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The impact of tillage system and herbicides on weed density, diversity and yield of cotton (*Gossipium hirsutum* L.) and maize (*Zea mays* L.) under the smallholder sector

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A B S T R A C T

The study was carried out to evaluate the impact of tillage system in combination with different herbicides on weed density, diversity, crop growth and yields on 18 farms in Kadoma, Zimbabwe. Experiments were set up as a split plot design with three replications on each farm. Tillage was the main plot (Conservation Tillage (CT), Conventional Tillage (CONV)) and weeding option (hand weeding, cyanazine, atrazine, glyphosate only and mixture of cyanazine + alachlor and atrazine + alachlor) as the sub-plots. Due to the heterogeneous nature of farmers' resource base, the farms were grouped into three farm types: high (Type 1), medium (Type 2) and poorly resourced farmers (Type 3). The hand hoe weeded treatments had 49 percent higher total weed densities in CT relative to CONV, and was statistically similar to the glyphosate treatment. The mixed pre-emergence herbicides reduced the diversity indices by 69 and 70 percent when compared to the hand hoe weeded treatment under CT in cotton and maize, respectively. The effectiveness of all pre-emergence herbicides were not influenced by tillage but were affected by farmers resource endowments with pronounced effect in Farm Type 1. Maximum plant heights of 85 and 238 cm were recorded for mixed pre-emergence herbicides under CT for cotton and maize, respectively. Minimum plant heights of 75 and 217 cm were recorded for the respective hand hoe weeded treatments. The hand hoe weeded treatments resulted in average cotton lint yield of 1497 and 2018 kg ha^{-1} for maize. The mixed pre-emergence herbicides treatments gave yields of 2138 and 2356 kg ha^{-1} of cotton and maize, respectively. The higher weed densities in CT under hand weeded treatments underscored the need for other weeding options. Similarly, a mixture of cyanazine + alachlor in cotton and atrazine + alachlor in maize is recommended for suppressing broad and grass weed populations and enhancing yields in CT systems.

1. Introduction

Conservation Agriculture (CA) is being promoted as a sustainable method of farming that leads to increased yields and reduced soil erosion and labour requirements for land preparation (Govaerts et al., 2009). In Zimbabwe, a hand based CA system (more appropriately Conservation Tillage (CT)/Reduced Tillage) is being widely promoted in the smallholder farming communities since 2004 (Marongwe et al., 2012). The central component of this package is the planting basin, which is a small hole dug with a hand hoe in which seeds are sown (Mazvimavi and Twomlow, 2009). The hand based CA system is particularly appropriate to southern Africa because the majority of smallholder farmers struggle to plant their fields on time due to lack of draught animals (Wall, 2007). Smallholder farmers without animal draught power can plant soon after effective rains rather than waiting for draught animals to become available several weeks into the season.

Notwithstanding that CA could increase crop production for smallholder farmers, weed management, particularly in the early years of adoption (Mazvimavi and Twomlow, 2009), has been one of the primary production challenges for smallholder farmers adopting this system. Traditionally, tillage is used as a means of preparing a weed free seedbed. However, due to the absence of

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tillage in CA, the density of weeds would be expected to increase particularly early in the season (Johansen et al., 2012). Farmers often delay weeding early in the season concentrating on planting, because of the limited labour (Makanganise et al., 2002). Most of the farmers would rather prefer to continue planting their fields as they take advantage of the moisture. Consequently, the delay in weeding often results in increased crop-weed competition for light, water and nutrients (Meksawat and Pornprom, 2010). Crop yield losses under un-weeded conditions have been reported to be more than 30 percent in Zimbabwe (Mashingaidze, 2004).

The predominant weed control practice on smallholder farms under CT is hand hoe weeding. Other methods of weed control, which include the use of ox drawn implements such as ploughs and tine cultivators are discouraged because they increase tillage (Vissoh et al., 2004). However, hand hoe weeding is slow and constitutes 50–70 percent of total labour time for smallholder farmers (Chikoye et al., 2007). The increased weed density and labour requirements in CT exacerbate the labour shortfalls already pervassive in the smallholder farming sector. Rural – urban migration of young people, including to neighbouring countries, has affected the availability of labour required for hand hoe weeding within the smallholder farming communities.

Considering the numerous challenges faced by smallholder farmers on weed management, the use of the hand hoe as the only method of weed control in CT is not adequate to meet increased weed challenges. This underlines the need for other effective weed management options, which take into consideration the increased weed density and diversity in CT. Herbicide usage may increase the capacity of smallholder farmers to effectively deal with weed pressure, especially during the critical weed free period and in wet conditions. Glyphosate and pre-emergence herbicides such as atrazine, cyanazine and alachlor have been used effectively in conventional tillage (CONV). However, the effectiveness of herbicides validated for use in CONV systems may be different under CT systems which have higher weed densities and a very different and diverse weed spectrum. The objective of this study was to evaluate the effectiveness of herbicides under CT systems through their effect on weed emergence, crop growth and yield.

2. Materials and methods

2.1. Study area

The study was conducted in Donain (18°31′S; 29°40″E), Kadoma, Zimbabwe. The climate of the area is sub-humid tropical with a unimodal rainfall distribution starting in November and ending in April. The average rainfall ranges from 650 to 800 mm year^{-1}. Mean long term average annual minimum temperature for the study area ranges from 10 to 14 °C while mean maximum temperatures range from 28 to 35 °C. The soils range from sands, red loams to clays derived from schist, ironstone and granitic parent material. The soil pH ranged from 5.3 to 7.40.

2.2. Experimental procedure

Field trials were conducted during the 2009/2010 and 2010/2011 cropping seasons. A cotton crop was planted during 2009/2010 followed by maize in the 2010/2011 season. Local extension officers assisted in the selection of the 18 smallholder farmers' fields that were used in the study area. Information concerning farmers' resources and soil types was collected for each of the selected farmers during visits to each of the fields and discussions with each individual farmer.

The experiment was laid out as a split plot replicated three times at each farm. Tillage was the main plot encompassing tillage systems with two levels i.e. conventional and conservation tillage. Weeding options represented sub plots with four levels as follows:

1) Hand hoe weeding at three, six and nine weeks after crop emergence (WACE) for both crops.
2) Cyanazine (2-(4-chloro-6-ethlyamino-1, 3, 5-triazin-2-ylamino)-2-ethlypropionitrile) at 4 kg a.i ha^{-1} for cotton and atrazine [2-chloro-4-(ethylamino)-6-(ospropylamino) s-triazine] for maize at 1.46 kg a.i ha^{-1} applied as pre-emergence herbicide.
3) Glyphosate ((glycin, N-(phosphomethyl)-D) $C_6H_{19}N_5S$) at 0.9 kg a.i ha^{-1} at planting followed by hand hoeing at 6 WACE for both crops.
4) Alachlor (2-chloro-N-(2, 6-diethylyphenyl)-N-(methoxymthyl) acetamide) 0. 960 kg a.i ha^{-1} tank mixed with cyanazine at 4 kg a.i ha^{-1} applied pre-emergence for cotton and alachlor 0.960 kg a.i ha^{-1} tank mixed with atrazine at 1.46 kg a.i ha^{-1}applied as pre-emergence herbicides for the maize crop.

The main plot size was 21.6*6 m and the sub plot measured 6*5.4 m. A medium staple cotton (*Gossipium hirsutum* L.) and medium maturity maize (*Zea Mays* L.) variety were planted in all the 18 farmers' fields. The cotton crop was sown in rows 0.90 m apart and 0.3 m spacing within rows to give a population of 37,037 plants ha^{-1}. Maize was sown at a spacing of 0.75 m between rows and 0.6 m within rows with two plants per station to give a population of 44,000 plants ha^{-1}. All farmers applied a basal fertiliser for maize (8N–14P–8K) and cotton (5N–8P–10K), at a rate of 200 kg ha^{-1}. A nitrogen fertiliser (34.5% N) was split applied to both cotton and maize at a rate of 100 kg ha^{-1} at 6 and 9 WACE. All herbicides were applied with a knapsack sprayer that delivered 15 L spray solution through flat fan nozzles that evenly covered a swath width of 0.3 m. The spray volume was 200 L ha^{-1} and spray pressure was 250 kPa.

Weed seedlings were counted in three 0.35 m^2 quadrats placed diagonally in each sub plot. A method described by Barbour et al. (1987) was used to determine the number of quadrats required to obtain a representative sample in each plot. Weed species diversity was calculated for each treatment after Magurran (1988) as shown below:

$$\text{Diversity index} \quad H' = \sum_{i=1}^{S} \frac{n_i}{N} \ln \frac{n_i}{N} \tag{1}$$

where, S = total number of species; N = total number of individuals in a given area; n_i = number of individuals of the ith species of the area; H measures species diversity through proportional abundance of species, with a higher value signifying a more diverse community. Yield assessment for cotton and maize were determined by measuring the cotton lint and maize grain weight from four middle rows of each net plot measuring 4m. Maize grain yield was adjusted to a standard moisture of 12.5 percent and cotton lint yield was adjusted to 14 percent moisture content.

2.3. Data analysis

Before statistical analysis was performed on the weeds data, a Bartlett's test (Snedecor and Cochran, 1983) was carried out to determine the homogeneity of variances. Square root (x + 0.5) transformation was deemed appropriate for the data which had values less than 10 and had zeros present. All the data was subjected to analysis of variance (ANOVA) using SAS procedures (SAS, 2010). The farmer groups (high, medium and low resourced were denoted as Farm Type 1, 2 and 3, respectively in the results section) were used as covariates in the ANOVA to improve the precision of treatment comparisons. The Standard Error of the Difference (SED) was used for mean separation when treatments were significantly different ($P < 0.05$).

3. Results

3.1. Total weed density

3.1.1. Cotton

The pre-emergence herbicides effectively suppressed weed density at 3 WACE in CT and the lowest (7.06 weed seedlings m^{-2}) weed density was in the atrazine + alachlor treatment followed by the cyanazine (9.53 weed seedlings m^{-2}) alone treatment (Fig. 1A). The hand hoe weeded plots in CT resulted in the highest (13.15 weed seedlings m^{-2}) weed density though it was statistically similar ($P > 0.05$) to glyphosate only plots (11.16 weed seedlings m^{-2}). In CONV the hand hoe weeded treatment also resulted in the highest weed density (10.19 weed seedlings m^{-2}) and all the herbicide applied treatments were statistically similar ($P > 0.05$). When comparing the effect of weeding options under the two tillage systems, the hand hoe and the glyphosate weeding options in CT were less effective in controlling weeds relative to the same treatments in CONV. The effectiveness of cyanazine + alachlor and cyanazine alone treatment in CT were statistically similar ($P > 0.05$).

At 6 WACE in CT, the highest weed density was observed in the hand hoe weeded treatment and it was statistically similar ($P > 0.05$) to the glyphosate treatment (Fig. 1B). The atrazine + alachlor treatment had the lowest weed density followed by the cyanazine treatment. Similar results were observed in CONV where the hand hoe weeded treatment had the highest weed density and lowest weed density in cyanazine + alachlor and cyanazine only treatments. The weed densities in all the weeding options under both CT and CONV were statistically similar ($P > 0.05$) at 9 WACE (Fig. 1C).

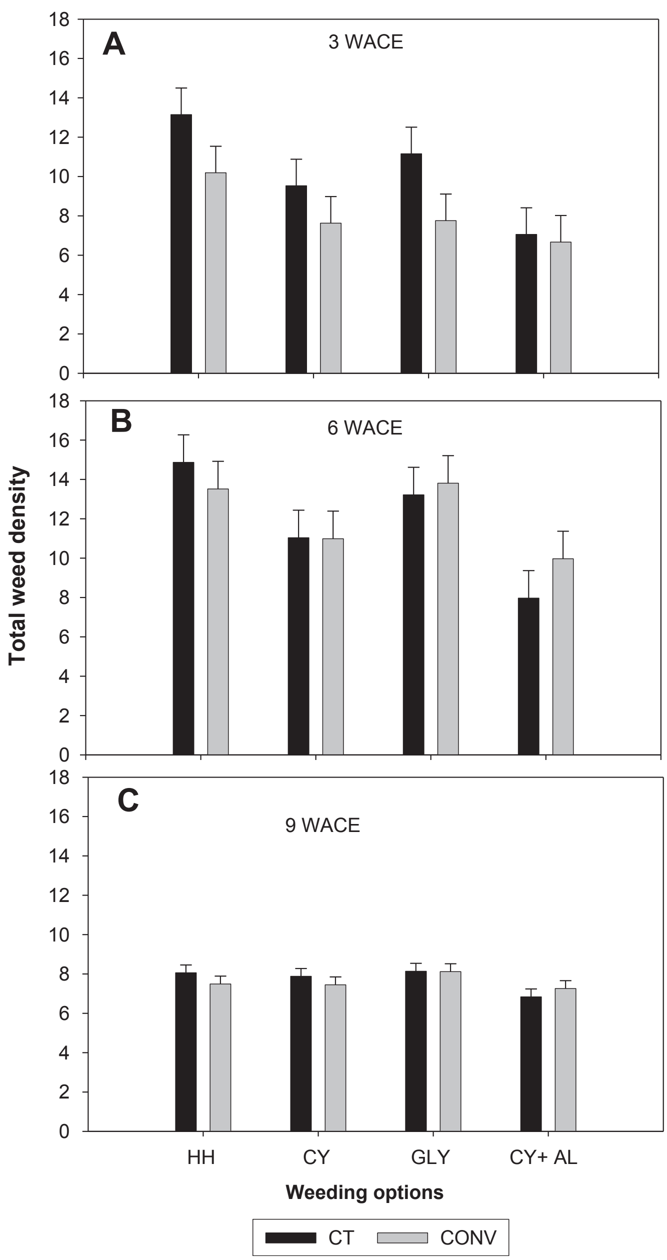

Fig. 1. Effect of tillage and weeding treatment on square root ($x + 0.5$) transformed weed densities data at 3, 6 and 9 weeks after crop emergence (WACE) during 2009/2010 season under cotton. Error bars represent ± SED; CT = Conservation Tillage; CONV = Conventional Tillage; HH = hand hoe; CY = cyanazine; GLY = glyphosate; AL = alachlor; CY + AL = Cyanazine + Alachlor.

3.1.2. Maize

At 3 WACE under CT the weed densities for atrazine + alachlor (9.61 weed seedlings m^{-2}) and cyanazine only plots (8.91 weed seedlings m^{-2}) were statistically similar ($P > 0.05$). The weed densities in the hand hoe weeded (12.06 weed seedlings m^{-2}) and the glyphosate treatment (11.93 weed seedlings m^{-2}) were also statistically similar (Fig. 2A). Similarly, in CONV the pre-emergence herbicide applied treatments had similar effects and the hand hoe and glyphosate treatments were statistically similar ($P > 0.05$). The hand hoe weeded treatments had higher weed densities than pre-emergence herbicide applied treatments. The hand hoe weeded treatment in CT had 19 percent higher weed densities than the hand hoe weeded treatment in CONV. The glyphosate treatment in CT had 17 percent higher weed densities relative to CONV. The pre-emergence herbicides had similar effects in both CT and CONV.

At 6 WACE, there was no significant difference ($P > 0.05$) on the weed density in CT and CONV for all the treatments (Fig. 2B). In CT, the hand hoe weeded treatment (12.81 weed seedlings m^{-2}) had the highest weed densities whilst the atrazine + alachlor (8.66 weed seedlings m^{-2}) had the lowest weed densities though it was statistically at par to the atrazine only treatment (10.15 weed seedlings m^{-2}). In CONV at 6 WACE, the hand hoe weeded treatment was statistically similar to the atrazine (10.59 weed seedlings m^{-2}) and the glyphosate treatment (11.34 weed seedlings m^{-2}). The atrazine + alachlor treatment (8.85 weed seedlings m^{-2}) was still effective in suppressing weeds at 6 WACE when compared to the hand hoe (12.10 weed seedlings m^{-2}) weeded plot indicated by the lowest weed density.

3.2. Weed diversity

3.2.1. Cotton

The weed diversity was significantly ($P < 0.05$) influenced by weeding treatment (Fig. 3A). The cyanazine + alachlor treatment reduced the weed diversity indices by 70 and 60 percent when compared to the hand hoe weeded treatments in CT and CONV, respectively. However, the weed diversity for the cyanazine + alachlor treatment did not differ with the cyanazine only treatment indicating that the cyanazine treatment had impact on the weed diversity. The pre-emergence herbicides had similar effects on weed diversity in CT and CONV whilst the hand hoe weeded and glyphosate treatments had higher diversity indices in CT relative to CONV.

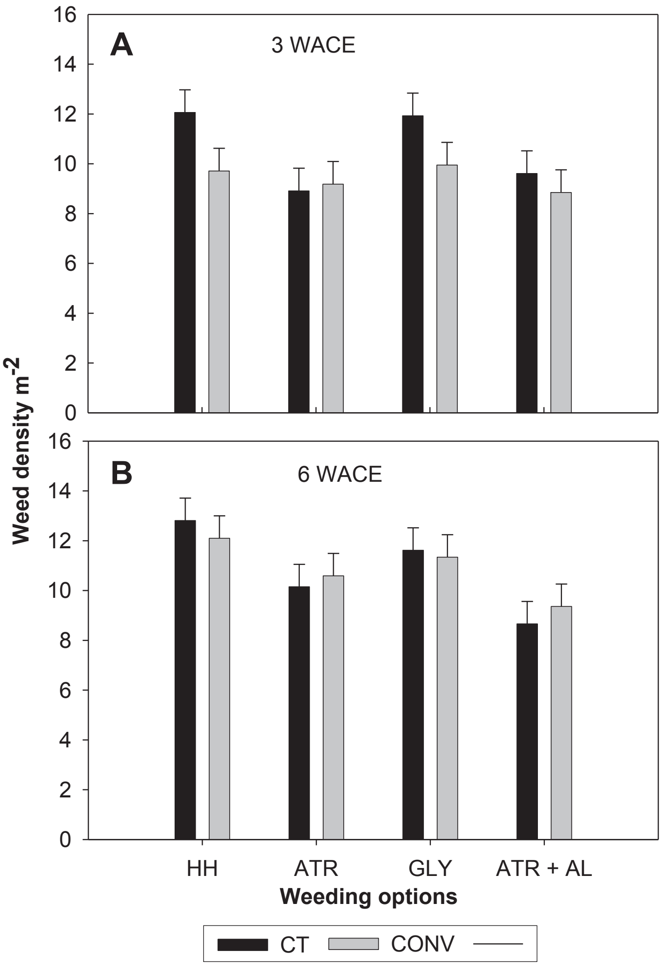

Fig. 2. Effect of tillage and weeding treatment on square root ($x + 0.5$) transformed weed densities data at 3 and 6 weeks after crop emergence (WACE) during 2010/2011 season under maize. Error bars represent ± SED; CT = Conservation Tillage; CONV = Conventional Tillage; HH = hand hoe; ATR= Atrazine; GLY = glyphosate; AL = alachlor; ATR + AL = Atrazine + Alachlor.

3.2.2. Maize

The diversity indices also showed a significant response to herbicide treatment in maize resulting in the lowest diversity indices in the atrazine + alachlor treatment though it was statistically at par ($P > 0.05$) with the cyanazine only (0.24) treatment in both tillage systems (Fig. 3B). The weed diversity index was highest in the hand hoe weeded treatment (0.93) though it was statically similar ($P > 0.05$) to the glyphosate treatment (0.79). The weed diversity index for cyanazine + alachlor and cyanazine only did not differ between the tillage systems.

3.3. Farm typologies and weed densities

3.3.1. Cotton

A further analysis of the weed density data with farm typology as a covariate in the ANOVA revealed a significant ($P < 0.05$) effect of the covariate on the weed density. There were differential effects of weeding treatment on weed density among the farm typologies (Farm Type 1, 2 and 3) (Fig. 4). During the 2009/2010 season, on Farm Type 1 at 3 WACE the cyanazine + alachlor applied treatment (3.94 weed seedlings m^{-2}) suppressed weed densities effectively and had the lowest weed densities though it was statistically similar ($P > 0.05$) to the cyanazine applied treatment (3 weed seedlings m^{-2}) in CT (Fig. 4A). The hand hoe weeded treatment (9.50 weed seedlings m^{-2}) resulted in the highest weed densities and it was statistically similar to the glyphosate treatment (9.04 weed seedlings m^{-2}). In CONV a similar trend was also observed where the glyphosate treatment (6.44 weed seedlings m^{-2}) was statistically similar ($P > 0.05$) to hand hoe weeded treatment (5.34 weed seedlings m^{-2}), while cyanazine + alachlor treatment (2 weed seedlings m^{-2}) had similar effects to cyanazine only treatment (2.51 weed seedlings m^{-2}). The weed densities in the hand hoe weeded treatments under CT were 33 percent higher than the densities recorded in the same treatment under CONV. The weed densities under CT in the glyphosate-applied treatment were 39 percent higher than the glyphosate treatment under CONV. There was no significant difference on the weed densities in pre-emergence applied treatments under CT and CONV.

At 6 WACE the hand hoe weeded treatment was not effective in weed control and resulted in the highest weed densities, secondly followed by glyphosate treatment and both of these treatments were statistically similar (Fig. 4B). The third in ranking was the cyanazine only treatment and fourthly the lowest densities were recorded in the cyanazine + alachlor treatment (2.56 weed seedlings m^{-2}). In CONV, a similar trend was observed with the highest weed densities in the hand hoe weed treatment while the lowest density was recorded in the cyanazine + alachlor treatment. All the treatments had similar effects in CT and CONV.

The pre-emergence herbicides (cyanazine + alachlor and cyanazine alone) were still effective at 9 WACE in suppressing

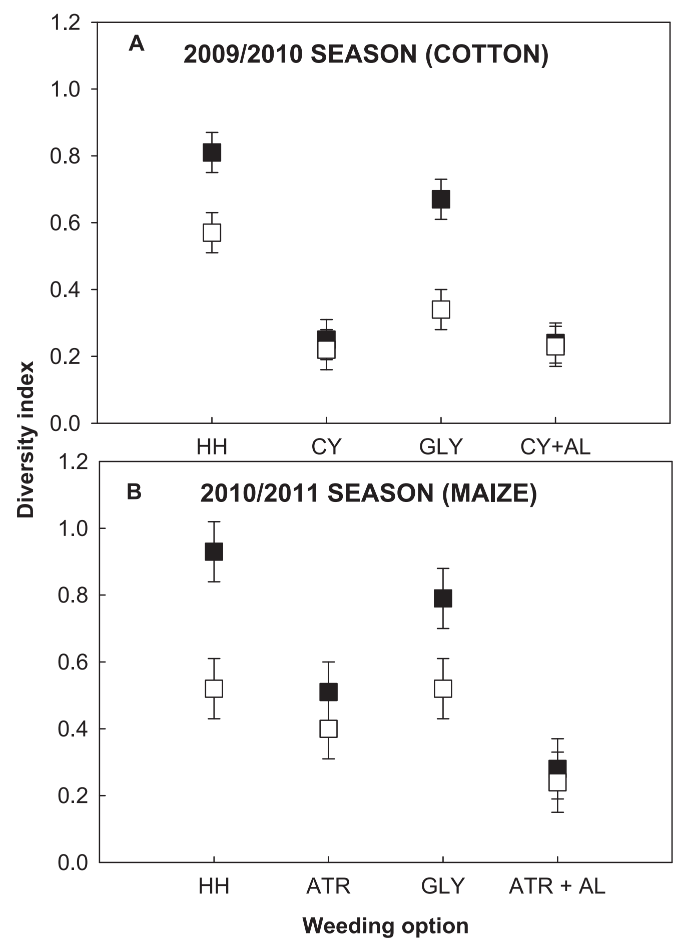

Fig. 3. Effect of tillage, weeding treatment on diversity indices recorded during 2009/2010 and 2010/2011seasons. Error bars represent ± SED; HH = hand hoe; CT= Conservation Tillage; CONV Conventional Tillage; CY = Cyanazine; GLY = Glyphosate, AL = Alachlor; ATR = Atrazine; ATR + AL = Atrazine + Alachlor.

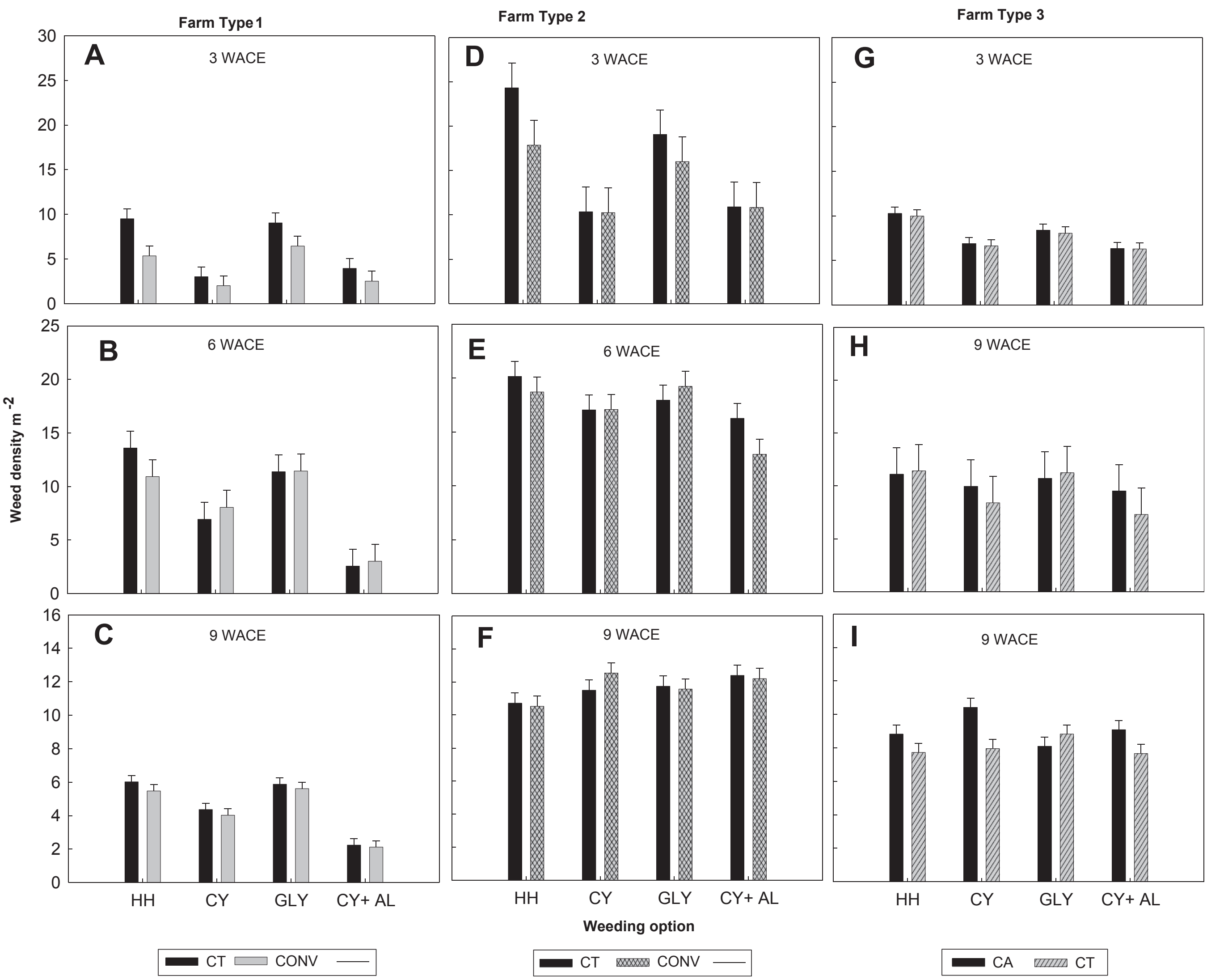

Fig. 4. Effect of tillage and weeding treatment on weed densities of square root ($x + 0.5$) transformed data on three farm typologies recorded during 2009/2010 season under cotton. (WACE) = Weeks after crop emergence, Error bars represent ± SED; CT = Conservation Tillage; CONV = Conventional Tillage; HH = hand hoe; CY = cyanazine; GLY = glyphosate; AL = alachlor; CY + AL = Cyanazine + Alachlor.

weeds and resulted in the lowest weed densities and the two treatments were both statistically similar (Fig. 4C). The weed densities in the hand hoe weeded treatment in CT had similar effects in CONV and consequently resulted in the highest weed densities.

The results for Farm Type 2 also showed higher weed densities at 3 WACE for hand hoe weeded plots in CT which were significantly ($P < 0.05$) different from the pre-emergence herbicides applied treatments (Fig. 4D). Whilst, in CONV at 3 WACE the hand hoe weeded treatment resulted in the highest weed density (17.85 weed seedlings m^{-2}) (Fig. 4D). At the same time at 3 WACE in CONV the lowest weed density was observed for cyanazine + alachlor (10.83 weed seedlings m^{-2}) which was not significantly ($P > 0.05$) different from cyanazine (10.25 weed seedlings m^{-2}) alone application. At 6 WACE, the cyanazine and cyanazine + alachlor treatments were still effective in suppressing weed densities and had the lowest weed densities (Fig. 4E). The effectiveness of the herbicides was reduced at 9 WACE and all the treatments were statistically similar (Fig. 4F).

In Farm Type 3 at 3 WACE the cyanazine + alachlor treatment suppressed weed densities by 38 and 37 percent in CT and CONV when compared to the hand weeded treatment (Fig. 4G). The cyanazine alone treatment also suppressed weed densities and the weed densities were 34 and 33 percent lower than the hand weeded treatment in CT and CONV, respectively (Fig. 4G). There was no significant effect of treatment observed at 6 and 9 WACE in Farm Type 3 (Fig. 4H and I).

3.3.2. *Maize*

The results for 2010/2011 season also showed effective suppression of weed density with pre-emergence herbicides, which was dependant on the farmers' resources (Fig. 5). On Farm Type 1 under CT the atrazine + alachlor treatments had the lowest weed density which was 69 and 53 percent lower than the hand hoe weeded treatment at 3 and 6 WACE, respectively (Fig. 5A and B). In CONV, the atrazine + alachlor treatments were 59 and 73 percent lower than the hand hoe weeded treatment. The pre-emergence herbicides applied treatments were statistically similar at 3 and 6 WACE. The hand hoe weeded treatment also had similar effects with the glyphosate treatment at 3 and 6 WACE. There was a significant effect of tillage on the hand hoe weeded treatment where the

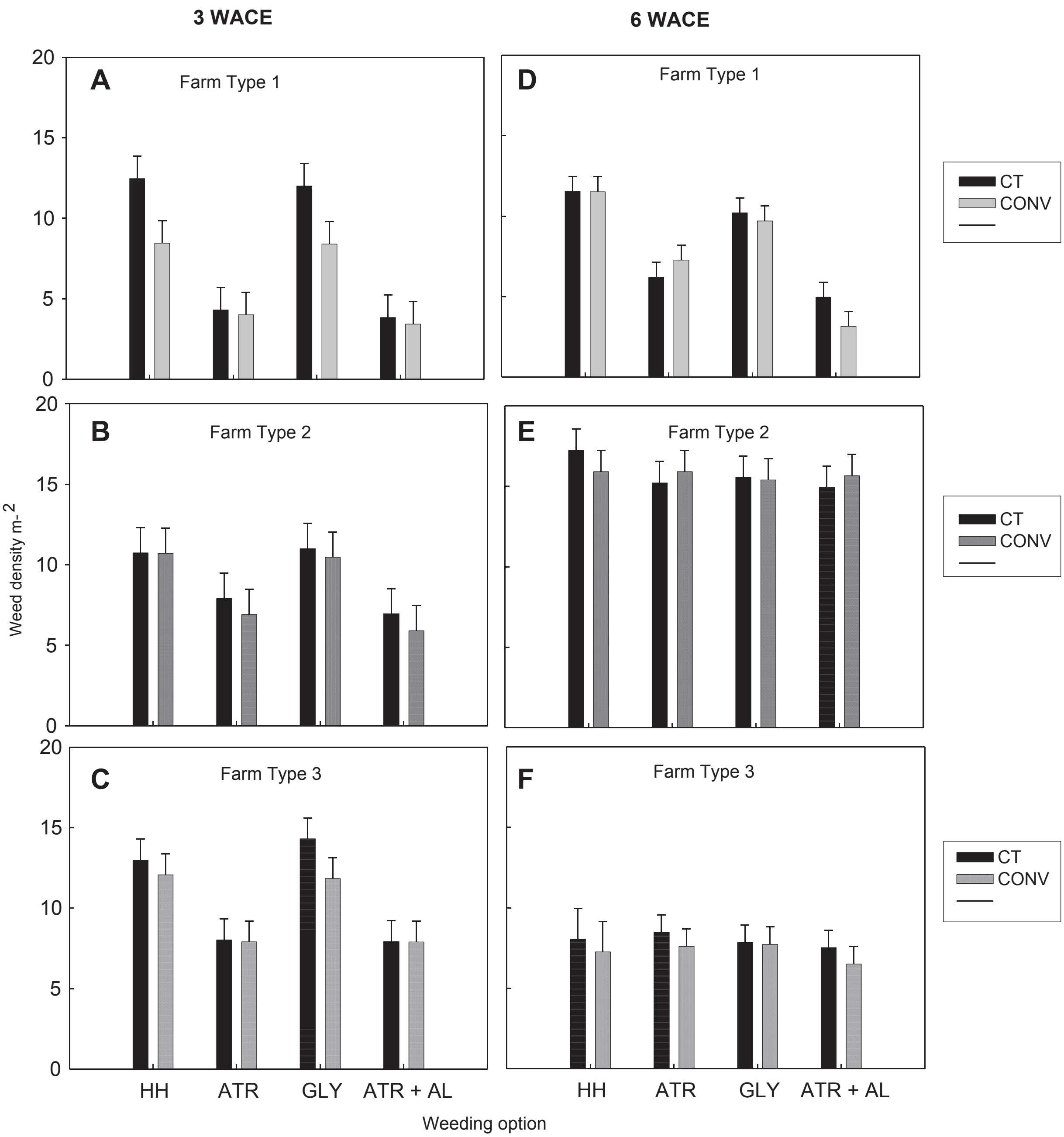

Fig. 5. Effect of tillage and weeding treatment on weed densities of square root ($x + 0.5$) transformed data on three farm typologies recorded during 2010/2011 season under maize. (WACE) = Weeks after crop emergence, Error bars represent ± SED; CT = Conservation Tillage; CONV = Conventional Tillage; HH = hand hoe; ATR = Atrazine; GLY = glyphosate; AL = alachlor; ATR + AL = Atrazine + Alachlor.

treatment in CT had 32 percent higher weed density than relative to the CONV treatment at 3 WACE. However, in the pre-emergence herbicide applied plots there was no significant effect of tillage.

In Farm Type 2 at 3 WACE the lowest weed density (6.95 m^{-2}; 5.90 m^{-2}) was recorded in pre-emergence tank mixed herbicides (cyanazine + atrazine) in CT and CONV, respectively (Fig. 5C and D). On the other hand, the highest weed density was for hand hoe weeded treatment (10.74 m^{-2} and 10.71 $m^{-2)}$ in CT and CONV, respectively (Fig. 5C and D). The glyphosate treatment had the second highest weed density at 3 WACE and it was statistically similar to the atrazine only treatment in both tillage systems. There was no significant effect of tillage resulting in similar weed densities in CT and CONV at 6 WACE in all treatments.

The atrazine + alachlor treatment in Farm Type 3 resulted in the lowest weed density at 3 WACE which was statistically similar to the atrazine only treatment in both tillage systems (Fig. 5E). The effectiveness of hand hoe weeded and the glyphosate treatment were similar in both tillage systems. At 6 WACE in Farm Type 3, no significant ($P > 0.05$) effect of treatment was observed in both tillage systems (Fig. 5F).

3.4. Plant height and crop yields

3.4.1. Cotton

During the 2009/2010 season the weeding treatment significantly ($P < 0.05$) affected the cotton plant heights (Table 1). The interaction of treatment*weeding treatment was not significant ($P > 0.05$) on plant heights and therefore the main effects are presented in Table 1. The cyanazine + alachlor treatment resulted in the maximum plant heights which were 12 percent higher than those for the hand hoe weeded treatment. The plant heights for the cyanazine treatment were statistically similar ($P > 0.05$) to the cyanazine treatment. The hand hoe weeded treatment was also statistically similar ($P > 0.05$) to the cyanazine treatment. Tillage significantly ($P < 0.05$) influenced the plant heights and resulted in 10 percent higher plants in CT than in CONV. The effective suppression of weeds by cyanazine + alachlor treatment resulted in the highest cotton lint yields which were 26 percent higher than the hand hoe weeded treatment (Table 1). The second highest yields was observed in the cyanazine only treatment though it was statistically similar ($P > 0.05$) to the glyphosate and the hand hoe weeded treatment. The yields obtained for CT and CONV were all statistically similar ($P > 0.05$).

3.4.2. Maize

The atrazine + alachlor treatment reduced the weed competition which resulted in the maximum plant heights though statistically similar to the atrazine only treatment (Table 1). The second highest plants were achieved in the atrazine applied treatments, thirdly the glyphosate treatments and lastly the hand hoe weeded treatments. Tillage significantly ($P < 0.05$) affected plant heights and resulted in plants which were 15 percent taller in CT than in CONV. The higher weed densities in the hand weeded plots reduced maize grain yields by 10 percent when compared to the atrazine + alachlor treatment. The yields obtained in the atrazine + alachlor treatments and atrazine alone treatments were statistically similar ($P > 0.05$). Tillage had a significant ($P < 0.05$) influence on the maize yields and resulted in higher yields in CT than in CONV.

4. Discussion

The effective suppression of weeds by pre-emergence herbicides (atrazine, alachlor and cyanazine) during the first 6 WACE helps to reduce labour requirements for weeding early in the season, which is usually scarce in the smallholder farming sector. These findings are in agreement with the findings of Chikoye et al. (2007) who found out that pre-emergence herbicides significantly reduced weed densities early in the season. In this study a mixture of alachlor with atrazine or cyanazine, herbicides ensured maximum weed suppression than individual herbicides. In a study by Mashingaidze (2004), atrazine proved to be the best for controlling weeds compared to other herbicidal treatments when applied as a pre-emergence herbicide in maize. Atrazine and cyanazine mainly control broad-leaved weeds whereas alachlor controls grass weeds and in this study the mixtures and single application of herbicides had similar effects on weed control. The herbicides can be applied as single applications but a mixture of the two herbicides is important in avoiding build up of grass weeds. Glyphosate treatment only controlled existing weeds at planting and the weed cohorts that emerged after crop emergence required subsequent hand hoe weeding. Glyphosate needs to be supplemented with pre-emergence herbicides, which suppress weed emergence after planting.

The differential effects of herbicides on weed density on the farms could be a reflection of factors such as farm management, and extrinsic environmental factors such as soil types and pH. The difference in management strategies and soil types can alter weed communities and densities, which in turn, affect the effectiveness of herbicides. Herbicides are less effective at high weed densities as the increased weed density in a given volume of soil decrease the level of herbicide uptake (Gopal et al., 2010). Therefore, high weed densities in Farm Type 2 could have contributed to reduced effective suppression of weed densities than in Type 1 farms. Hence, an increase in the dosage of herbicides could increase the effectiveness of the herbicides in controlling weeds. Farm Type 3 had low weed densities; therefore, the reduced effect of herbicides in these fields could not have been attributed to weed density. The low pH observed in these fields could have reduced the effectiveness of herbicides in weed control. According to Kells and Meggitt (1985), low soil pH reduces herbicide efficacy. There could be other factors, which reduced the effectiveness of herbicides in Farm Type 3, for example, the high rainfall received after applying the herbicides could have reduced the effectiveness of the herbicides. Moderate rainfall is desirable soon after herbicide application because it enables the herbicides to make contact with the germinating seedlings. However, high rainfall soon after applying herbicides is not desirable because it washes away herbicides resulting in reduced herbicide effectiveness.

This study revealed that optimal weed management strategies and herbicide usage must be specific to individual field conditions. It is important to consider the distribution pattern of weeds, to determine what the likely weed species will be before implementing new weed management strategies. Ideally, farmers in transition to CT should scout the fields regularly to determine which weed species is becoming pervasive and to determine the density of each problem weed and use the information to develop optimal weed control options.

Although many factors can alter herbicide performance, there is not a consistent effect of tillage on chemical weed control. Johnson et al. (1989) reviewed several studies and found that some studies reported poor herbicidal weed control in CT whilst some studies found comparable weed control with pre-emergence herbicides in both CT and CONV systems. The weed species encountered in this study were similar in CT and CONV, therefore, tillage did not influence weed species composition. Chauhan and Opena (2012) also made similar conclusions that herbicidal requirements within tillage systems are similar.

In this study, herbicides changed the weed community structure by reducing the weed diversity indices. It is, therefore, important to note how quickly herbicides can alter the weed communities. The diversity of weed communities determines the strategies required

Table 1
Effect of tillage system and weeding treatment on cotton plant heights and lint yields during 2009/2010 season.

	2009/2010 season (cotton)	
	Plant height (cm)	Cotton lint yield kg ha^{-1}
Weeding treatment		
Hand weeding	75b	1497b
Cyanazine	83a	1729b
Glyphosate	76b	1620b
Cyanazine + Alachlor	85a	2019a
$SED_{(0.05)}$	1.1	93.45
Tillage		
Conservation Tillage	84a	1717a
Conventional Tillage	76b	1715a
$SED_{(0.05)}$	1.56	–
	2010/2011 season (maize)	
	Plant height (cm)	Maize grain yield kg ha^{-1}
Weeding treatment		
Hand weeding	217c	2138c
Atrazine	236a	2372a
Glyphosate	225b	2251b
Atrazine + Alachlor	238a	2356a
$SED_{(0.05)}$	1.41	21
Tillage		
Conservation Tillage	247a	2343a
Conventional Tillage	210b	2220b
$SED_{(0.05)}$	0.99	30

for weed control and the observed higher weed diversity in CT may underscore the need to alter weed management strategies. The weed diversity in this study appears to be directional rather than random and thus supports the observation by Miyazawa et al. (2004) that weed diversities were reduced by herbicides. However, the short duration of this study may make it difficult to authenticate this hypothesis.

The increased plant heights within herbicide applied plots is in agreement with the findings of Soltani et al. (2006) where maximum plant height resulted with the usage of herbicides for weed control. On the contrary, Usman, et al. (2010) reported that herbicides usage reduced plant heights due to phyto-toxicity of the herbicides. The effects of tillage, weeding treatments, and their interactions show that environment and management also have an effect on plant height rather than genetic control only.

The yields were higher in pre-emergence herbicide applied treatments due to reduced crop-weed competition, these findings also agree with Chhokar et al. (2008) that herbicides reduced crop-weed competition and increased crop yields. These results suggest that the adoption of CT in the SH sector may increase in farmers' fields if effective weed control methods are adopted. The higher yields in CT were a result of enhanced fertilizer and water use efficiency. These results concur with the findings of Erenstein et al. (2008) who reported higher productivity for CT over CONV due to early sowing, improved soil fertility level, enhanced water and fertilizer usage efficiency.

The findings of this study raise the possibility of inclusion of pre-emergence herbicides in CT in the smallholder sector. The effective weed control achieved with herbicides could help farmers to exploit CT without weed management problems. However, there is need for training on usage of herbicides and to determine appropriate herbicide dosage for each farm type. Wall (2007) noted that with time, CT weed management decreases weed density. If the weed density decreases the herbicide doses also decreases and ultimately reduce reliance on herbicides for weed control in CT.

5. Conclusion

It can be concluded that the hand hoe weeding option was not effective in controlling weeds in CT. The herbicides controlled weeds to a varying level depending on the farm type and significantly affected weed diversity and parameters such as weed density m^{-2}, plant height and grain yield. Among the herbicidal treatments, tank mix of cyanazine + alachlor in cotton and alachlor + atrazine in maize were the most effective broad-spectrum herbicides which controlled both grasses and broad-leaved weeds and gave the highest grain yield. Research results indicate that there may not be differences in herbicide efficacy with differences in tillage. However, the herbicides offered different weed control under different soil types and management which shows that herbicide doses need to be specific for each field, and blanket recommendations will not be appropriate.

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