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C. Thierfelder [a];P. C. Wall [a]
[a] CIMMYT, Harare, Zimbabwe

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Investigating Conservation Agriculture (CA) Systems in Zambia and Zimbabwe to Mitigate Future Effects of Climate Change

C. THIERFELDER and P. C. WALL
CIMMYT, Harare, Zimbabwe

Most models predict that climate change will affect the southern African region both through temperature rises and increased frequency and severity of drought. Conservation agriculture (CA) based on minimal soil disturbance, crop residue retention, and crop rotations offers potential solutions to mitigate the effects of seasonal drought. In Zimbabwe and Zambia, we investigated the effects of different maize-based CA systems on water relations and crop productivity from 2005-2009 and compared results with conventionally plowed plots. In all seasons, we found higher water infiltration on CA plots, and it was three to five times higher on direct-seeded CA plots compared to conventionally plowed control plots in 2009. This led to higher available soil moisture on CA plots. The increase in soil moisture will enable crops to overcome seasonal dry spells, mitigate the effects of drought, reduce the risk of crop failure, and secure livelihoods in the region.

KEYWORDS *Conservation agriculture, soil moisture, infiltration, climate change, mitigation*

INTRODUCTION

Climatic models suggest that the southern African region will be strongly affected by future climatic changes: they predict higher temperatures and

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Address correspondence to C. Thierfelder at CIMMYT, P.O. Box MP 163, Mount Pleasant, Harare, Zimbabwe. E-mail: c.thierfelder@cgiar.org

an increased frequency and severity of drought, which will prejudice crop production if there is no adaptation or change of existing cropping systems. Using the results of 20 general circulation models, Lobell and colleagues (2008) estimated that temperatures in southern Africa would increase by roughly 1.0°C, and that precipitation would fall by 10%. They determined that maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) would be the crops most negatively affected in the region, with estimated reductions in yield of close to 30% and 15%, respectively. Maize is the staple food crop for most of the population in southern African region and accounts for approximately 50% of the caloric intake (Dowswell, Paliwal, & Cantrell 1996). A reduction in yield of this important crop would have negative effects on food security. The predicted lower rainfall increases the need for more water-efficient cropping systems to mitigate the effects of climate change. Adaptation strategies could include changes in varieties, planting dates, or changing from highly sensitive to less sensitive crops, i.e., sorghum (*Sorghum bicolor* L.) (Lobell et al. 2008). The most promising changes, however, involve more efficient use of rainfall: higher infiltration, less water runoff, and reduced evaporation. The more rainfall water that can be retained and stored on-site, the more there is available for crop production.

Conservation agriculture (CA) is a relatively new system in the region. It is based on three principles: a) minimum soil disturbance and therefore minimum tillage; b) permanent soil surface cover with crop residues or living plants; and c) crop rotations. Conservation agriculture involves a complete change in management, including different seeding techniques, weed control, and fertilization strategies. Residue-management practices and crop rotations, and changes from traditional systems to CA, can therefore be complex for farmers (Wall 2007). Benefits of CA systems have been widely published in literature (see reviews by Reicosky 2000; FAO 2002; Wall 2007; Hobbs 2007); however, concerns over its feasibility in southern Africa have also been highlighted by Bolliger (2007) and Giller et al. (2009). These concerns need to be addressed by scientific research.

This paper reports results from two trials in Zimbabwe and Zambia, established to monitor and compare the long-term effects of CA and conventional systems on soil quality under southern African conditions. Results from the 2005/06-2008/09 seasons presented here focus mainly on field measurements of water infiltration, soil moisture status, and crop productivity. The paper aims at testing the hypothesis that CA has the potential to mitigate seasonal droughts, thus improving rainfall-use efficiency (RUE) and maize grain yield.

MATERIAL AND METHODS

Multi-season long-term trials comparing CA and conventional agriculture systems were established in 2004 at Henderson Research Station (HRS), Mashonaland Central Province, Zimbabwe (17.57°S; 30.99°E; 1136 m.a.s.l., mean annual rainfall 884 mm) on sandy soils with predominant *Arenosols* and *Luvisols,* and in 2005 at Monze, Farmer Training Centre (MFTC), Southern Province, Zambia (16.24°S; 27.44°E; 1103 m.a.s.l, mean annual rainfall 748 mm) on fine-textured *Lixisols* (FAO 1998). For further details on local circumstances and treatment on these fully replicated trials, see Thierfelder and Wall (2009).

In this paper, we compare water infiltration, soil moisture relations, and maize grain yield in three treatments at each site. At HRS, a traditional farmers' practice consisting of shallow moldboard plowing with animal traction was compared with a direct-seeded CA treatment and an animal-drawn, rip line-seeded CA treatment with continuous maize. The direct-seeded treatment at HRS was seeded with an animal traction direct seeder from Irmãos Fitarelli Máquinas Agricolas, Brazil, only in 2005 but with a manual jab-planter from November 2006 onwards. Both CA treatments were seeded into untilled soil.

At MFTC, the same plowed traditional farmers' practice was compared with a direct-seeded CA treatment with continuous maize and a direct-seeded CA treatment with maize in a two-year rotation with cotton (*Gossypium hirsutum* L.). The latter treatments were seeded into untilled soil again with an animal traction direct seeder from Fitarelli, Brazil.

At both sites, commercial maize hybrids were seeded in rows spaced 90 cm apart. In all manually seeded treatments, seed was placed in these rows with three seeds per station and 50 cm between planting stations, later thinned to 44,000 plants ha^{-1}. The direct seeder was calibrated to the same final population after thinning. All crops were fertilized with a basal dressing of 163 kg ha^{-1} Compound D ($7N:14P_2O_5:7K_2O$ in Zimbabwe and $10N:20P_2O_5:10K_2O$ in Zambia) at seeding. In the manually sown treatments, fertilizer was placed alongside the planting station, whereas in the other treatments it was dribbled in the row by the direct seeding equipment. Top-dressing at a rate of 200 kg $ha^{-1}$of ammonium nitrate (34.5%N) or urea (46%N) was applied to all treatments in Zimbabwe and Zambia, respectively, as an equally split application at 4 and 7 weeks after crop emergence. Therefore, all treatments at each site received the same amount of fertilizer.

Weed control was achieved by an application of glyphosate (N-(phosphonomethyl)glycine, 41 % active ingredient) before maize emergence at a rate of 3 liters ha^{-1} followed by regular hand-weeding as necessary. At harvest, ears were removed from the plots and the remaining crop residues (stover) retained on the CA treatments and removed from the conventionally plowed treatment. Stover yields ranged from 3.2 to 6.5 t ha^{-1}. Rainfalls in each cropping season are shown in Table 1. Throughout the experiment, there was no severe drought at both sites, but the experiment at MFTC in Zambia experienced seasonal moisture stress in December/January 2005 and December 2008.

TABLE 1 Annual Rainfall in Each Cropping Season, MFTC and HRS 2005/06-2008/09

	Rainfall during cropping season (mm)			
Location	2005/2006	2006/2007	2007/2008	2008/2009
Henderson Research Station	1096	534	1060	710
Monze, Farmer Training Centre	734	551	1033	761

In all seasons, infiltration measurements were carried out with a small rainfall simulator described by Amézquita, Cobo, & Torres (1999), and Thierfelder and Wall (2009). Simulated rainfall of approximately 100 mm h^{-1} was applied to an area of 36 cm x 44 cm for 60 min, and runoff measured on an area of 32.5 cm x 40 cm (0.13 m^{-2}). Difference between water applied and runoff was recorded as water infiltration. Infiltration measurements were made at both sites in January when the maize crop was at or just before the tassling/silking stage. Infiltration simulations were replicated on three different sites in each plot, mainly in the inter-row space, when the soil was at or close to field capacity.

Capacitance probes (PR-2 probes from Delta-T Devices Ltd., UK) were used for soil moisture measurement. Access tubes were installed in the field in all treatments (3 access tubes per plot in 3 replicates) and moisture content monitored to 1-m depth twice per week during the cropping season. Average soil moisture data from 0-60 cm depth are presented here, and available soil moisture was calculated for the first 60 cm.

At physiological maturity, the maize crop was harvested; ears and aboveground biomass were collected and weighed; and subsamples were taken for determination of moisture content. A subsample of 20 ears per plot was shelled to calculate grain yield, which was then calculated on a hectare basis at 12.5% moisture.

Statistical analyses were carried out using STATISTIX for personal computers (Statistix, 2008). Final infiltration rate, soil moisture, and yield data were tested for normality. Analyses of variances (ANOVA) were conducted following the general linear model (GLM) procedure at a probability level of $P \leq 0.05$. Where significance was detected, means were compared using an LSD test.

RESULTS

Final infiltration rate on both sites was significantly higher on CA fields in all years except HRS in January 2006 (Table 2). Infiltration on CA treatments at MFTC was three and five times greater than the plowed treatment in 2008 and 2009, respectively.

Average soil moisture in the top 60 cm of soil at HRS was greater on CA treatments in all cropping seasons (Table 3). In the two final seasons,

TABLE 2 Effect of Conservation Agriculture on Final Water Infiltration Rate After 60 min of Simulated Rainfall of 100 mm h^{-1} Intensity. Monze Farmer Training Centre (MFTC), Zambia and Henderson Research Station (HRS), Zimbabwe

		Cropping season			
Site	Treatment	Jan 2006	Jan 2007	Jan 2008	Jan 2009
		Infiltration rate (mm h^{-1})			
HRS	Conventional plowing	31.6 a	51.5 b	26.3 b	25.3 c
	Direct seeding	47.2 a	74.8 a	50.4 a	78.2 a
	Rip-line seeding	36.6 a	69.7 a	50.5 a	63.3 b
MFTC	Conventional plowing	33.6 b[a]	25.3 b	9.6 b	9.6 b
	Direct seeding	52.7 a	47.4 a	33.5 a	46.5 a
	Direct seeded maize after cotton	–	47.6 a	31.1 a	48.7 a

[a] Note: Means followed by the same letter in column are not significantly different at $P \leq 0.05$ probability level, LSD test.

TABLE 3 Effects of Conservation Agriculture on Average Soil Moisture Content in the top 60 cm of the Soil Profile. Monze Farmer Training Centre (MFTC), Zambia, and Henderson Research Station (HRS), Zimbabwe

	Average soil moisture 0–60 cm (mm)	
	HRS	MFTC
2005/06 season		
Conventional plowing	105 c	135 a
Direct seeding	125 a	133 a
Rip line seeding	120 b	
2006/07 season		
Conventional plowing	66 b	124 c
Direct seeding	80 a	127 b
Rip line seeding	81 a	
Direct-seeded rotation		135 a
2007/08 season		
Conventional plowing	108 c	131 b
Direct seeding	126 b	128 b
Rip line seeding	141 a	
Direct-seeded rotation		139 a
2008/09 season		
Conventional plowing	241 c	142 b
Direct seeding	264 b	150 a
Rip line seeding	272 a	
Direct-seeded rotation		153 a

[a] Note: Means followed by the same letter in column are not significantly different at $P \leq 0.05$ probability level, LSD-test.

soil moisture was highest in the rip line-seeded treatment. At MFTC, difference in soil moisture between the plowed and direct-seeded treatments was not significant in 2005/2006 and 2007/2008, but the direct-seeded rotation always had the highest average soil moisture throughout the seasons. In the

2005/2006 and 2008/2009 seasons at MFTC, the seasonal pattern of available soil moisture in the top 60 cm of soil (Figures 1 and 2) showed clear periods of moisture stress. Maize plants in the plowed treatment were severely affected from December 2005 to January 2006. The reduction in available soil moisture in December 2008 was not as marked, but the plowed treatment was again more affected. Both CA treatments had higher available soil moisture in the first 60 cm in this period.

At HRS, higher soil moisture did not necessarily result in higher maize productivity on CA fields as waterlogging in the wetter years prevented better crop performance. Only in 2008/2009 were crop yields significantly greater in the rip line-seeded than in the plowed treatment. Maize grain yields were consistently higher on CA than on the plowed treatment at MFTC (Table 4), whereby the yields of maize seeded in rotation at this site were always significantly higher than that of the other treatments. Yield differences between the direct-seeded sole maize treatment and the plowed treatment at MFTC were only significant in the 2005/2006 season.

DISCUSSION

Results from HRS and MFTC confirm that doing away with tillage and leaving the soil covered with mulch leads to higher infiltration rates: Infiltration rates

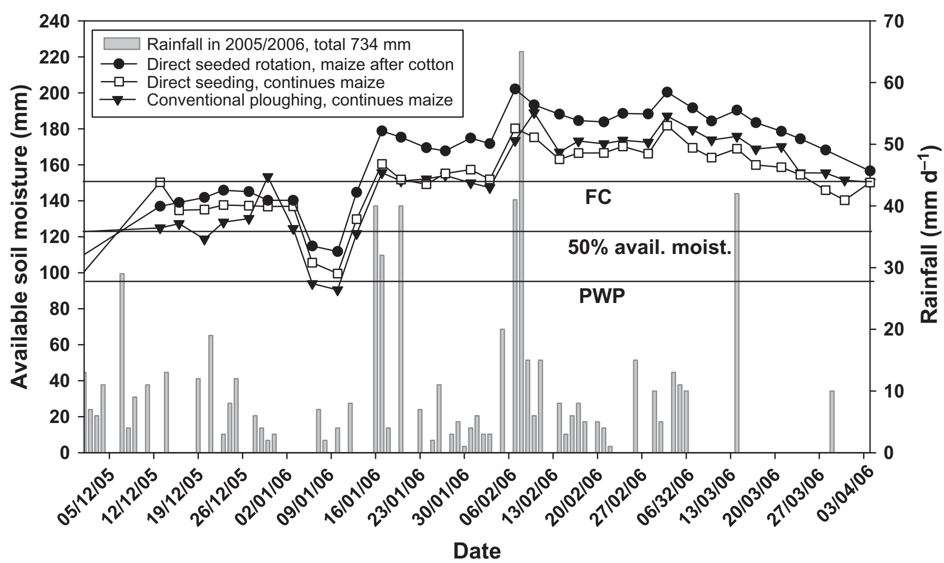

FIGURE 1 Available soil moisture (mm) in the top 60 cm of soil in one conventionally plowed and two conservation agriculture treatments, MFTC, 2005/06. FC = field capacity; 50% avail. moisture = 50% available moisture content; and PWP = permanent wilting percentage.

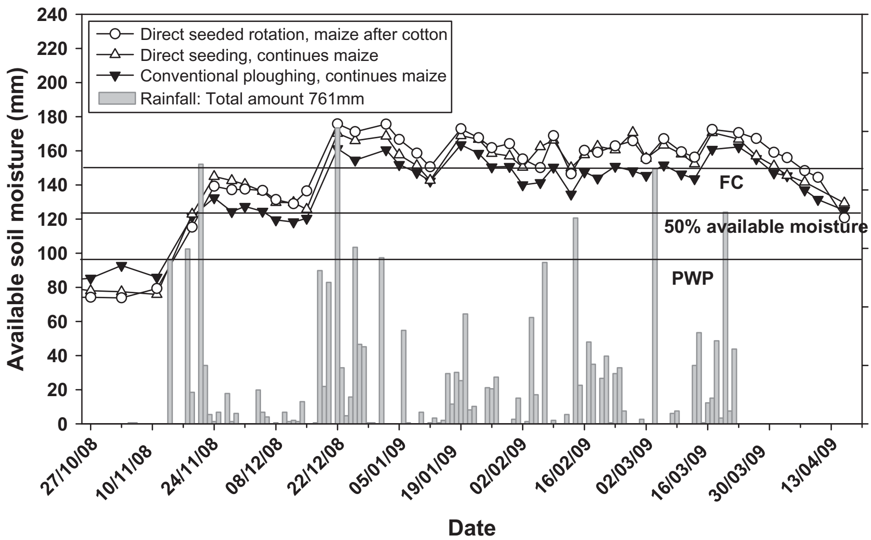

FIGURE 2 Available soil moisture (mm) in the top 60 cm of soil in one conventionally plowed and two conservation agriculture treatments, MFTC, 2008/2009. FC = field capacity; 50% available moisture = 50% available moisture content; PWP = permanent wilting percentage.

TABLE 4 Effect of Conventionally Plowed and Conservation Agriculture on Maize Grain Yield (kg ha^{-1}), Monze Farmer Training Centre (MFTC), Zambia, and Henderson Research Station (HRS), Zimbabwe

Site	Treatment	Cropping season 2005/2006	2006/2007	2007/2008	2008/2009
		Infiltration rate (mm h^{-1})			
HRS	Conventional plowing	3254 a	4358 a	1192 a	1789 b
	Direct seeding	2456 a	5234 a	1151 a	2787 ab
	Rip line seeding	3250 a	4344 a	1442 a	3553 a
MFTC	Conventional plowing	3620 b[a]	4878 b	4084 b	3302 b
	Direct seeding	4894 a	5142 ab	4559 ab	3905 ab
	Direct-seeded rotation	–	6221 b	5985 a	4541 a

[a] Note: Means followed by the same letter in column are not significantly different at $P \leq 0.05$ probability level.

on residue-protected, undisturbed soils were higher than on conventionally plowed plots without residues, at both sites. This is consistent with results from past studies (Derpsch, Sidiras, & Roth 1986; Roth et al. 1988).

At both sites, higher infiltration resulted in higher soil moisture, although differences between CA treatments and the conventional plowed control were not always significant. Higher soil moisture translated into higher maize yields in the direct-seeded rotation treatment at MFTC. A favorable soil structure created by the deep rooting of the preceding cotton crop may have contributed to better maize crop performance. Periods of moisture stress during the season, especially during critical stages for plant development and yield determination (e.g., germination, silking) had an effect on maize yields. However, there were periods of marked moisture stress in only two of the four seasons. In times of heavy rainfall or on soils with impeded drainage, increased infiltration and soil moisture under CA can also have adverse effects, as was clearly observed in the 2005/2006 and 2007/2008 seasons at HRS, when extremely high rainfall led to waterlogging and therefore lower yields on CA plots than on conventionally tilled plots.

CONCLUSION

Conservation agriculture has the potential to improve soil-water balance of maize crops in southern Africa, which is threatened by increased severity and frequency of drought as a result of climate change. In the trials reported here, the water infiltration rates and soil moisture content were higher on CA fields than on the plowed treatment, although this only translated into higher maize grain yield in seasons when there was marked moisture stress. There is evidence from this experiment that increased water retention on CA fields improves the resilience against seasonal dry spells and therefore reduces the risk of crop failure for smallholder farmers in southern Africa. However, excess water that led to waterlogging in very wet years at HRS had negative effects on maize yield.

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