Renewable Agriculture and Food Systems: 31(5); 414–428 doi:10.1017/S1742170515000332

Conservation agriculture and drought-tolerant germplasm: Reaping the benefits of climate-smart agriculture technologies in central Mozambique

Christian Thierfelder[1*], Leonard Rusinamhodzi[2], Peter Setimela[1], Forbes Walker[3] and Neal S. Eash[2]

[1]CIMMYT, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe.
[2]CIMMYT, P.O. Box 1041-00621, ICRAF House, United Nations Avenue, Gigiri, Nairobi, Kenya.
[3]Department of Biosystems Engineering & Soil Science, University of Tennessee Institute of Agriculture, 2506 E.J. Chapman Drive, Knoxville, TN 37996-4531, USA.
*Corresponding author: c.thierfelder@cgiar.org

Accepted 26 August 2015; First published online 30 September 2015 **Research Paper**

Abstract

Conservation agriculture (CA) based on minimum soil disturbance, crop residue retention and crop rotations is considered as a soil and crop management system that could potentially increase soil quality and mitigate the negative effects of climate variability. When CA is combined with drought-tolerant (DT) maize varieties, farmers can reap the benefits of both—genetic improvement and sustainable land management. New initiatives were started in 2007 in Mozambique to test the two climate-smart agriculture technologies on farmers' fields. Long-term trends showed that direct seeded manual CA treatments outyielded conventional tillage treatments in up to 89% of cases on maize and in 90% of cases on legume in direct yield comparisons. Improved DT maize varieties outyielded the traditional control variety by 26–46% (695–1422 kg ha^{-1}) on different tillage treatment, across sites and season. However a direct interaction between tillage treatment and variety performance could not be established. Maize and legume grain yields on CA plots in this long-term dataset did not increase with increased years of practice due to on-site variability between farmer replicates. It was evident from the farmers' choice that, beside taste and good milling quality, farmers in drought-prone environments considered the potential of a variety to mature faster more important than larger potential yields of long season varieties. Population growth, labor shortage to clear new land areas and limited land resources in future will force farmers to change toward more permanent and sustainable cropping systems and CA is a viable option to improve their food security and livelihoods.

Key words: direct seeding, maize varieties, drought-tolerance, climate variability, adaptation, sustainable intensification

Introduction

In most parts of sub-Saharan Africa, up to 90% of the food consumed is produced under small-scale rain-fed conditions. Southern Africa is generally considered to be most vulnerable to the devastating effects of climate variability (Rohrbach, 2003; Challinor et al., 2007; Mapfumo et al., 2013). Although projections are rather uncertain (Lobell and Burke, 2008; Lobell et al., 2008), the negative effects of climate variability are likely to be increased temperatures and erratic rainfall (Challinor et al., 2007; Thornton et al., 2011; Cairns et al., 2013*a*). Unreliable weather forecasts increase the uncertainty for smallholder farmers to respond to potential future climate threats.

Options are needed to respond to the increased risk associated with a variable climate to achieve food security (Cairns et al., 2012). The underlying hypothesis of this paper is that a combination of conservation agriculture (CA) and locally adapted and drought-tolerant (DT) open pollinated varieties (OPVs) will enable farmers to better respond to a changing climate.

CA is a cropping system based on minimum soil disturbance, retention of living or dead plant material as soil cover and rotation or intercropping of different crop species (Kassam et al., 2009). Plot-level benefits from southern Africa have shown that minimum soil disturbance and crop residue cover has the potential to maintain or increase high levels of water infiltration which leads to more available water in the soil and groundwater (Thierfelder and Wall, 2009, 2010). Mulch cover on the soil surface lessens evaporative losses and maintains a positive water balance (Roth et al., 1988; Findeling et al., 2003; Thierfelder and Wall, 2009; Rockström et al., 2009). The combined effects of minimum soil disturbance, crop residue retention and rotations may also lead to slow increases in soil carbon (Scopel et al., 2005) which further improves water-holding capacity, specifically in sandy soils (Chivenge et al., 2007; Thierfelder and Wall, 2012).

Besides adaptation to the effects of climate variability, CA has been demonstrated to reduce the emission of greenhouse gases (CO_2 and CH_4) (Reicosky and Lindstrom, 1993; Reicosky, 2000; Johnson et al., 2005; O'Dell et al., 2015) although there is controversy to what extent CA contributes to mitigation in tropical and sub-tropical environments (Powlson et al., 2014). Nevertheless, CA is considered to be a 'climate-smart agriculture system' with the potential to reduce the negative effects of climate variability (Thierfelder and Wall, 2010).

Although the strategy of using CA shows promise, there are also concerns about CA as a solution to constraints of small-scale farmers in southern Africa (Bolliger, 2007; Giller et al., 2009; Baudron et al., 2012). While field-level benefits seem to be widely acknowledged, there are contestations on how CA fits at the farm and community levels (Thierfelder et al., 2014).

Breeding for drought-tolerance could assist farmers as well to respond to the negative effects of climate variability in Africa (Cairns et al., 2012; Cairns et al., 2013*a*). In the past, farmers in drought-prone areas grew crop species such as sorghum and millet which are more drought-tolerant than maize (Blum and Sullivan, 1986; Muchow, 1989). In large areas of sub-Saharan Africa, sorghum and millet are therefore chosen as subsistence cereals (Rohrbach, 2003). However in southern Africa, farmers prefer to grow maize due to its high yield potential in seasons with normal rainfall distribution and the taste of the maize porridge, which is preferred over sorghum. Nevertheless, they risk losing 2 out of 5 years maize harvests due to drought (Nyamangara et al., 2013). Maize has become the predominant crop in Southern Africa (Dowswell et al., 1996; Kassie et al., 2012) and strategies are required to better adapt maize to the effects of climate variability. The projected increased frequency of mid-season dry spells (Tadross et al., 2009) requires varieties that can withstand long periods of water stress.

Substantial progress has been made in increasing grain yields under drought stress (Cairns et al., 2013*a*). New varieties in CIMMYT's eastern and southern Africa drought breeding program are evaluated under three water treatments: (i) managed drought stress, with stress applied at flowering; (ii) random drought stress; and (iii) optimal, well-watered conditions. Promising hybrids and OPVs with improved grain yield under managed drought stress are further tested in regional trials managed by CIMMYT, national partners and private seed companies in eastern and southern Africa at more than 90 locations (Magorokosho et al., 2009). This approach has been successfully used to develop new varieties (hybrids and OPVs) with improved grain yield under drought stress and higher yield potential (Setimela et al., 2012). Recent on-farm trials in eastern and southern Africa of new drought-tolerant hybrids showed a 35 and 25% yield advantage against farmers, own varieties under low (<3 t ha^{-1}) and high yield (>3 t ha^{-1}) conditions, respectively (Cairns et al., 2013*a*). To facilitate farmers' access to these new varieties, extensive training and support is currently being given to small and medium enterprises within eastern and southern Africa to enable seed production and dissemination and variety registration (Cairns et al., 2013*b*).

The inclusion of legume crops such as pigeonpea (*Cajanus cajan* (L.) Millsp.) and cowpea (*Vigna unguiculata* (Walp)) in the cropping systems may further help to overcome climate related losses as both crops are drought resistant and often ensure food security when the main crop fails (Rusinamhodzi et al., 2012).

The objective of this study was to test different drought-tolerant maize varieties under CA and assess their performance under different agro-ecological environments. We tested both CA systems and drought-tolerant maize varieties on farmers' fields in central and northern Mozambique. Special emphasis was placed on possible synergistic effects of both improved management practices compared with the current traditional farmer practices. Several surveys were further commissioned to better understand farmers' ability to access improved maize varieties and also to capture farmer's perception and selection criteria for improved varieties.

Materials and Methods

Site descriptions

The study was carried out between 2007 and 2014 in five target communities of central and northern Mozambique (Table 1, Fig. 1). Mozambique is a sub-tropical country with a sub-humid and in some parts arid climate, situated between latitude 10° and 27°S and 30° and 41°E in south-eastern Africa. The selection of target communities was based on a rainfall gradient from north to south and the availability of an extension officer at the selected site. Further important selection criteria were accessibility of the farming community and relative uniformity of soil types within the community.

The communities were selected in four districts of Nhamatanda, Gondola, Báruè and Angonia, located in the three provinces, Sofala, Manica and Tete (Fig. 1).

Table 1. Geographic location of target communities where maize varieties were evaluated under CA.

District	Site name	Latitude	Longitude	Altitude	Soil texture (0–30 cm)	Rainfall range (mm)	Rainfall mean (mm)
Nhamatanda	Lamego	−19.350	34.345	23	Loamy sand	233–902	493
Gondola	Pumbuto	−19.001	33.720	537	Loamy sand	869–1171	952
Barue	Nhamizhinga	−18.365	33.209	636	Sandy loam	1035–1609	1240
Barue	Malomwe	−18.108	33.193	593	Loamy sand	408–1659	1040
Angonia	Nzewe	−14.519	34.304	1388	Sandy loam	534–1055	831

Note: Malomwe and Pumbuto were initiated in 2008; Nhamizhinga followed in 2009; Nzewe and Lamego followed in 2010.

The initial communities were Malomwe in Báruè and Pumbuto in Gondola districts where the study started in the 2007/2008 cropping season. In 2008/2009, Nhamizinga in Báruè district followed. The latest sites were established in Lamego, Nhamatanda district and Nzewe, Angonia district, which all started in the 2009/2010 cropping season. The sites are characterized by a unimodal rainfall distribution (i.e., one main rainfall season), which lasts from the end of October to April in Sofala and Manica. The site in Tete normally receives effective planting rains from December to May. Rainfall in Lamego is characterized by frequent droughts and a large rainfall range (233–902 mm). Pumbuto and Nhamizhinga have a more evenly distributed seasonal rainfall, while rainfall in Malomwe and Nzewe is characterized by strong fluctuations between years (Table 1 and Fig. 2). The sites have moderately sandy textured soils ranging from loamy sands to sandy loams (Table 1). Maize is the main food crop grown in all areas, often in monoculture but sometimes intercropped with pigeonpea, common beans (*Vicia faba* L.) and cowpea. In some areas groundnuts (*Arachis hypogaea* L.) and cassava (*Manihot esculenta* Crantz) are important food and cash crops.

Field experiments

At each community, at least six farmers were selected to host a field experiment. The selection of actual trial sites was achieved through a participatory selection process in a community awareness meeting at the onset of the trial. Initial field experiments were laid out in Malomwe and Pumbuto with three general treatments comparing a conventional farming practice with two CA practices. The management at each site was by farmers with local supervision by an extension officer and scientific oversight by agronomists and socio-economists from CIMMYT. The treatments were as follows:

(a) Conventional tillage treatment (control) planted with maize after land clearing and burning of crop residues in the field. In sites of Manica and Sofala the maize was planted with a hoe in 90 cm rows and 50 cm in-row spacing with two living plants per station to achieve a plant population of 44,444 plants ha^{-1}. In Tete, the rows spacing was 75 × 25 cm^2, leaving one plant per station and an overall plant population of 53,333 plants ha^{-1} due to the higher yield potential in the north.

(b) CA practice with planting basins, maize seeded in pre-prepared planting basins with dimensions of 15 × 15 × 15 cm^3 in 90 cm rows (75 cm in Tete) and 50 cm between basins. The target population was the same as in the conventional control. All crop residues from land clearing were left on the soil surface as mulch as well as after each consecutive harvest. The rate of mulch was aimed at 2.5–3 t ha^{-1} of crop residues. Where groundcover was not sufficient, locally found hyparrhenia grass (*Hyparrhenia* ssp.) was used to increase the overall groundcover to at least 30% cover.

(c) CA practice with a jab planter or pointed stick, maize planted directly without previous land preparation in 90 cm rows and 25 cm in-row spacing and leaving one plant per station (target population 44,444 plants ha^{-1}, 53,333 ha^{-1} in Tete); all residues were kept on the soil surface as in the basin treatment.

In the 2009/2010 cropping season, a rotation component was introduced in Nhamizhinga, Malomwe and Lamego and all main treatments were split in half—one side was planted with maize, the other was planted with cowpeas. Maize plots were further subdivided into five sub-treatments consisting of a traditional open pollinated maize variety (OPV) commonly labeled as 'Matuba' and four improved open pollinated maize varieties (ZM309, ZM401, ZM523 and ZM625). The sites in Pumputo and Nzewe followed the same planting pattern in the 2011/2012 cropping season. Although there is no uniform Matuba variety in Mozambique as OPVs are developed from populations, this variety was the best available choice of a traditional control variety. We tried to minimize the experimental error by purchasing Matuba centrally and distributing it to the different on-farm locations. All ZM varieties were new products from CIMMYT's breeding pipeline which are selected under drought stress. ZM309 and ZM401 are short season, early maturing varieties (110–120 days to maturity), while ZM523 and ZM625 are medium- to long-season varieties (120–140 days to maturity).

Maize and cowpea was planted in full rotation in Lamego, Pumbuto, Nhamizhinga and Malomwe. In

https://doi.org/10.1017/S1742170515000332 Published online by Cambridge University Press

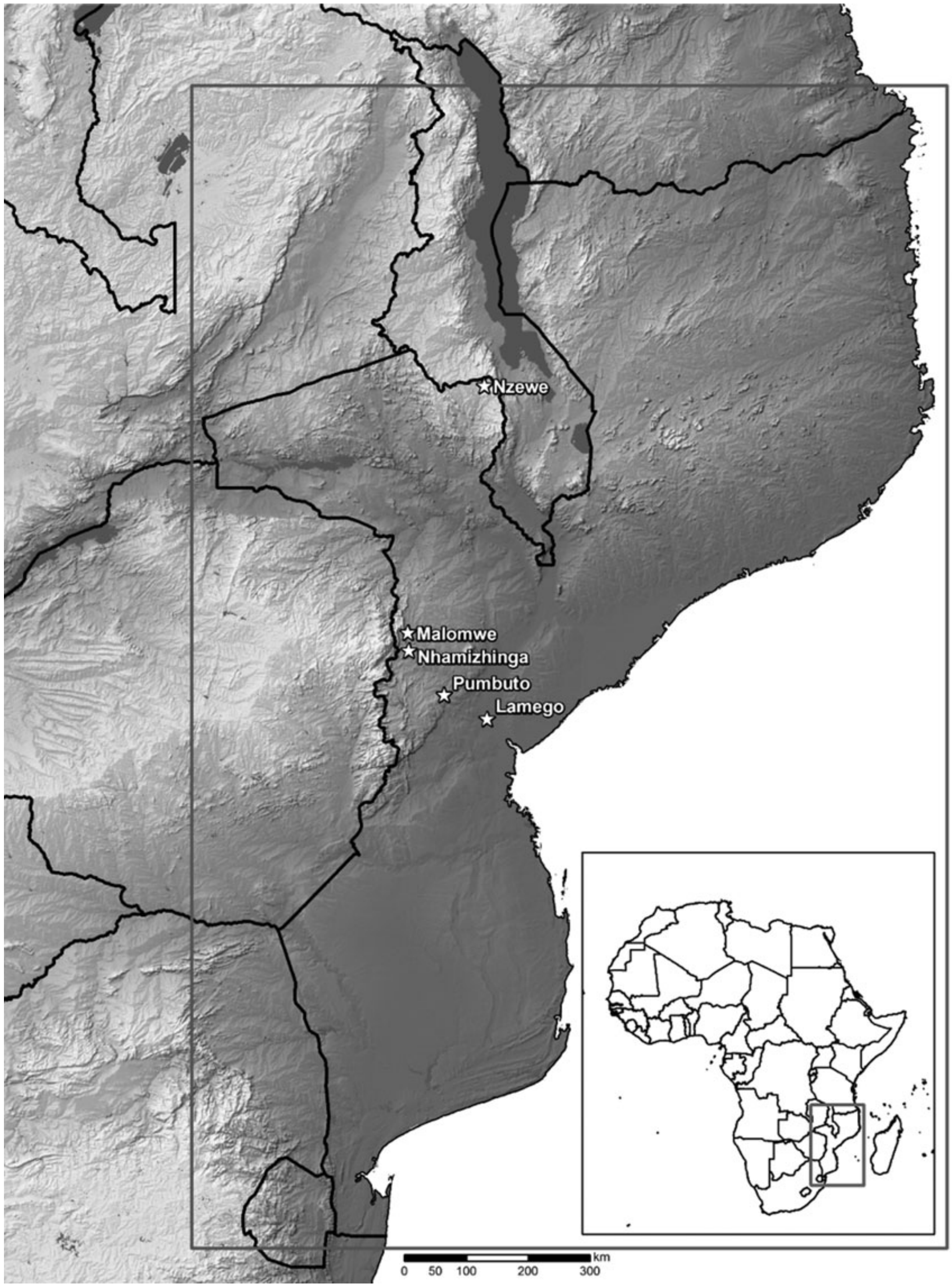

Figure 1. Geographic location of all experimental sites in central and northern Mozambique.

Nzewe, farmers rejected cowpea but opted for common bean (*Phaseolus vulgaris* L.) as their rotational crop.

Maize was fertilized with 58N:24P_2O_5:12K_2O applied as basal dressing at planting and as top-dressing at 4 weeks after planting. The same amount of fertilizer was applied to all treatments. Weed control on all CA plots was achieved with an initial application of glyphosate (glyphosate [N-(phosphonomethyl) glycine] at a rate of 3 liters ha^{-1}) and manual hand hoe weeding. In conventional systems, farmers used the hand hoe only for weed control. Legume treatments only received a basal dressing of 12N:24P_2O_5:12K_2O at planting and no further mineral fertilizer application.

https://doi.org/10.1017/S1742170515000332 Published online by Cambridge University Press

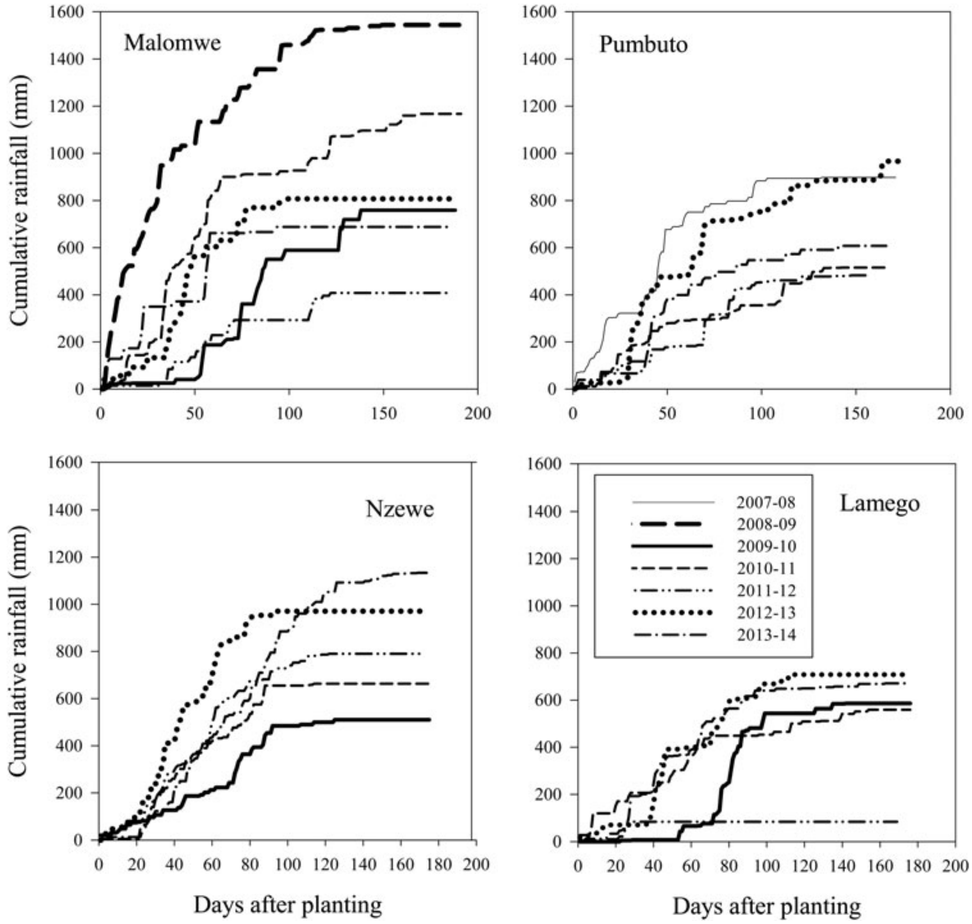

Figure 2. Rainfall distribution in four target communities of central and northern Mozambique.

Pest control especially on the cowpea was achieved through regular (bi-weekly) spray of Dimethoate (*O,O*-dimethyl *S*-[2-(methylamino)-2-oxoethyl] dithiophosphate) as they were most affected by control aphids (*Aphis* ssp.) and elegant grasshoppers (*Zonocerus elegans* Thunberg).

Harvest procedures

Maize and legume yield was estimated from 10 subsamples (9 m^2 each) per main treatment but separated by sub-treatment to get individual yields of each variety. Harvest was done at physiological maturity and the fresh produce (cobs or pods) and biomass weighed in the field. Sub-samples of grain and biomass were air dried, shelled and a grain moisture taken. The grain yield data were expressed in kg ha^{-1} at 12.5% moisture content.

Seed survey

A seed survey was conducted in 2011 with farmers who live within the communities, are host farmers of trials or have geographic access to it. The survey was done to identify the importance of specific traits in maize varieties and to find out how improved maize varieties were perceived by farmers around the demonstration plots. A total of 145 farmers were interviewed in this survey. Only 48 farmers had distinct knowledge about the improved varieties (ZM309–ZM625), while others grew Matuba or different maize varieties. Primary data were collected from farmers using a structured questionnaire designed to capture maize varieties grown in the study area, the traits in maize varieties that farmers perceive as important or influencing their decision to adopt a given variety. The survey was done at a convenient time when maize was close to maturity and most of the traits could be directly evaluated (husk cover, ear size, ear aspect, kernel lines, kernel size color, lodging amongst others). Some maize crops of each variety were used for a pounding test and for roasting to find out how the poundability and taste would be.

Calculations and statistical analyses

Yield data were tested for normality and homogeneity of variance using the Kolmogorov-Smirnov test. The generalized linear model (GLM) in SAS 9.2 (TS2MO) of the SAS System for Windows © 2002–2008 was used to test the individual and interactive effects of tillage treatment (i.e., tillage), site, season, crop variety, fertilizer application on crop yields. When the Fisher-test was significant, a Least Significant Difference test ($P \leq 0.05$) was used to separate the means.

Yield benefit of CA was calculated as the grain yield differences between CA and the conventional practice (CP). Relative yield of CA and CP were also plotted and the advantage of each treatment was evaluated through construction of a 1:1 line. When CA yields were larger than corresponding CP yields, the data point were above the 1:1 line and vice versa.

The Generalized Linear Mixed Models (GLMM) used for the two crops were:

(a) Maize model $Y_{ijkm} = \alpha + \beta SS_i + \gamma TR_j + \delta VR_k + \varepsilon SN_m + \zeta(SS_i.TR_j) + \eta(SS_{i..}VR_k) + \theta(TR_j.VR_k) + \lambda\ (SS_{i.}SN_m) + \xi\ (TR_j.SN_m) + \pi\ (VR_k.SN_m) + \rho(SS_i.TR_j.VR_k) + \varsigma(SS_i.TR_j.SN_m) + \sigma(SS_i.VR_k.SN_m) + \tau(TR_j.VR_k.SN_m) + \upsilon(SS_i.TR_j.VR_k.SN_m) + R$

(b) Cowpea model $Y_{ijm} = \alpha + \beta SS_i + \gamma TR_j + \delta VR_m + \zeta(SS_{i.}TR_j) + \eta(SS_{i..}VR_m) + \theta(TR_j.VR_m) + \rho(SS_i.TR_j.VR_m) + R$

where SS_i represents the ith site, TR_j represents the jth tillage treatment, VR_k is the kth variety and SN_m represents the mth season, R is the residual and β, γ, δ, ε, ζ, η, θ, λ, ν, ξ, π, ρ, ς, σ and τ represent the fixed and random effects values.

Results

Maize grain yield

Average maize grain yields on both CA treatments (basin planting and direct seeding) and the conventional control treatment varied at different sites and years (Figs 3a–e). At Lamego (3a), the driest site, there was a complete crop failure in the first season due to drought but from year two onwards significantly greater maize yields were recorded on both CA treatments from 2011 to 2014. At Malomwe (3b), yield benefits were more variable but significant differences between CA and conventional treatments were recorded in four out of seven cropping seasons with the direct seeding treatment outyielding the conventional control in in 2009, 2011, 2013 and 2014. At Nhamizhinga (3c) the direct seeding treatment outyielded the control in four out of six seasons, whereas the basin treatment in two out of six seasons only. At Pumbuto (3d), significant difference between CA and control treatments were recorded after the second, sixth and seventh cropping seasons. At Nzewe (3e), significantly higher yields between the direct seeded treatment and the control plot were recorded in the fourth and fifth cropping seasons under treatment 2013 and 2014 where direct seeding outyielded the control. The basin treatment did not perform well in this area. Average yield increases between the basin treatments and the conventional control were 504 kg ha^{-1} and 800 kg ha^{-1} between direct seeding and the conventional control.

Direct yield comparison between the conventional control treatment and the two CA treatments showed that most of the data points were above the 1:1 line (Fig. 6a). In about 83% of cases, there was a positive yield benefit for basin planting and in 89% of all cases, it was positive for direct seeding. In some few cases, CA treatments exceeded the 1:2 line implying that at this particular site and year the yield on CA treatments was twice as much as the conventional control treatment.

The specific performance of improved maize varieties by tillage treatment was analyzed from 2010 to 2013 (Fig. 5). The results showed that the improved varieties ZM523 and ZM625 had greater yields than the traditional variety Matuba under conventional agriculture. Under basin planting, all ZM varieties outyielded Matuba. The same trend was recorded under direct seeding (Fig. 5).

Results from the GLMM showed that cropping season, site, tillage management and crop variety had a strong significant effect ($P < 0.001$) on maize grain yield (Table 2). Site characteristics had the strongest effect on crop yield ($F = 223.4$), followed by season ($F = 146.3$) and treatment. The interactions (site×variety) and (season×variety) were highly significant, suggesting that crop varieties can be targeted to both sites and cropping seasons (wet versus dry) for improved crop productivity. The interaction site×tillage treatment was also significant suggesting that tillage was important in some sites and not in others. The interactions between season and tillage treatment was significant ($P < 0.01$) but the factor was less strong ($F = 3.15$) than the other factors. There was a strong significant effect in the interaction of season×variety indicating that the quality of the season had a strong effect on the variety performance. Also the interaction of season×site×variety was significant which implies that the quality of season and the difference in sites influences the variety performance at each site. However, there were no significant interactions between, treatment×variety; site×treatment×variety or season×treatment×variety (Table 2). The interaction between all factors (variety×tillage×treatment×season) was also not significant.

Legume grain yield

Cowpea grain yield was significantly higher at Lamego (Fig. 4a) on a direct seeded treatment in 2011 and between both CA treatments and the control in 2013. In 2014, the basin treatment outyielded the control only. Season 2010/2011 was heavily affected by drought and no yield was obtained in this season. In Malomwe (4b), the conventional treatment outyielded CA treatments in the first cropping season 2009/2010 but from there onwards CA had greater yields with the exception of 2012/2013. At Nhamizhinga (4c), greater yields were

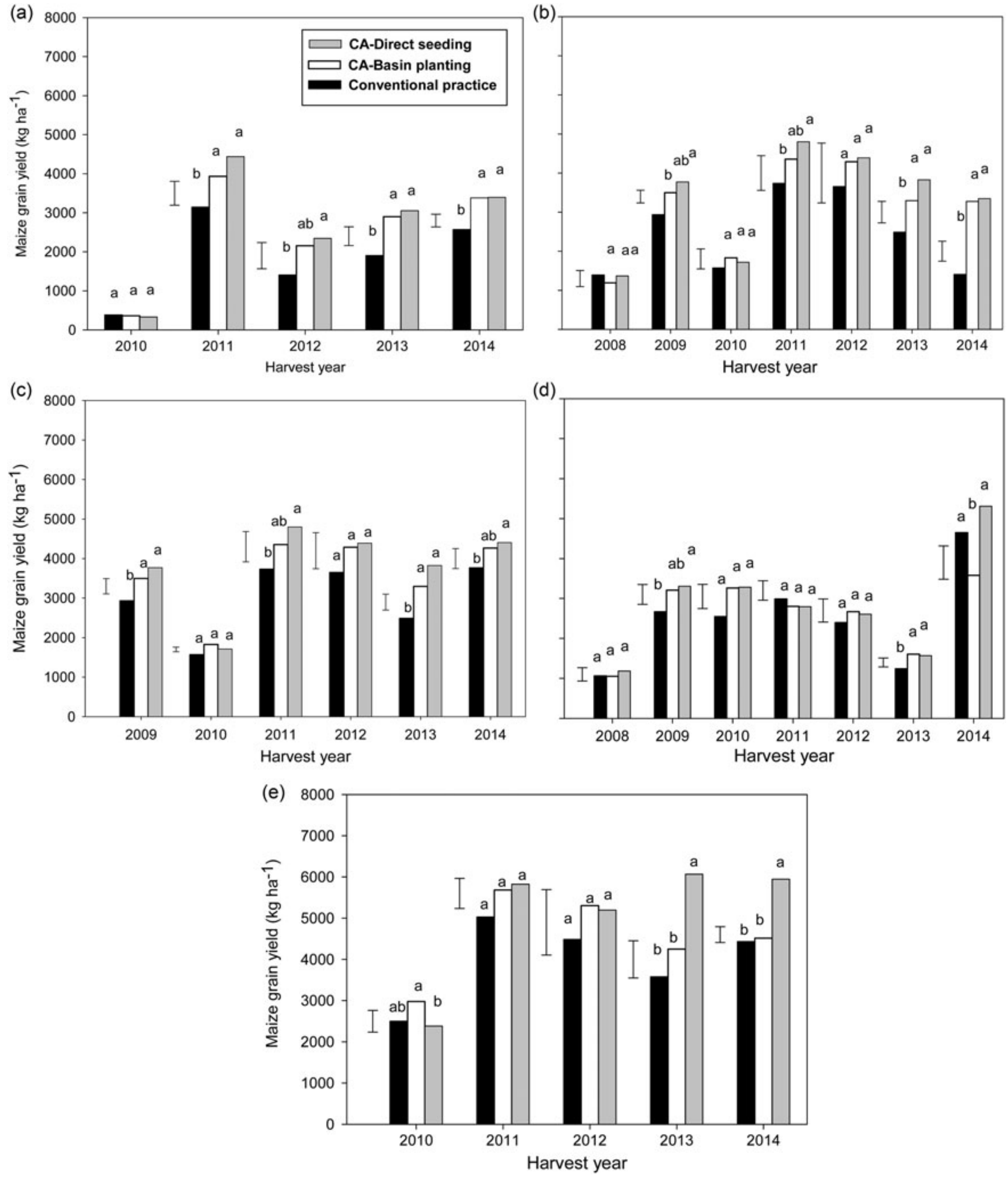

Figure 3. (a–e) Average maize grain yield in five target communities (Lamego (a); Malomwe (b); Nhamizhinga (c); Pumbuto (d); Nzewe (e)) in two conservation agriculture and one conventional crop management systems, 2008–2013. Error bars show the standard error of difference (SED) in a particular year; means followed by the same letter above the bar chart are not significantly different at ($P \leq 0.05$) probability level.

recorded between the basin treatment and the conventional control in 2010, 2011 and 2014 and the direct seeded treatment and the control in 2010 and 2014. At Pumbuto (4d), the direct seeding treatment outyielded the conventional tillage treatment in 2012 and 2013. At Nzewe (4e), the yield of common beans was significantly higher on direct seeding than the control in the first recorded cropping season (2011/2012) only.

Yield increases on legume crops averaged across sites and seasons were 156 kg ha^{-1} on the basin planted treatment and 175 kg ha^{-1} on the direct seeded treatment as compared with the conventional control. CA treatment response was positive with most comparisons displaying a positive trend toward CA (Fig. 6b) in the direct comparison of CA versus conventional treatments.

The GLMM of legumes showed significant effects ($P <$ 0.001) of site, season and tillage on legume grain yield (Table 3). The site had the strongest factor on legume performance ($F = 59.3$) followed by season ($F = 39.0$). The interactions between treat×season, treat×site and

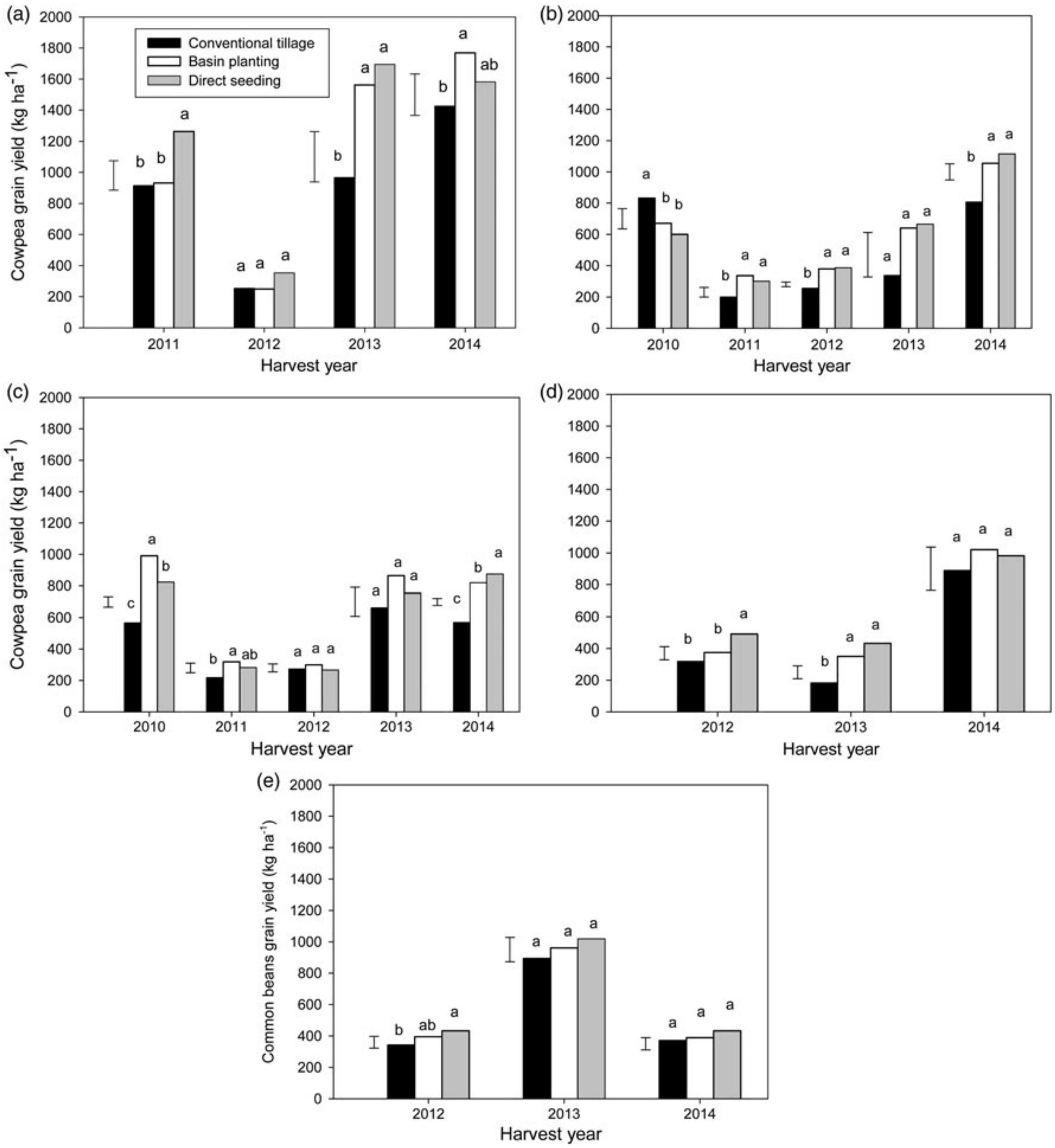

Figure 4. (a-e) Average cowpea and beans grain yield in five target communities (Lamego (a); Malomwe (b); Nhamizhinga (c); Pumbuto (d); Nzewe (e)) in two conservation agriculture and one conventional crop management systems, 2010–2013. Error bars show the standard error of difference (SED) in a particular year; means followed by the same letter above the bar chart are not significantly different at probability level $P \leq 0.05$.

treat×site×season was insignificant suggesting that the cowpea grain yield in each tillage treatment was not dependent on the site or season. However, the interaction of site×season was highly significant suggesting that some sites are more pronounced to adverse seasons than others.

Maize traits considered as important by farmers

The targeted seed survey involving 145 farmers in target communities showed that farmers valued different traits differently (Table 4). Farmers rated good stable yield as most important (94%) followed by weevil resistance (81%) and resistance to specific diseases (e.g., ear rot 77%). Early maturity was stated as a factor very important to farmers in that particular area (73%). Not as important to farmers was the aspect (phenotypic appearance) of the cob (35%) and the color of the grain (39%).

Farmers' ratings of varieties according to traits

Farmers were asked to evaluate the maize varieties that were on display on the demonstration plots (Table 5).

https://doi.org/10.1017/S1742170515000332 Published online by Cambridge University Press

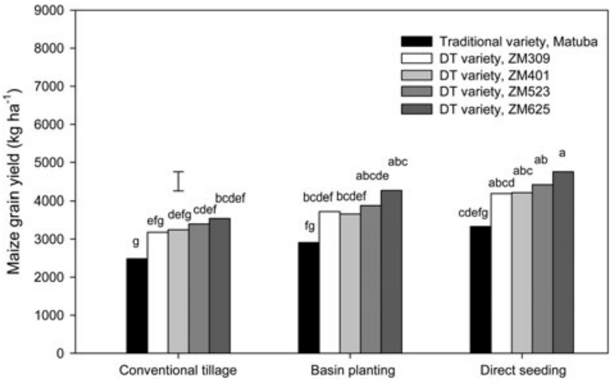

Figure 5. Overall varietal performance in two CA and one conventional agriculture cropping system in Mozambique across sites and years, 2010–2014. The error bar shows the standard error of difference (SED) of varieties across cropping systems; means followed by the same letter above the bar chart are not significantly different at ($P \leq 0.05$) probability level.

Table 2. Output of the GLMM procedures for explaining variability in maize grain yields due to tillage, fertilizer, season, site and crop variety under farmer conditions in central Mozambique.

Source	DF	*F* value	*P* > *F*
Season	6	146.29	<0.001
Site	4	223.39	<0.001
Trt	2	106.87	<0.001
Var	4	48.9	<0.001
Season×Site	19	42.59	<0.001
Season×Trt	12	3.15	<0.001
Site×Trt	8	6.41	<0.001
Season×Var	16	7.46	<0.001
Site×Var	16	4.57	<0.001
Trt×Var	8	0.64	0.741
Season×Site×Trt	38	2.04	<0.001
Season×Site×Var	48	2.49	<0.001
Season×Trt×Var	32	0.44	0.997
Site×Trt×Var	32	0.96	0.54
Season×Site×Trt×Var	96	0.56	1.00

Note: Trt, tillage treatment; Var, variety.

The traditional variety, Matuba was generally liked because it had good husk cover (65%), low incidence of ear rot (62%), low rate of lodging (60%) and lack of weevils at harvest (59%). Traits that were not rated highly were white color (33%), large kernel size (28%), good yields (20%) and early maturity (15%).

For ZM309 the following maize traits were rated highly: early maturity (85%), no ear rot (67%), many kernel lines (63%) and 61% on diseases resistance. The worst observed traits in ZM309 were good yield (13%), no lodging (13%), no weevils at harvest (11%) and ear aspect cited by 8.7% of the farmers.

ZM401 variety traits were rated differently. Farmers liked its taste (53%), weevil resistance and early maturity (both 52%) and many kernel lines (51%). Less important traits to farmers were no ear rot (17%), early maturity (15.2%), no weevils at harvest (11%) and husk cover cited by 11% of the farmers.

For ZM523, the variety traits liked by farmers were good yield (63%), good taste (62%), large kernel size (61%) and nice ear aspect (57%). The worst observed traits in ZM523 were early maturity (too much time needed to mature) and no ear rot with 15% response and no lodging (11%).

Good traits on ZM625 were large ear size (76%) large kernel size (74%), good yields and good taste (63%) and nice ear aspect (54%). The worst observed traits in ZM625 were no weevils at harvest (35%), followed by ear rot (33%), good husk cover (28%) and no lodging (28%). As ZM625 is a long season variety, it was the characteristic of early maturity that was not rated here.

Discussion

Agronomic performance

In the majority of comparisons in the different years, CA treatments outperformed the conventional control treatment. However, due to variability between farmer replicates at each site, these were not always significant—only in 17 out of 30 maize yield comparisons and 11 out of 20 legume yield comparisons was a significant yield difference established. This result confirms previous findings from the region (Ngwira et al., 2012; Thierfelder et al., 2013*a*, *b*; Thierfelder et al., 2015) and is in contrast with other studies from Pittelkow et al. (2015) and Corbeels et al. (2014), who looked at either incomplete CA systems (Pittelkow et al., 2015) or had a more variable dataset. Giller et al. (2009) stated that significant maize yields gains in CA cropping systems can only be reaped in the longer term which was also confirmed by Nyamangara et al. (2013) on sandy soils in Zimbabwe. It was observed that yield differences between the conventional treatment with residue removal and significant soil disturbance and different CA treatments at some locations were evident in a very short time, which was valid for both cereals and legumes. However, a clear yield trend with increasing years of practice could not be established. This may be attributed to the relative short experimental period at each site. As significant improvement in soil quality with CA is rather unlikely to occur in a short time frame (Nyamangara et al., 2013, 2014), the main benefits from no-tillage and residue retention will have likely come from increased infiltration and better water-use-efficiency, which was previously observed by Rockström et al. (2009) and Thierfelder and Wall (2009) in Zambia as well as Thierfelder et al. (2013*a*) and Ngwira et al. (2013) in Malawi.

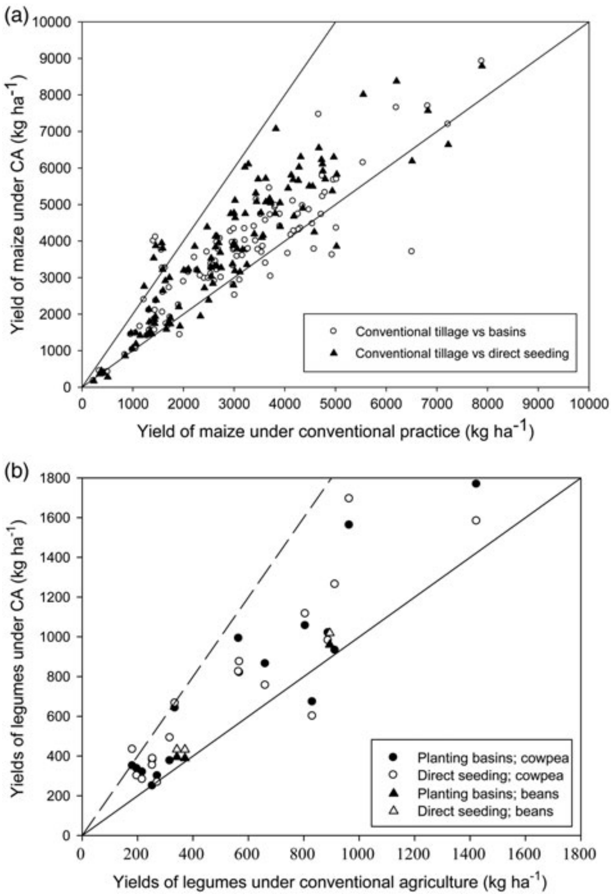

Figure 6. Yield comparison between different management strategies on maize varieties (a) and legume (b) crops in five target communities of Mozambique 2008–2013. Each dot represents a mean CA yield of farmer replicates in a target community in a particular year plotted against a conventional system. Dots above the 1:1 represent a benefit toward CA, dots below the 1:1 line favors the conventional system in the comparison.

Table 3. Output of the GLMM procedures for explaining variability in legume grain yields due to tillage, season and site under farmer conditions in central Mozambique.

Source	DF	*F* value	*P* > *F*
Season	4	38.95	<0.001
Site	4	59.3	<0.001
Trt	2	11.43	<0.001
Site×Season	11	9.6	<0.001
Trt×Season	8	0.78	0.616
Trt×Site	8	0.83	0.573
Trt×Site×Season	22	0.67	0.864

Note: Trt, tillage treatment.

Direct seeded treatments outyielded the basin treatment only occasionally (in Nzewe in 2013 and 2014 and in Pumbuto in 2014 on maize) indicating that both CA treatments were, in general, suitable systems in the drier areas, but direct seeding was more suitable in the high rainfall areas of northern Mozambique. In high rainfall areas, the basins, which are also considered as water harvesting systems, tend to accumulate too much water turning a potential benefit into a disadvantage. This highlights the need to adapt the right CA systems to different agro-ecologies and rainfall regimes.

Table 4. Maize traits considered important in maize varieties (in percent).

Trait	Not important (%)	Important (%)	Very important (%)
Good husk cover	2	23	75
Large ear size	7	35	58
Nice ear aspect	22	43	35
Many kernel lines	15	38	47
Good taste	6	33	61
Large kernel size	17	35	47
No weevils at harvest	6	14	81
Early maturity	8	19	73
No diseases	1	23	76
White color	15	46	39
No ear rot	4	20	77
Good yield	1	5	94
No lodging	7	43	50

Other studies do not show that legumes respond as quickly as maize to soil quality improvements as was previously stated in studies from Zimbabwe and Mozambique (Mupangwa et al., 2012; Rusinamhodzi et al., 2012; Thierfelder et al., 2012). This was not confirmed by our data. Maize comparisons had 83% and 89% positive responses when CA treatments were directly compared on-site with the respective conventional control treatment. On legumes, the yield benefit was 90% on both basins and direct seeding.

However, the decision by farmers to invest in CA in Mozambique and its limitations were also discussed previously (Rusinamhodzi et al., 2012). More awareness, training and knowledge exchange is needed to make farmers aware about the benefits of CA in years to come and to facilitate higher adoption rates. In large areas of Mozambique, shifting cultivation as well as slash and burn agriculture (Chitemene system) is still common. An investment in long-term soil fertility improvement such as CA is difficult under such circumstances because farmers will always change locations (if they can) once the soil fertility is depleted. Nevertheless, increased population pressure, future negative effects of climate variability expected for southern Africa and Mozambique in particular (Lobell et al., 2008; Cairns et al., 2013*a*; Cairns et al., 2013*b*) and increased pressure to produce food from available land resources will force farmers to move away from traditional shifting cultivation to more intensive and permanent farming systems.

https://doi.org/10.1017/S1742170515000332 Published online by Cambridge University Press

Table 5. Farmer ratings of maize varieties (in percent) according to different traits.

Trait	Rate	Matuba (%)	ZM309 (%)	ZM401 (%)	ZM523 (%)	ZM625 (%)
Husk cover	Good	65	58	34	24	20
	Regular	33	33	55	70	52
	Bad	3	8	11	7	28
	N	76	48	47	46	46
Ear size	Good	29	28	30	63	76
	Regular	50	70	70	37	22
	Bad	21	2	0	0	2
	N	76	46	46	46	46
Ear aspect	Good	54	46	37	57	54
	Regular	38	46	54	44	35
	Bad	8	9	9	0	11
	N	74	46	46	46	46
Number of kernel lines	Good	58	63	52	33	35
	Regular	33	35	46	63	52
	Bad	9	2	2	4	13
	N	76	46	46	46	46
Taste	Good	58	58	53	62	63
	Regular	29	38	44	38	35
	Bad	13	4	2	0	2
	N	76	45	45	45	46
Kernel size	Good	25	30	39	61	74
	Regular	47	61	59	39	24
	Bad	28	9	2	0	2
	N	76	46	46	46	47
No weevils infestation at harvest	Good	59	61	52	48	30
	Regular	33	28	37	44	35
	Bad	8	11	11	9	35
	N	75	46	46	46	46
Early maturity	Good	46	85	52	17	
	Regular	40	9	33	67	
	Bad	15	7	15	15	
	N	76	46	46	46	
Diseases	Good	51	61	43	39	36
	Regular	41	30	50	52	46
	Bad	8	9	7	9	18
	N	74	44	44	44	44
White color	Good	25	35	39	48	54
	Regular	41	61	61	50	41
	Bad	33	4	0	2	4
	N	75	46	46	46	46
No ear rot	Good	62	67	44	44	33
	Regular	29	28	39	41	35
	Bad	9	4	17	15	33
	N	76	46	46	46	46
Yield	Good	50	39	44	63	63
	Regular	30	48	50	35	37
	Bad	20	13	7	2	0
	N	76	46	46	46	46
No lodging	Good	60	54	39	39	34
	Regular	34	33	52	50	38
	Bad	7	13	9	11	28
	N	74	46	46	46	47

CA could be one way of sustainable intensification in this environment.

Variety performance

Regardless of site and season, improved drought-tolerant varieties outyielded Matuba between 28 and 43% in a conventional system, between 26 and 46% in a basin planting system and between 26 and 43% in a direct seeding system. This confirms that there is a huge benefit for farmers to switch to new drought-tolerant germplasm (Bänziger et al., 2006; Cairns et al., 2013*a*) regardless of the way it is planted. However, planting the highest yielding variety in the dataset (i.e., ZM625) under direct seeding gave a 91% (2268 kg ha^{-1}) yield benefit as compared with planting the traditional variety in the conventional systems.

The results from the GLMM indicate that variety was strongly influenced by season and site and not by tillage treatment as previously suggested by Gwenzi et al. (2008) for Zimbabwe. A direct interaction between tillage treatment and variety performance (e.g., treat×var, season×treat×var and season×site×treat×var) could not be established indicating that increases in maize grain yield due to treatment occurred similarly on different maize varieties. Breeding efforts to adapt varieties to site and season characteristics therefore, seem to be the most effective way to achieve breeding progress instead of selection for different tillage treatments.

Improved varieties are not a well-known part of the cropping systems in Mozambique. Most of Mozambique's maize growing area (90–99%) is sown to recycled or traditional maize varieties (Cavane and Donovan, 2011; Kassie et al., 2013). The adoption rate in Mozambique of improved maize varieties is still very low (Langyintuo et al., 2008); although there are increased efforts by the United States Agency for International Development (USAID) and the Alliance for a Green Revolution (AGRA) in Africa to increase access to and improved use of improved varieties. The lack of use by smallholder farmers may be explained by the lack of knowledge about their potential and the lack of access to a secure market that would help to facilitate selling of any additional surplus expected with improved varieties. Lack of knowledge and poor adoption of improved maize varieties by farmers may be due to the fact that there are very few seed companies in Mozambique and they mainly do not promote improved varieties (Kassie et al., 2013). Furthermore, the weak public extension services that are understaffed and underfunded cannot support variety promotion independently.

Farmer perception about improved varieties

This research added an important component to agronomic research results—the farmers' perception about varieties. Farmers considered it very important that the early season variety ZM309 was also resistant to weevils and common diseases, had little lodging and good husk cover, which they rated as higher than greater yields on other longer season varieties. The popularity of ZM309 is confirmed by farmers in other southern African countries, where it has also been released (DTMA, 2013). The longer season variety ZM625 was indeed acknowledged by farmers for being high yielding, having a large ear and kernel size, but it was not preferred by farmers due to the longer time needed for maturity. In an area of climate risk expressed by highly variable rainfall patterns (e.g., too little rainfall, too much rainfall, delayed rainfall and mid-season dry spells), it makes sense for farmers to aim for short season varieties, as was observed in target communities of Sofala and Manica. The perceived risk of crop failure makes farmers realize that an early season variety will probably not give the highest yield, but will provide at least some stable and reliable yield in most cropping seasons. Farmers also indicated that an early maturing variety will 'give food on the table' in the critical hunger months of February and March, when grain reserves from the previous cropping season are running low. The short maturity opens up the possibility of planting a legume (e.g., cowpea) into the standing maize crop (as a relay crop) or after the maize has matured (Dakora et al., 1987; Rao and Mathuva, 2000; Tarawali et al., 2002). The use of short season varieties and a mixed use of short season and longer season varieties, as are often applied by farmers, need to be further explored and understood.

Conclusion

This study in central and northern Mozambique focused on the performance of improved DT maize varieties under different sites and crop management practices and included an assessment of the perception of farmers about improved maize varieties. The results show that CA systems outperformed the conventional tillage treatment in the majority of seasons; although the difference was not always significant due to variability between farmer replicates. This was valid for both maize and legumes in target communities of Mozambique. Average maize yield gains within one site and year ranged between 504 and 800 kg ha^{-1} on basins and direct seeded maize treatments, respectively, as compared with the control treatment. On legumes, the average yield gain was 156–175 kg ha^{-1} on basins and direct seeded treatments, respectively. The performance of improved maize varieties was on average greater than the traditional local variety Matuba. Maize yield was strongly influenced by the factors season, site, treatment and variety. However, a direct interaction between tillage treatment and maize variety performance (e.g., treat×var, season×treat×var and season×site×treat×var) could not be established, which indicates that the variety performance did not depend on the tillage treatment, but more on site and season characteristics. Legume yields were significantly affected by site and season, but all treatment interactions with site and season were insignificant.

Farmers lack access to improved varieties, have limited knowledge and face serious cash constraints to buy improved varieties. This has led to the widespread use of old recycled varieties and traditional landraces that are locally adapted to diseases and pests, but lack the capacity to perform under drought and heat stress.

Farmers' rationale suggests that they prefer not only grain yields as the main deciding factor for growing an improved variety, but also value other important traits. Early maturity and resistance to pests were considered important traits to reduce the risk of crop failure as well as pre- and post-harvest losses. This often led to the preferred selection of the short season variety (ZM309), instead of longer season varieties.

The increased need to grow more food for smallholder farmers in Mozambique in light of future threats of projected climate variability requires more climate-resilient and permanent agriculture systems. Growing improved varieties under CA is one avenue to sustainable intensification which can provide multiple yield benefits for farmers in Mozambique.

Acknowledgments. We thank the USAID under the Platform for Agriculture Research and Innovation (PARTI) and SANREM CRSP Projects and the International Fund for Agriculture Development (IFAD) for having supported this work financially from 2008 to 2014. The work is embedded into the MAIZE and CCAFS CGIAR research programs. Their financial and logistical support is greatly acknowledged. Special thanks go to Stephanie Cheesman, Ivan Cuvaca, Antonio Rocha and Alberto Vura and numerous extension officers from Sofala, Manica and Tete, who assisted in managing trials and collecting field data.

References

Bänziger, M., Setimela, P.S., Hodson, D., and Vivek, B. 2006. Breeding for improved abiotic stress tolerance in maize adapted to southern Africa. Agricultural Water Management 80(1–3):212–224.

Baudron, F., Tittonell, P., Corbeels, M., Letourmy, P., and Giller, K.E. 2012. Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. Field Crops Research 132:117–128.

Blum, A., and Sullivan, C. 1986. The comparative drought resistance of landraces of sorghum and millet from dry and humid regions. Annals of Botany 57(6):835–846.

Bolliger, A. 2007. Is zero-till an appropriate agricultural alternative for disadvantaged smallholders of South Africa? A study of surrogate systems and strategies, smallholder sensitivities and soil glycoproteins. PhD thesis, University of Copenhagen 67 pp.

Cairns, J.E., Sonder, K., Zaidi, P.H., Verhulst, N., Mahuku, G., Babu, R., Nair, S.K., Das, B., Govaerts, B., Vinayan, M.T., Rashid, Z., Noor, J.J., Devi, P., San Vicente, F., and Prasanna, B.M. 2012. Maize production in a changing climate: Impacts, adaptation, and mitigation strategies. Advances in Agronomy 114: 1–58.

Cairns, J.E., Crossa, J., Zaidi, P., Grudloyma, P., Sanchez, C., Araus, J.L., Thaitad, S., Makumbi, D., Magorokosho, C., and Bänziger, M. 2013*a*. Identification of drought, heat, and combined drought and heat tolerant donors in maize. Crop Science 53(4):1335–1346.

Cairns, J.E., Hellin, J., Sonder, K., Araus, J.L., MacRobert, J.F., Thierfelder, C., and Prasanna, B. 2013*b*. Adapting maize production to climate change in sub-Saharan Africa. Food Security 5(3):345–360.

Cavane, E., and Donovan, C. 2011. Determinants of adoption of improved maize varieties and chemical fertilizers in Mozambique. Journal of International Agricultural and Extension Education 18(3):5–21.

Challinor, A., Wheeler, T., Garforth, C., Craufurd, P., and Kassam, A. 2007. Assessing the vulnerability of food crop systems in Africa to climate change. Climatic Change 83(3):381–399.

Chivenge, P.P., Murwira, H.K., Giller, K.E., Mapfumo, P., and Six, J. 2007. Long-term impact of reduced tillage and residue management on soil carbon stabilization: Implications for conservation agriculture on contrasting soils. Soil and Tillage Research 94(2):328–337.

Corbeels, M., Sakyi, R.K., Kühne, R.F., and Whitbread, A. 2014. Meta-analysis of crop responses to conservation agriculture in sub-Saharan Africa. CCAFS Report No. 12. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen.

Dakora, F.D., Aboyinga, R.A., Mahama, Y., and Apaseku, J. 1987. Assessment of N2 fixation in groundnut (*Arachis hypogaea* L.) and cowpea (*Vigna unguiculata* L. Walp) and their relative N contribution to a succeeding maize crop in Northern Ghana. MIRCEN Journal of Applied Microbiology and Biotechnology 3(4):389–399.

Dowswell, C.R., Paliwal, R.L., and Cantrell, R.P. 1996. Maize in the Third World. Westview Press, Boulder, CO.

DTMA. 2013. Drought-tolerant maize for Africa: released DT varieties Available at Web site http://dtma.cimmyt.org/index.php/varieties/dt-maize-varieties: CIMMYT, Mexico.

Findeling, A., Ruy, S., and Scopel, E. 2003. Modelling the effects of a partial residue mulch on runoff using a physically based approach. Journal of Hydrology 275(1–2): 49–66.

Giller, K.E., Witter, E., Corbeels, M., and Tittonell, P. 2009. Conservation agriculture and smallholder farming in Africa: The heretic's view. Field Crops Research 114:23–34.

Gwenzi, W., Taru, M., Mutema, Z., Gotosa, J., and Mushiri, S. 2008. Tillage system and genotype effects on rainfed maize (*Zea mays* L.) productivity in semi-arid Zimbabwe. African Journal of Agricultural Research 3(2):101–110.

Johnson, J.M.F., Reicosky, D.C., Allmaras, R.R., Sauer, T.J., Venterea, R.T., and Dell, C.J. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. Soil and Tillage Research 83(1):73–94.

Kassam, A., Friedrich, T., Shaxson, F., and Pretty, J. 2009. The spread of conservation agriculture: Justification,sustainability and uptake. International Journal of Agricultural Sustainability 7(4):292–320.

Kassie, G., Erenstein, O., Mwangi, W., MacRobert, J., Setimela, P., and Shiferaw, B. 2013. Political and economic features of the maize seed industry in southern Africa. Agrekon 52(2):104–127.

Kassie, G.T., Erenstein, O., Mwangi, W., La Rovere, R., Setimela, P., and Langyintuo, A. 2012. Characterization of maize production in southern Africa: Synthesis of CIMMYT/ DTMA household level farming system surveys in Angola, Malawi, Mozambique, Zambia and Zimbabwe. CIMMYT, Mexico, Socio-Economics Program Working Paper 4.

Langyintuo, A.S., Diallo, W., MacRobert, A., Dixon, J.J., and Banziger, M. 2008. An analysis of the bottlenecks affecting the production and deployment of maize seed in eastern and southern Africa: CIMMYT.

Lobell, D.B., and Burke, M.B. 2008. Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Environmental Research Letters 3(3): 034007.

Lobell, D.B., Burke, M.B., Tebaldi, C., Mastrandrea, M.D., Falcon, W.P., and Naylor, R.L. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science 319:607–610.

Magorokosho, C., Vivek, B., and MacRobert, J. 2009. Characterization of maize germplasm grown in Eastern and Southern Africa: results of the 2008 regional trials coordinated by CIMMYT. CIMMYT, Harare, Zimbabwe.

Mapfumo, P., Adjei-Nsiah, S., Mtambanengwe, F., Chikowo, R., and Giller, K.E. 2013. Participatory action research (PAR) as an entry point for supporting climate change adaptation by smallholder farmers in Africa. Environmental Development 5:6–22.

Muchow, R. 1989. Comparative productivity of maize, sorghum and pearl millet in a semi-arid tropical environment II. Effect of water deficits. Field Crops Research 20 (3):207–219.

Mupangwa, W., Twomlow, S., and Walker, S. 2012. Reduced tillage, mulching and rotational effects on maize (*Zea mays* L.), cowpea (*Vigna unguiculata* (Walp) L.) and sorghum (*Sorghum bicolor* L. (Moench)) yields under semi-arid conditions. Field Crops Research 132(0):139–148.

Ngwira, A.R., Aune, J.B., and Mkwinda, S. 2012. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field crops research 132:149–57.

Ngwira, A.R., Thierfelder, C., and Lambert, D.M. 2013. Conservation agriculture systems for Malawian smallholder farmers: long-term effects on crop productivity, profitability and soil quality. Renewable Agriculture and Food Systems 28(04):350–363.

Nyamangara, J., Masvaya, E.N., Tirivavi, R., and Nyengerai, K. 2013. Effect of hand-hoe based conservation agriculture on soil fertility and maize yield in selected smallholder areas in Zimbabwe. Soil and Tillage Research 126:19–25.

Nyamangara, J., Marondedze, A., Masvaya, E., Mawodza, T., Nyawasha, R., Nyengerai, K., Tirivavi, R., Nyamugafata, P. and Wuta, M. 2014. Influence of basin-based conservation agriculture on selected soil quality parameters under smallholder farming in Zimbabwe. Soil Use and Management 30(4):550–559.

O'Dell, D., Sauer, T.J., Hicks, B.B., Thierfelder, C., Lambert, D. M., Logan, J. and Eash, N.S. 2015. A short-term assessment of carbon dioxide fluxes under contrasting agricultural and soil management practices in Zimbabwe. Journal of Agriculture Science 7(3):32–48.

Pittelkow, C.M., Liang, X., Linquist, B.A., Van Groenigen, K.J., Lee, J., Lundy, M.E., van Gestel, N., Six, J., Venterea, R.T., and van Kessel, C. 2015. Productivity limits and potentials of the principles of conservation agriculture. Nature 517 (7534):365–368.

Powlson, D.S., Stirling, C.M., Jat, M., Gerard, B.G., Palm, C.A., Sanchez, P.A., and Cassman, K.G. 2014. Limited potential of no-till agriculture for climate change mitigation. Nature Climate Change 4(8):678–683.

Rao, M., and Mathuva, M. 2000. Legumes for improving maize yields and income in semi-arid Kenya. Agriculture, Ecosystems and Environment 78(2):123–137.

Reicosky, D.C. 2000. Tillage induced CO 2 emissions from soil. Nutrient Cycling in Agro-ecosystems 49:273–285.

Reicosky, D.C., and Lindstrom, M.J. 1993. Fall tillage method: effect on short-term carbon dioxide flux from soil. Agronomy Journal 85(6):1237–1243.

Rockström, J., Kaumbutho, P., Mwalley, J., Nzabi, A.W., Temesgen, M., Mawenya, L., Barron, J., Mutua, J., and Damgaard-Larsen, S. 2009. Conservation farming strategies in East and Southern Africa: yields and rain water productivity from on-farm action research. Soil and Tillage Research 103(1):23–32.

Rohrbach, D. 2003 (editor). Improving the commercial viability of sorghum and pearl millet in Africa. Workshop on the proteins of sorghum and millets: Enhancing nutritional and functional properties for Africa.

Roth, C.H., Meyer, B., Frede, H.G., and Derpsch, R. 1988. Effect of mulch rates and tillage systems on infiltrability and other soil physical properties of an Oxisol in Parafla, Brazil. Soil and Tillage Research 11:81–91.

Rusinamhodzi, L., Corbeels, M., Nyamangara, J., and Giller, K.E. 2012. Maize–grain legume intercropping is an attractive option for ecological intensification that reduces climatic risk for smallholder farmers in central Mozambique. Field Crops Research 136:12–22.

Scopel, E., Findeling, A., Chavez Guerra, E., and Corbeels, M. 2005. Impact of direct sowing mulch-based cropping systems on soil carbon, soil erosion and maize yield. Agronomy for Sustainable Development 25:425–432.

Setimela, P., MacRobert, J., Atlin, G., Magorokosho, C., Tarekegne, A., Makumbi, D., and Taye, G. 2012. editor Performance of elite maize varieties tested on-farm trials in eastern and southern Africa. ASA, CSSA, and SSSA International Annual Meetings 21–24 October, 2012; Cincinnati, Ohio, USA.

Tadross, M., Suarez, P., Lotsch, A., Hachigonta, S., Mdoka, M., Unganai, L., Lucio, F., Kamdonyo, D., and Muchinda, M. 2009. Growing-season rainfall and scenarios of future change in southeast Africa: Implications for cultivating maize. Climate Research 40(2–3):147–161.

Tarawali, S.A., Singh, B.B., Gupta, S.C., Tabo, R., Harris, F., Nokoe, F., Fernandez-Rivera, S., Bationo, A., Manyong, V.M., Makinde, K., and Odion, B. 2002. Cowpea as a key factor for a new approach to integrated crop-livestock systems research in the dry savannas of West Africa. In: Fatokun, C.A., Tartawali, S.A., Singh, B.B., Kormawa, P.M., and Tamo, M. (Eds.), Challenges and opportunities for enhancing sustainable cowpea production. IITA, Ibadan, Nigeria, pp. 233–251.

Thierfelder, C., and Wall, P.C. 2009. Effects of conservation agriculture techniques on infiltration and soil water content in Zambia and Zimbabwe. Soil and Tillage Research 105(2): 217–227.

Thierfelder, C., and Wall, P.C. 2010. Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. Journal of Crop Improvement 24(2):113–121.

Thierfelder, C., and Wall, P.C. 2012. Effects of conservation agriculture on soil quality and productivity in contrasting agro-ecological environments of Zimbabwe. Soil Use and Management 28(2):209–220.

Thierfelder, C., Cheesman, S., and Rusinamhodzi, L. 2012. A comparative analysis of conservation agriculture systems: benefits and challenges of rotations and intercropping in Zimbabwe. Field Crops Research 137:237–250.

Thierfelder, C., Chisui, J.L., Gama, M., Cheesman, S., Jere, Z. D., Bunderson, W.T., Eash, N.S., Ngwira, A., and Rusinamhodzi, L. 2013*a*. Maize-based conservation agriculture systems in Malawi: Long-term trends in productivity. Field Crop Research 142:47–57.

Thierfelder, C., Mwila, M., and Rusinamhodzi, L. 2013*b*. Conservation agriculture in eastern and southern provinces of Zambia: Long-term effects on soil quality and maize productivity. Soil and Tillage Research 126:246–258.

Thierfelder, C., Rusinamhodzi, L., Ngwira, A.R., Mupangwa, W., Nyagumbo, I., Kassie, G.T. and Cairns, J.E. 2014. Conservation agriculture in Southern Africa: Advances in knowledge. Renewable Agriculture and Food Systems, online first, 1–21, doi: 10.1017/S1742170513000550.

Thierfelder, C., Matemba-Mutasa, R., and Rusinamhodzi, L. 2015. Yield response of maize (*Zea mays* L.) to conservation agriculture cropping system in southern Africa. Soil and Tillage Research 146:230–242.

Thornton, P.K., Jones, P.G., Ericksen, P.J., and Challinor, A.J. 2011. Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences 369(1934):117–136.