CHAPTER 3

CROP YIELD AND WEED GROWTH UNDER CONSERVATION AGRICULTURE IN SEMI-ARID ZIMBABWE

ABSTRACT

Constraints to effective weed management may be the main reason for the small area under minimum tillage (MT) in smallholder farming in southern Africa. The effect of maize residue mulching and intensity of hand hoe weeding on the growth of weeds, cowpea (*Vigna unguiculata cv.* IT 86D-719) and sorghum (*Sorghum bicolor cv.* Macia) was investigated in the fifth and sixth years of a conservation agriculture (CA) field experiment at Matopos Research Station (28^0 30.92`E, $20^0$ 23.32`S). The experiment was a split-plot randomized complete block design with three replications. Tillage was the main plot factor (conventional tillage (CONV) - mouldboard plough compared against MT systems - ripper tine and planting basins) and maize residue mulch rate (0, 4 and 8 t ha^{-1}) the sub-plot factor. Hoe weeding was done either four times (high weeding intensity) or twice (low weeding intensity) during the cropping season. Planting and weeding were done at the same time in all treatments. There was markedly greater early season weed growth in MT systems relative to CONV tillage in both crop species. In sorghum, MT (planting basins: 40.3 kg ha^{-1}; ripper tine: 34.8 kg ha^{-1}) systems had higher cumulative weed biomass measured after planting than CONV tillage (29.9 kg ha^{-1}) system. Maize mulching was generally associated with increased mid- to late- season weed growth in the two crops probably due to improved soil moisture conservation during periods of low precipitation. Weed suppression by the maize mulch was observed only in sorghum and limited to early in the cropping season with no effect observed for the remainder of the sorghum rotation phase. The high weeding intensity treatment had lower weed growth in both crops and better sorghum yield than low weeding intensity. The MT systems had poor crop establishment which translated into low yields. Cowpea grain yield obtained from MT systems was less than 300 kg ha^{-1} compared to 413 kg ha^{-1} in CONV tillage. The poor sorghum establishment in MT systems translated into low grain yield as sorghum grain yield was lowest in planting basins (2 602 kg ha^{-1}) and highest in CONV tillage with 4 159 kg ha^{-1}. Results suggest that CA systems require early and frequent hoe weeding even after four years to reduce weed infestations and improve crop growth. This higher demand on a smallholder household's limited labour supply throughout the cropping season will be a key determinant of the spread and adoption of CA in southern Africa.

Keywords: Conservation agriculture, maize residue mulch, hoe weeding, cowpea, sorghum, weeds

3.1 INTRODUCTION

Conservation agriculture (CA) is being promoted to smallholder farmers in sub-Saharan Africa to increase productivity, reduce farmers' vulnerability to drought, and address low draught power ownership levels and to combat increasing levels of land degradation (FAO, 2010). The majority of smallholder farmers in the region are only practicing minimum tillage without crop residue mulching and crop rotation (Haggblade & Tembo, 2003; Mazvimavi & Twomlow, 2009). Yield increases of between 30 and 120 % have been reported under the MT systems of planting basin and ripper tine. However, the fields are reported to require more weeding effort than conventional plough tillage. In southern Africa there have been reports of a doubling in labour required for hand hoe weeding of maize and cotton grown under planting basins (Haggblade & Tembo, 2003) as well as increases in weeding frequency compared to conventional mouldboard plough tillage (Baudron *et al.*, 2007; Mazvimavi & Twomlow, 2009).

Promoters of CA attribute the weed problems reported on smallholder farmers' fields to partial adoption of CA. They argue that in CA weeds are only a problem in the first two years and, thereafter, weed infestations and weeding effort decline with time under CA (FAO, 2012a). However, the is no empirical evidence from southern Africa to support these claims but are based on sparse reports from South America from large mechanised farms where CA consists of permanent soil cover, diverse crop rotations including cover crops and efficient weed control using herbicides. Furthermore, reports of the serious challenges faced by smallholder farmers in Brazil with respect to weed management under CA have largely been. Under smallholder conditions, weed pressure has remained high under CA requiring increased herbicide use compared to conventional tillage even after more than 10 years of CA practices in Brazil

(Bolliger *et al*., 2006, Gowing & Palmer, 2008). The smallholder farmers occasionally resort to tillage in order to control weeds in CA (Ribeiro *et al*., 2005).

Specific research on weed population dynamics under CA as it is being recommended for smallholder farmers in southern Africa is lacking. Previous studies in the region evaluated the effect of minimum tillage (Vogel, 1994; Mabasa *et al*., 1998) or conservation tillage (Gill *et al*. 1992; Vogel, 1994, Muliokela *et al*. 2001) but not the simultaneous application of all the three principles on field weed infestation.

This study investigated whether weed infestation and requirement for hoe weeding were lower under CA than in conventional mouldboard plough tillage in the fifth and sixth year of CA and had the following specific objectives:

1. To determine the effect of tillage on weed density, cowpea and sorghum growth in the second phase of a maize-cowpea-sorghum three-year cropping system;
2. To quantify the effect of maize mulch rates on weed, cowpea and sorghum growth under the different tillage systems;
3. To determine the effect of intensity of hand hoe weeding on weed and crop growth in the fifth and sixth years of CA.

3.2 MATERIALS AND METHODS

3.2.1 Location

The study was conducted in the fifth (2008/09) and sixth (2009/10) years of a CA field experiment established in 2004 at West Acre Creek of Matopos Research Station Farm, Zimbabwe (28^0 30.92`E, $20^0$ 23.32`S; 1 344 m above sea level). The station is characterized by semi-arid climatic conditions and is considered to be representative of climatic conditions found in southwest Zimbabwe and much of Botswana, southern Mozambique and southern Zambia (Twomlow *et al*., 2006). The rainfall season is unimodal with distinct wet (November – March) and dry (April – October) seasons. The wet season is characterized by highly variable rainfall (250 – 1400 mm) with a mean long-term annual rainfall of 580 mm. The soil at the site is derived from micaceous schists and is classified as a Chromic-Leptic Cambisol (FAO, 1998) with 45% clay, 19% silt and 36% sand in the 0 – 0.44 m layer (Moyo, 2001). The soil is prone to waterlogging during exceptionally wet seasons. In 2008, the upper 0.15 m soil layer had a pH (water) of 6, a soil organic carbon content of 1.2% and bulk density of 1.4 g cm^{-3} (Mupangwa, 2009).

3.2.2 Treatments and experimental layout

In 2004, an experiment was designed to compare the effect of minimum tillage and maize residue mulching on soil water and crop yields of a three-year maize-cowpea-sorghum rotation (Mupangwa, 2009). The experiment was set up as a split-plot with plots arranged in a randomized complete block design with three replications. Tillage system was the main plot (63 x 6 m) factor and maize residue mulching the sub-plot (8 x 6 m) factor. In 2008 and 2009, hand hoe weeding intensity was added as a treatment factor at two levels (high and low weeding intensity). The weeding treatments were superimposed on sub-plots that received maize mulch rates of 0, 4 and 8 t ha^{-1} with each mulch rate replicated twice per main plot. The use of high maize residue mulch rates used in this study was based on findings of previous research from both tropical and temperate regions that demonstrated that effective weed suppression occurred under mulch rates that provided at least 60% soil cover (Gill *et al*., 1992; Bilalis *et al*., 2003; Christofolleti *et al*., 2007). Previous reports at the same site had shown that retention of maize residue at 2 t ha-1 had a comparable weed density to that under where no maize mulch rate was retained (Mupangwa, 2009; Mashingaidze *et al*., 2009a) An assessment of soil cover provided by maize residue at the study site indicated that 60% soil cover was achieved at a maize mulch rate of 4 t ha^{-1}. However, since maize residue yields from the 2007/08 season averaged 1.5 t ha^{-1}, additional maize residue was imported from neighbouring fields to achieve the treatment rates. In the sorghum phase of the rotation during 2009/10 season, cowpea residue was not retained as with its low C:N ratio it decomposes rapidly resulting in limited soil cover at planting. Instead, the available maize residue from fields at Matopos Research Station was used to provide mulch cover in sorghum.

Weeding at the high intensity treatment was carried out a week before planting, a week after planting (WAP), at 5 WAP and before harvesting (weeding W1 to W4 in Fig. 3.1). The high weeding intensity treatment followed the CA recommendation of frequent weeding aimed at minimizing weed seed return to the soil seed bank. This weeding regime's objective was to provide a clean seedbed for the crop, remove the first weed flush to emerge with the crop, reduce weed competition during the critical first 40 days of crops' growth and remove last weed cohorts emerging at end of the rains. The low weeding intensity treatment comprised hoe weeding a week before planting and at 5 WAP (weeding W1 and W3 in Fig.3.1). This treatment simulated the smallholder farmer practice of planting into a clean seedbed after early summer mouldboard ploughing and then hoe weeding 40 or more days after planting (Twomlow *et al*., 2006).

3.2.3 Crop management

3.2.3.1 Land preparation

Weeds were removed from all plots using hand hoes in June 2008. Maize residue was uniformly applied to sub-plots as surface mulch in August 2008. Planting basin (PB) and ripper tine (RT) tillage were carried out in September 2008 as per guidelines of the Zimbabwean CA Taskforce (Twomlow *et al*., 2008; ZCATF, 2009). Planting basins with dimensions of 0.15 m (length) x 0.15 m (width) x 0.15 m (depth) were dug using hand hoes at an inter-row spacing of 0.9 m and intra-row spacing of 0.6 m. Rip lines were opened at 0.9 m inter-row spacing using a commercially available ZimPlow® ripper tine attached to the beam of a donkey-drawn mouldboard plough. A ripping depth of between 0.15 m and 0.18 m was achieved with a single pass of the implement. In November 2008, to prevent incorporation of maize residue during ploughing, residues were removed from mouldboard plough (CONV tillage) plots before ploughing. At the first effective rains (50 mm) ploughing was done using a donkey-drawn ZimPlow® VS200 mouldboard plough and a depth of 0.15 m was achieved. Maize residues were returned to CONV tillage plots after which planting furrows were opened using hand hoes at an inter-row spacing of 0.6 m recommended for cowpeas in Zimbabwe. No basal fertilizer was applied.

The same land preparation methods were carried out in the 2009/10 cropping season. However, two additional dry-season hoe weedings were done, in August 2009 before mulching and in September 2009 prior to PB and RT tillage, in order to keep plots weed-free. The high weed growth observed during the period between June and September 2009 was probably due to residual soil moisture from the wet 2008/09 season that may have promoted increased weed germination and growth. The basin and rip line positions were maintained across the two seasons, as they had been in the previous four seasons (Mupangwa, 2009). In the 2009/10 season, cattle kraal manure (17.5% organic carbon, 0.13% N, 0.11% P) was applied as a basal soil fertility amendment at a rate of 3 t ha^{-1}. Manure was spot applied into planting basins and banded along the rip line in September 2009. As in the 2008/09 season, ploughing was done at first effective rains in November 2009 and planting furrows were opened at the recommended spacing for sorghum of 0.75 m and manure was banded along the furrows.

3.2.3.2 Planting and management

Since the majority of smallholder farmers in Zimbabwe commonly retain seed of minor crops such as cowpea, retained cowpea seed of an early maturing, semi-determinate cowpea variety, IT 86D-719 (source: IITA, Nigeria) was planted in all tillage systems on 26 December 2008. In both PB and RT, the recommendation of the Zimbabwean CA Taskforce (Twomlow *et al*., 2008; ZCATF, 2009) was followed in planting cowpea. Five cowpea seeds were planted per planting basin and thinned to four seedlings at 4 WAP to give a cowpea density of 74 074 plants ha^{-1}. In RT tillage, two cowpea seeds were planted per planting station and stations were spaced 0.15 m apart. At 4 WAP, the cowpea seedlings were thinned to one seedling per planting station to achieve the same cowpea density in RT as in PB. In CONV tillage, one cowpea seed was planted at an intra-row spacing of 0.25 m to achieve the recommended cowpea density of 66 667 plants ha^{-1}. The cowpea crop was not fertilized since most smallholder farmers neither apply manure nor inorganic fertilizer to legume crops (Ncube, 2007). Thiodan 35EC (80 ml in 20L water) was sprayed on cowpea at 4 WAP and during flowering to control aphids (*Aphis craccivora* L.). Thinning, spraying and weeding were carried at the same time in all tillage systems. The cowpea crop was harvested in April 2009.

An early maturing sorghum variety Macia was planted on 2 December 2009. In PB, the same planting and thinning method used in cowpeas was used to give a sorghum density of 74 074 plants ha^{-1}. In both RT and CONV tillage, sorghum seed was dribbled along planting furrows and thinned at 4 WAP to an intra-row spacing of 0.15 m to give a density of 74 074 plants ha^{-1} in RT and 88 889 plants ha^{-1} in CONV tillage. Ammonium nitrate (34.5% N) was applied to sorghum at a rate of 20 kg N ha^{-1} as topdressing at 5 WAP. Planting, weeding and fertilizer application were carried at the same time in all treatments. Sorghum was harvested in April 2010.

3.2.4 Data collection

3.2.4.1 Weed density and biomass

Weed density and biomass per sub-plot were determined from 0.6 x 0.9 m quadrats that were randomly placed at two positions in each sub-plot. The quadrats were placed centred on the inter-row so as to include four planting basins in PB and two rip furrows in RT. Weed density data was collected before weeding at 1 week before planting, 1 and 4 WAP; and at 9 and 13 WAP. Weed biomass in the 2008/09 season was collected starting at 4 WAP, and at all weed sampling times in 2009/10 season. Weeds sampled in each sub-plot were cut at ground level and oven-dried at 60 ^{0}C to constant weight and the dry weight determined. The timing of the weed sampling aimed to measure weeds just before planting, first flush of weeds that emerged with the crop, within the critical period of weed control and at crop canopy closure.

3.2.4.2 Crop yield

Cowpea was harvested at one picking when pods were observed to be fully mature and dry. Sorghum was harvested when heads were observed to be uniformly mature and dry. The number of plants, grain yield and stover (above-ground biomass minus grain) dry matter were determined from a net plot of four central rows each 6 m long in both cowpea and sorghum. In addition, cowpea pod number per plant and sorghum heads per net plot were determined from a sample of 10 plants from within the net plot. Grain yield was standardized to 12.5% moisture content.

3.2.5 Statistical analysis

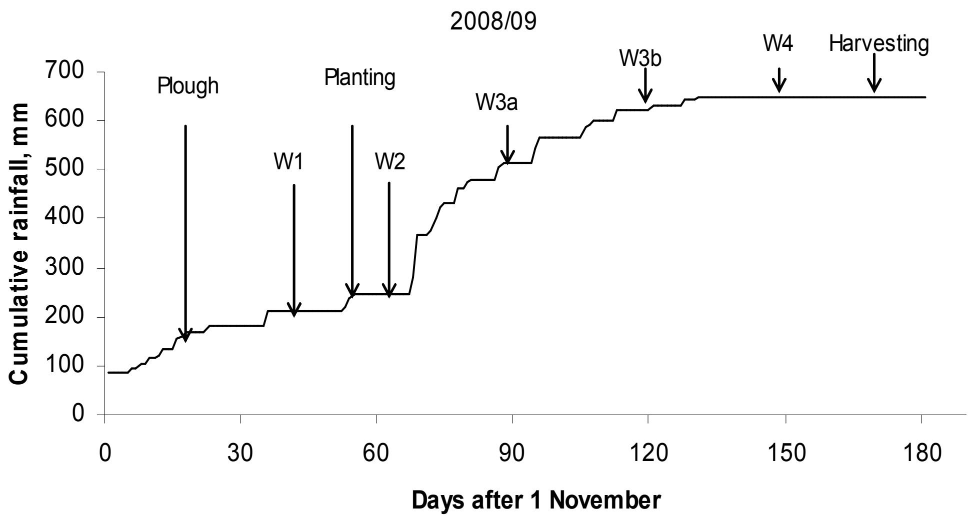
Prior to analysis, plots of residuals vs predicted values generated using GenStat Release 9.1 for the different transformations indicated that the square root (x +0.5) transformation improved variance homogeneity (Gomez & Gomez, 1984) of weed density and biomass in both the 2008/09 and 2009/10 cropping seasons. All weed and crop data were subjected to analysis of variance using GenStat Release 9.1 (Lawes Agricultural Trust, 2006). The means of the treatments were separated by least significant difference (LSD) at 5% level of significance.

3.3 RESULTS AND DISCUSSION

3.3.1 Seasonal rainfall

In both seasons, the start of the rainy season and distribution of rain within the season influenced the timing of crop management practices (Fig. 3.1). The low precipitation received after ploughing in the 2008/09 cropping season resulted in cowpea being planted in the last week of December 2008, more than a month after ploughing. The month of January 2009 received 42% of the total 2008/09 seasonal rainfall and the incessant rains led to re-weeding of all sub-plots (weeding W3a and W3b in Fig. 3.1) as hoe weeding was observed to be ineffective under the excessively wet soil conditions. The continuous rainfall also made it difficult to spray Thiodan 35EC for aphid control at two week intervals as is recommended. Cowpea establishment was poor in this season probably due to high seedling mortality as cowpea is prone to fungal diseases under wet conditions (Dugje *et al*., 2009).

The 2009/10 season was characterized by good early rainfall distribution and consequently sorghum was planted in early December 2009, a week after ploughing. The rains peaked in December (29% of total seasonal rainfall) but declined from January to March 2010. However, the rains increased in April 2010 resulting in 20% of the season's rains falling after the sorghum crop had reached physiological maturity. Both seasons received more than the long-term 69 year mean annual rainfall of 580 mm for Matopos Research Station.



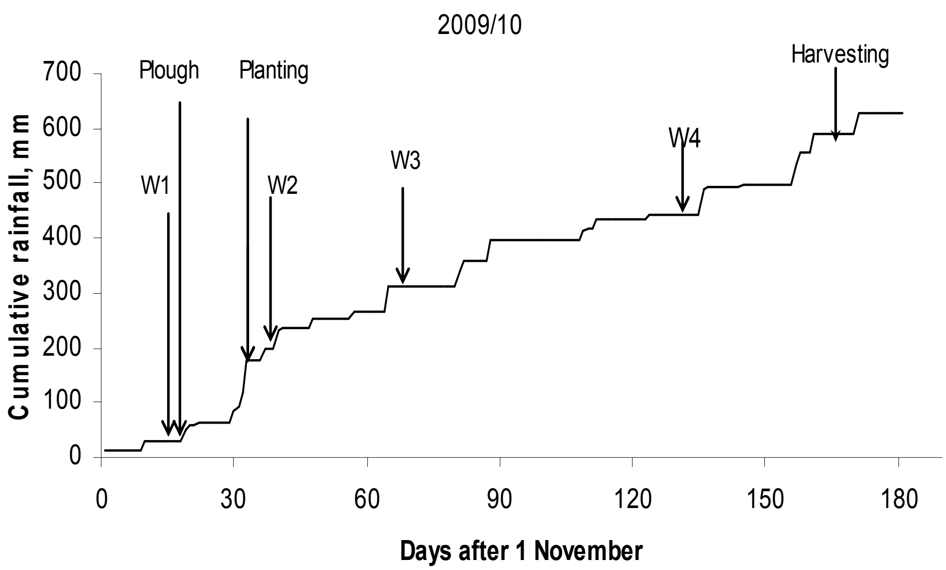


Fig. 3.1 Cumulative daily rainfall received and the timing of crop management practices at Matopos, Zimbabwe in the 2008/09 and 2009/10 cropping seasons. W1, W2, W3 and W4: high intensity hoe weeding operations; W1 and W3: low intensity hoe weeding operations

3.3.2 Weed density and biomass

There was no significant ($P > 0.05$) tillage x maize mulch rate x weeding intensity interaction on weed density and biomass in both crops. The significant two-way interactions were the tillage x weeding intensity interaction was significant ($P < 0.05$) for weed biomass at 4 WAP in cowpea (Fig. 3.2) and tillage x maize mulch rate interaction on weed biomass at 4 WAP in sorghum (Fig. 3.3). The significant main treatment and interactions effects are discussed below in detail under the respective subtitles.

3.3.2.1 Effects of tillage

Tillage had a significant ($P < 0.05$) effect on weed density one week before cowpea was planted where ripper tine had 3-fold and PB 2-fold the weed density (3.4 $m^{-2)}$ of the CONV tillage system. Weed emergence under MT systems was higher than under CONV tillage because without soil inversion weed seeds remained in the soil surface layer where suitable environmental conditions may have stimulated weed germination. The surface soil layer is characterized by high light penetration, high levels of O_2 gas, thermal fluctuations and moisture oscillations which often trigger seed germination (Benvenuti *et al*., 2001). In contrast, under CONV tillage most weed seeds were buried at soil depths where conditions induced seed dormancy leading to low weed emergence.

Similar results were in the season that preceded the cowpea phase being reported on in this study by Mashingaidze *et al.* (2009b) which demonstrated that even in the fourth year of CA a greater weed density resulted in MT than in CONV tillage systems. This may necessitate earlier weeding in RT and PB tillage systems than would be the case in CONV tillage, at a time when labor demand is still high. The low weed infestation observed in CONV tillage plots at 28 days after ploughing in this study (Plate 3.1) is in agreement with the findings of Mabasa *et al, (*1998) from on-farm studies in Zimbabwe that showed that early summer ploughing reduced the need for subsequent weeding for up to four weeks after crop emergence.

Plate 3.1 Low weed infestation in a) CONV tillage compared to b) RT a week after cowpea was planted at Matopos Research Station during the 2008/09 season. *Abbreviations:* CONV - Mouldboard plough; RT – Ripper tine

In cowpeas, MT systems were found to have significantly ($P < 0.05$) greater weed biomass than CONV tillage at 4 WAP (Table 3.1). However, this effect was confounded within the significant ($P < 0.05$) tillage x weeding intensity interaction which showed that MT systems had 37% more weed biomass than CONV tillage only in the low weeding intensity treatment (Fig. 3.2). The absence of a significant difference between MT and CONV tillage systems when a second within cropping season weeding was carried out a week after cowpea was planted demonstrated the need for more frequent hoe weeding in MT systems to achieve weed levels comparable to those in CONV tillage. The same trend of higher weed growth in the less intensive tillage systems was also observed in sorghum. A week before sorghum was planted; PB had the highest weed biomass ($P < 0.05$) of the three tillage systems (Table 3.1). The weed biomass in PB was 58%

more than in CONV tillage with weed biomass in RT being intermediate but not significantly different to that in CONV tillage. In the week after sorghum was planted, MT systems had double ($P < 0.05$) the weed biomass of CONV tillage. As a result, total weed biomass of MT systems was 16% higher ($P < 0.01$) than that of CONV tillage (Table 3.1). Since weed density measured after planting did not significantly vary with tillage in both seasons, the differences observed in weed biomass must have been mainly due to variation in weed growth between tillage systems.

Weeds such as *Commelina benghalensis* L., *Alternanthera repen* (L.) Link.*,* *Boerhavia diffusa* L., *Leucas martinicensis* (Jacq.)R.Br. and some grass species were observed to grow rapidly with the first effective rains in MT systems in both seasons. The weed *A. repens* has a deep tap root that allows plant to regenerate and tolerate drought. *Commelina benghalensis* has stems with high moisture content and once plant is well-rooted it can survive without moisture (Wilson, 1981). In addition, *C. benghalensis* has rhizomes which re-grow rapidly at onset of rains (Holm *et al*., 1971).The undisturbed root systems and rhizomes under MT systems may have given these weeds a head start at the onset of the rainy season and resulted in greater weed biomass accumulation under MT systems than CONV tillage. Perennial weeds have been reported to establish rapidly in non-inversion tillage fields in studies done by Makanganise *et al*. (2001) in Zimbabwe; Kombiok and Alhassan (2007) in Ghana. In addition, the weeds *C. benghalensis* and *A. repens* as well as *Portulaca oleracea* L., were observed to quickly regenerate after hoe weeding under wet conditions. This suggests that shallow hoe weeding as done in this study was not fully effective in controlling these weeds. It may, in fact, have increased weed infestations when the cut stems gave rise to new weed plants. However, this issue can be resolved by removing weeds from field after hoeing as is done by some smallholder farmers so as to prevent uprooted weeds from re-establishing under wet conditions.

Both PB and RT tillage systems had greater weed growth than CONV tillage early in the cropping season. This period falls within the first third of most crops life cycle that is required to be kept weed free to avert yield loss (Mashingaidze, 2004). According to Akobundu (1987) sorghum required 35 and cowpea 40 weed free-days after planting to prevent weeds from causing significant yield reduction. The increased weed growth under MT in both the 5th and 6th

years of the CA experiment contradicts literature (Wall, 2007; FAO, 2010) that states that weed growth will increase in the first years but decline and become easier to control with time in CA. The high early season weed growth suggests a potential for increased weed competition that would probably necessitate early weed control strategies to be implemented if significant crop yield losses are to be averted.

Table 3.1 Tillage main effect on weed biomass in cowpea and sorghum grown at Matopos Research Station in 2008/09 and 2009/10 seasons

Crop	Tillage system	Weed biomass(kg ha^{-1})					
		-1[§] WAP	1 WAP	4 WAP	9 WAP	13 WAP	Total[∞]
Cowpea	CONV			29.4	17.5	21.6	41.9
	RT			42.8	14.2	19.0	49.6
	PB			40.5	14.6	18.4	48.1
	LSD $_{(0.05)}$			8.26	ns	ns	ns
Sorghum	CONV	8.9	1.8	20.0	13.6	5.0	29.9
	RT	10.2	5.8	22.3	14.5	6.0	34.8
	PB	14.4	7.3	26.0	14.7	7.1	40.3
	LSD $_{(0.05)}$	3.49	2.62	ns	ns	ns	4.13

[§]One week before planting; [∞]Cumulative weed biomass after planting (WAP). Square root (x + 0.5) transformed data presented. *Abbreviations*: CONV - Mouldboard plough; RT - Ripper tine; PB - Planting basin; LSD - least significant difference; ns - not significantly different.

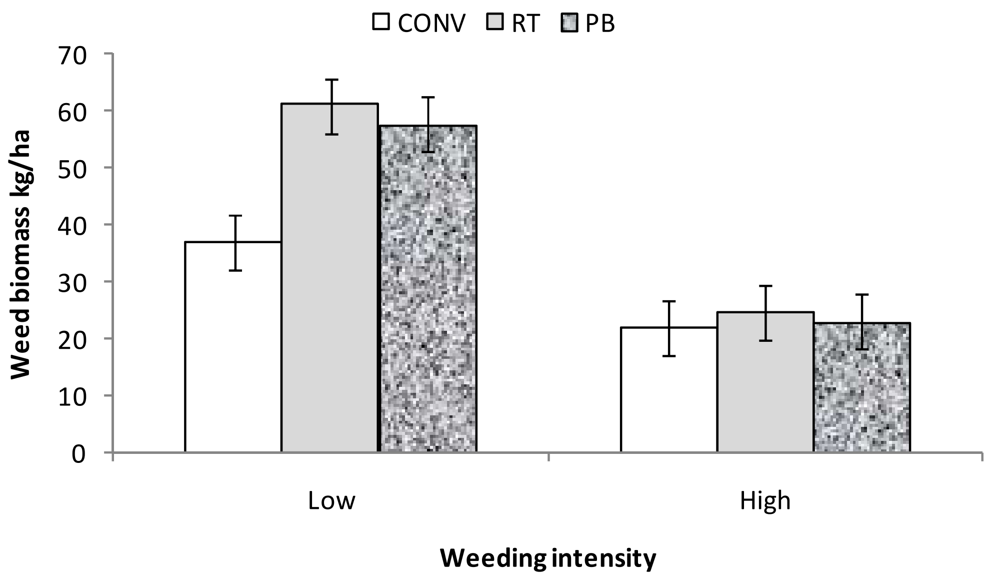


Fig. 3.2 Tillage x weeding intensity interaction on weed biomass at 4 WAP in cowpea grown in 2008/09 at Matopos, Zimbabwe. Narrow bars represent ±SED. Square root (x + 0.5) transformed data presented. *Abbreviations*: CONV - Mouldboard plough; RT – Ripper tine; PB – Planting basins; SED - standard error of difference of the means

3.3.2.2 Effects of maize mulch rate

Maize residue mulching significantly ($P < 0.01$) increased total weed density in cowpea by at least 7% compared to the un-mulched treatment (Table 3.2). Although the trend of increased weed density with mulching was observed at all sampling times in cowpeas, the effect was only significant as from the middle of the 2008/09 cropping season. Weed density increased by at least 16% ($P < 0.05$) at 9 WAP and 20% ($P < 0.01$) at 13 WAP in mulched plots. In sorghum, the maize mulch rate of 4 t ha^{-1} had the highest weed density at 4 WAP and when summed across all sampling times (Table 3.2). Maize mulch application was also associated with high weed biomass in sorghum at both 9 and 13 WAP (Table 3.2). Weed biomass increased by at least 22% ($P < 0.01$) at 9 WAP and 13% ($P < 0.05$) at 13 WAP under mulching. Consequently, it would appear from these observations that the retention of maize residue rather than suppressing weeds as is widely reported (Bilalis *et al.,* 2003; FAO, 2010) increased the emergence of weed seedlings and their subsequent survival rate compared to un-mulched plots.

Soils under maize mulch were reported to have had higher soil water content than un-mulched soils by Mupangwa *et al*. (2007) in the first phase of the maize-cowpea-sorghum rotation of this study at Matopos Research Station. It may, therefore, be that the high weed growth under mulch was due to improved water conservation than in un-mulched soils. Corresponding results were obtained by Buhler *et al*. (1996) in the USA who reported that in a below average rainfall season the retention of 5 t ha^{-1} of maize residue resulted in increased weed density of some annual weed species due to improved soil moisture conditions. According to Mohler and Teasdale (1993) 'safe sites' maybe created under the residue where more uniform soil moisture and moderate temperatures are maintained during hot dry periods and these can increase weed germination and growth.

While an increase in weed density and biomass at the end of the crop's life cycle may not be important in terms of crop/weed competition, these late weeds if allowed to shed seeds add to the weed seed bank and become a source of future weed infestations. In fact weeds growing over the winter period in Zimbabwe have been shown to deplete residual soil moisture (Bruneau & Twomlow, 1999). In order to prevent replenishment of the soil weed seed bank and conserve residual soil moisture for the next season, smallholder farmers should be encouraged to control the late season weeds. However, competition for labour is likely to occur between weeding and harvesting as farmers will be beginning to harvest the early planted crops. This is then followed by harvesting of all other crops before livestock are allowed to graze freely in fields. In fact Mazvimavi *et al*. (2011) report that in Zimbabwe only about 56% of smallholder CF farmers weeded their fields soon after harvesting in May/ June (winter weeding) during the 2008/09 cropping season. The rest of the farmers weeded fields during planting basin preparation which is usually carried out by smallholder farmers from August to as late as November.

Maize residue mulching did, however, suppress weed growth but this was only observed in sorghum and confined to early cropping season. Retention of maize mulch at the highest rate of 8 t ha^{-1} decreased ($P < 0.05$) decreased weed biomass at 1 WAP by 19% (Table 3.2). No significant suppression in weed growth was observed at the intermediate maize mulch rate of 4 t ha^{-1}. There was a significant ($P < 0.01$) tillage x maize mulch rate interaction on weed biomass at 4 WAP that showed that mulching at both rates reduced weed biomass only under PB tillage systems (Fig. 3.3). In this study, maize residue mulching was observed to provide a soil cover of 60% at 4 t ha^{-1} and 100% at 8 t ha^{-1} and the shading effect of the mulch probably led to a reduction in soil temperature oscillations and the amount of light reaching the soil surface. Since temperature and light are important cues for seed dormancy and germination for most annual weed species, shading of the soil surface by the mulch early in the season before the sorghum canopy had fully formed resulted in suppression of weed emergence and growth.

Bilalis *et al*. (2003) observed that both weed density and biomass decreased with increased wheat residue mulch on an organic farm in Greece. In Zambia, Gill *et al.* (1992) found that 5 t ha^{-1} of grass (*Cynodon* species) residues significantly reduced weed biomass in the first 42 days of maize growth in a MT system. Mashingaidze *et al*. (1995) in work done in Zimbabwe using wheat residues as mulch also observed greater suppression in weed emergence in MT systems than in conventional tillage. The concentration of weed seeds in the soil surface in MT systems may make them more susceptible to the effects of mulch on weed germination than weed seeds in CONV that are buried at greater soil depths.

While the observed weed suppression may be useful in reducing labour demands early in the cropping season, only a minority of smallholder farmers are able to retain maize residue at the levels (4 t ha^{-1} or more) used in this study in their fields. The amount of crop residue available for use as mulch is limited by low biomass production under rainfed conditions in semi-arid areas of southern Africa (Wall, 2007). In addition, the multiple uses of crop residues that include residue use as feed for livestock in the mixed crop/livestock farming systems common under smallholder agriculture in southern Africa and the use of crop residues for composting further reduce crop residue availability for mulching. Due to these constraints, the rates of crop residue available for mulching in marginal areas are so low that they are unlikely to eliminate the need for early weeding in MT systems as suggested by Gill *et al*. (1992).

The observation that maize residue mulching consistently resulted in increased weed density and biomass from the middle of the season had not been reported before in southern Africa. The finding is important in that one of the major reasons given to farmers for adopting crop residue mulching is weed suppression. However, this study showed that maize mulching can result in increased weed pressure that can reduce crop yield if not controlled. There is a need to carry out a similar study on a sandy soil to verify whether the same weed responses as observed under the clay loam in this study occur. If similar results were to be observed on a lighter textured soils it could be concluded that in terms of weed suppression, smallholder farmers in semi-arid areas may be better off using residues to feed livestock and composting as maize residue mulching is associated with increased late season weed growth that may require late season weeding to prevent seed return as recommended under CA.

Table 3.2 Maize mulch rate main effect on weed density (m^{-2}) and biomass (kg ha^{-1}) growth in cowpea and sorghum grown at Matopos Research Station in 2008/09 and 2009/10 seasons

Crop	Mulch t ha^{-1}	Weed growth					
		-1[∞]WAP	1 WAP	4 WAP	9 WAP	13 WAP	Total[§]
Weed density m^{-2}							
Cowpea	0	9.1	5.8	7.6	5.8	5.9b	13.0
	4	9.8	7.2	8.4	6.9	7.1a	14.6
	8	8.9	5.6	8.2	6.7	7.1a	13.9
	LSD $_{(0.05)}$	ns	ns	ns	0.85	0.60	1.87
Sorghum	0	12.3	5.6	24.9	11.5	16.4	34.2
	4	11.4	4.2	21.8	14.2	21.3	35.3
	8	9.7	5.0	21.6	17.1	18.6	35.7
	LSD $_{(0.05)}$	ns	ns	ns	2.63	1.16	ns
Weed biomass kg ha^{-1}							
Cowpea	0			36.8	15.5	18.2	44.8
	4			41.6	15.2	20.7	50.4
	8			34.4	15.5	20.0	44.4
	LSD $_{(0.05)}$			ns	ns	ns	ns
Sorghum	0	3.4	8.0	10.8	5.5	5.2	15.7
	4	3.7	7.6	12.6	5.8	5.5	17.0
	8	3.2	6.5	10.7	6.3	5.0	15.0
	LSD $_{(0.05)}$	ns	1.07	1.30	ns	ns	1.44

[∞]One week before planting; [§]Cumulative weed biomass weeks after planting (WAP). Square root ($x + 0.5$) transformed data presented. *Abbreviations*: LSD - least significant difference; ns - not significantly different.

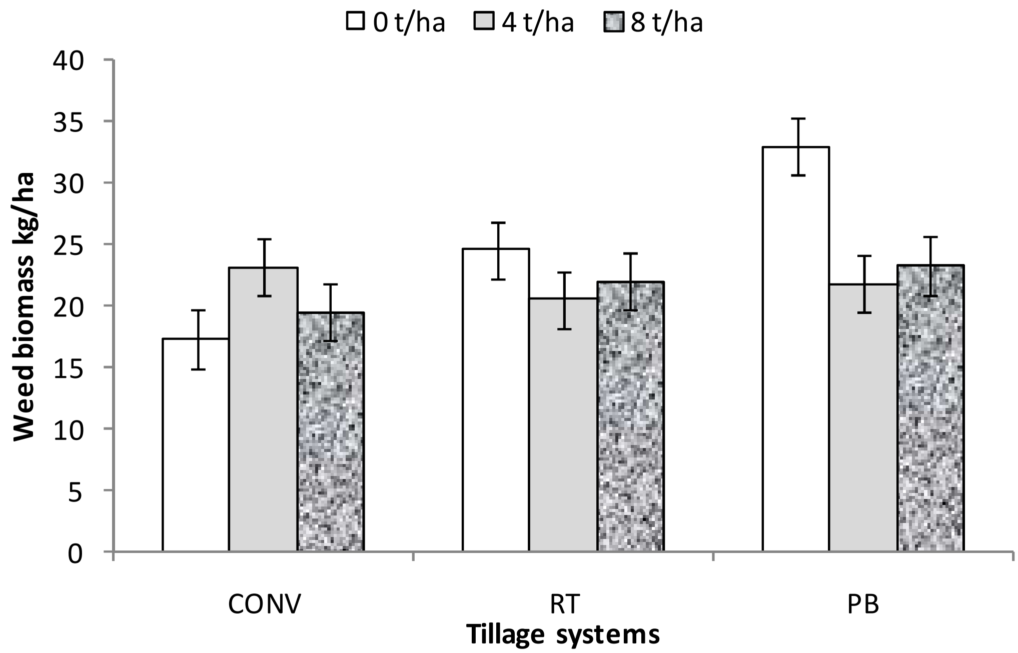


Fig. 3.3 Tillage x maize mulch rate interaction on weed biomass at 4 WAP in sorghum at Matopos, Zimbabwe in the 2009/10 season. Narrow bars represent ± SED. Square root (x + 0.5) transformed data presented. *Abbreviations*: CONV - Mouldboard plough; RT - Ripper tine; PB - Planting basins; SED - standard error of difference of the means

3.3.2.3 Effect of intensity of hoe weeding

In cowpea, the low weeding intensity treatment increased ($P < 0.05$) weed density by 13% at 13 WAP and this translated into significantly ($P < 0.001$) higher weed biomass measured at 13 WAP (Table 3.3). At 4 WAP, higher weed biomass was observed in the low weeding intensity treatment than in high weeding intensity only in PB and RT tillage systems (Fig. 3.2). There was no difference in weed biomass at 4 WAP between the MT and CONV tillage systems at the high weeding intensity treatment. Similar results were obtained by Tørreson *et al.* (2003) in a field study in Norway where the use of herbicides diminished differences between tillage systems compared to where no herbicides were applied. The high weeding intensity treatment significantly ($P < 0.001$) reduced total weed biomass (between 4 and 13 WAP) by 48% compared to the low weeding intensity treatment in cowpeas. In sorghum, weeding four times within the cropping season significantly reduced weed biomass and density at 4, 9 and 13 WAP (Table 3.3). In addition, the plots that had received the high weeding intensity treatment when cowpea was grown in 2008/09 season had a weed density at 1 WAP that was 19% ($P < 0.01$) less than that of the low weeding intensity treatment (Table 3.3). When summed over all weed sampling times after sorghum was planted, the high weeding treatment reduced weed density by 36% and weed biomass by 53% compared to the low weeding intensity treatment.

Thus, frequent hand hoe weeding, as demonstrated in a number of studies throughout Africa (Mashingaidze, 2004; Chikoye *et al*., 2007; Gianessi, 2009), can significantly reduce both weed emergence and growth across the cropping season. It was also effective in reducing early season weed growth in sorghum grown under MT (Plate 3.2) to the level found in CONV tillage. However, the four hoe weedings in addition to the dry season weeding(s) carried out in this study may not be a feasible option for the majority of resource-poor smallholder farmers. Although promoters of CA argue that weed management inputs decline after the first three years (FAO, 2012; Thiefelder & Wall, undated)) the findings from this study after four years of CA appear not to support this. Bolliger *et al*. (2006) report that the majority of smallholder zero-till (CA) farmers in southern Brazil find it difficult to control weeds without herbicides more than 20 years after replacing ploughing with zero-till. This dependence by zero-till smallholder farmers in Brazil on herbicides for effective weed control is reported to have increased herbicide use by 17% compared to conventional tillage.

Consequently, this high weeding demand for MT systems will probably limit the area under these tillage systems in smallholder crop production systems. Labour required for hoe weeding under CONV tillage in semi-arid Zimbabwe has been reported at 133 and 173 person hours ha^{-1} by Ellis-Jones et al. (1993) and Vogel (1994), respectively. In contrast, MT systems are associated with increased labour requirements for hoe weeding with mulch ripping requiring 173 person hours ha^{-1} and hand hoeing tillage 204 person hours ha^{-1} (Vogel, 1994). Although mulch ripping was observed to suppress weeds, more time was required during weeding as maize stalks present on the soil surface obstructed hoe weeding The requirement for frequent weeding throughout the cropping season is likely to exacerbate the labour constraints faced by the majority of smallholder farmers in southern Africa. The high prevalence of HIV/AIDS in Zimbabwe has reduced labour availability in communal areas (Mashingaidze, 2004). Labour intensive technologies such as CA are likely to adversely affect the quality of life of women and children as they bear most most of the weeding burden in smallholder agriculture. It is, therefore, likely that the area under PB and RT systems will be limited by the difficulty experienced by smallholder farmers in carrying out timely and frequent year-long weed management over large areas using the labour-intensive hand hoe weeding method.

Research in CA should focus on low-cost cultural practices such intercropping cover crops such as cowpea with main crops, selection of competitive crops and cultivars, improved fertility management and optimum crop densities so as to minimize weed growth. In order to facilitate adoption on large areas the use of burn-down herbicides such as glyphosate and paraquat should be considered for weed control before crop emergence. Spot application of herbicides to patches with troublesome weeds can also be an option. The use of soil applied pre-emergence herbicides and post-emergence during cropping season may, however, prove to be too knowledge intensive for smallholder farmers. This is because use of some herbicides requires that information on soil pH, organic matter and clay content be known to determine appropriate application rates. This information is largely unknown to most smallholder farmers. Glyphosate is often the herbicide recommended for use in CA. However, use of glyphosate continuously will eventually result in emergence of weed species resistant to the herbicide. Weed species resistant to glyphosate have been reported in the USA and other parts of the world (Prather *et al*., 2000). In order to minimize the development of herbicide resistance, farmers should rotate herbicides with different modes of actions. This, however, assumes that smallholder farmer is knowledgeable on modes of action of herbicides and the different herbicides are available on the market which is unlikely to be the case in smallholder agriculture in Zimbabwe. Therefore, research should be aimed at developing an Integrated Weed Management program that diversifies selection pressure in fields.

Table 3.3 Effect of hoe weeding intensity main effect on weed density (m^{-2}) and biomass (kg ha^{-1}) in cowpea and sorghum grown at Matopos Research Station in 2008/09 and 2009/10 seasons

Crop	Weeding intensity	Weed growth					
		-1[∞] WAP	1 WAP	4 WAP	9 WAP	13 WAP	Total [§]
Weed density m^{-2}							
Cowpea	Low			8.1	6.5	7.1	14.2
	High			8.1	6.5	6.3	13.5
	$LSD_{(0.05)}$			ns	ns	0.79	ns
Sorghum	Low		8.2	14.5	6.9	6.5	19.4
	High		6.7	8.2	4.7	3.9	12.4
	$LSD_{(0.05)}$		0.94	1.14	0.75	1.00	1.23
Weed biomass kg ha^{-1}							
Cowpea	Low			51.9	15.9	25.1	61.6
	High			23.2	14.9	14.2	32.6
	$LSD_{(0.05)}$			6.49	ns	3.59	5.48
Sorghum	Low	10.6	5.2	31.6	16.8	9.0	47.7
	High	11.6	4.6	14.0	11.8	3.0	22.3
	$LSD_{(0.05)}$	ns	ns	4.16	0.70	6.89	5.03

[∞] One week before planting; [§] Cumulative weed growth weeks after planting (WAP). Square root (x + 0.5) transformed data presented. *Abbreviations*: LSD - least significant difference; ns - not significantly different.

Plate 3.2 Higher weed growth observed four weeks after sorghum was planted in PB sub-plot (a) weeded only before planting compared to another PB sub-plot (b) weeded at one week before planting and 1 week after planting at Matopos Research Station during the 2009/10 season. *Abbreviations:* PB - Planting basins

3.3.3 Crop performance

3.3.3.1 Cowpea

Cowpea population attained in sub-plots for all treaments in the 2008/09 season was less than 50% of the recommended population of 66 667 plants ha^{-1}. The use of retained seed, late planting and the incessant rainfall received in January 2009 (Fig. 3.1) likely contributed to poor crop establishment. Conventional tillage had the highest number of pods per plant which translated into significantly ($P < 0.05$) higher grain yield (81%) than in MT systems (Table 3.4). Cowpea grain yield in 2008/09 season was low and close to the Zimbabwe national average yield for smallholder farmers of 300 kg ha^{-1} (Nhamo *et al*., 2003). However, high grain yield of over 1

200 kg ha^{-1} of the cowpea cultivar IT86 D-179 have been reported by Mupangwa (2009) in the first phase of the maize-cowpea-sorghum rotation of this CA experiment and by Fatokun (2002) in Nigeria. In both studies, there was good cowpea establishment and growth due to conducive environmental and management conditions. Olufajo and Singh (2002) identified low plant population as one of the major factors limiting yield in cowpea production. In addition, although no formal aphid assessment was done, there was probably poor aphid control in this study as the incessant rains during January 2009 (Fig. 3.1) limited the number of spray applications to only two during the period with severe aphid infestation. Schulz *et al*. (2001) reported that cowpea that is not adequately protected from insect damage produces less grain and more leaf and vine dry matter. This is borne out by the high cowpea stover (> 1 300 kg ha^{-1}) in all the tillage systems (Table 3.4) and this translated to low harvest indexes of between 8 and 17%.

Maize residue mulching had no effect on cowpea yield (Table 3.4) in this relatively wet season. Although the high weeding intensity treatment increased cowpea grain yield by 23%, the yield difference between the two weeding intensities was not statistically significant. Akobundu (1982) found at least two weedings in the first 5 weeks of cowpea growth to be sufficient to avert yield decline from weed infestation under humid conditions. Hoe weeding in the low weeding intensity treatment was carried out within this critical period. It may, therefore, be difficult to convince smallholder farmers to carry out more weedings later in the season for no additional yield benefit for a crop that, although it is an important food source, receives a lower level of management compared to major staples crops such as maize and cash crops like cotton (*Gossypium hirsutum* L.) in smallholder agriculture.

Table 3.4 Response of cowpea yield to tillage, maize mulch rate and hand hoe weeding intensity at Matopos, Zimbabwe in 2008/09 season

Tillage	Maize mulch rate (tha^{-1})	Pods $plant^{-1}$		Grain yield ($kgha^{-1}$)		Stover (kg ha^{-1})	
		Weeding intensity					
		High	Low	High	Low	High	Low
CONV	0	29	19	546	392	2654	1429
	4	26	22	580	287	3457	1975
	8	23	21	372	299	3179	1975
	Mean	26	21	499	326	3097	1793
RT	0	22	23	313	351	1173	1440
	4	25	15	251	252	1605	1029
	8	21	22	232	231	1337	1379
	Mean	23	20	265	278	1372	1283
PB	0	15	16	246	255	1317	1235
	4	14	13	252	204	1399	1193
	8	14	15	224	188	1440	1770
	Mean	14	15	241	216	1385	1399
$LSD_{0.05}$ (Tillage)		4.2		120.2		5061.3	
$LSD_{0.05}$ (Mulch)		3.6		78.5		3535.2	
$LSD_{0.05}$ (Tillage x Mulch)		2.4		79.3		2845.7	
$LSD_{0.05}$ (Weeding)		6.2		136.0		6123.1	
$LSD_{0.05}$ (Tillage X Weeding)		4.1		137.0		4928.9	
$LSD_{0.05}$ (Mulch x Weeding)		4.4		119.7		4748.6	
$LSD_{0.05}$ (Tillage x Mulch x Weeding)		7.7		207.		8219.6	

Abbreviation: CONV - Mouldboard plough; RT - Ripper tine; PB - Planting basins; LSD - least significant difference

3.3.3.2 Sorghum

In sorghum, CONV tillage had the highest plant density at harvesting, with the density in PB being 81% lower than in CONV tillage (Table 3.5). The wide spacing of 0.9 x 0.6 m that is recommended in PB tillage systems by the Zimbabwe CA Taskforce (Twomlow *et al*. 2008a; ZCATF, 2009) may have been one of the factors responsible for the low sorghum density in PB. The low sorghum stand in PB tillage systems probably contributed to the low grain yield as sorghum grain yield at Matopos in 2009/10 season was positively correlated ($P < 0.01$; r^2 =

0.411) with sorghum density. The sorghum grain yield obtained under CONV tillage was 1 557 kg more than for PB with the same trend in sorghum stover yield.

Maize residue mulching significantly ($P < 0.05$) reduced sorghum grain yield by 15% (Table 3.5). The high weed biomass under mulched plots at both 9 and 13 WAP (Table 3.2) probably reduced sorghum yield through increased competition during the boot stage. On average, the sorghum crop in this study was observed to have reached 50% booting at 9 WAP. Since potential seed number per panicle is determined during the boot stage (Vanderlip, 1993) increased weed competition may have reduced seed number per panicle and ultimately grain yield. This is because seed number per panicle is highly related to sorghum grain yield (Heinrich *et al.*, (1983). Weed biomass at 13 WAP was observed to be negatively correlated ($P < 0.01$; $r^2 = 0.36$) to sorghum grain yield with the same trend observed at 9 WAP. The grain yield obtained under the low weeding intensity treatment was significantly ($P < 0.05$) lower (19%) than that obtained at the high weeding intensity treatment (Table 3.5) indicating the benefits of high weeding intensity on sorghum yield. However, the industrial and commercial use of sorghum and all small grains is very limited in Zimbabwe (Sukume *et al.*, 2005). In semi-arid areas in Zimbabwe, sorghum production was reported to be unprofitable due to a combination of low yields (< 500kg ha^{-1}) and the low producer price (Hikwa *et al.*, 2009). In this study improved fertility and weeding increased sorghum yield to over 2.5 t ha^{-1} in all tillage systems. However, the associated cost of the extra inputs, labour for weeding and bird scaring are likely to make sorghum production less profitable compared to maize which has a more ready market. These issues and the fact that sorghum plays a minor role in food security in Zimbabwe (Rukuni *et al*., 2006) maybe the reason sorghum ranks after maize and pearl millet in terms of production in Zimbabwe.

Table 3.5. Response of sorghum yield to tillage, maize mulch and weeding intensity treatments at Matopos, Zimbabwe in 2009/10 season

Tillage	Mulch rate (tha^{-1})	Ears ha^{-1}		Grain yield ($kgha^{-1}$)		Stover ($kg\ ha^{-1}$)	
		Weeding intensity					
		High	Low	High	Low	High	Low
CONV	0	81667	71852	5378	3896	5050	3944
	4	74259	72222	3503	4474	5370	4367
	8	63889	64074	4122	3581	5092	4983
	Mean	73272	69383	4334	3984	5171	4431
RT	0	46451	56636	5031	3500	3676	2022
	4	59877	66204	3859	2886	3771	3328
	8	52315	59259	3697	3580	3705	2578
	Mean	52881	60699	4196	3322	3717	2643
PB	0	31790	41975	2885	2535	2206	1536
	4	32407	38117	3193	1775	2961	1385
	8	32099	42284	2853	2372	2633	2320
	Mean	32099	40792	2977	2227	2600	1747
$LSD_{0.05}$ (Tillage)		18848.7		752.4		925.4	
$LSD_{0.05}$ (Mulch)		8255.4		485.9		464.9	
$LSD_{0.05}$ (Tillage x Mulch)		53050.1		526.7		339.5	
$LSD_{0.05}$ (Weeding)		14298.8		841.7		805.2	
$LSD_{0.05}$ (Tillage X Weeding)		9266.6		912.3		588.1	
$LSD_{0.05}$ (Mulch x Weeding)		10090.2		775.4		596.3	
$LSD_{0.05}$ (Tillage x Mulch x Weeding)		17476.7		1343.1		1032.9	

Abbreviation: CONV - Mouldboard plough; RT - Ripper tine; PB - Planting basins; LSD - least significant difference

3.4 CONCLUSION

In contrast to claims that weed pressure is only high within the first three of CA adoption, this study demonstrated CA systems that are being currently recommended to smallholder farmers had higher early season weed infestation than CONV tillage five and six years after CA adoption. This greater early season weed pressure under CA would require early and more frequent weeding to avert significant crop yield loss that is likely to exacerbate existing labour bottlenecks in smallholder crop production systems. Contrary to the widely held belief of suppression of weed growth on mulching, maize residue mulching increased mid-to-late season weed growth in both seasons of the study suggesting that this practice can aggravate problems with weed control faced by smallholder farmers that have replaced CONV tillage with CA in semi-arid areas. Based on the high weed growth and low grain yield in both crop species on mulching, there was limited justification for retaining maize residue as mulch in the medium term in CA. Overall weed growth was decreased and crop grain yield improved with increasing hand hoe weeding intensity irrespective of the tillage systems demonstrating that early and frequent hoe weeding is effective in controlling weeds. However, the majority of smallholder farmers lack sufficient labour to carry out the four hoe weedings as done in this study. Low cowpea and sorghum grain yields were realized in MT systems probably due to poorer crop establishment compared to CONV tillage. The use of retained cowpea seed in this study and excessive rains soon after planting probably contributed to poor cowpea establishment and low grain yield observed especially under CA. In order for CA to be practiced on large areas by smallholder farmers, there is need for research on the economic feasibility of using herbicides and cultural practices such as intercropping with fast growing legume for early season weed control. Research on optimal spacing and density of small grains and legumes is required so as to improve on crop yield and also aid in weed management in CA. There is need for long term studies of weed population dynamics under CA to be done under both heavy and light textured soils.