machinga district. This was a pilot application of the National Forest Landscape Restoration Opportunities Assessment and Restoration Opportunities Assessment Methodology (ROAM) USAID/Malawi-funded Protecting Ecosystems and Restoring Forests in Malawi (PERFORM) project. These communities surrounding Liwonde Forest Reserve were selected for this pilot activity due to the scale of degradation and deforestation (PERFORM report, 2014). Secondly, Machinga is the second poorest district in Malawi, with 73% of the rural population below the national poverty datum line. Thirdly, Machinga is one of the districts where USAID fostered integration of activities by projects that benefited from US Government assistance.

Based on the geo-spatial analysis, observed successful restoration practices implemented by different stakeholders including international and non-governmental organisations and existing institutions and regulations governing sustainable use of forest resources, restoration opportunities in tandem with the communities to implement these were prioritised. The greatest restoration opportunities and proven practices were natural forest management, agricultural technologies (mainly conservation agriculture combined with drought tolerant crop species and varieties), and other agroforestry practices on cropland such as farmer-managed natural regeneration. Smaller opportunities to implement restoration through check dams and contour bunds for erosion control and water harvesting, assisted natural regeneration of degraded forests, promotion of village forests and woodlots, and tree planting and assisted regeneration along stream banks were also collaborated. Villages were purposively selected to represent forest management types, agricultural technologies and other small restoration practices implemented by the project.

In each EPA we undertook four focus group discussions with men and women who were actively engaged in at least three technologies promoted by PERFORM except for Mtubwi EPA were six focus group discussion were done due to difference in locations and livelihoods assets. Each focus group comprised 10–12 farmers in gender-separated groups. Village chiefs working together with lead farmers and local total land care officers selected the farmers.

2.2. Data collection

A mixed methods approach combining focus group based participatory appraisal tools and semi structured interview, was used to obtain a thorough understanding of the vulnerabilities of the Liwonde forest fringe communities to climate change and assess the efficacy of suites of adaptation options promoted (Marshall et al., 2016).

In this study we used a range of participatory appraisal assessment tools including: a) hazard and vulnerability mapping; b) vulnerability matrices; c) transact walk to understand evolution forest degradation; d) field profiles; e) seasonal calendars to understand how vulnerability is expressed at different times of the year; f) vulnerability matrices that link climate stressors or hazards with sensitivity of forest ecosystem and farming system; g) adaptation and livelihoods assets; h) wealth ranking; i) climate impact; j) key informant interviews (KIIs) with community traditional leaders, community organization representative and government official working in the agriculture, forestry and social welfare departments, livelihood portfolio evolution and household portfolio management; and k) village history.

At community level, FGDs and KIIs assessed farm-specific gender differentiated climate impacts and disaster risks including underlying causes, impacts on agricultural livelihood portfolios, and the activities and resources of women and men farmers. The objective of the FGDs was to assess the current and likely impacts of future climate change and identify experiences and adaptation capacities of women and men farmers in the face of climate hazards and extreme events. The FGDs used a mix of participatory techniques to collect risk and vulnerability data which include: a) participatory story-telling on farming activities, adaptation strategies, and women-led initiatives; b) matrix ranking to self-assess local climate hazards, extreme weather events, sensitivity and impacts; and c) community group presentations to analyze the key findings.

During the FGDs, men and women groups (with the assistance of researcher facilitators) developed risk assessment sheets describing the range of climate and extreme weather events and other non-climate calamities contributing socioeconomic risks to agricultural livelihoods described in the sustainable livelihoods framework (Chambers and Conway, 1992). The design of participatory model of vulnerability assessment at community level provided flexibility while comprehending farmers' and key informant perspective of vulnerability. Information from FGDs and key informant interviews were complemented with field observations, and secondary data on climate trends and hazards, sensitivity of the agriculture sector and household socioeconomic and vulnerability assessment obtained from different stakeholder organizations, consisting of published and unpublished assessment reports.

Qualitative data analysis was undertaken, using NVivo 10, via thematic analysis, where data are grouped into themes regarding the climate hazards and extreme weather risks/ impacts, socioeconomic risks to agricultural portfolios and adaptation strategies and technology trends. Coding was applied to all the transcripts at three levels: initial/open coding, focused coding and thematic coding as recommended by Strauss and Corbin, (1990). The transcribed interviews were coded line by line during the initial coding process and open coding continued until no further new codes emerged (QSR, 2012). At the second level, open codes were re-examined before developing themes in a third level of coding, following the adductive reasoning approach. Data obtained from matrix rankings were tabulated, mean values calculated. In examining the qualitative data, important timeline features were extracted and discussed in relation to the climate hazards and agricultural portfolios. The community-level risk and hazard specific data were triangulated with key informant interviews, secondary data from country level vulnerability assessments reports.

We carried out 102 individual semi-structured interviews with 44 men and 58 women from the four EPAs. These interviews were designed to elicit information about farmers' understanding of the linkage of climate change, forest ecosystem services and agriculture. We also asked farmers about their history, thematic reasons for engaging in the selected adaptation technologies, forest ecosystem services, production, and management, their experience and perception with Perform promoted technologies. The other purpose of the semi structured interviews was to corroborate information from the forest management and livelihood assets focus group discussions. We complemented the information the interview with on-farm trial long term data to validate farmers' identified and prioritised climate smart agricultural technologies.

FGD with a mixture of men and women in Domasi.

FGD with Men, Domasi EPA.

FGD with Men, Mpungu village.

Wrap up meeting with Men and Women at Mpungu village.

3. Results and Discussion

This section presents the results of communities' perception of forest ecosystem services, agriculture, and climate change linkage in the area, vulnerabilities and adaptation strategies.

3.1. Salient characteristics of case study communities surrounding Liwonde forest, Machinga, southern Malawi

Descriptive statistics for the socioeconomic characteristics of the sampled nine communities surrounding the Liwonde forest reserve are shown in Table 1. Five communities (two in Domasi, two in Nsamana and one in Upper Mtubwi) represented high rainfall area and four communities (two in Mbonechera and two in lower Mtubwi) represented low rainfall area. Approximately 57% of the sampled households were female-headed households. More than a third of these were defacto female-headed households since their spouses have migrated to cities or neighbouring countries for employment. The average land cultivated ranged from 1.2 acres to 2 acres, the biggest average cultivated land size found in the high rain fall area. The results also highlighted that the highest proportion of poor households were found in low rainfall area about 73% and 71% in Mbonechera and Lower Mtubwi respectively. Crop production is the main livelihood strategy in all the nine communities.

Table 1 results also highlighted crop diversification was the main coping strategy for both climate and market shocks. The farmers in all the nine communities cultivated at least three different crop species and more than 2 maize varieties. More than 50% of the households in the nine communities were Muslims and about 35% were Christians. The result highlighted that Domasi communities have the highest proportion of households participating in savings club whilst Upper Mtubwi has the least proportion of participants.

3.2. Knowledge of forest ecosystem services, agriculture and climate change linkage

The respondents from the nine communities demonstrated that they were aware of forest ecosystem services and their importance to agriculture and microclimate as indicated in Table 2. For communities that depended on Lake Chilwa for their livelihood such as Domasi and Nsanama, the respondents expressed very well the importance of forest services for relief rainfall, water regulation and erosion reduction. Respondents from the four

Table 1. Salient characteristics of the case study communities around Liwonde Reserve Forest.

Characteristics	Domasi	Mbonechera	Upper Mtubwi	Lower Mtubwi	Nsamana
Ave. household size	5 (1.5)	7 (1.3)	6 (1.3)	7 (2.0)	7 (2.7)
% *defacto* female head households	36	29	37	34	40
% *dejure* female headed households	21	26	17	12	24
Ave. cultivated land size (acres)	2.0 (3.2)	1.2 (0.9	1.3 (1.1)	1.2 (0.7)	1.3 (1.1)
Wealth ranking[2] Better off	16	6	15	11	13
Medium	57	21	31	18	20
Poor	27	73	56	71	67
Key livelihood strategies	a. Crop production b. Horticulture c. Casual labor	Crop production Causal labor Remittances	Crop production Off farm employment Casual labor	Crop production Casual labor horticulture	Crop production Small businesses Remittances
Crop diversification diversity	Maize, Rice and beans	Maize, sorghum, sweet potatoes. Cassava	Maize, pigeon pea, rice, sweet potatoes	Maize, Pigeon pea, groundnuts	Maize, pigeon pea, cassava, sweet potatoes
% household in church/Muslim organisation	86	73	79	82	89
% households in saving clubs	67	61	47	55	59

2 Wealth ranking based on type of houses, livestock ownership and food security

communities highlighted that they have observed a positive correlation between deforestation and reduction in rainfall, increase in temperature and siltation of Lake Chilwa (Table 2). The respondents concurred that the greatest impact was felt in 2012 when the lake dried up which was their main source of livelihood. As a matter of fact, records show that the lake has dried completely nine times from 1900 to 2018. Receding and drying events are linked to impacts of extreme weather events characteristic of climate change. These effects are compounded by deforestation and degradation of the catchment leading to soil erosion and siltation. The communities also linked disappearance of tree species with rainfall and seepage reduction.

In communities such as Mbonechera, lower and upper Mtubwi where wetlands or dambos played an important role for agricultural production, respondents ranked water regulation in dambos and perennial rivers as the most important forest ecosystem services. Nsanama communities also attributed increase of stream bank cultivation as a major drive of climate change resulting in drying up of the perennial river (Table 2).

The climate stressors for forest ecosystem service varied across communities. For communities close to Lake Chilwa, such as Domasi and Nsanama, they linked increased erratic onset of rain, droughts and floods to deforestation and forest ecosystem service reduction (Table 2). For Mbonechera and lower Mtubwi, increased crop failures due to increased frequency of droughts and dry spell were identified as the most important climate stressors of forest ecosystem services. Participants from Domasi, Mbonechara and Nsanama stressed that the shortening of the growing season due to climate change had greatly impacted their livelihoods (Table 2). They reiterated that about a decade ago the season was about five months-long allowing them to produce two crops per season. They would grow maize for food security from November to March then plant beans, pigeon pea or sweet potatoes, as relay crops. Nowadays they rely on a single crop which is bound to fail due to increased frequency of droughts (Table 2). Agricultural productivity and diversification are further compounded by poor soil fertility, increased input costs and land constraints. Only farmers from Mbonechera and Nsanama communities have observed frequency of heat waves and increased disappearance of hydrophilic stress as a result of climate change. Participants from Upper Mtubwi underlined that temperature have become so unpredictable since 2015 (Table 2). They are experiencing cold spells in October which used to be the hottest month. The participants reiterated that this was affecting flowering of some tree species and reproduction of small ruminants and pigs.

The main non-climate stressors identified as main drivers of forest ecosystem degradation were population increase, political and economic policy change (Table 2). In all the four communities forest degradation was associated with change from one party state to multi-party state. The change in governments that occurred in 1994 and 2005 were associated with increased forest ecosystem degradation (Table 2). All the four communities concurred that population increase in the 1990s also contributed to increased forest ecosystem degradation. Policy and market failures brought about by political change were also blamed for the poor forest governance. Participants from all the four communities concurred that democracy rendered local institution and formal ineffective. For example, in Domasi, Nsanama and Upper Mtubwi participants could recite how the forest police were ill-treated at a political rally in 2014 and how this resulted in an open access problem. They also reiterated that good policies, project and advocacy efforts which have been implemented

People walking in Lake Chirwa, as fishing boats lie idle on the dry lake in 2018. Photo by Dr Zacharia .K. Magombo of Malawi Herbaria and Botanical Gardens.

in their communities targeted wrong people and socially excluding the charcoal makers. Mbonechera and Nsamana community participants stressed that increased influx of emigrants from known charcoal-making areas in the southern region contributed significantly to forest degradation. According to the participants' narration, this happened after government change in 2005. The government allocated Likwenu, Milala, Mpelesi estates to people from the rural areas around Blantyre and Zomba, neglecting the local population. This created commons management and land ownership problems. The inhabitants of these two communities felt that these emigrants were benefiting from the forest ecosystem services they had preserved over a long time. Secondly, due to poor integration of the formal and informal institutions, the emigrants were encroaching into the forest designated to these communities (Table 2). The created rivalry in the extraction of the forestry ecosystem services led to rapid depletion. For example, participants from low Mtubwi community stressed that despite having agreed that people would only harvest trees that have dried naturally, they had observed that carpenters in their community would collude with block forest reserve watchmen and debark the type of trees they wanted.

Table 2. Community knowledge and trajectories of forestry ecosystem services, climate change and farming system linkage.

Communities Trajectories	DOMASI	Mbonechera	Lower Mtubwi	Upper Mtubwi	Nsamana
Perceived start of forest degradation	1985	2005	2000	1994	1994
Perceived start of climate change	1990	1990s	2000	2007	1990s
Knowledge of the Forest ecosystem services	• Hydrological cycle • Erosion • Water regulation in Lake Chirwa	• Erosion- formation of gulley • Water regulation in dambos and perennial rivers • Habitat for animals	• Water regulation in dambos	• Water regulation in dambos & rivers • Micro-climate Wind breaks • Erosion	• Observed positive correlation between deforestation and harsh weather. • Change in microclimate • Drying up of rivers as trees along the banks disappear
Key climate stressors	• Floods • Frequent dry spells • Erratic onset of rains • Early cessation of the season • Shortening of growing season • Windy	• Droughts • Frequent dry spells • Increased heat waves • Shortening of growing season • Erratic onset of season • Early cessation of season • Reduction of annual rainfall	• Erratic onset of rainfall season • Uneven distribution of rainfall • Change of seasons	• Increase dry spells • Unpredictable temperature - extremely cold in October • Erratic onset of the season	• Frequent dry spell and droughts • Erratic onset of rains • Shortening of the growing season • Increased heat wave
Non-climate stressors	• Population increase • ESAP, market dynamic • Policy change	• Influx of emigrants • Political change • Policy change	• Forest governance • Population increase • Market forces • Urban expansion	• Political change • Population increase	• Change in forest governance • Political change • Population increases • Influx of emigrants
Impacts	• Siltation of the lake • Reduction in fisheries • Irrigation water reduction • Extinction of important trees along the river banks • Migration of man and youths • Loss of income sources • Reduction in agricultural incomes	• Perennial rivers drying up • Dambos drying up • Extinction of wildlife & trees • Seasonal migration of adult males • Loss of income sources	• Dambos drying up • Agricultural land reduction • Migration of youths, men • Extinction of tree species • Domestic Water scarcity	• Reduction of irrigation water • Siltation of lake Chirwa • Social fabric disintegration • Reduction of agricultural income	• Lake Chilwa drying up • Migration of men and youths • Loss of key livelihood strategies • Reduction of irrigation water and domestic water • Long to get domestic water

3.3. Forest ecosystem governance in the communities surrounding Liwonde forest

For all the nine communities, forest resources are key livelihood assets. In all the communities except Mbonechera firewood and charcoal production were ranked as the most important key resources extracted in the Liwonde forest reserve. According to participants they were the only available economic opportunity and source of income that was easily accessible to all households in the communities. Timber extraction was ranked as the second most important key forest resource in all the communities. Non timber forestry products extraction (NTFPs) was only prominent in Lower Mtubwi and Nsamana communities. The commonly extracted NTFPs were mushrooms and herbs to cure ailments, livestock and poultry diseases.

All the communities were aware of forest ecosystem co-management but they perceived the arrangement differently. All the communities had a superficial understanding of co-management and acknowledged that they had a block in the Liwonde reserve forest under their care. In terms of power sharing agreement, the benefits and their responsibilities in managing the blocks, all communities professed ignorance. Each community confirmed that they had a block management committee that represented the community at relevant stakeholder meetings. Though all communities acknowledged improved access to forest resources with the new strategy. They stressed that the current strategy had weakened both the informal and formal institutions that existed leading to pseudo open access problems. Participants from Mbonechera and Lower Mtubwi perceived that the transition from the conventional system of management where government/ forestry department enforcement was the dominant was not well managed. They also presumed that this was further reinforced by the current status whereby most community members perceived that participation in the co-management arrangement was voluntarily.

The communities' members also alleged that most people involved in charcoal making as livelihood were socially excluded. It was interesting to note that the participants from Upper Mtubwi concurred with all the other communities. However, they perceived that the incoherence between the informal and formal institution had created the open access problems. Policy failures particularly as it relates to hydro-electric power generation, employment creation and defining democracy were identified in the communities as underlying cause of poor forest reserve governance. Participants form all the communities concurred that both formal and informal institutions enforcement were temporarily deterrents, limited livelihood diversification options and lack of alternative employment opportunities took presidency over the desired long-term impacts of forest protection measures. The Mbonechera and lower Mtubwi communities also highlighted that lack of clarity and understanding of power sharing agreement, benefits and responsibility under the co-management strategy had also increased rivalry in forest extraction. Both communities noted that neighbouring communities from the other side of the mountain were encroaching into their blocks whilst preserving their village lots for future use. They also echoed that because of unclearly stipulated private benefits and responsibility of the co-management, community members collude to deplete the forest resource in the blocks.

3.4. Climatic risks, forest and Agricultural vulnerability of the Liwonde forest fringe Communities, Machinga

The impacts of climate change on forest resources, combined with increased forest management challenges increase the vulnerability of Liwonde forest fringe communities. All the communities around the reserve, revealed that climate change hazards in the form of late onset of rains, increased dry spell, severe droughts and temperature are common phenomena (Tables 4, 5, 6). All the nine communities reiterated that since 1990 severe droughts have been occurring once every three years with 2012 drought being the most devastating (Tables 4, 5, 6). Participants from all the communities also associated the 2012 and 2018 severe droughts with the drying of Lake Chilwa. The lake was the main source of livelihood for more than 50% of the community members, directly as fishermen and irrigation water source, indirectly as market for agricultural produce and forest products in particular charcoal and firewood. Communities in the rain shadow, Mbonechera and Lower Mtubwi have become extremely vulnerable to late on-set of rains, dry spells and severe droughts (Tables 4 and 5). For example, participants from in Mbonechera community echoed that since the year 2000 they have been experiencing an average of 3 dry spells. They also noted that they have observed shortening of the growing season and since the millennium they have never had successful season. The reiterated that every season has it on dynamics it is either those who plant early are able to harvest or those who plant late (Table 4). Land and input access constraints increased their vulnerability, more than 60% of the household could not afford to vary planting dates or varieties due to poverty or land constraints. For communities such as Domasi, agricultural production and forest resources have also been extremely vulnerable to floods (Table 4). The farmers from the nine communities concurred that their communities' vulnerabilities to these climate hazards are further intensified by the interaction of climatic shocks with social, economic, and biophysical

Table 3. **Forest ecosystem governance in the communities surrounding Liwonde forest.**

Community	Key forest resources	Existing governance strategy	Community perception of governance strategy strength	Community perception of governance strategy weakness
Domasi	Charcoal production, timber	• Co-management government and market driven • Managing 2 blocks 121.06 and 144.54 hectares respectively	• Community managed use /access rights	• enforcement of forest ecosystem use/access rules very week leading to open access problems • Participation in the co-management is voluntarily • Majority of the charcoal maker excluded
Mbonechera	Firewood and timber	Government dominated Co-management Allocated 164.96 hectare block in the Liwonde forest reserve A village woodlot	• Welcomed the allocation of blocks in the reserve as better strategy to manage common pool resources	• Transition from traditional institution not well managed • Community involvement in the management superficial • Poor integration of local institutions and traditional authority in the co-management of forest ecosystems • Forest guard have no incentives to enforce compliance rules and manage extraction efficiently • Increased deforestation • Encroachment from other communities • Instability in government policies
Lower Mtubwi	Charcoal production, timber, pit sawing and NTFPs	Pilot co-management government and market driven Covered 2 blocks Kwilasya block -114.69 ha Naunga block – 129.8 ha	• Improved community engagement. • Active Village Development Committees • Village woodlots well managed	• Transition from government dominated forest management to co-management not well managed. • Poorly paid forest guard accepting bribes • Lack of other economic opportunities forcing people to rely solely on the forest • Increase demand from the Liwonde Boma and electricity cuts weakening forest bylaw enforcement • Encroachment by other communities into Naunga block triggering open access problems
Upper Mtubwi	Charcoal production, timber,	• Government dominated Co-management • Allocated two blocks 118.15 ha • 109.35 ha	• Improved forest resources access and use rights	• Lack of coherence of informal and formal institutions. • Democracy making governance of forest resource usage impossible • Exclusion of the main forest dependent community members in most forest rehabilitation programs
Nsanama	Charcoal production, timber, pit sawing and NTFPs	• Government dominated Co-management • Allocated 189.59 ha block in the Liwonde forest reserve	• Improved community access/use of forest ecosystem services	• Less than a third of community members are participating in the co-management because it is voluntarily. • Co-management weakened law enforcement both informal and formal leading to open access problems • Increased electricity power cuts, policy changes, loss of livelihood sources rendering the governance strategy ineffective

Table 4. Summary of climatic risks, forest and Agricultural vulnerability of the Domasi and Upper Mtubwi Communities, Machinga district.

	Domasi					Upper Mtubwi				
		Adaptation strategies					Adaptation strategies			
Climate hazard	Current risk	Proactive	Reactive	Agricultural production vulnerability profile	Forest vulnerability profile	Current risk	Proactive	Reactive	Agricultural production vulnerability profile	Forest ecosystem vulnerability profile
Heat wave	Medium	• Mulching • intercropping	None	Least vulnerable	Least vulnerable	Medium	• Mulching • Agroforestry • Drought tolerant varieties	None	Vulnerable	Vulnerable
Erratic season onset	Very high	• Varying planting dates • Crop & variety diversification • CA	• Migration • Charcoal selling • Brick selling	Extremely vulnerable	Extremely vulnerable	Very high	• CA • Varying planting dates • Crop & variety diversification	• Stream bank cultivation • Charcoal selling • Migration	Extremely vulnerable	Extremely vulnerable
Early season termination	Medium	• Planting short season varieties • Crop diversification • Stream bank/ dambo cultivation • Irrigation	• Small business. Renting out land • Casual labor • Migration	Vulnerable	Vulnerable	High	• Varying planting dates • CA • Crop & variety diversification	• Timber selling • Selling small stock • Casual labor • Migration	Vulnerable	Vulnerable
Flash floods/ cyclones	Very high	• Forest regeneration • Woodlots • Watershed management	• Charcoal selling • Migration • Casual labor	Extremely vulnerable	Extremely vulnerable	Medium	• Forest regeneration • Watershed management • Crop & variety diversification	• Selling small stock • Casual labor • Migration	Vulnerable	Vulnerable
Dry spells	Very high	• Varying planting dates • Crop & variety diversification • Irrigation	• Charcoal making • Small business • land selling & renting out • Casual labor	Extremely vulnerable	More vulnerable	Very high	• Varying planting dates & varieties • Dibble stick CA • Crop diversification	• Stream bank cultivation selling small stock • Casual labor • Migration	More vulnerable	More vulnerable
Severe droughts	Medium	• CA & intercropping • Planting short season varieties • Crop diversification	• Charcoal selling • Selling small stock & land • Migration	More vulnerable	Extremely vulnerable	High	• Varying planting dates • CA • Crop & variety diversification • Stone bunds & terracing	• Selling small stock • Migration • Timber selling	More vulnerable	More vulnerable

Table 5. Summary of climatic risks, forest and Agricultural vulnerability of Lower Mtubwi and Mbonechera Communities, Machinga district.

	Lower Mtubwi					Mbonechera				
Climate hazard	Current risk	Adaptation strategies: Proactive	Adaptation strategies: Reactive	Agricultural production vulnerability profile	Forest vulnerability profile	Current risk	Adaptation strategies: Proactive	Adaptation strategies: Reactive	Agricultural production vulnerability profile	Forest ecosystem vulnerability profile
Heat wave	Very high	• Mulching • Intercropping	• None	More vulnerable	Extremely vulnerability	Medium	• Mulching • Agroforestry • Drought tolerant varieties	None	More vulnerable	Extremely vulnerable
Erratic season onset	Very high	• Varying planting dates • Crop & variety diversification • CA • Stream bank cultivation	• Migration • Timber & Charcoal selling • Brick selling • Stream bank cultivation	Extremely vulnerable	Extremely vulnerability	Very high	• CA • Varying planting dates • Crop & variety diversification	• Timber selling	Extremely vulnerable	Extremely vulnerable
Early season termination	Very high	• Planting short season varieties • Crop diversification • Stream bank/ dambo cultivation • Irrigation	• Small business. • Casual labor • Migration	Most vulnerable	Most vulnerable	High	• Varying planting dates • CA • Crop & variety diversification	• Timber selling • Selling small stock • Casual labor • Migration	Extremely vulnerable	Extremely vulnerable
Flash floods/ cyclones	Medium	• Forest regeneration • Woodlots • Watershed management	• Charcoal selling • Migration • Casual labor	Least vulnerable	Least vulnerable	Medium	• Tree bunds • Crop & variety diversification	• Selling small stock • Casual labor • Migration	Least vulnerable	Least vulnerable
Dry spells	Very high	• Varying planting dates • Crop & variety diversification • Stream bank cultivation	• Casual labor • Migration • Charcoal making • Small business • Casual labor • Stream bank cultivation	Extremely vulnerable	Extremely vulnerable	Very high	• Varying planting dates & varieties • CA • Crop diversification	• Selling small stock • Casual labor • Migration	Extremely vulnerable	Extremely vulnerable
Severe droughts	Very high	• CA & intercropping • Planting short season varieties • Crop diversification	• Charcoal selling • Selling small stock & land • Migration	Extremely vulnerable	Extremely vulnerable	High	• Varying planting dates • CA • Crop & variety diversification • Stone bunds & terracing	• Selling small stock • Migration • Timber selling	Vulnerable	Vulnerable

Table 6. Summary of climatic risks, forest and Agricultural vulnerability of Nsamana Community, Machinga district.

Climate hazard	Future risk	Adaptation Strategies		Agricultural vulnerability profile	Forest ecosystem vulnerability profile
		Proactive adaptation strategies	Reactive		
Heat wave	High	• Mulching • Intercropping	• None	Vulnerable	Vulnerable
Flash floods/ cyclones	Medium	• Forest regeneration • Woodlots • Watershed management • Stream bank tree regeneration	• Charcoal selling • Migration • Casual labor	Least vulnerable	Least vulnerable
Erratic season onset	Very high	• Varying planting dates • Crop & varieties diversification • CA	• Small business, • Casual labor, • Charcoal selling	Extremely vulnerable	Extremely vulnerable
Early season termination	Very high	• Planting short season varieties • CA	• Small business, • Casual labor, • Charcoal selling	More vulnerable	More vulnerable
Dry spells	Very high	• Varying planting dates • Crop diversification and varieties • CA • Agroforestry • Tied ridges	• Small business, • Casual labor	Most vulnerable	Most vulnerable
Severe droughts	High	• Varying planting dates & varieties • Various CA forms & Agroforestry • Crop diversification	• Reducing meals, • Dropping children from school, • Migration, • Charcoal selling.	Most vulnerable	Most vulnerable

Quantification of costs and benefits of CSA promoted in the Liwonde forest fringe communities in Malawi

Table 7. Gross Margin Analysis (US$ ha^{-1}) of different combinations of CSA practices practised farmers in the Liwonde forest fringe communities in Malawi (2018/19 season

CSA Technology	CA	Non-CA	Mbeya	Non- Mbeya	Pigeon Pea intercrop	Sole Maize
Gross Benefits	**846.25**	**559.15**	**934.66**	**769.78**	**627.99**	**578.52**
Input costs						
Labor costs	48	67	62	59	59	72
Maize seed costs	65	65	65	65	65	65
Legume seed costs	0	0	0	0	35	0
Fertilizer cost	293	293	78	293	293	293
Total costs	**406**	**425**	**205**	**417**	**452**	**430**
Net benefits	**440.25**	**134.15**	**729.66**	**352.78**	**175.99**	**148.52**
Return on Investment	**1.08**	**0.32**	**3.56**	**0.85**	**0.39**	**0.35**
Return to labor $ invested	**10.2**	**3.0**	**12.8**	**7.0**	**4.0**	**3.1**

factors (Tables 4, 5, 6). For example, in Domasi and Upper Mtubwi community members observed that severe droughts occurred simultaneously with macroeconomic turbulence creating multiple sources of food insecurity (Tables 4 and 5). They reiterated that the severe 2012 drought also coincided with the country's worst economic depression leading to deep poverty and migration of productive member to urban areas and neighbouring countries. They also echoed that the conflation of these shocks with economic depression further undermined private investments in soil fertility improvement contributing to further soil fertility depletion. The Mbonechera, Lowe Mtubwi and Nsanama farmers linked severe droughts to policy and political changes. In particular, 1994, 2012 and 2014 droughts, the community perceived that the effects were worsened by change of government and weakening of the currency resulting in increased maize grain prices (Tables 4, 5, 6).

Overall, the nine communities confirmed climate change have profound effects on both natural forest ecosystem and agricultural production. Participants from all the communities emphasised that they had observed changes in climate in the past two decades particularly the current one. These changes included increased heat waves, erratic on-set of rains, increased frequency of dry spell and severe droughts. The communities concurred that the notable severe drought, dry spells and heat wave occurred in 2012, 2016 and 2018 respectively (Tables 4, 5, 6). They also highlighted that climate change has increased vulnerability and reduced resilience of forest ecosystems and agricultural production systems. It was noted that, as a result of frequent severe droughts, the forest ecosystems services, in particular regulation services, are becoming more vulnerable and their long-term adaptation capacity is decreasing drastically. While impact on agricultural systems varied across communities, it was generally observed that increased temperatures, shortening of the growing season and increased frequency of severe droughts had resulted in loss of important tree species and biodiversity resulting in disruption of ecosystem services such as wetlands for agriculture (Tables 4, 5, 6). In Mbonechera and Domasi communities it was highlighted that loss of wetlands had decreased agricultural incomes by up to 50%.

3.5 Integrated strategies for improving Agricultural and forest ecosystems resilience to climate change and variability

For all these forest fringe communities, forest resources represent their key livelihood asset to adapt to climate change impacts. They also revealed that forest ecosystem services have the potential to support their communities' adaptation to the impacts of climate change through micro climates, water regulation services and strengthening livelihood opportunities – such water for irrigation. For example, farmers from Mbonechera and Nsanama communities underscored the importance of forest resources, agroforestry, and water berry trees along streams for water and soil conservation. Domasi community participants reiterated that they had come to realise the importance of forest ecosystem services in providing micro-climate and relief rainfall. They all concurred that in the previous years before democracy (1994) when the forest were well protected they never experienced floods and severe droughts. They expressed concern on how they wish the previous forest management institution could be restored to help the forest rejuvenate to its original status. Participants from other communities emphasised more on the role of forest ecosystem resources as to reactive strategies in the face of climate calamities.

Integration of adaptation strategies with short and long term benefits were most preferred in all the communities (Figure 2 and 3). Among the CSA technologies promoted by Perform, drought tolerant maize and rice varieties, orange fresh sweet potatoes, treadle pumps, rocket stoves and chicken pass-on were ranked as the most important adaptation strategies in Domasi community (Figure 2). It was interesting to note that rocket stoves were ranked highly in this community by male participants. Drought tolerant maize varieties and high value Kilombero rice varieties introduced by the project were ranked highly and most preferred by male participants in this community (Figure 2). The males in this community were merchandisers hence they greatly appreciated

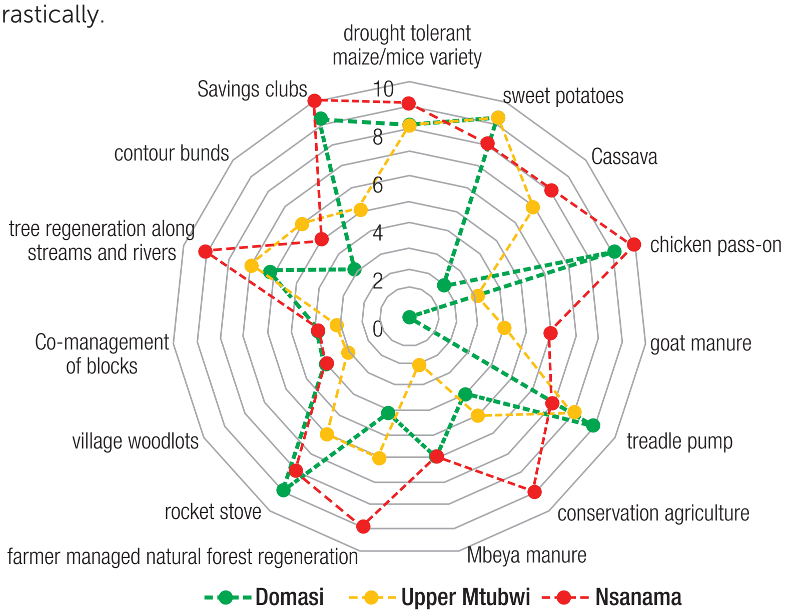

Figure 2. Integrated strategies for improving Agricultural and forest ecosystems resilience to climate change and variability high potential communities.

technologies that make their crop produce fetch higher prices on the market. The male participants reiterated that with the short season drought tolerant maize and high value kilombero rice variety they were able to enter the winter market early and fetch good prices. Both female and male participants in this community also rated crop species diversity as the most important adaptation strategy. This community is closest to Lake Chilwa, irrigation have been part of their tradition hence they ranked use of treadle pumps as the most important adaptation strategy. The Domasi community members (males and females) greatly valued the chicken pass-on strategy as substitute of forest resource extraction in times of need (Figure 2). Female participants reiterated that it was most prestigious to sell chicken along the highway relative to selling charcoal or wood when faced with a calamity. They also highlighted that due to the depletion of the forest it was also taking longer to extract and sell forest resources in the times of need. They also stressed that they could also use the chickens as collateral to borrow money in times of need which they could not do with forest resource extraction. Overall the Domasi community highlighted that CSA technologies that improve their income flow and reduce labor constraints such as the currently promoted combination of technologies were highly regarded in their community.

Crop diversification into drought tolerant crops such as maize, sweet potatoes and cassava were ranked as most important adaptation strategies in upper Mtubwi (Figure 2). During the interactive discussion, farmers also emphasised that they supplemented their rainfed crop produce using income derived from selling horticultural crops. In this community treadle pumps were rated highly among the available adaptation strategies. It was saddening to note that due to increased exposure to climate shocks the social integration had degenerated in this community resulting in the failure of chicken pass-on projects. During the interactive discussion, both male and female participants in this community stressed that several organisations had introduced goat and chicken pass-on programs, but they had failed even to cover ten percent of the community. The first beneficiaries failed to pass on chicken to the next beneficiaries for selfish reasons. They had observed the first beneficiaries would either manure the sickly goats/chickens or postpone the passing on until the supposed beneficiary loose interest in following it (Figure 2).

In Nsamana community, integrated soil and water conservation strategies such as conservation agriculture and farmer managed natural forest regeneration, with crop species diversification and drought tolerant varieties were rated highly as most important adaptation strategies (Figure 2). The participants perceived that about 40% of the community members were practicing conservation agriculture. Farmers in this community highlighted that drought tolerant crops such as cassava and sweet potatoes have become important adaptation strategies for erratic onset of rains, dry spells, moderate and severe droughts. Due to increased scarcity of water for domestic use and increased distances to fetch firewood, farmers in this community highly valued the integration of rocket stoves, farmer managed natural forest regeneration and forest tree regeneration along the rivers and streams. chicken pass-on program was also highly rated as an adaptation strategy to climate change in this community (Figure 2).

Communities that were more prone to droughts, Mbonechera and Lower Mtubwi utilized more of the promoted strategies compared to the three other communities (Figure 3). During the interactive discussion, farmers from the two communities emphasised that due to increased crop failures and shortening of the rainfall season they had observed that integration of agriculture-related and non-agricultural strategies were very effective to deal with climate change effects. In Mbonechera, both female and male farmers perceived that combination of CA with diversified crop species and drought tolerant varieties as very important adaptation strategies for erratic onset of rains, increased dry spell and early termination of rains. During the interactive discussion, both male and female participants in this community stressed the importance of farmer natural forest regeneration, rocket stoves, village savings and loan clubs and chicken pass-on in moderating climate change effects. For example, female participants

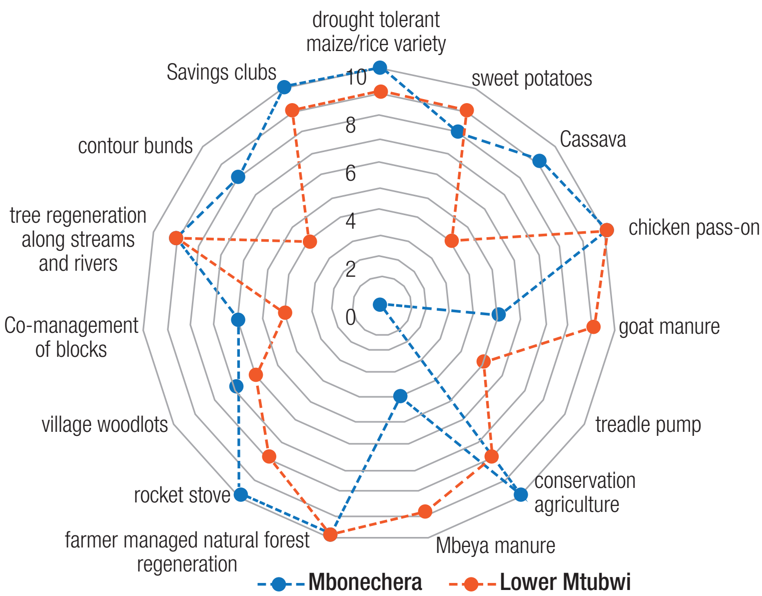

Figure 3. Integrated strategies for improving Agricultural and forest ecosystems resilience to climate change and variability low potential communities.

expressed the importance of saving clubs in providing resources to buy seed for replanting with increased erratic onset of seasons (Figure 3). The male participants in the same community underscored the importance of chicken pass-on schemes in moderating the climate change effects, reducing their reliance on the forest resources for cash liquidities. The existence of a lucrative market for indigenous chicken in the Liwonde Township increase the significance of the chicken pass-on strategy. Contrary to other communities, TLC Rocket stove were not highly rated in Lower Mtubwi. During the interactive discussion, both male and female farmers revealed that due to their proximity to the Liwonde Township and accessible roads they had been target of many fuel wood efficient stoves dissemination initiatives. Tree regeneration along rivers and streams was of importance in both communities because of increased water scarcity for domestic use (Figure 3).

The gross margin analysis carried out from data obtained from a sample of CSA technologies adopters in the nine communities revealed clear benefit of these technologies relative to the traditional systems. The economic analysis further showed that CSA are profitable and worthy for the Machinga communities that are vulnerable to climate risks. The Mbeya manure provided the highest net-returns, return to investment and labor relative to CA, Non-CA, pigeon pea inter-crop and conventional maize only. The significant reduction in fertilizer cost and crop failure risk associated with Mbeya fertilizer made this CSA practice worthy to the vulnerable households in the Liwonde forest fringe communities. For every labor hour invested, farmers could get up to US$12.80, and US$10.20 in return on Mbeya manure and CA respectively compared to US$3.1 on conventional maize only. For every dollar invested for inputs, farmers would gain up to US$3.56 and US$1.08 on Mbeya manure and CA compared with up to US$0.35 on conventional maize only. The estimated profitability of Mbeya manure and CA system over the conventional system in the land constrained communities was attributed to improved land and labor use efficiency and increased crop yields. Mbeya manure had the highest net return which suggests that farmers who are able to adapt and adopt this CSA have a better chance of recovering their investments relative to conventional sole maize system.

4. Conclusion

The main objective of the study was to understand the link between climate change, forest ecosystem services and agricultural production of Liwonde forest fringe communities. We contributed to the empirical literature on CSA by exploring the vulnerability of forest ecosystem and smallholder farming systems to climate change as well as identifying suites of adaptation options.

The findings revealed that farmers from all the nine communities understood the linkage between climate change, forest ecosystem services and agriculture. Although they could not articulate the science, their explanation of climate change trajectories, observed changes in forest ecosystems resources and agriculture production were in tandem with projected changes. Climate change impacts on agriculture production and forest resources combined with increased forest management challenges increase the vulnerability of Liwonde forest fringe communities. The most common climate change hazards in the Liwonde forest fringe communities included erratic onset of rains, increased dry spell, severe droughts and heat waves. The main non –climate stressors identified as main drivers of forest ecosystem degradation and low agricultural productivity were population increase, political and economic policy change. Policy and market failures brought about by political change were also blamed for the poor forest governance. Forest resources were key livelihood assets for the nine communities. Charcoal production was ranked as the most important key resource extracted in the Liwonde forest reserve in eight of the communities. All the nine communities had a superficial understanding of co-management and acknowledged that they had a block in the Liwonde reserve forest under their care. They all had concern on the effectiveness of the current co-management strategy particularly how the transition was managed and the incoherence between the informal and formal institution.

To manage the impact of climate change on forest ecosystem resources and agricultural production systems, these Liwonde forest fringe communities employed a combination of agricultural and non-agricultural innovations promoted by Perform at vary intensities. For Domasi, Nsamana, and Upper Mtubwi communities on the windward side of the Liwonde forest reserve integration of agricultural innovations such as drought tolerant crop varieties, cropping diversification and tredible pumps and non-agricultural innovations such rocket stoves and regeneration of trees along streams and rivers were the highly rated adaptation strategies for climate shocks. This mix of adaptation strategies had proved to be effective in helping the farmers in building both forest ecosystem services and agricultural resilience. For Mbonechera and Lower Mtubwi communities on the leeward side, integration of agricultural innovations such as, chicken pass-on, CA combined with crop diversification and drought tolerant crop varieties and non-agricultural innovations such as savings club, rocket stoves were considered effective in building forest resource and agricultural resilience. These results suggested that interventions aimed at reducing the vulnerability of forest resources and agricultural production to climate shocks should not only focus on agricultural technologies but also non-agricultural technologies. The importance of interventions that provide easily access to cash in times of need such as chickens, goats and savings is paramount to improved resilience of forest ecosystems and agricultural systems.

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International Maize and Wheat Improvement Center

For more information

CIMMYT –Zimbabwe:
Peter Setimela
12.KM peg Mazowe Road.
P.O. Box MP163
Mount Pleasant
Harare, Zimbabwe
e-mail: p.setimela @cgiar.org

Contact at USDA:
Caitlin Corner-Dolloff
1400 Independence Ave SW
Washington, DC 20250
(202) 260-8289
e-mail: Caitlin.Corner-Dolloff@fas.usda.gov