Feasibility study for Climate-Smart Agriculture Systems in Southern Africa

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Table of Contents

Executive summary

Climate variability and change is projected to increasingly affect smallholder farming systems in southern Africa and the maize value chain will particularly suffer from the late onset of and more erratic rainfalls. Heat stress will further affect maize-based cropping systems as temperature is projected to increase by 2.1-2.7°C.

Based on CSA practices, prioritized in national and regional workshops, a study was conducted using historical data collected by the International Maize and Wheat Improvement Centre (CIMMYT) and its national partners to better understand the benefits and challenges of CSA technologies and to assess their feasibility for a large outscaling initiative in southern Africa. The specific objective of the study was to assess their economic, biophysical, environmental and social benefits using existing available long-term data. For completeness a summary of challenges in their implementation was also provided.

The study was carried out in target areas of Zambia, Malawi and Zimbabwe where such long-term data existed. The CSA technologies under survey were mostly conservation agriculture (CA)-based interventions as this was the only long-term data available. All sites had at least two CSA comparisons and a conventional control practice which was considered not climate-smart. Maize-based cropping systems consisted of other complimentary CSA practices e.g. rotations with legumes and agroforestry species, drought-tolerant maize varieties, targeted application of fertilizer and manure amongst others, which were however not the primary focus of this study.

Based on partial budget conducted for all the areas, the results showed positive economic indicators for most CSA practices in form of a positive Net Present Value (NPV) and a greater Internal Rate of Return (IRR), which was greater than the discount rate. All the prioritized CSA options required at least a year to provide economic returns (increased productivity and income) as reflected by the payback period. In Malawi the CA-maize/legume intercropping treatment had the greatest NPV, IRR, Return on Investment (ROI), Return on Labour (ROI) as compared with the conventional practice. In Eastern Zambia, the CA-maize/legume intercropping treatment was the most profitable manual systems, whereas the ripline seeded CA-maize-legume rotation was the most profitable animal traction system as compared to the conventional practice. In Zimbabwe the CA-ripline seeded maize-legume rotation was again the most profitable practice while direct seeding was more profitable in southern Zambia.

The biophysical benefits have been greatest in system comparisons in Malawi and in southern Zambia. CSA systems out-yielded the conventional control in most cases and in some it reached more than 60% yield gain. The benefits were usually more consistent, the longer the CSA practice was applied. The benefits in the CSA systems practiced in Eastern Zambia and Southern Zimbabwe were less obvious, mostly due to the relatively short duration of implementation, variability between farm sites and unpredictable weather events (floods and droughts) at the respective sites. Overall, at all sites averaged, there was a clear positive yield benefit across sites and seasons when comparing CSA practices with conventional control treatments. An additional regional study across many agro-ecologies clearly show increased resilience against heat and drought stress especially on sandy and loamy soils.

Yield benefits under CSA management are likely a response of improved soil quality which is a result of no-tillage, residue retention and crop rotations and additional complimentary practices implemented at the sites. CSA systems increased water infiltration which translated into increased soil moisture during the cropping season. The CSA systems also reduced soil erosion and increased soil

carbon at some sites. Supporting soil quality data were derived from strategically located on-station trials where soil carbon and erosion measurements were possible. The data from on-farm soil carbon measurements, which is currently been summarized, will further support the results of this study.

Social benefits of CSA included reductions in farm labour for weeding and planting which preferentially benefit women and children. Labour benefits for planting were dramatically reduced specifically in Malawi where farmers practice ridge and furrow land preparation as the conventional control practice and where weed control is manual with a hoe. Direct seeding and weed control with herbicides could potentially reduce the labour burden on women and children by 25-45 labour days. In addition, the more diversified diet resulting from rotations and intercropping systems with legumes greatly benefitted livelihoods as they improve the nutrition of smallholders in the households.

Challenges in the implementation of a range of CSA practices have been documented and require some adaptive and participatory action. However these challenges are surmountable and will enable cash constraint and risk averse farmers to adopt climate-smart options.

We conclude that CSA practices provide substantial financial and biophysical benefits which often increase over time. These translated into environmental and social benefits for smallholder farmers which is the base for a strong business case for scaling.

Plate 1: Maize-soybean rotation planted under CSA

1. Introduction

Agricultural production in southern Africa is constrained by numerous factors. Amongst them are frequent droughts and in-seasonal dry-spells, heat stress, declining soil fertility, excessive water run-off and soil erosion, unsustainable land-use practices and limited adoption of improved agricultural technologies (Thierfelder et al. 2015e). Climate projections for southern Africa until 2050 suggest temperature increases by on average 2.1-2.7°C (Cairns et al. 2012), which will lead to a delay in the onset of the rainy seasons, increased heat stress and more extreme weather events (e.g. excessive rainfall and drought stress) (Burke et al. 2009). Maize production, is projected to decrease by 10-30% until 2030 and up to 50% until 2080 if no measures are taken to adapt to climate variability and change (Lobell et al. 2008; UNEP/GRID-ARENAL 2016).

To address climate-related challenges, the concept of climate-smart agriculture (CSA) has been developed (FAO 2013; Lipper et al. 2014). For a cropping systems to be labelled "climate-smart" it has to deliver on three main aspects: a) it has to increase productivity and profitability; b) it has to adapt to the negative effects of climate change and build resilience; and c) it has to mitigate the negative effects by reducing greenhouse gas emissions and/or increase carbon sequestration (Thierfelder et al. 2017).

Adaptation to climate change can be achieved through individual and a combinations of technologies such as agro-forestry, conservation agriculture (CA)[1], drought-tolerant and low N-stress tolerant maize and legume varieties, improved feeding and grazing systems for livestock amongst others. Yield benefit of 30-50% can be achieved by using a combination of CSA technologies under drought (Thierfelder et al. 2015f) and profits increase by 40-100% (Thierfelder et al. 2015a).

Due to the urgent need and projected benefits of CSA in southern Africa, the project "Out scaling climate-smart technologies to smallholder farmers in Malawi, Zambia and Zimbabwe" has been formulated to develop a business case for scaling CSA in the region. It aims at: a) understanding the vulnerability of current farming systems; b) prioritization of some "best bet" CSA technologies; and c) quantifying the benefits of selected climate-smart agriculture technologies using data from a combination of historical on-farm and on-station trial data as well as surveys conducted in different cropping seasons. The aim of the project is to compile available data to convert them into a ***Feasibility Study*** as a basis for formulating a comprehensive and ***Bankable Investment Proposal*** for scaling CSA in the southern African region.

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[1] Conservation agriculture is understood to be a cropping system based on the three principles of minimum soil disturbance, crop residue retention and crop rotation

2. Approach and Data sources

2.1 Prioritization of Climate Smart Agriculture Technologies

A wealth of knowledge on potential climate smart-agriculture technologies in maize value chains is known in the region. There was need to identify and prioritize technologies that are relevant to identified hazards and risks and that address and lower bio-physical and socio-economic impacts of these hazards and risks to farmers. This was done in a two-staged process:

2.2.1 Prioritization of technologies in Zimbabwe, Malawi and Zambia

Three meetings were held in the different countries involving key stakeholders including farmers. Participant's evaluated technologies based on their productivity, adaptation and mitigation potential and rated the technologies in a participatory group process. Participants rated diversification crops, different types of conservation agriculture systems (e.g. ripping and direct seeding in Zambia, basins in Zimbabwe), drought-tolerant germplasm (all countries), varying planting dates and supplementary irrigation as potential adaptation measures. Agroforestry and afforestation as potential adaptation measures were usually rated slightly lower. In Zimbabwe, integration of livestock was also mentioned as a potential and viable adaptation option as farmers are able to eat and sell this asset in case of a potential crisis.

2.2.2. Prioritization of technologies in a regional workshop

In a regional workshop held from August 7-9, 2018 in Lusaka, key stakeholder and Directors of Research and Extension were asked to go through a participatory prioritization and selection exercise following the "Climate Proofing Tool for SADC" developed by GIZ (Heine et al. 2016). The groups, divided by agro-ecology brainstormed on available adaptation measures that lower the impacts of climate change in their areas and ranked them based on a range of criteria (effectiveness, costs, feasibility, political/social acceptance, relative speed of benefit, no regret potential, alignment with donor support and alignment with policy). Co-benefits of the technologies were identified as mitigation potential and gender sensitivity. Participants of the regional workshop identified both single component technologies as well as more complex cropping systems (e.g. conservation agriculture). The highest scoring adaptation strategies in most areas were diversification and intercropping as well as drought tolerant germplasm. This was followed by supplementary irrigation and conservation agriculture interventions. In one area (southern Zimbabwe/Southern Zambia), soil fertility management and pro-active risk management through staggered maize planting ranked also very high. Based on this assessment and relevance, the available data for developing a feasibility study of climate-smart agriculture technologies was gathered, analyzed and used in this report.

2.2 Data sources from on-station and on-farm sites

The project used a mixed methods approach to evaluate the feasibility of climate-smart agriculture systems in southern Africa. The approach and data analysis is predominantly built on historical data, generated in 19 on-farm communities in three target countries, Malawi, Zambia and Zimbabwe, where different CSA practices have been implemented cumulatively since 2005. The on-farm communities are spread around different agro-ecologies in southern Africa and cover low and mid-altitude areas, low to high rainfall regimes and different soil types (from sandy soils to sandy clay loams).

Table 1: Target communities grouped into Agro-ecologies in southern Africa

Country	District	Description	Agro-ecoregion	Site(s)	Latitude	Longitude	Altitude	Soil type	Seasonal rainfall	CSA systems
Malawi	Nkhotakota	Central Malawi	Mid altitude, high rainfall, alluvial soil	Zidyana	-13.2281	34.26341	514	haplic Luvisol	1429	Manual CA
Malawi	**Nkhotakota**	**Central Malawi**	**Mid altitude, high rainfall, alluvial soil**	**Mwansambo**	**-13.2904**	**34.13204**	**660**	**Haplic Lixisols**	**1371**	**Manual CA**
Malawi	Nkhotakota	Central Malawi	Mid altitude, high rainfall, alluvial soil	Linga	−12.80	34.20000	491	Alluvialsoils	1237	Manual CA
Malawi	Salima	Central Malawi	Mid altitude, high rainfall, alluvial soil	Chinguluwe	-13.6932	34.23582	653	Eutric Cambisols	1241	Manual CA
Malawi	Dowa	Central Malawi	Mid altitude, high rainfall, alluvial soil	Chipeni	-13.7631	34.05322	1164	Chromic Luvisols	883	Manual CA
Malawi	**Balaka**	**Southern Malawi**	**Low altitude, low rainfall, sandy soils**	**Lemu**	**-14.7801**	**35.02718**	**687**	**Chromic Luvisols**	**862**	**Manual CA**
Malawi	Balaka	Southern Malawi	Low altitude, low rainfall, sandy soils	Malula	-14.9593	34.98556	613	Eutric Fluvisols	717	Manual CA
Malawi	Balaka	Southern Malawi	Low altitude, low rainfall, sandy soils	Herbert	-14.8844	35.04552	635	Chromic Luvisols	684	Manual CA
Malawi	Machinga	Southern Malawi	Low altitude, low rainfall, sandy soils	Matandika	-15.1801	35.27642	683	Cambic Arenosols	874	Manual CA
Malawi	Zomba	Southern Malawi	Low altitude, low rainfall, sandy soils	Songani	-15.2980	35.39610	815	Ferralitic soils	1371	Manual CA
Zambia	Katete	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Kawalala	-14.0953	31.48860	938	Acrisols	800-1000	AT CA
Zambia	**Chipata**	**Eastern Zambia**	**Mid altitude, high rainfall, Ferralitic soils**	**Chanje**	**-13.2330**	**32.47892**	**917**	**Luvisols**	**800-1000**	**Manual CA**
Zambia	Chipata	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Kapara	-13.3013	32.29310	739	Luvisols	800-1000	AT CA
Zambia	Chipata	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Mtaya	-13.3438	32.31201	747	Luvisols	800-1000	Manual CA
Zambia	Lundazi	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Vuu	-12.1602	33.02291	1096	Acrisols	800-1000	Manual CA
Zambia	Lundazi	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Hoya	-12.0715	33.07986	1103	Acrisols	800-1000	AT CA
Zambia	Monze	Southern Zim/Zam	Low to midaltitude, low rainfall, sandy/loamy soils	Malende	-16.2545	27.41943	676	Chromic Lixisols	748	AT CA
Zimbabwe	**Zaka**	**Southern Zim/Zam**	**Low to midaltitude, low rainfall, sandy/loamy soils**	**Bvukururu**	**-20.1750**	**31.38000**	**1120**	**Arenosols**	**500-700**	**AT CA**
Zimbabwe	Zaka	Southern Zim/Zam	Low to midaltitude, low rainfall, sandy/loamy soils	Zishiri	-20.1679	31.28126	1121	Arenosols	500-700	AT CA
Supporting long-term trial stations										
Malawi	Lilongwe	Central Malawi	Mid altitude, high rainfall, alluvial soil	Chitedze	-13.9732	33.65403	1146	Chromic Luvisol	960	Manual CA
Zambia	Chipata	Eastern Zambia	Mid altitude, high rainfall, Ferralitic soils	Msekera	-13.6212	32.59765	1018	Luvisol	800-1000	Manual/AT CA
Zambia	Monze	Southern Zim/Zam	low to midaltitude, low rainfall, sandy/loamy soils	Monze	-16.2402	27.44145	676	Chromic Lixisols	748	Manual/AT CA
Zimbabwe	Mazowe	Southern Zim/Zam	low to midaltitude, low rainfall, sandy/loamy soils	Henderson	-17.5727	30.98740	1268	Arensols and Luvisols	884	Manual/AT CA
Zimbabwe	Goromonzi	Southern Zim/Zam	low to midaltitude, low rainfall, sandy/loamy soils	Domboshawa	-17.6077	31.40373	1543	Areni-Gleyic Luvisol	600-800	Manual/AT CA

Notes: Communities marked in bold will be the sites where a Vulnerability Assessment (VA) took place as representative sites of the agro-ecology. CA = conservation agriculture systems, there will be usually two CA systems with several CSA practices compared with a conventional control. Manual CA systems are done with planting stick (Dibble stick) while AT CA are seeded in riplines created by an animal traction ripper or animal traction direct seeder.

Data included in the studies were from on-farm trial and had to satisfy the following characteristics:

a. Treatments included a conventional tillage control and at least two CSA treatment interventions which were replicated at least four times in each target community in each year;
b. Trials were conducted in on-farm communities scattered around different agro-ecologies with a cluster of farms being the trial replicates at each community;
c. Trial replicates in each target community were established close to each other to reduce the influence of soil heterogeneity and rainfall variability;
d. Trials were managed by farmers with oversight by an extension officer and researchers from the national agriculture research services (NARS) and CIMMYT
e. Trials were established under rain-fed conditions in southern Africa and not irrigated;
f. The test crop in these trials was maize as the predominant food crop in southern Africa, although some treatments where intercropped with either cowpeas or pigeon peas
g. At most sites, a full rotation of maize with legumes was practiced annually (with cowpeas, soybeans, pigeon peas or groundnuts as rotational crops).
h. For ease of analysis and better understanding of datasets, we grouped treatments into four major agro-ecologies and analyzed the data accordingly (Table 1).

As mentioned before, data was mainly gathered from long-term on-farm trials managed by CIMMYT and its partners, and here the main systems tested were based on the principles of conservation agriculture (CA). All CA systems tested were planted under no-tillage, while the conventional comparison systems was planted under tilled conditions (both manual and animal traction tillage). All CA systems had residues retained at a rate of at least 2.5 t ha^{-1} while they were burned, removed or grazed in the conventional system. The treatments tested were mostly animal traction systems in southern Zimbabwe and southern and parts of eastern Zambia, while predominantly manual systems were analyzed in southern, central Malawi and parts of eastern Zambia (see Table 2 for further explanation).

All sites had complimentary climate smart agriculture interventions under research using combinations of drought-tolerant maize varieties, different legumes as intercrops, targeted fertilizer application etc., which, however, were not the primary concern for this analysis.

Some of the data has been reported in previous publications in different contexts (Thierfelder et al. 2013c; Thierfelder et al. 2013b; Thierfelder and Wall 2012; Thierfelder et al. 2012a; Ngwira et al. 2012; Thierfelder et al. 2014; Thierfelder et al. 2015c) and more details about trial establishment, fertilizer levels, plant populations and varieties can be found there. Economic and social benefits data was collected in representative sites to enrich the study with socio-economic data.

Specific data needed for the feasibility study could not be collected in the on-farm sites and here on-station trial data from regional LT trials, which have been established in representative agro-ecologies, were used to support the study. In particular, erosion, soil carbon, water infiltration and soil moisture data was captured in on-station long-term trials from Henderson Research Station and Monze Farmer Training Centre where trials have been established since 2004 and 2005. A regional Carbon study is underway. However, by the time of finalizing the report, the data was not yet available.

Table 2: Treatment tested in different target areas of southern Africa under the CCARDESA/GIZ project

Site cluster	Conventional system	CA option 1	CA option 2	CA option 3
Central Malawi	Ridge tillage, maize-legume rotation	Dibble stick, maize- legume rotation	Dibble stick, maize/legume intercropping-legume rotation	
	All maize is fully rotated with groundnuts since 2010 and since 2013, maize plots are sub-divided into 6 subplots testing 5 drought-tolerant maize varieties and a conventional control. Fertilizer level is 69 kg ha^{-1} N:21 kg ha^{-1} P$_2$O$_5$:0 kg ha^{-1} K$_2$0: 4 kg ha^{-1}S			
Southern Malawi	Ridge tillage, maize-legume rotation	Dibble stick, maize- legume rotation	Dibble stick, maize/legume intercropping--legume rotation	
	All maize is fully rotated with pigeon peas, cowpeas or groundnuts since 2011 depending on sites and since 2013, maize plots are sub-divided into 6 subplots testing 5 drought-tolerant maize varieties and a conventional control; Fertilizer level is 69 kg ha^{-1} N:21 kg ha^{-1} P$_2$O$_5$:0 kg ha^{-1} K$_2$0: 4 kg ha^{-1}S			
Eastern Zambia (manual)	Ridge tillage, maize	Dibble stick, maize	Dibble stick, maize-legume intercropping	Dibble stick, maize- rotation
Eastern Zambia (animal traction)	Conventional mouldboard ploughing, maize	Ripline seeding/direct seeding, maize	Ripline seeding/direct seeding, maize-legume rotation	
	All maize was planted as continuous sole crop, intercrop or in full rotation; Fertilizer level is 108 kg ha^{-1} N:40 kg ha^{-1} P$_2$O$_5$: 20 kg ha^{-1} K$_2$0			
Southern Zim/Zam	Conventional mouldboard ploughing, maize-legume rotation	Ripline seeding maize- legume rotation	Direct seeding, maize- legume rotation	
	All maize is fully rotated with cowpeas since 2008 in Zambia and since 2012 in Zimbabwe. Since 2013, maize plots are sub-divided into 4 subplots testing 3 drought-tolerant maize varieties and one conventional control; Fertilizer levels in Zimbabwe were 80 kg ha^{-1} N:23 kg ha^{-1} P$_2$O$_5$: 12 kg ha^{-1} K$_2$0 and in Zambia 108 kg ha^{-1} N:40 kg ha^{-1} P$_2$O$_5$: 20 kg ha^{-1} K$_2$0			

2.2. Data sources and analyses for social and economic studies

For the analysis of social and economic benefits we used the data collected in on-farm study communities. Cost Benefit Analysis (CBA), a basic approach for the evaluation of net social or private welfare from technologies, practices/projects was adopted. CBA is a comparison between the present value of the streams of benefits and the present value of all investment and recurrent costs (de Graaff and Kessler 2009).

CBA in the context of this study was employed to evaluate the on-farm benefits and costs associated with adopting at least a combination of two CSA practices, improved drought tolerant maize & legume varieties. The scale of the CBA in this study was farm level and the objective was a financial analysis of the benefits and costs from the CSA adoption. CBA is used in this study as decision tool after computing all cost and benefits valued in local currency and converted to US dollars.

Data on economic viability of CSA measures and conventional practices were obtained using a standardized protocol from on-farm trial. Additional information on the benefits and costs of the CSA were collected from a 2012; 2014 and 2015 households surveys of randomly selected households. The validity of information provided by individual farmers was verified through interviews with key informants, agricultural extension officers as well as focus group discussions. The unit for comparison used in the CBA was 1 hectare (1 ha) of land. The net benefits of each CSA option was evaluated against average net benefits from conventional traditional practices for that particular year. The CBA of CSA options required an in-depth understanding of the effectiveness of CSA to minimize climate risk, increase crop yields, save labour and deliver other benefits. Data from on-farm experiments and formal surveys were itemized into costs and benefits. Production costs include labour, equipment maintenance, and material required during land preparation, planting, seeding, fertilization, weeding, and harvesting. However, the partial budgets did not take into account fixed costs, such as value of land, interest on capital, and depreciation as is customary practice (CIMMYT 1988). Benefits included all gains in current production caused by implementing CSA measures. The major benefit considered in the analysis - based on the information provided by farmers - were increased yield and saved labour due to adoption of the CSA practice. Benefits (yield of grain, biomass and nitrogen benefits) were converted into monetary values by multiplying it with the market price and then summed to obtain the total benefit.

Three CBA indicators were used in the CBA: Net Present Value (NPV), the Internal Rate of Return (IRR) and payback period supported by Return on Investment (RoI) and Return on Labour (RoL). Though adoption of CSA occurred at irregular frequencies based on the panel data, empirical evidence revealed that most of the CSA practices assessed have been promoted by the projects for at least 5 years, thus providing sufficient time to capture their impacts. Therefore, an ex-post CBA approach was adopted.

The NPV was used to sum the incremental flow of net benefits generated by the CSA options over 4, 5 and 6 years for Malawi, Zambia and Zimbabwe respectively. NPV shows the present value of net benefit stream generated by each CSA option being compared over their lifetime period and is calculated as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Where: Bt = benefits at time t, Ct = investment and recurrent cost at time t, t = time horizon, and r discount rate.

A nominal discount rate of 30% was applied. This is the same as the prevailing commercial bank prime lending interest rates in the three countries. It was assumed that this reflects the farmer' time preference for his/her money and also what the farmer would seek from an investment with high risk. Empirical evidence shows that the Malawi and Zambian Kwacha were overvalued by 10-20% for part of the study period hence the high prime lending interest rate. An investment is technically and economically feasible if the NPV is positive.

The IRR determines the discount rate that makes the net present worth of the incremental net benefit stream or incremental net cash flow equal zero. It represents the maximum interest that an investment could pay for the resources used if the investment is to recover its initial and operating costs and still break even (Gittinger 1982). As land and labour are often most productive resources available to smallholders, high returns to land and labour are often critical in the adoption process. Any CSA with IRR exceeding the discount rate is considered economically viable. It is determined as follows:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t} = 0 \quad IRR >$$

Where: Bt = benefits at time t, Ct = investment and recurrent cost at time t, t = time horizon, and r discount rate.

The payback period (PP) is the time required for the amount invested in a CSA practice to be repaid by the net cash flow generated. It is a simple way to evaluate the risk associated with the investment (Turner and Taylor 1998).

$$Payback\ period = \frac{Initial\ investment}{netcashflow\ period}$$

The NPV, IRR, and PP were determined for the different combinations of CSA practices commonly adopted in the different agro-ecological zones. Each combination has its own production, mitigation and adaptation functions and therefore generates a different stream of costs and benefits.

3. Benefits of CSA practices

In past research, CSA practices have been evaluated mostly on bio-physical benefits only. It was the aim of this study to provide a more holistic view and scientific evidence about the potential benefits of CSA to the wider public. In particular, it was important to better understand what financial benefits can be expected from a CSA intervention based on the gross receipts (yield) and costs (labour and input costs). In addition, it is important to summarize the environmental benefits of such interventions to better judge what potential adaptation and mitigation benefits can be derived. Finally, CSA practices need to be socially acceptable as well and should not lead to disproportional labour burdens on women and children or other negative side effects. These different aspects will be analyzed in the following chapters. Data from the different agro-ecologies were analyzed and categorized under different subject areas to better understand the feasibility, viability and social benefits. The subject areas to be discussed in the next chapters are: a) economic benefits; b) bio-physical benefits; c) environmental benefits and d) social benefits. These will be summarized and discussed at the end.

3.1 Economic benefits

Economic benefits of CSA technologies are realized in financial benefits accruing directly to farmers who have adopted CSA technologies and positive spill-overs into the macro-economy. The financial benefits largely stem from the ability of CSA technologies to increase yield, reduce degradation and through labour savings. Average smallholder conventional yields for maize in Zimbabwe are less than 1 t·ha^{-1} and slightly higher in Malawi and Zambia (± 2 t·ha^{-1})(Thierfelder et al. 2015b). CSA technologies increase production hence a farmer has a larger surplus to sell which increases household revenue and reduces household expenditure through supplementary purchases of maize. Increase in local production of maize strengthens the maize value chain, reduces food aid and imports, and ultimately results in increased resilience of the target countries.

3.1.1 Cost Benefit analysis: Malawi

From the partial budget generated (see ANNEX S1-S6) the CBAs were conducted. At the farm level, all CSA options analysed were economically viable (i.e. a positive NPV and IRR greater than the discount rate). All the prioritized CSA options required at least half a year to provide economic returns (increased productivity and income) as reflected by the payback period (Tables 3-4).

In southern Malawi communities, CA maize-legume intercrop was the most economically viable CSA option. It had comparatively higher NPV, IRR, ROL, and ROI compared to CA maize-legume rotation, and the conventional traditional system in all the three communities. For the 7-year period the estimated NPVs for 1 hectare of maize intercropped with pigeon pea and discounted at 30% were US$219, US$903, and US$1036 for Herbert, Malula and Matandika respectively (Table 3). Whilst for the conventional system for the same period and discount rate the NPVs were US$95, US$252, and US$113 for Herbert, Malula and Matandika, respectively. The estimated profitability of CA maize-legume intercropping system over the other CSA practices and the conventional system in the land constrained communities is attributed to improved land and labour use efficiency and increased crop yields. CA maize-legume intercropping had the highest internal rate of return (IRR) which suggests that farmers who are able to adopt this CSA have a better chance of recovering their investments than with CA maize and the conventional maize system.

Table 3: Summary of Net Present Value (NPV), returns on investment (ROI), Payback, Internal Rate of Return (IRR) in communities of Central and Southern Malawi

Malawi South	Community	CSA	NPV1 12%	NPV2 30%	ROL $	ROI $	Payback	IRR %
	Herbert	Conventional, sole maize-rotation	130.50	94.85	2.80	0.46	8.68	49
		CA, sole maize-rotation	265.43	195.28	15.28	0.89	0.73	50
		CA maize/legume Intercrop-rotation	494.78	348.59	17.98	1.77	1.27	53
	Malula	Conventional, sole maize-rotation	334.68	252.32	6.04	1.09	1.84	51
		CA, sole maize-rotation	573.95	451.03	27.61	1.80	0.79	53
		CA maize/legume Intercrop-rotation	1220.24	902.82	47.90	3.97	0.28	58
	Matandika	Conventional, sole maize-rotation	147.51	113.26	3.27	0.48	2.43	46
		CA, sole maize-rotation	527.00	400.33	28.19	1.74	0.93	53
		CA maize/legume Intercrop-rotation	1488.55	1036.39	63.48	5.15	0.22	59
Malawi Central	**Mwansambo**	Conventional, sole maize-rotation	433.78	323.56	8.45	1.49	1.07	0.51
		CA, sole maize-rotation	696.57	680.89	30.15	2.37	0.46	4.16
		CA maize/legume Intercrop-rotation	697.15	677.13	28.57	2.38	0.47	3.29
	Chinguluwe	Conventional, sole maize-rotation	234.43	168.22	4.95	0.91	11.45	0.48
		CA, sole maize-rotation	356.17	271.41	15.41	1.26	1.18	0.54
		CA maize/legume Intercrop-rotation	446.62	345.91	18.45	1.60	0.99	0.56
	Zidyana	Conventional, sole maize-rotation	217.94	162.01	4.66	0.76	2.21	0.51
		CA, sole maize-rotation	480.09	358.13	21.13	1.72	0.76	0.51
		CA maize/legume Intercrop-rotation	454.22	339.38	18.56	1.53	0.85	0.52
	Chipeni	Conventional, sole maize-rotation	180.28	114.21	4.67	0.65	0.73	0.41
		CA, sole maize-rotation	389.08	293.36	17.56	1.30	0.79	0.53
		CA maize/legume Intercrop-rotation	378.88	282.30	17.56	1.32	0.81	0.51

Plate 2: Women often carring the brunt of work in farming communties (left), while direct seeding technologies are reducing on-farm labour for planting (right)

Plate 3: Ripline seeding is an alternative to the mouldboard plough (left), seeding into undisturbed soil with residue cover (right)

Plate 4: The principle of conservation agriculture (minimum soil disturbance, crop residue retention and crop rotations (left and right)

The IRR for CA maize legume intercropping were 53%, 58%, 59% compared to the conventional system (49%, 51% and 46%) for Herbert, Malula and Matandika, respectively (Table 3). As this exceeds the discount rate of 30% it can be considered more profitable. CA maize-legume intercropping produced two crops (maize and pigeonpea) on the same piece of land using less labour for land preparation and weeding. This system is therefore a viable option for land and labour constrained farmers. Considering the decision criterion, CA maize-legume intercropping generated the highest net welfare considering the existing conditions (drought risk severity, erratic onset of the season). The results further showed that it takes longer for the farmers to recover their working capital for the conventional maize an average of 8.7, 1.8, 2.4 years for Herbert, Malula and Matandika, respectively, compared to an average of 1 year or less for the CA maize and CA maize legume intercrop as measured by the payback period (Table 3).

For the central region the CA systems provide similar benefits (Table 3). Thus CA maize- or CA maize-legume intercrop are both economically feasible. These two CSA practices have higher NPV, IRR, ROL, and ROI relative to the conventional traditional system. For the estimated 7-year period the NPV using 30% discount rate for 1 hectare of CA maize ranged from US$162 to US$ 680, CA-maize-legume intercropping ranged from US$282 to US$677, compared to US$122 to US$323 for the conventionally tilled maize (Table 3). The profitability of the CA maize system was context specific in central Malawi. Mwansambo had the highest internal rate of return (IRR) for the CA maize of 416%, which suggests that farmers who are able to adopt CA maize stand a much higher chance of recovering their investments than with the conventional maize system. It is interesting to note that the CA maize system provide higher profitability as measures by ROL and ROI compared to CA maize legume intercrop system in central Malawi.

3.1.2 Cost Benefit analysis: Zambia

In the manual systems of Eastern Zambia CA maize-legume intercropping was the most economically feasible CSA option in all the communities except Chanje (Table 4). It had the highest NPV, IRR, ROL and ROI compared to other CSA options and conventional maize system per hectare of maize. For the 6-year period the estimated NPV using 30% discount rate for the CA maize legume intercrop were US$255, US$418, US$613 for Chanje, Mtaya and Vuu, respectively. Whilst for the conventional system for the same period and discount rate the NPVs were US$108, US$ 94, and US$ 173 for the three sites, respectively. The economic viability of the CA maize-legume intercropping system is attributed to the improved soil and water conservation and the yield of two crops at the same time which increased the overall benefits of the system. The CA maize legume intercropping had the highest return to labour and investment for all the three communities practicing manual system. For example, for the Vuu community every dollar invested in labour and working capital generated and additional $2.4 and $20.5, respectively. The higher rate of return (IRR) and return on labour of this system suggests that farmers who are able to adopt CA maize-legume intercropping have a better chance of recovering from climate shocks. The results also show that CA maize-legume rotation is an economically viable CSA option relative to the conventional system measured by the positive NPV, IRR and ROL. The CSA options require between one and two years to provide economic returns (increased productivity and income) as reflected by the payback period suggesting that they are the best bet technologies for cash constrained smallholder farmers (Table 4).

Table 4: Summary of Net Present Value (NPV), returns on investment (ROI), Payback, Internal Rate of Return (IRR) in communities Eastern Zambia

Community		CSA	NPV1 12%	NPV2 30%	ROL $	ROI $	Payback	IRR %
Manual CA system	**Chanje**	Conventional maize	179.94	107.64	0.6	2.8	6.5	57
		CA sole maize	325.31	189.92	1.0	7.7	2.2	55
		CA maize-cowpea intercrop	464.25	254.91	1.3	9.5	1.5	52
		CA maize -cowpea rotation	516.66	279.67	1.6	12.9	1.4	51
	Mtaya	Conventional maize	181.46	94.62	0.7	2.5	8.1	50
		CA sole maize	468.62	340.81	1.4	9.8	1.8	78
		CA maize-cowpea intercrop	582.87	417.84	1.7	10.5	1.7	76
		CA maize -cowpea rotation	240.03	187.81	0.7	5.4	0.4	95
	Vuu	Conventional maize	251.97	172.99	1.1	7.6	1.4	69
		CA sole maize	685.47	548.12	2.2	18.7	0.5	102
		CA maize-cowpea intercrop	777.83	613.24	2.4	20.5	0.5	97
		CA maize -cowpea rotation	673.38	534.05	2.3	20.9	0.6	99
Animal traction CA system	**Hoya**	Conventional maize	277.72	221.95	0.9	6.5	2.2	82
		Ripper CA, sole maize	500.50	380.97	1.6	14.1	0.8	87
		Ripper CA maize-soy rotation	620.24	460.35	2.0	17.8	0.6	102
	Kawalala	Conventional maize	451.05	332.87	1.5	9.7	2.3	81
		Ripper CA, sole maize	533.26	398.83	1.7	16.8	1.0	83
		Ripper CA maize-soy rotation	362.22	296.10	1.0	9.5	0.8	111
	Kapara	Conventional maize	309.80	233.59	1.0	5.9	1.6	85
		Direct Seeder Maize continuous	306.31	270.32	0.8	6.1	1.1	165
		Direct Seeder maize-soy rotation	365.22	311.98	0.9	6.6	0.8	135

For the mechanised CA systems in Eastern Zambia, ripline seeded CA maize-legume rotation was the most economically viable CSA option as measured by the highest NPVs, IRR and the shortest payback period (Table 4). For example, in the Hoya community, for the 6-year period the CA maize-legume rotation NPV was US$ 460, IRR was 114% compared to US$222 and 82% for the conventional system, respectively. It also had the highest return to labour and investment implying that it is the most appropriate technology for labour and cash constrained smallholder farmers. For the direct seeding

systems with animal traction (Kapara), CA maize continues and CA maize-legume rotation had the highest NPV (US$270 and US$312) and IRRs of 165% and 133% which suggests that farmers who are able to adopt this practice have a better chance of recovering their investments than conventional tillage (Table 4). In southern Zambia, the direct seeded maize had also the highest NPV (US$843) under the 30% discount rate and an IRR (102%) compared to the Ripper CA maize and conventional maize treatment (Table 5), although the payback period was shorter in the conventional treatment..

Table 5: Summary of Net Present Value (NPV), returns on investment (ROI), Payback, Internal Rate of Return (IRR) in communities Southern Zambia

Community		CSA	NPV1 12%	NPV2 30%	ROL $	ROI $	Payback	IRR %
Southern Zambia	Monze	Conventional ploughing, maize	389.36	305.25	7.84	1.23	0.04	95
		Ripper, Maize	961.05	761.31	27.81	2.84	0.85	99
		Direct Seeder, Maize	1054.68	843.27	30.52	3.12	0.86	102

3.1.3 Cost Benefit analysis: Zimbabwe

In both communities of Southern Zimbabwe, CA-ripping with maize proved to be the best CSA option in terms of profitability and climate risk reduction. Based on the 7 years estimates, 30% discount rate for a hectare, the CA ripping treatment had the highest NPV (US$257) and an IRR (84%) in Bvukururu. The implication of these results is that farmers who are able to adopt this practice have a better chance of recovering their investments and higher economic benefits relative to other CSA options and the conventional maize system considering the prevailing semi-arid and poor soil fertility conditions. The payback period is about 1.37 years compared to a minimum of 11.98 years for the conventional maize system. The ripping treatment provided a higher income with much lower initial investment but ROL and ROI were almost the same with the conventional system.

Although we found that Basin-CA would have a higher NPV and IRR, we would not recommend further promotion of CA-basins as this systems has had limited adoption in the past due to labour burdens and cultural constraints (Thierfelder et al. 2016; Arslan et al. 2014; Umar 2014).

Table 6: Summary of Net Present Value (NPV), returns on investment (ROI), Payback, Internal Rate of Return (IRR) in two communities southern Zimbabwe

Community	CSA	NPV1 12%	NPV2 30%	ROL $	ROI $	Payback	IRR %
Bvukururu	Conventional, maize-rotation	316.18	229.52	2.58	0.72	11.98	78
	Ripper, maize-rotation	342.14	256.88	2.47	0.72	1.37	84
	Direct Seeder, maize-rotation	225.56	141.69	1.99	0.51	2.19	60
Zishiri	Conventional, maize-rotation	131.39	104.30	0.27	1.57	7.00	99
	Ripper, maize-rotation	264.62	184.93	0.60	2.22	1.37	72
	Direct Seeder, maize-rotation	120.75	46.41	0.39	1.81	5.34	41

In summary, significant economic benefits were discovered in different areas and different cropping systems. The NPV, IRR, ROL and ROI where highest and payback period lowest in the CA treatments with maize intercropping in Malawi and Eastern Zambia. Amongst the animal traction systems the ripline seeded system with full rotation was considered the most economically viable treatment in southern Zimbabwe and eastern Zambia. In Southern Zambia, the direct seeding system was the most economical treatment.

3.2 Biophysical benefits

Using the results of LT datasets that CIMMYT generated with the National Agriculture Research and Extension Services (NARES) and NGO partners (e.g. TLC) in the last decade, we could analyze the yields in time series depending on the length of research we conducted in different target communities on-site.

Overall yield benefits of CSA systems across sites and seasons in each agro-ecology were positive (Figure 1). However, looking at the four general agro-ecologies we had to further refine the yield comparisons in Eastern Zambia as the predominant treatment were both animal traction and manual systems. In addition, during analysis we discovered that the sites in Monze (southern Zambia) and Zaka (southern Zimbabwe) had more distinct differences than expected due to more favorable soil types (e.g. *Lixisols* in Monze as compared to more sandy soil types (*Arenolsols)* in Zaka). We therefore further separated Monze from Zaka sites in the analysis.

3.2.1 Central and Southern Malawi

Yield analyses from the two agro-ecologies of Malawi showed that yield benefits were more variable in Central Malawi as compared with southern Malawi. (Figure 2 -3). In Central Malawi, the first consistent yield benefits between the two CSA options tested and the conventional control were only measured after the 5th cropping season and were then maintained in most of the following season (Figure 2). Very large yield difference were recorded in the harvest year 2012, which coincided with a dry year with very erratic rainfalls and longer dry spells.

Due to large variability between farmers and farms, not all years resulted in significant yield benefits in the Central Malawian sites. However overall, averaging all observations throughout all years, led to a yield benefit of 23% and 26% (894 kg ha^{-1}- 941 kg ha^{-1}) yield benefit in CA with sole maize and CA with maize/legume intercropping, respectively, over the control. In none of the years, the conventional practice outyielded any of the CSA practices which is remarkable as the majority of farmers still practice the tillage-based agriculture system.

In southern Malawi, average yields were generally lower than in central Malawi due to lower overall rainfalls (Figure 3) in this lower potential area. However, yield benefits of CSA treatments were apparent in 9 out of 11 cropping seasons with greatest yield benefits for example in the drought year 2011/2012. Yield benefits were higher in this drought prone environment for CSA treatments and ranged between 39%-36% (1161 kg ha^{-1}- 1071 kg ha^{-1}) in CA systems with sole maize and CA with maize/legume intercropping, respectively, over the control.

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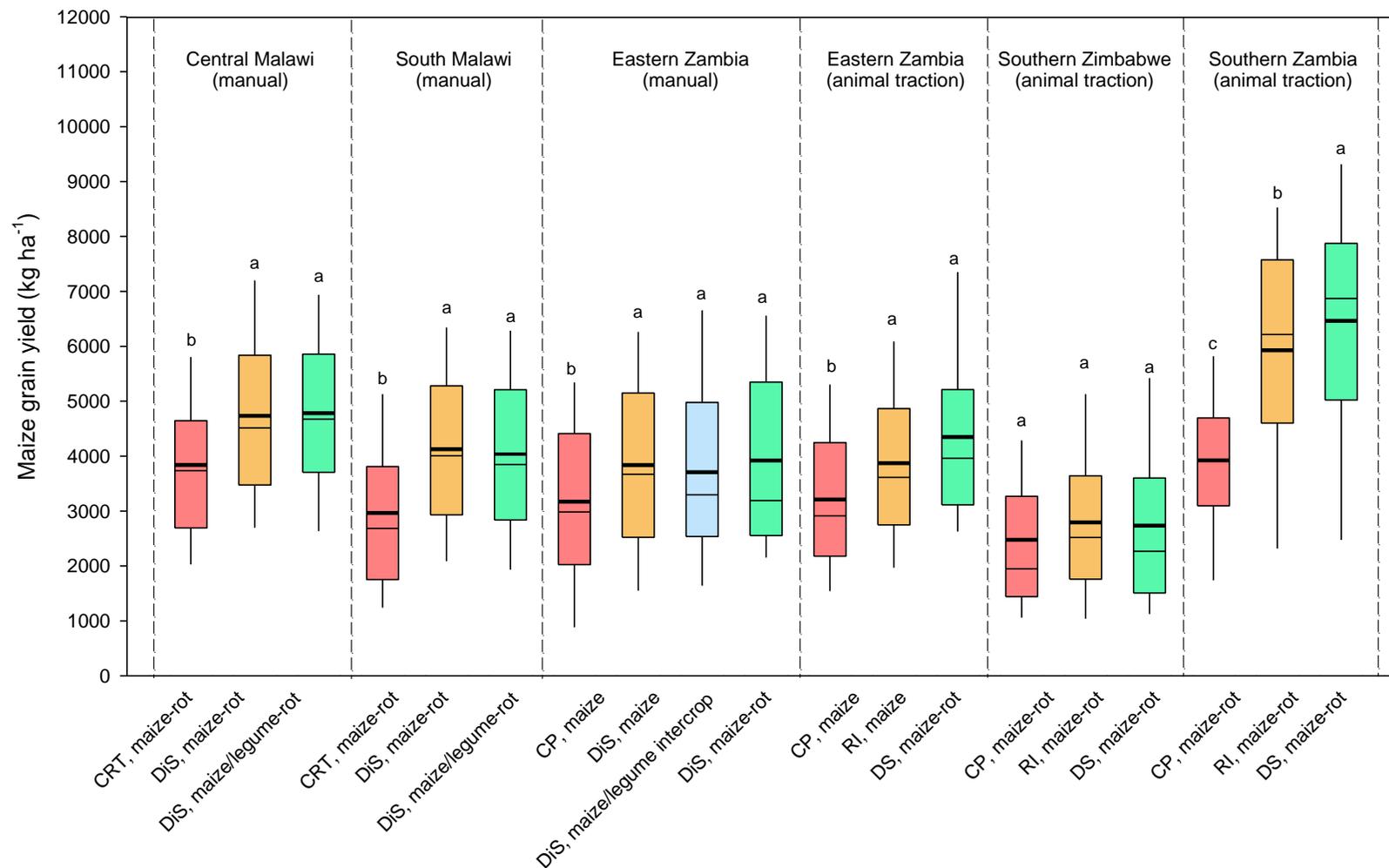
Figure 1: Maize yield response to CSA treatments in four target agro-ecologies in southern Africa. CRT- conventional ridge tillage; DiS-dibble stick; CP-conventional moldboard ploughing, RI- ripping; DS-direct seeding. Boxplots show the distribution of all available maize grain yield results from all farmers in the target communities. The boxplot shows the 25% and 75% quartile, the whiskers the 95% confidence interval. Mean letters above the whiskers of each treatment that show a different letter are significantly different at P<0.05 probability level.
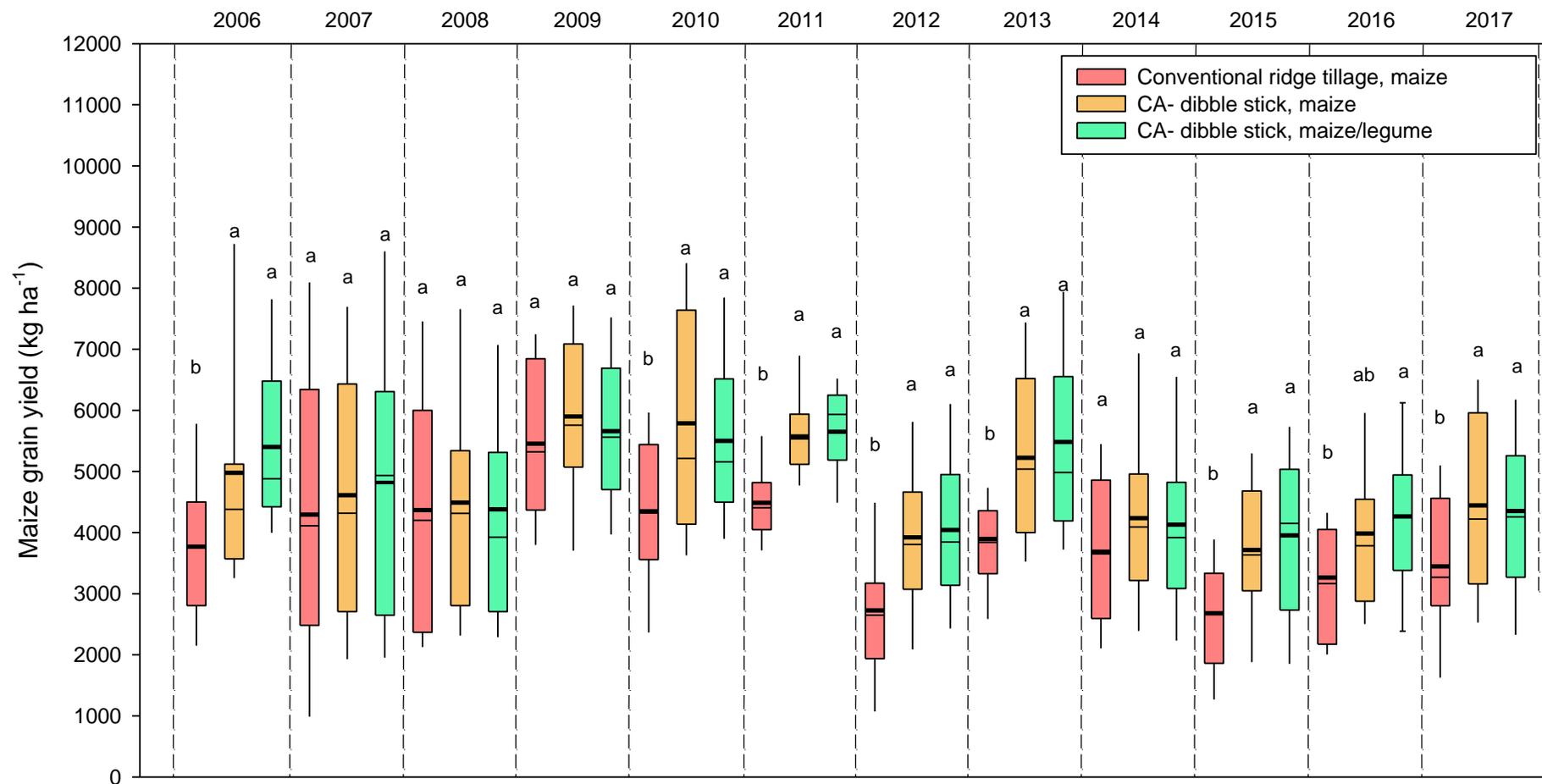
Figure 2: Maize yield response to CSA treatments in five target communities of Central Malawi, 2006-2017. Boxplots show the distribution of all available maize grain yield results from all farmers in the target communities. The boxplot shows the 25% and 75% quartile, the whiskers the 95% confidence interval. Mean letters above the whiskers of each treatment that show a different letter are significantly different at P<0.05 probability level.
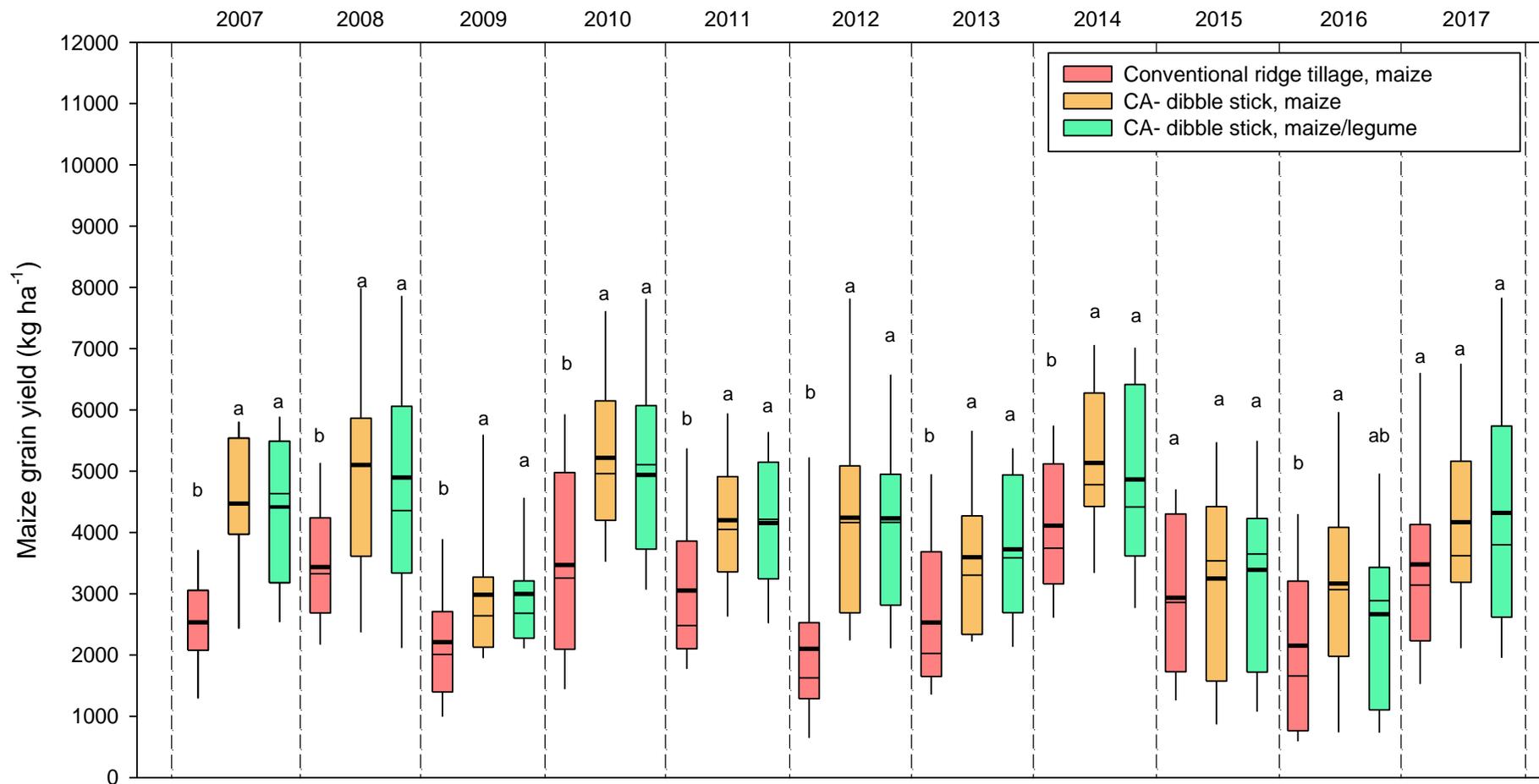
Figure 3: Maize yield response to CSA treatments in five target communities of Southern Malawi, 2007-2017. Boxplots show the distribution of all available maize grain yield results from all farmers in the target communities. The boxplot shows the 25% and 75% quartile, the whiskers the 95% confidence interval. Mean letters above the whiskers of each treatment that show a different letter are significantly different at P<0.05 probability level.

3.2.2 Eastern Zambia

In eastern Zambia, there were moderate yield benefits in both the manual systems and the animal traction systems (Figure 4a and b). Yet, they were more pronounced in the animal traction systems (4b) than in the manual systems (4a). Significant yield benefits in CSA treatments were only discovered in 2 out of 6 seasons in the manual systems (Figure 4a) and in 4 out of 6 years in the animal traction systems (Figure 4b). Overall yield benefits (Figure 1) were lower than in Malawi and ranged between 17%-27% (536-749 kg ha^{-1}) in the manual systems and 20%-35% (662-1139 kg ha^{-1}) in the animal traction systems. Highest yielding in this comparison was in both cases the treatment in full rotation with legumes. However, full rotation also means that there is maize yield only every second season as in the first season there will be a legume grown instead of maize which has an effect on the overall economic benefit as already confirmed in the economic chapter where the most economical treatment was the maize/legume intercropping treatment under CA.

3.2.3 Southern Zimbabwe and Southern Zambia

In the dry areas of southern Zimbabwe and southern Zambia there was a distinct difference between both countries (Figure 5a and b). While there was only a marginal yield gains in CSA systems in Zimbabwe leading to no significant yield benefit in the different years (Figure 5a), there was a much greater and more consistent yield benefit when practicing ripline seeding and direct seeding in Monze, Zambia (Figure 5b). However, this only started to emerge after the third cropping season in Monze and was maintained thereafter. The overall analysis showed that direct seeding in southern Zambia was the highest yielding treatment with a yield benefit of 61% (2091 kg ha^{-1}) over the control. Second was the ripline seeding with a yield benefit of 49% (1698 kg ha^{-1}) over the conventional practices, respectively. In southern Zimbabwe, the yield benefits were between 11%-13% (260-390 kg ha^{-1}).

In summary, with the exception of southern Zimbabwe, there were consistent positive trends of all CSA treatments tested in the different agro-ecologies and in most cases they became stronger, the longer the systems were practiced. However, the systems as tested and practiced in the different target areas were affected by considerable variability between farmers in each area and in-season variability, as affected by external stress factors (e.g. droughts or in-season dry-spells). Average yields in southern Zambia for example ranged from 2.2t ha^{-1} in the El Niño year 2015/2016 to 6.9t ha^{-1} in the very good 2016/2017 cropping season. Results from Malawi were generally more consistent due to the nature of the conventional practices in Malawi, which is more disturbing than for example in Southern Zimbabwe.

Plate 5: Doubled-up legume systems are one CSA intervention that sustainably increase maize productivity (left –legume phase and right - maize phase)


Plate 6: Numerous legumes are available for rotation in maize-based CSA farming systems (groundnuts on the left and cowpea and groundnuts on the right)

*Plate 7:* Performance of CSA practices on the left of each picture as compared with the farmer practices on the right
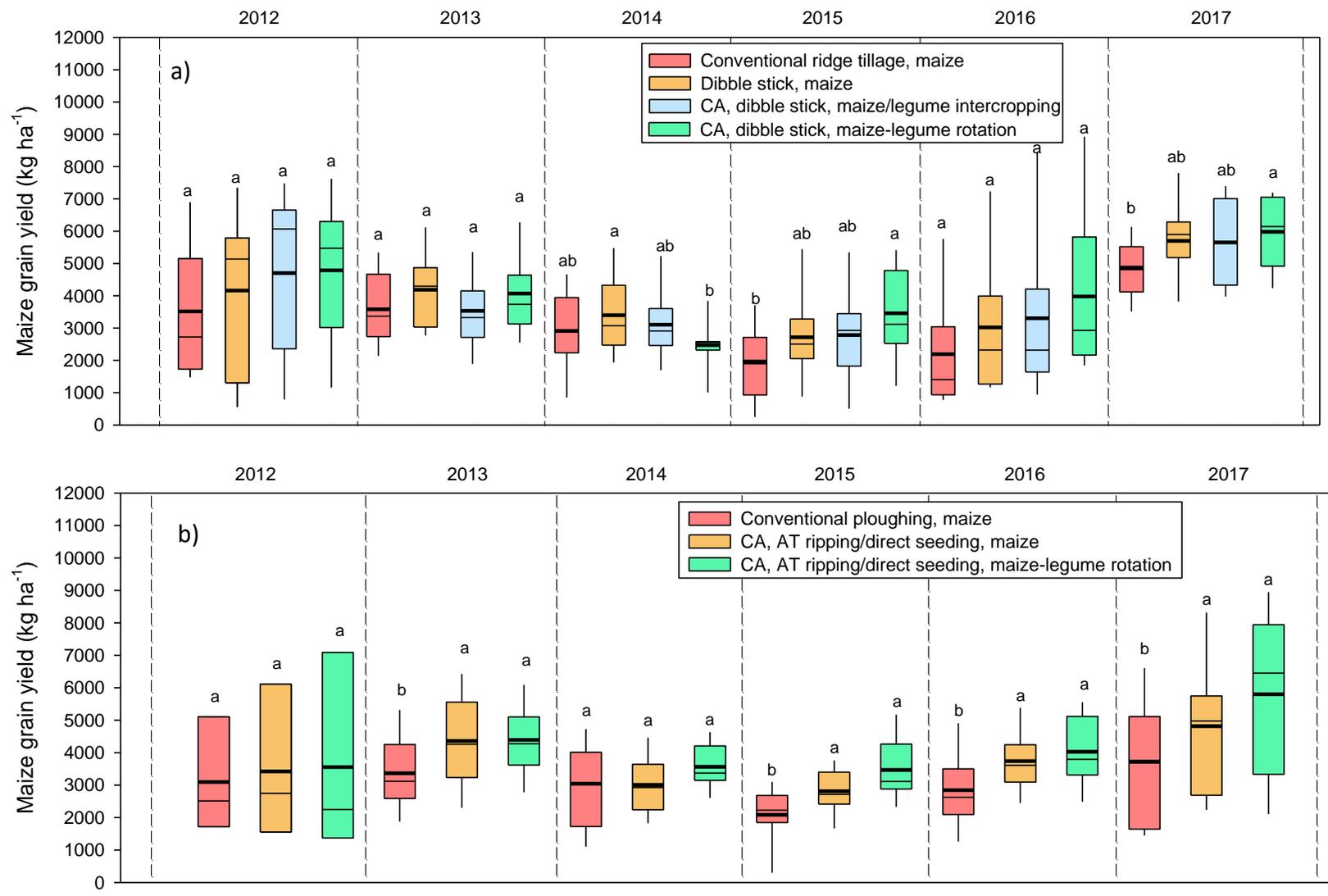
Figure 4: Maize yield response to CSA treatments in manual (a) and animal traction systems (b) in six target communities of Eastern Zambia, 2012-2017.

Notes: Mean letters above the whiskers of each treatment that show a different letter are significantly different at P<0.05 probability level
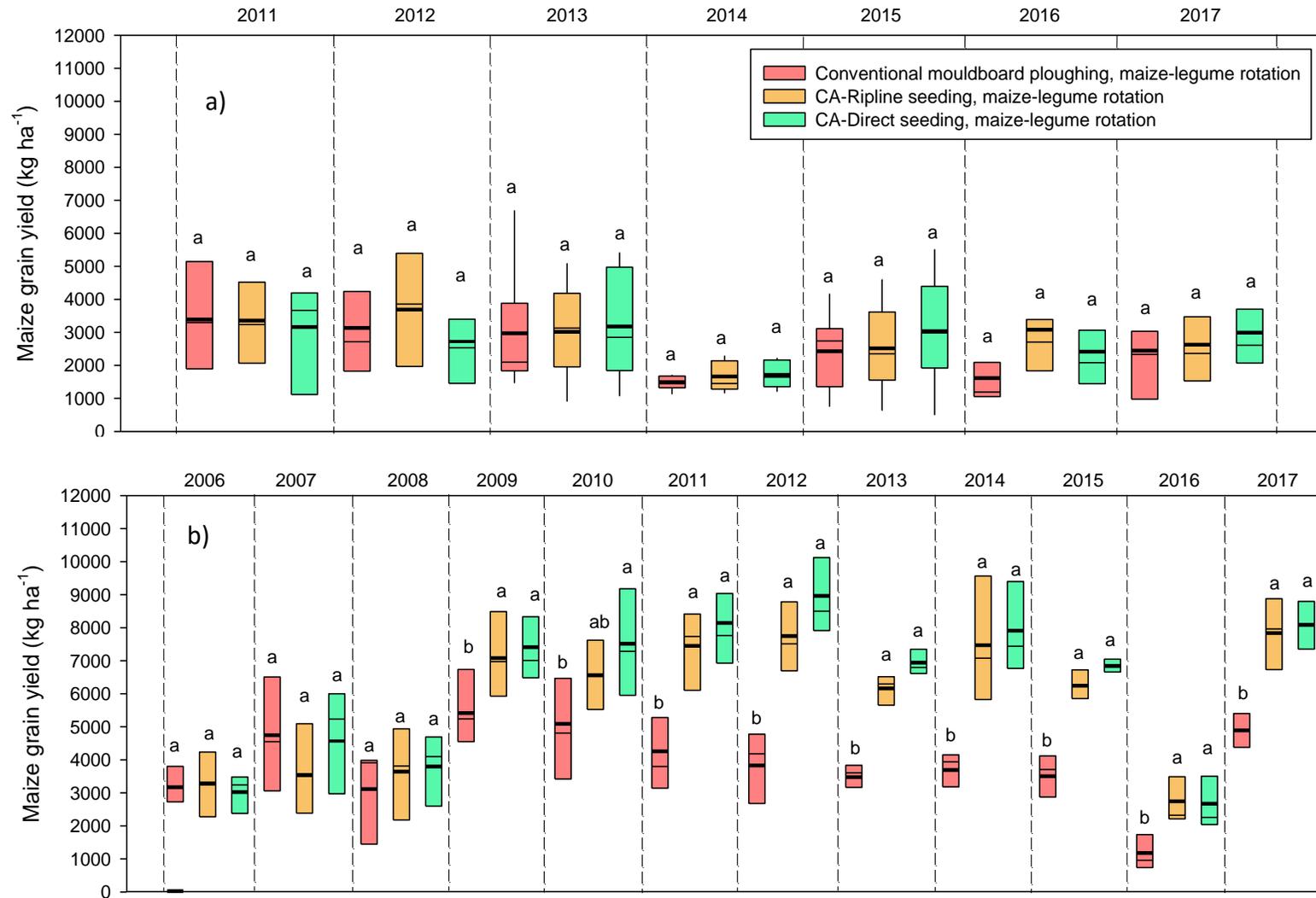
Figure 5: Maize yield response to CSA treatments in and animal traction systems in three target communities of southern Zimbabwe (a) and Zambia (b), 2011-2017. Mean letters above the whiskers of each treatment that show a different letter are significantly different at P<0.05 probability level

To enrich our existing results, a regional study done by Steward et al. (2018) using all regional on-farm data from CIMMYT trials in a meta-regression analysis under combined drought and heat stress showed clear benefits of CSA over conventional systems. Results highlighted that precipitation balance (calculated as positive and negative moisture stress) and heat stress risk at anthesis (defined as $\log_e(GDD_{30+}+1)$) have a non-linear effect (i.e. there is an interaction between them) on conservation agriculture yield performance relative to the conventional practice (Figure 6).

Yields under conservation agriculture were generally greater than the conventional practice in drier growing seasons (precipitation balance less than 200 mm, where precipitation balance is the difference between seasonal rainfall and potential evapotranspiration) and decreased as precipitation balance falls (Figure 6). Heat stress also affected conservation agriculture performance, but depended on soil clay content. For southern Africa, where the majority of soil types have sandy to sandy loam soil texture, there is great confidence that the CSA practices studied will have a significant positive benefit on climate adaptation (Steward et al. 2018).
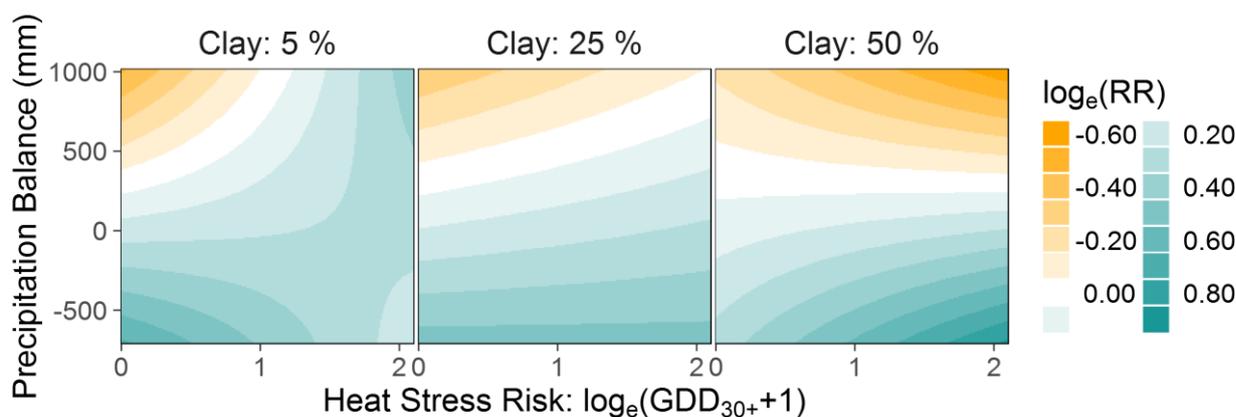
Figure 6: The effect of heat stress at anthesis ($\log_e(GDD_{30+}+1)$) and growing season precipitation balance (precipitation – potential evapotranspiration) on conservation agriculture yield performance relative to conventional practice ($\log_e(RR)$) across low (left), medium (middle), and high (right) soil clay contents. Negative values of precipitation balance, toward the bottom of panels, indicate a rainfall deficit while moving from left to the right in the panel signifies increasing heat stress. Blue colours in the graph indicate that conservation agriculture outperforms conventional practice and vice-versa for orange. The graph includes crop diversification in no-till systems (additional predictions with no crop diversification. Source: Steward et al. (2018).

3.3 Environmental benefits

To build resilience against climate stress there is need to store enough moisture in the soil to make sure this is available during heat and drought stress. Increased infiltration enables a faster built-up of water resources and reduces soil erosion and surface run-off. Sequestration of soil carbon shows the mitigation benefit of CSA by storing CO_2 as soil carbon in the soil. We therefore researched a range of indicators meant to improve the adaptation and mitigation to climate change in on station trials in southern Zambia and Zimbabwe and the results are summarized below.

3.3.1 Water infiltration

Due to no-tillage land preparation used in the specific CSA practices and the rotation and residue management as mulch, a beneficial soil pore structure developed over time that enabled more sustained infiltration into the soil. This benefit can usually be measured from the onset of CSA implementation and is a very good indicator for increased adaptive capacity and resilience (Steward et al. 2018; Thierfelder and Wall 2010a; Thierfelder and Wall 2009).

We summarized the results from the last cropping season when infiltration was measured (Figure 7a and b) at Monze Farmer Training Centre (southern Zambia) and Henderson Research Station (Zimbabwe) with a mini-rainfall simulator. At Henderson, four CA treatments were compared with a conventionally ploughed control treatment whereas in Monze, three CA treatments were compared with the ploughed control (Figure 7a and b). The rainfall simulator irrigates a defined soil area with a known rainfall intensity and the run-off is measured. The difference is then defined as water infiltration.

The results from the simulation measurement show a distinct difference at both trial locations where all CA systems are clearly segregating from the conventional farmer's practices (Figure 7a and b). The soil type played a significant role as well at both sites. At Henderson the soil is characterized by more sand and a clay-rich denser sub-soil, whereas in Monze the soil is generally more fertile and richer in clay. At Henderson, the final infiltration rate of CA treatments was 48.5 mm h^{-1} higher than the conventional practice. At Monze, the final infiltration rates of all CA treatments were 39.4mm h^{-1} higher than the conventionally control practice (Figure 7b). At Monze, the final infiltration rate in the control was as low as 10.4 mm ha^{-1}. Overall infiltration was higher at Henderson on the sandy soil than on the clay-rich soils of Monze.

3.3.2 Soil moisture

Increased infiltration can only be a benefit if it translates into increased soil moisture for plant production. We analyzed soil moisture at the same two stations for the last three cropping systems and found interesting results (Figure 8 and Figure 9). The general trend during the cropping season at Henderson showed that the conventional system had equal soil moisture contents at the onset of study. During the cropping season, the CA practices separated always from the conventional system. The graph showed some anomalies in the first dry season as there are some moisture peaks that must have been in response to rainfalls that fell during this time. For security reasons at this relatively remote location we do not measure rainfall during the dry season, hence no recording of any daily rainfall was captured during this time. Interestingly, the conventional treatment never surpassed the other treatments at any given time (Figure 8).
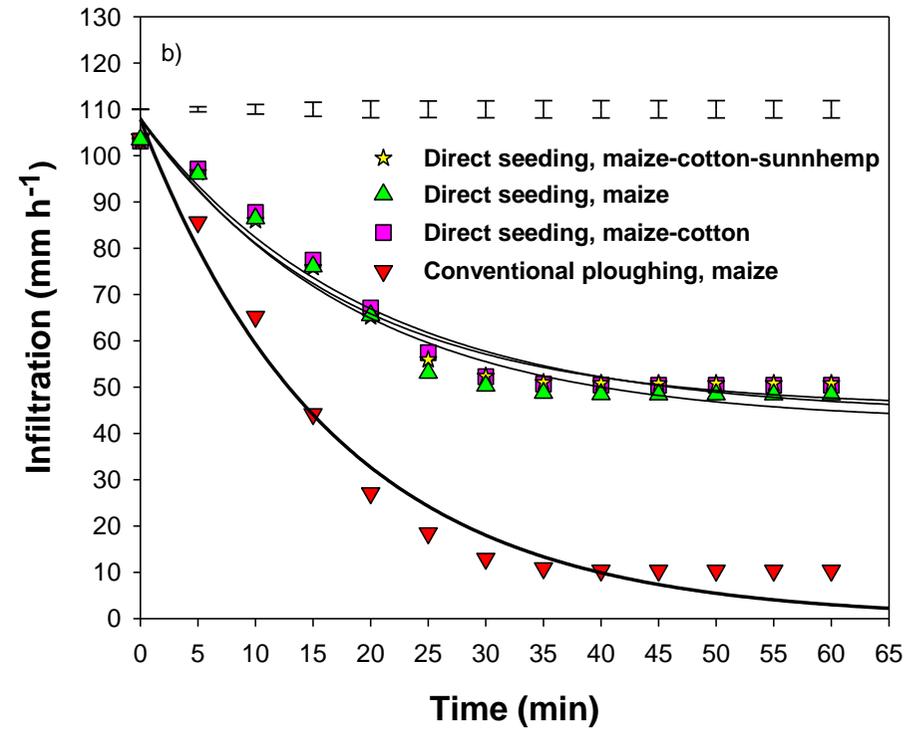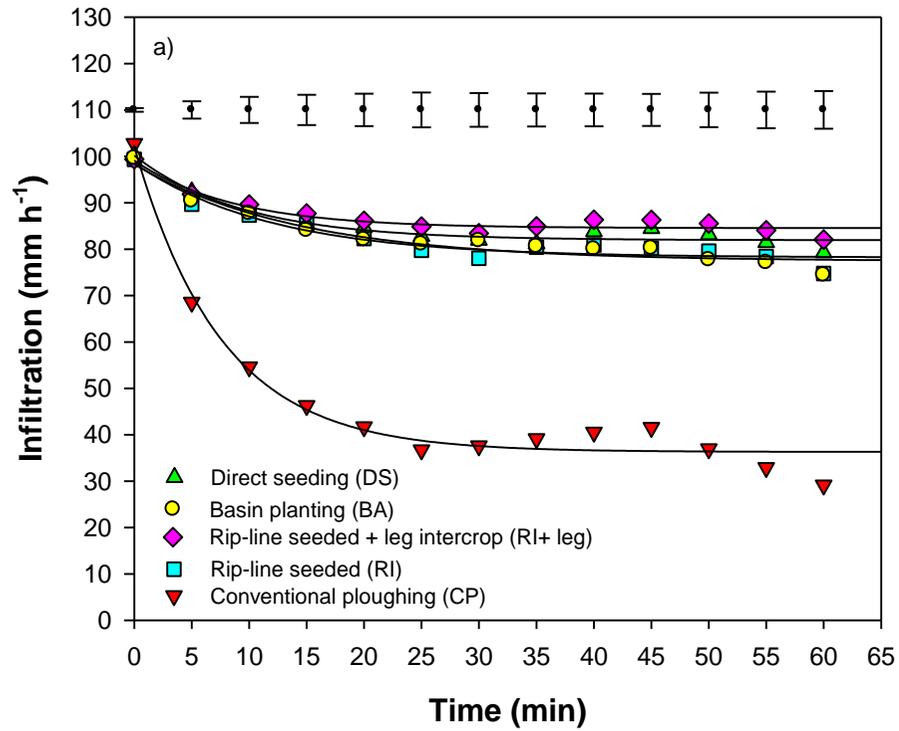
Figure 7a and b: Infiltration rate as measured by a mini-rainfall simulator in a conventionally ploughed treatment and different CSA practices in a CA long-term trials of Zimbabwe (a) and Zambia (b), January 2017
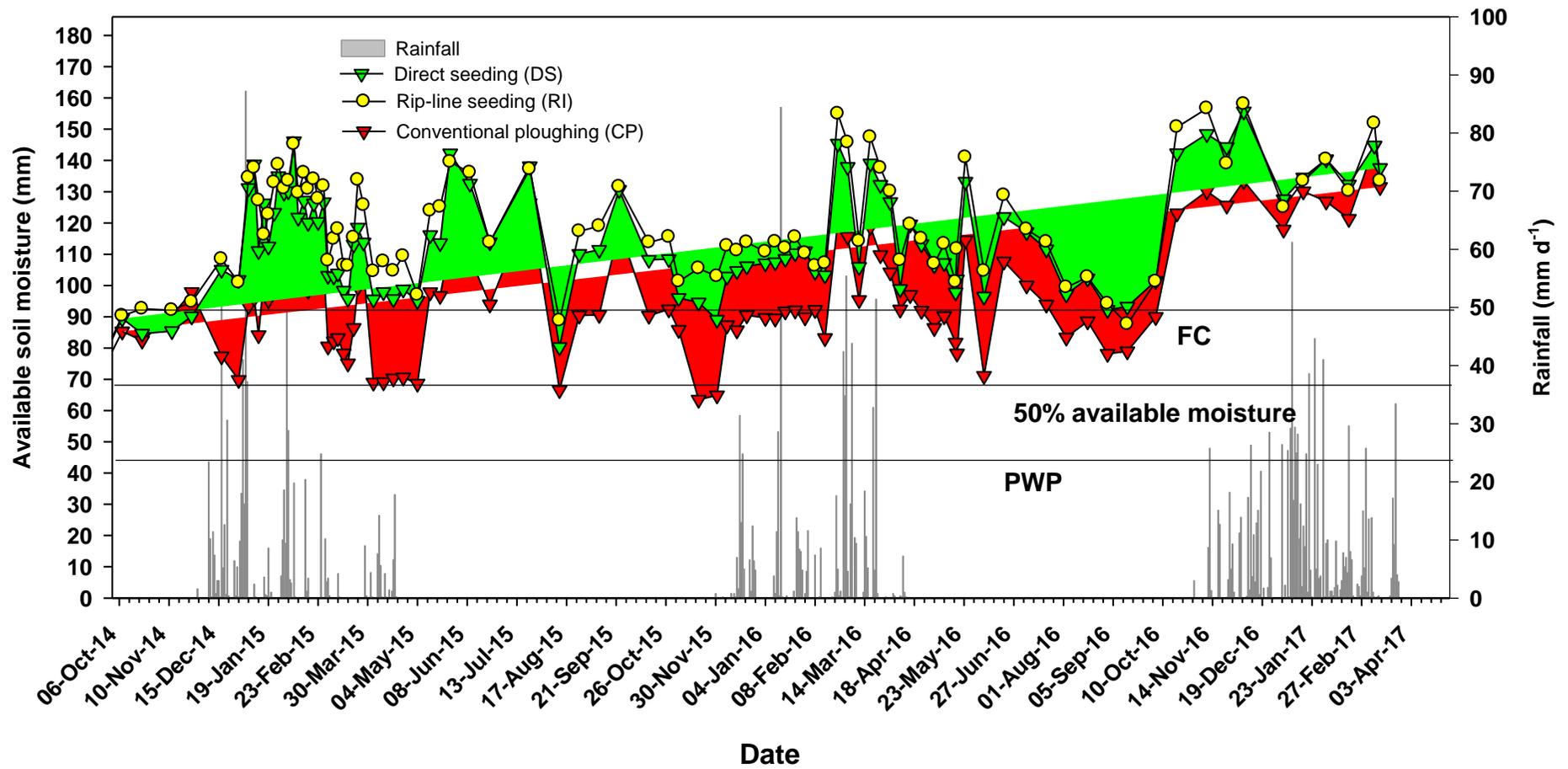
Figure 8: Available soil moisture in 0-60cm depth at the Henderson Research Station, Zimbabwe, 2014-2017; PWP-permanent wilting percentage; FC – field capacity
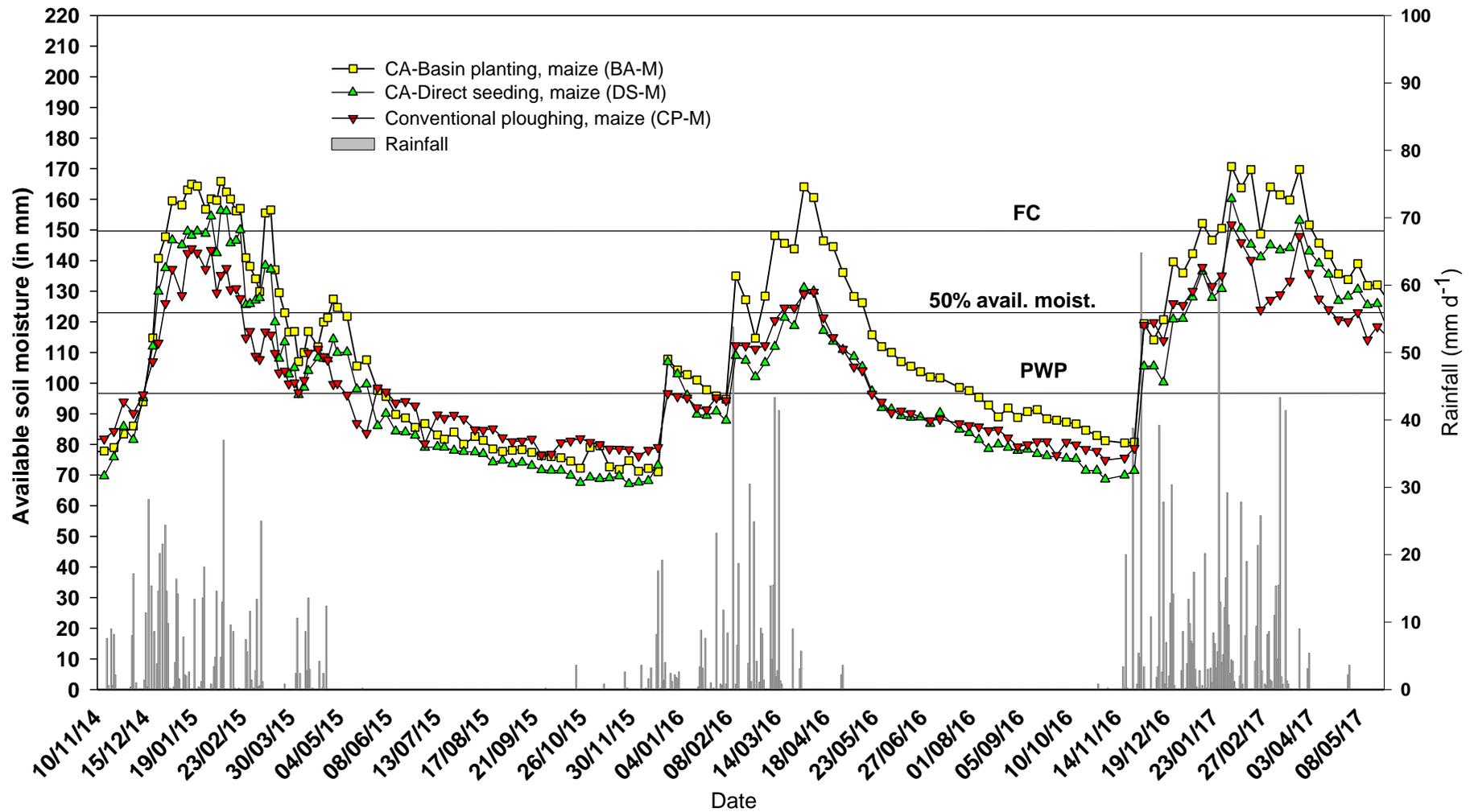
Figure 9: Available soil moisture in 0-60cm depth at the Monze Farmer Training Centre, Southern Zambia, 2014-2017; PWP-permanent wilting percentage; FC – field capacity

At Monze, the CA basin planted treatment had always the highest soil moisture content, supporting the argument that basins are water-harvesting technologies (Figure 9) and is more climate smart. The direct seeding treatment was not as effective in maintaining higher soil moisture and lowest was the conventional ploughed treatment. The greatest difference between basins and the conventional practice was recorded in the El Niño year (2015/2016) where some of the treatments fell below the permanent wilting point at the onset of the cropping season with associated effects on crop yields at the end (Figure 9).

3.3.3 Soil erosion

Soil erosion was measured at the Henderson Research Station, the only place where there is sufficient slope to install run-off plots in three treatments (Figure 10). The cumulative erosion load on the ploughed treatment with residue removal had dramatically high soil erosion rates and reached 143t ha^{-1} after 12 cropping season. This translates to approximately 11.8t ha^{-1} a^{-1} soil loss on average per cropping season. Cumulative soil erosion was lower in both CSA practices with 52.3 and 56.7 t ha^{-1} after 12 cropping season in a ripline seeded maize with legume intercropping and a direct seeded maize treatment (Figure 10). This translates to an average soil loss of 4.3-4.7 t ha^{-1} a^{-1} in the two treatments (64-61% less than the conventional practices). Soil loss and the associated run-off are the most critical factors in long-term sustainability as most of the fertile topsoil is washed away in the conventional treatment, which reduces the water holding capacity and the resilience to withstand climate stress. It has to be noted, however, that even the two CA treatments still have high erosion loads which is mainly a response to the sandy soil structure and heavy rainstorms experienced at the site during the study.
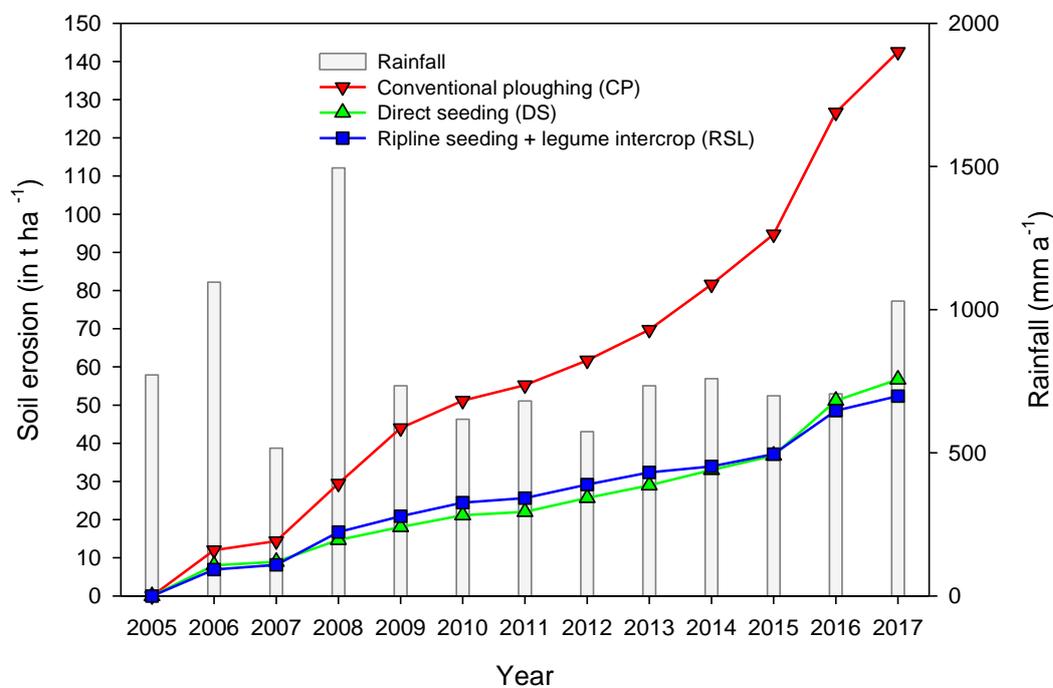
Figure 10: Cumulative soil erosion and sediment load (in t ha^{-1}) in two CA and a conventional ploughed system at Henderson Research Station, Zimbabwe; 2005-2017
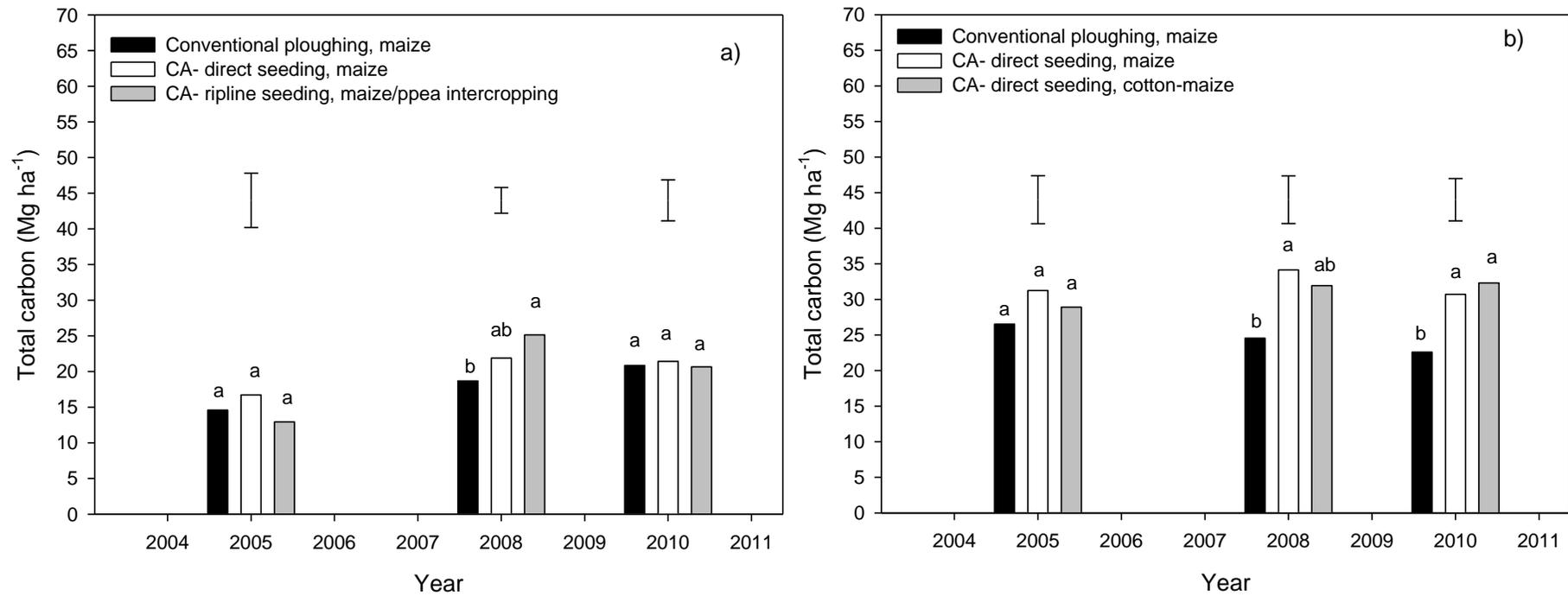
Figure 11a and b: Soil carbon development of time in different CSA interventions as compared with a conventional control at Henderson Research Station (a), Zimbabwe and at Monze Farmer Training Centre (b), Zambia

3.3.4 Soil organic carbon

Soil carbon was measured in on-farm trials during the project. However the results of the analysis was not available by the time of writing this report. We therefore used other historical data from on-station trials that show the development in soil carbon over time (Figure 11a and b). The results from Henderson Research Station (Figure 11a) showed an increase in soil carbon from 2004-2008 in all treatments with the greatest increase (of 12.9 t ha^{-1}) experienced in the maize legume intercropping system that was ripline seeded. This was slightly reduced in 2010 where no significant difference between treatments was discovered (Figure 11a). At Monze Farmer Training Centre (Figure 11b) there was a decrease in soil carbon in the conventional ploughed control with sole maize and residue removal over time while it increased in both CA systems from 2004-2010. The greatest increase was found in a direct seeded maize-cotton rotation which increased by 3.6 t ha^{-1} over time. In the same time, the conventional control decreased by 3.9 t ha^{-1}. The reason for an increase in carbon at Monze (Figure 11b) and inconclusive results from Henderson (Figure 11a) in CSA practices can we related to the soil types that are present and the protection of organic carbon from decomposition in micro-aggregates at Monze which was previously confirmed by Chivenge et al. (2007). At Henderson, where the soil type is predominantly sandy there was less of such protection and there is no real increase in carbon over time. Interestingly the data on soil carbon in CSA systems is highly contested as some studies acknowledge an increase and others have not found any (Powlson et al. 2016; Rusinamhodzi et al. 2012; Cheesman et al. 2016; Thierfelder et al. 2017; Ligowe et al. 2017; Corbeels et al. 2018) which highlights the context-specific nature of soil carbon increase in different CSA systems (Corbeels et al. 2018).

3.4 Social benefits

The most apparent social benefit of the promoted CSA practices was increased maize productivity (see Figures 1-5). CSA practices promoted in these drought zones reduced the potential yield loss due to moisture stress by up to 60%, hence increasing household food availability and stability. As an example we can highlight the 2014/15 and 2015/16 cropping seasons in southern Malawi and Zimbabwe where maize productivity decreased drastically due to moisture stress whereas maize plots under CSA practices performed much better than the conventional plots reducing the need for food aid and the lean month period in February/March of each year that followed the drought periods.

This benefit is of great value to women as custodians of household food and nutritional security particularly in these communities. Women's abilities to adapt their farming practices to cope with the effects of climate change and variability strongly contribute to family health and nutrition. Findings from the focus group discussion and participatory evaluation revealed that women benefited greatly from particularly CA maize-legume intercropping. This option improved household dietary diversity particularly when maize was intercropped with cowpea. The leaves provided relish either fresh or dried. The cowpea grains had several uses in the household including improving nutrition for the children. During the focus group discussion in the 5 communities in the three countries, women highlighted that they make different patties with grain and they also blend the cowpea grain with maize to enrich their maize meal.

The results of analyzing labor saving as a social benefit showed that on average across the CSA practices, labor demand decreased at least by 25-45 person days ha^{-1} (Figures 12 and 13). This was mainly attributed to reductions in weeding and for land preparation.
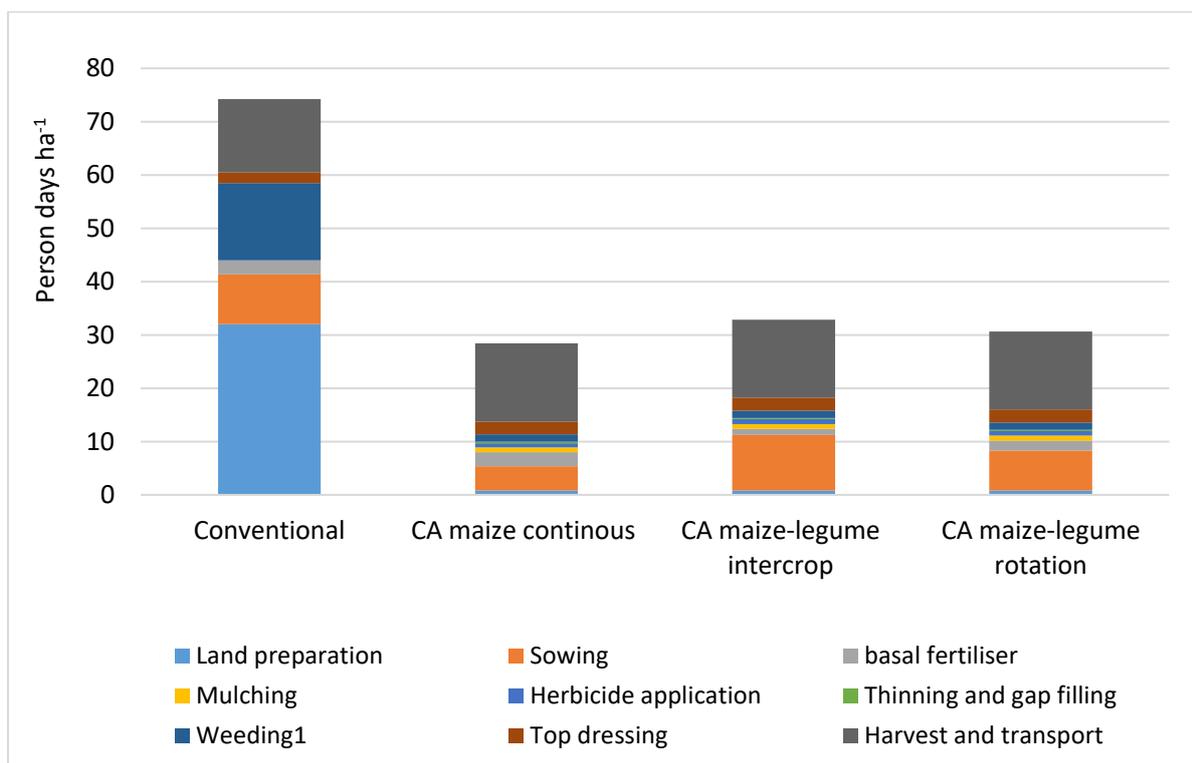
**Figure 12:** Labour demand for different Manual CSA practices in Eastern Zambia
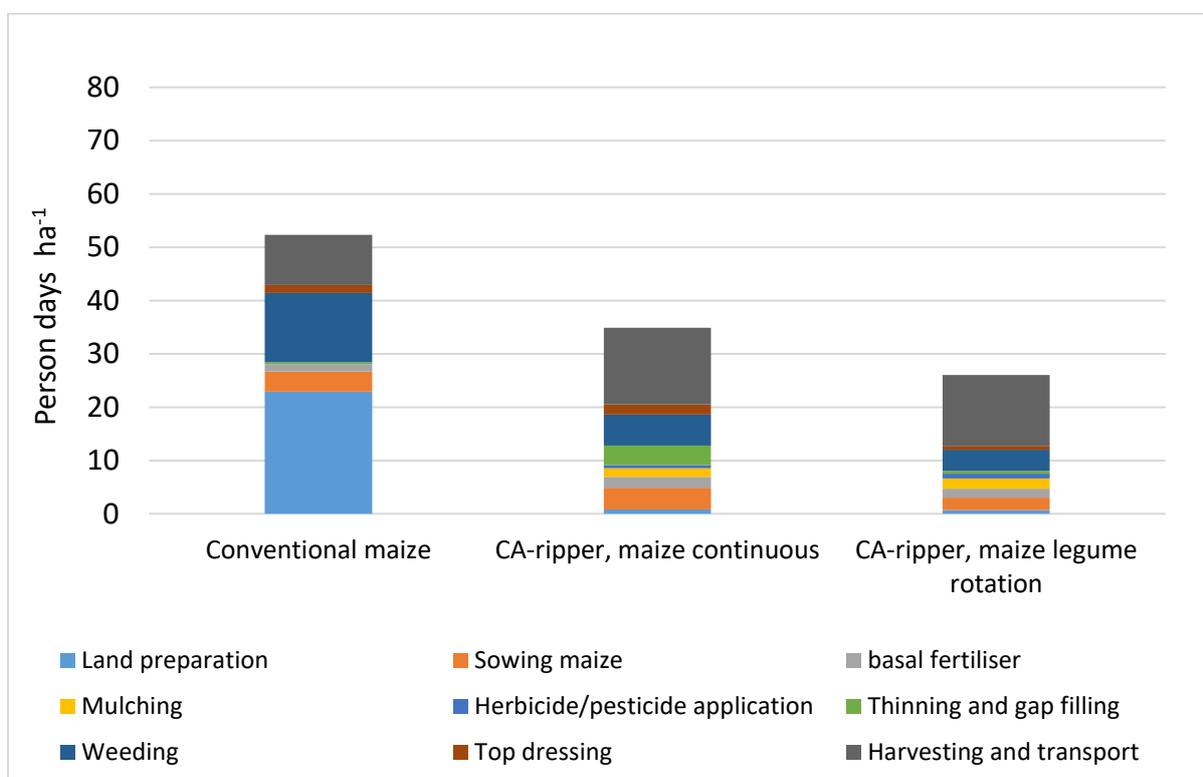
Figure 13: Labour demand for different animal traction CSA practices in Eastern Zambia

The labour saving in land preparation under CSA practices in Figure 12 and 13 are associated with shifting from ridging in the conventional practices to direct seeding using a dibble stick or a ripper under CSA in Malawi and Zambia. In southern Zambia and Zimbabwe, the land preparation was with animal traction, labour saving in land preparation were mainly reduced draught power and time per hectare. Use of pre-emergency herbicides further reduced labour demand for the first and second weeding. Such weeding reductions over time were acknowledged by farmers and have been confirmed in the partial budget analysis. As weeding is a labour task predominantly done by women and children, there is a direct social benefit associated with a reduction in on-farm weeding labour.

4. Challenges with the implementation of CSA practices

Due to the site specific nature, exposure and specific risks, the implementation of CSA practices as described in the previous chapters has not been without challenges and may still require research on solutions to the upcoming threats expected from climate variability and change (Thierfelder et al. 2017).

4.1 Crop residues- benefits, conflicts and trade-offs

Crop residues are essential in the CSA practices described above. They protect the soil from the heavy impact of rainfall, reduce evaporation, and halt soil erosion and run-off through greater infiltration. They lead to increased soil moisture thus making the system more resilient against climate stress (Thierfelder and Wall 2009; Mupangwa et al. 2016). Residues encourage soil life and enhance biological activity (De la Cruz-Barrón et al. 2017). Although they may be associated with the carry-over of some pest and diseases (e.g. stalkborers hibernate on cereal crop residues as well as the spores of some fungal leave diseases), they are also providing additional benefits in form of biological pest control. Between crop residues we find increases in predatory spiders and shelter for ants (Kaluzi et al. 2017).

However, due to limited soil moisture in southern Africa and a relatively short growing period they are a scarce resource (Mupangwa and Thierfelder 2014) and intensive crop livestock interactions and trade-offs are associated with them (Valbuena et al. 2012). Crop residues are used for fodder, building material, fuel, surface retention, grazing during the dry season and are in very high demand, which limits their availability. Leaving crop residues on the soil surface under such circumstances is very challenging and has been one of the main reasons why farmers did not make use of the full benefits of CSA practices (Mupangwa and Thierfelder 2014). Alternative strategies to retain crop residues have been explored which range from temporarily removing the residues and applying them again, the use of grass and leave litter as available replacements, growing living crop residues in form of intercrops or applying leaves and branches from intercropped shrubs (Thierfelder et al. 2015d). However, none of these options have so far been fully satisfactory. Community agreements are therefore required to improve local by-laws against free grazing systems to allow for CA farmers to keep their residues.

4.2 Rotations and other diversification options

Traditionally farmers in southern Africa use some forms of diversification (Giller 2001), although rotations and intercropping strategies are often not strategic, vary in space and time and are highly dependent on available markets for rotational crops or alternative benefits (Thierfelder and Wall 2010b). Also in land constrained situations as found in Malawi, farmers rarely use full rotations of

maize with leguminous or cash crops due to their primary food security concerns. The dominance of maize in the farming system is one of reasons why soils are increasingly degraded and the nutritional status of some smallholder farmers is compromised. For current cropping systems to become more climate-smart, it is essential that more diversification options are implemented.

Some rotations have been tried in southern Africa. For example, in the higher rainfall areas of Zimbabwe and Zambia, CSA systems with maize-soybean and maize-cowpea rotations have been successfully extended (Thierfelder et al. 2012b). In Central Malawi and Eastern Zambia, maize-groundnut rotations have been widely promoted (Bunderson et al. 2017) and in southern Zambia, the use of maize-cotton-sunnhemp rotations were common, although the cotton price drop in recent years made the rotation unviable for smallholders (Thierfelder et al. 2013a).

For farmers with limited land holdings, intercropping has been an acceptable way to diversify. Farmers in all southern Africa, traditionally intercrop maize with pumpkins. There has been a push since the late 1990s to also incorporate grain legumes as intercrops. One of the most successful examples is the maize-pigeonpea system as well as the groundnut-pigeonpea doubled up legume systems (Smith et al. 2016; Snapp et al. 2003; Snapp et al. 2002). Due to the slow growth of pigeonpea in the intercropping systems, there is little competition at the onset and once the pigeonpea matures, the companion crop is already harvested. Other intercropping systems including green manures and grain legumes are currently under research with the aim of increasing groundcover, improve soil fertility, supress weeds, increase fodder for livestock and improved the nutrition of farmers (Mhlanga et al. 2016; Mhlanga et al. 2015b). A range of crops have been tested (e.g. lablab, velvet bean, jack bean, cowpea etc.) and even tree-based systems with *Gliricidia sepium* using chop and drop strategies are disseminated by several NGOs (Thierfelder et al. 2018; Lewis et al. 2011).

4.3 Weeds and their management

Weeds and their control have been a major deterrent for smallholder farmers to adopt specific CSA systems in southern Africa (Muoni et al. 2013; Mashingaidze et al. 2012). The primary reason of tillage is to remove the weeds and to prepare a clean seedbed (Corbeels et al. 2015). If ploughing is abandoned, there have to be alternative practices to manage the weeds. As most of the weed control is manual with hand hoes and/or with cultivators under animal traction, farmers do not appreciate an increase in manual labour and turn away from CSA in the first year(s) of practice if no alternatives are presented. The use of herbicides, at least for the first years of CSA promotion, has been one strategy that successfully led to increased adoption in Malawi and could be one of the entry points to make CSA more attractive to farmers as it addresses one of their most critical constraints (Ngwira et al. 2013; Baudron et al. 2015b). CSA systems using herbicides have also been considered more economical than systems using manual farm labour (Muoni et al. 2013) and lead to gradually decreasing weed seeds on the soil surface (Muoni et al. 2014). Yet, the accessibility and affordability of herbicides for smallholders as well as environmental concerns have been much debated in recent years (Lee and Thierfelder 2017). Research from southern Africa confirmed that rotations with competitive green manures as well as intercrops and/or increased groundcover are alternative strategies to reduce the weed pressure and to make CSA systems more attractive to smallholders (Mhlanga et al. 2016; Mhlanga et al. 2015a). These systems would also make current farming systems more climate smart.

4.4 Availability of appropriate scale machinery

Increasingly farmers face labour shortages on their farmland due to lack of available labour in the rural areas and lack of interest by the youth to accept the drudgery of farming. This has to be addressed with appropriate scale mechanization (Baudron et al. 2015a). Farmers have several options to change from manual, hoe-based systems to more mechanized systems using animal traction or small tractor drawn equipment mounted behind 2-wheel tractors. So far the availability of such equipment tailored to the needs of farmers has been an impediment to the widespread adoption of CSA practices.

The use of animal traction systems has been successfully tested in this study and the yield and labour benefits are apparent. Mechanization with 2-wheel tractors could be another option. However, these options are only profitable if they provide additional benefits and business opportunities (e.g. through shelling, threshing, pumping of water, transport etc.) for small entrepreneurs. Service provision is considered much more viable than farmers owning their own equipment. Future investment into mechanization have to take these points into account to be able to increase the productivity of farming under a changing climate.

4.5 Functional markets and enabling policies

Cropping systems have to be profitable from the start to make CSA options more attractive to cash constrained farmers. Rotation and intercropping systems that give additional cash benefits to smallholders from the on-set can improve the entry points. However, to achieve this, functional markets for both inputs and outputs are required to be able to access the necessary inputs and provide adequate prices for outputs. The collapse of the Indian market for pigeonpea was a classic example on how a CSA intervention like maize intercropped with pigeonpea was put under threat as farmers had no more output market for the commodity overnight. Functional and prospective markets will serves as push and pull for the adoption of more diversified CSA cropping systems.

Policy interventions that enable sustained uptake of CSA practices will continue to be required as current policies mainly focus on supporting single commodity interventions (seed or fertilizer) in subsidy programs instead of more holistic, sustainable and climate-smart interventions. The formulation of NAMAs and NAPAs are a good start in this direction which need to be backed by field-based action and support.

5. Summary and conclusion

A regional study was conducted summarizing results from long-term trials conducted by CIMMYT and partners in the region. The study focused on benefits and challenges of a range of maize-based CSA practices that were conducted in Southern and Central Malawi, Eastern and Southern Zambia and Southern Zimbabwe. Results generated from regional on-farm and on-station trials showed that CSA practices outperform conventional practices under climate stress while providing economic, social and environmental benefits to the farming communities.

The economic analysis of different CSA practices showed that the most beneficial manual cropping system was the maize/legume intercropping system seeded with a dibble stick in Malawi and Eastern Zambia. It had higher gross margins, net present values, returns to labour and investment and an increased internal rate of return. These cropping systems also had a generally shorter payback time which is a critical indicator for the longer term profitability. Amongst the animal traction systems, ripline seeding outperformed other treatments in eastern Zambia and southern Zimbabwe, whereas direct seeding was the top performer in southern Zambia with greatest and more consistent yields and profitability over time. The economic analysis clearly highlights that CSA practices were more economically viable than the conventional tillage-based agriculture systems and that investment in would provide greater returns to labour and cash constrained smallholder farmers.

Biophysical benefits were apparent at all sites, although significant benefits were only consistent in Malawi and southern Zambia. In other areas (e.g. eastern Zambia and southern Zimbabwe) CSA results were more variable, and, in the case of southern Zimbabwe, also not significantly different from the conventional tillage-based practice. Greatest yield benefits between the CSA and conventional practice were measured in southern Zambia were yield benefits on CA systems were on average more than 60% higher than the conventional practice. The generally positive yield trend, especially in the longer term give hope that improvements in soil quality and soil health enhance the adaptive capacity of CSA systems against climate stresses and will support farmers in their quest to become more climate resilient. A regional meta-regression analysis from southern Africa, completed in 2017, clearly shows the superiority of CSA systems under drought and heat stress, especially on sandy soils, whereas the benefits were smaller when soils had more clay or in moisture abundant situations.

Analyzing ecological factors showed that water infiltration under CSA was increased over the conventional control practice which led to greater available soil moisture during the cropping season at all sites measured. In addition, increased infiltration also reduced soil erosion and maintained soil loss and run-off at acceptable levels while it was excessive in the conventional treatment. Increases in soil carbon were detectable despite the short duration of trials, which points to the improvements in general soil quality and health expected from CSA interventions.

Social benefits were apparent from the PRAs done in target communities and reported in the Vulnerability Assessment. CSA practices generally reduced on-farm labour due to less labour needed for land preparation and weeding and improved yields. A more diversified cropping systems helped in increasing the nutrition and food security.

However, the extension of surveyed CSA systems has not been without challenges which require further investment in research and development. Amongst those challenges are the need to maintain sufficient groundcover to buffer the systems against climate variability and change. Other challenges

are the need to diversify the farming system which can be challenging for farmers with small landholdings. Weed control and the availability of specialized inputs (e.g. herbicides) and machinery further add to the challenges. Finally functional markets and enabling policies are critical to enhance CSA more at the plot and farm level as without functional input and output markets, farmers will likely not be willing to change the age-old practices towards more modern, sustainable and climate smart agriculture systems.

Acknowledgment

Plate 8: Farmers in Eastern Zambia celebrating their harvest from CSA practices

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