THE INFLUENCE OF FERTILIZER PLACEMENT ON MAIZE YIELD AND GROWTH OF WEEDS

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Abstract

Three field experiments were conducted in two seasons in Zimbabwe to study the effects of rate and method of placement of NPK fertilizer on productivity of maize and the emergence and growth of weeds. Compound D (8% N, 14% K_2O, 7% P_2O_5, 6,5% S) was applied at 75, 150 and 225 kg ha^{-1} using three placement methods *viz*. spot placement, banding and broadcasting in Experiment 1. The three placement methods were combined with four weed-free period and weedy periods in Experiment 2 and 3. Maize yield was highest at 150 kg ha^{-1} of compound D in Experiment 1. Banding consistently attained the highest maize grain yield, followed by spot placement and broadcasting. Early maize growth and grain yield data suggested that spot placement may reduce the yield response of the maize to fertilizer in water limited environments by predisposing maize plants to higher levels of moisture stress, when compared to banding. Spot and band placement increased radiation interception and early growth of maize and reduced the emergence, growth and seed production of weeds, compared to broadcasting; however the effects of fertilizer placement on weeds did not significantly affect the duration of critical period for weed control required to avert yield loss in maize. Our results suggest that smallholder farmers may maximize the benefits, of increased yield and suppression of weeds, derived from scarce fertilizer/manure resources by using precise methods of placement, more so with banding than spot placement.

Key words: Fertilizer, placement method, maize growth, maize grain yield, radiation interception, weed density, weed biomass, weed seed production

1.0 Introduction

Weed control is the dominant labour demanding occupation of smallholder farmers in semi-arid regions of Africa during the cropping season (Akobundu, 1991). Farmers invest large amounts of labour in weeding each season, approximately 35 to 70% of the total agricultural labour needed to produce crops which frequently exceeds the labour demand of all other livelihood operations for smallholder farmers. Severe labour bottlenecks are common during peak weeding, resulting in delayed weeding in large portions of the planted crops, well after they have suffered significant damage from weeds (Waddington and Karigwindi, 1996).

A paradigm shift from weed control to weed management is required to effectively address the problems caused by weeds for smallholder farmers. Weed control emphasizing the control of existing weed problems is a curative approach that produces short-term results but may create or worsen long-term problems (Buhler, 1999). Weed management places greater attention on the prevention of propagule production, reduction of weed emergence in a crop and minimizing weed interference with the crop through the integration of techniques, knowledge and management skills (Buhler, 1999; Zimdahl, 1991). Cultural weed management techniques such as narrow planting, use of competitive crop varieties, mixed cropping and precise placement of fertilizers and manures have potential to reduce emergence, growth and competitiveness of weeds (Swanton and Wiese, 1991).

The weed competition dynamics for applied fertilizer nutrients can be changed in favour of the crop by the method of placement of the fertilizer (Blackshaw *et al.*, 2002). Fertilizer placement in narrow bands below the soil surface in the crop row has been found to reduce the competitive ability of weeds compared to broadcast placement of fertilizer (Blackshaw *et al.*, 2000, 2002; Kirkland and Beckie, 1998; Mesbar and Miller, 1999). In the context of smallholder agriculture in semi-arid areas, fertilizer is a scarce and expensive resource whose benefits must be maximized by precisely placing it in the root zone of the crop. Most smallholder farmers cannot afford to apply the recommended fertilizer application rates and frequently apply 30-50% of the recommended application rates (Chivinge and Mariga, 1998). Previous research on fertilizer placement methods in Zimbabwe has concentrated on nutrient uptake and early growth by the crop without a concomitant look at the weed crop competition dynamics (Tanner, 1984). No studies have been done in Zimbabwe to optimize fertilizer practices combined with reducing weed emergence and growth in the crop (Chivinge and Mariga, 1998).

The objective of this study was to determine the effect of fertilizer rate of application and placement methods on weed emergence and growth of weeds, early growth, radiation interception and yield of the maize crop. Hypotheses tested were (a) precise placement of fertilizer will increase early growth, radiation interception by the maize crop and reduce weed emergence and growth (b) precise placement of fertilizer will reduce the weed-free period required to avert yield loss in maize.

2.0 Materials and Methods

Experiment 1 was carried out at the University of Zimbabwe campus in the 2001/02 season and Experiments 2 and 3 at the Rio Tinto Agricultural College in the 2002/03 season. The University of Zimbabwe campus site in Harare (17°50′ South and 31°30′ East, altitude of 1500 m), has red fersiallitic clay soils (30-40% clay) with an annual rainfall of 600-800 mm. received between. Growing season (November-May) temperatures range from 20 to 25 °C. The Rio Tinto Agricultural College site (29°30′ East and 19°20′ South) lies in the Zhombe district, in the rain shadow area of the Mapfungautsi plateau in the middle of Zimbabwe. The site is characterized by sandy clay loams of shallow depth (30 cm), derived from granite and dolorite parent material. Growing season temperatures are fairly high, on average about 30 °C. Frequent mid season droughts characterize the rainy season and total seasonal rainfall is 450 - 600 mm.. For the crop to be carried through the season supplementary irrigation was needed at the Rio Tinto site. For all the three experiments, the land was ploughed and planting was done in last quarter of November after the first effective rains.

Experiment 1: Rate and placement method of fertilizer

Experiment 1 was set up as a 3 × 3 factorial to determine the effect of fertilizer application rates and placement methods on the emergence and growth of weeds, early growth and maize grain yield.. It was laid out as a randomized complete block design with three replicates. Fertilizer application rates were 75, 150 and 225 kg ha^{-1}

of basal granular compound D fertilizer (8% N, 14% P_2O_5, 7% K_2O, 6.5% S). Fertilizer placement methods were spot placement, banding and broadcasting. Spot placement was achieved by placing the fertilizer into an opened planting station of about 5 cm depth. Banding was achieved by opening planting furrows approximately 5 cm deep using hoes and dribbling the required fertilizer in along the planting furrow, as evenly as possible, by hand. Broadcasting was achieved by evenly spreading the fertilizer onto the plot and incorporating it to 5-10 cm depth using hoes. Maize was planted at 90 cm × 30 cm spacing to achieve a density of 37,000 plants ha^{-1}. Two maize seeds were placed into each planting station and covered. Maize plants were thinned to one plant per station, two weeks after crop emergence (WAE). A short season three-way cross hybrid, SC 513 (Seed-Co®, Zimbabwe) was planted.

Weeds were counted at 5 and 8 WAE in three randomly placed 30 cm × 30 cm quadrats each, at two positions, in the maize row and in the middle of the maize inter-row. Counted weeds were cut at the ground level, oven-dried at 80 °C for 48 hours and weighed.

Four maize plants were randomly selected per plot (outside the net plot) at 5 WAE and used for leaf number, plant height and biomass determination. The gross plot was 4.5 m × 7 m with 5 maize rows. The net plot was 2.7 m × 5.0 m.

Photosynthetically active radiation (PAR) incident above the crop, at mid crop height and on the ground was measured at 8WAE using 191-SA line quantum sensors (Li-Cor, Lincoln, Nebraska, USA). Measurements were taken at two positions, in the row (adjacent to the maize stems along the maize row) and between rows (in the centre of the inter-row). Three replicate measurements were taken at 2, 4 and 6 m along the maize row in the net plot. The average PAR measurement for the three positions was used in the data analysis. Maize was hand harvested from the net plot, shelled by hand and moisture content measured. Grain yield was standardized to 12.5% moisture content.

Experiments 2 and 3: Fertilizer placement methods and the weedy/weed-free period

Experiments 2 and 3 were designed to study the effect of fertilizer placement method and different weed-free (Experiment 2) or weedy (Experiment 3) periods on maize yield and the emergence, growth and seed production of weeds. In both experiments, the fertilizer placement methods were spot placement, banding and broadcasting as described for Experiment 1. In both experiments, a 3 x 4 factorial design was used to study the combined effects of fertilizer placement method and weeding. In Experiment 2, four different weed-free period were tested: 3, 6, 9 and 12 weeks after emergence of the crop. After the required weed-free period, the crop was left unweeded. In experiment 3, four different weedy periods were compared; also 3, 6, 9, and 12 weeks. The crop was kept weed free after the weedy period was finished. Both experiments were laid out as randomized complete block designs with three replicates. One fertilizer application rate, 150 kg of compound D was used. Experiment 3 was planted at the same time and adjacent to Experiment 2.

PAR measurements were conducted as in Experiment 1, at 2 and 4 WAE. Maize early growth was assessed on five randomly selected maize plants which were harvested from outside the net plot area at 3 and 6 WAE. Maize height was measured using a tape measure from the ground to the tip of the maize funnel. Leaf area was measured using a LA-3100 leaf area meter (Li-Cor, Lincoln, Nebraska, USA). The maize plants were oven dried to a constant weight and weighed. Weed density and dry mass were determined as in Experiment 1, at 3, 6 and 9 WAE, before the weeding treatments scheduled for that time were implemented. Weed seed capsules were counted for the major species of weeds, as indicated by visual assessment of percent ground cover at maize physiological maturity at 15 WAE.

Maize was hand harvested from the net plots at 20 WAE and moisture content of shelled grain measured. A random sample of five cobs was taken from each plot and ear length, ear mass, number of kernel rows ear^{-1} and of kernels row determined.

Data Analysis

All weed density and weed seed capsule data were expressed m^{-2} and $\sqrt{x+0.5}$ transformed before statistical analysis (Steel and Torrie, 1984). In all experiments, maize grain yield was standardized to 12.5% moisture content. Data were analyzed by ANOVA using SAS Version 8 (SAS Institute 1999, Release 8, Cary, NC, USA). Means were separated using Fisher's Least significant difference (Lsd) at $P< 0.05$. Standard errors of the difference are shown for all figures.

3.0 Results

3.1 Growth and Yield of Maize

Maize grain yield in Experiment 1 increased by 30% when fertilizer application rate was increased from 75 to 150 kg ha^{-1} but decreased on further increasing the fertilizer rate to 225 kg ha^{-1} (Table 1). Plant dry weight varied from 18.3, 20.2 to 19.0 g $plant^{-1}$ and plant weight from 65, 74 to 70 $plant^{-1}$ as fertilizer rate was increased from 75, 150 to 225 kg ha^{-1}, respectively, but the effect of fertilizer rate was not significant ($P > 0.05$) on these two factors. Only number of leaves $plant^{-1}$ was significantly affected ($P < 0.05$) by fertilizer rate. The intermediate (8.6 leaves $plant^{-1}$) and highest (8.1 leaves $plant^{-1}$) fertilizer level had significantly higher number of leaves than the lowest (7.4 leaves $plant^{-1}$) fertilizer rate ($Lsd_{0.0} = 0.93$, $n = 9$). Maize grain yield was higher in the banded fertilizer placement treatment than in the broadcast placement treatment at all fertilizer application rates, however, the overall effect of fertilizer placement was not different ($P > 0.05$) in Experiment 1 (Table 1). Fertilizer placement did not significantly affect leaf number and plant dry weight, but plant height was significantly lowered when fertilizer was broadcast (62 cm $plant^{-1}$) rather than banded (72 cm $plant^{-1}$) or spot-applied (74 cm $plant^{-1}$) ($Lsd_{0.05} = 10.05$, $n = 9$).

Maintaining the crop weed-free for the first three weeks achieved 74, 86 and 87% of the maximum grain yield in the spot, band and broadcast treatments, respectively, in Experiment 2 (Fig. 1a). Keeping the crop longer weed free for more than 3 weeks did not result in further yield increase (Fig. 1a). Fertilizer placement did not affect the grain yield response to increasing the weed-free period as indicated by an insignificant fertilizer placement × weed-free period interaction ($P>0.05$). The banded treatment produced significantly higher maize grain yield than the broadcast treatment, averaged across the weed-free period treatments ($P<0.05$). The maize grain yield from the spot placed fertilizer treatment was intermediate between the banded and broadcast fertilizer placement treatments and did not differ significantly from either treatment (Fig. 1a). Plant height, biomass and LAI were lower upon broadcasting than with the other two placement methods in Experiment 2 (Fig. 2).

In Experiment 3, the fertilizer placement method ($P<0.01$) and the duration of the weedy period ($P<0.001$), both had a significant influence on maize grain yield. The two factors did not significantly interact indicating that yield response to weeding delay was similar in the three fertilizer placement methods (Fig. 1b). The banding of fertilizer produced higher maize grain yield than spot and broadcast placement methods, averaged across the weedy periods (Fig. 1b). Plants in the broadcasting treatment lagged behind those in the other two placement treatments in height, weight and leaf area (results not shown).

3.2 Maize Grain Yield Components

There were no significant fertilizer placement × weed-free/weedy period interactions in any of the maize grain yield components and, therefore, the main effects are presented. Table 4 shows the effects of fertilizer placement on maize yield components in Experiments 2 and 3. Spot and band placement of fertilizer resulted in significantly bigger ears (ear length and ear mass) than broadcasting in Experiment 2. In Experiment 3, all yield components increased from broadcasting to spot and band placement treatments, respectively (Table 4).

Increasing the duration of the weed-free period beyond three weeks did not significantly enhance maize yield components in Experiment 2 (Table 5). Increasing the duration of the weedy period reduced all grain yield components except number of kernel rows ear^{-1} in Experiment 3 (Table 5).

3.3 Weed Density and Biomass

In experiment 1, weed density as determined at 5 WAE was not significantly affected by fertilizer placement or rate of application. At 8 WAE, one significant difference was found between the density of weeds between the rows in the broadcast (6.6 m^{-2}) compared to the banding (5.88 m^{-2}) placement method ($Lsd_{0.05} = 0.657$; n = 9). No other significant differences were found. There was a significant interaction ($P < 0.01$) between fertilizer placement method and rate of application on weed biomass within the maize row at 5 WAE (Table 6). The biomass of weeds within the row decreased in the broadcast treatment with increased quantity of fertilizer applied. With spot and band placement methods of fertilizer application, the weed biomass increased in the row with increased quantity of fertilizer applied (Table 6).

In Experiment 2, there was a consistently higher weed density and biomass in the broadcast compared to the spot and band fertilizer placement treatments (Figs 4a and 4b). In Experiment 3, weed density tended not to statistically differ between the banding and broadcasting treatments with spot placement having the lowest weed density at 3, 6 and 9 WAE (Figure 4c).

There was a fertilizer placement method × weed free period interaction on weed biomass in Experiment 2. It required a weed free period of 6 WAE for the broadcast treatment to attain the same weed biomass as the spot and band placement treatments with a weed free period of 3 WAE (data not shown).

A higher weed density and biomass were measured within the rows than between the rows in Experiment 2 (Figures 5a and 5b). In Experiment 3, there was an interaction ($P < 0.05$) between fertilizer placement and sampling position on weed density at 3 WAE. Broadcasting the fertilizer produced the same weed density in the row and in the middle of the inter-row, while more weeds emerged in the row compared to the middle of the inter-row in the spot and band fertilizer placement methods (Figure 5c).

3.4 Seed Production by Weeds

A significantly higher number of weed seed capsules were counted in the broadcast compared to the spot and band fertilizer placement methods for *Commelina benghalensis* L., *Amaranthus hybridus* L. and all species (Figure 6a). For all species, a 9 week weed-free period was required to completely stop the addition of weeds to the seedbank (Fig. 6b). For *C. benghalensis*, there was a significant interaction between fertilizer placement method and weed-free period on its seed production. For the band and spot fertilizer placement methods, a weed-free period of 6 WAE was adequate to almost stop weed seed capsule production, while the same weed-free period in the broadcast treatment only resulted in a 20% reduction of seed capsule production (Figure 7a). A weed-free period of 9 WAE was required to stop additions of new seed by *C. benghalensis* to the seedbank in the broadcast treatment (Figure 7a). Weed seed production was nil in all the weeded treatments at 15 WAE, but in the unweeded treatment, seed capsule production decreased from broadcast, spot to band fertilizer placement method (Figure 7b).

3.5 Radiation Interception

There was no significant effect of fertilizer placement method on PAR reaching the ground in Experiment 1. PAR reaching the ground was significantly lower ($P < 0.05$) in 150 kg (1257 µmols m^{-2}) than at 75 kg (1444 µmols m^{-2}) and did not differ with the 225 kg ha-1 (1336 µmol m^{-2}) meaning that radiation interception was significantly higher at 150 kg than the 75 kg ha^{-1} fertilizer application rate at 8 WAE in Experiment 1. Percent of total PAR intercepted at 4 WAE was significantly higher ($P < 0.01$) in the spot (67.4%) and band (66.9%) fertilizer placement treatments than in the broadcast treatment (34.6%) in the middle of the row in Experiment 2. The unweeded treatments at 4 WAE intercepted 78% of the incoming radiation compared to 56.4% in the middle of the row than the treatments kept weed-free from 3 weeks onwards in Experiment 3, such that no differences could be detected among the three fertilizer placement methods in Experiment 3.

4.0 Discussion

4.1 Maize Grain Yield

The results of this study show that by promoting higher rates of early growth and concomitantly earlier attainment of full ground cover, precise methods of fertilizer placement (spot placement and banding) increased the competitiveness of the crop against weeds, significantly reducing weed density, biomass and seed production and increased crop yields when compared to broadcasting. The banding treatment consistently attained the highest maize grain yield, followed by spot placement, and broadcasting attained the lowest, during the three experiments of this study. Our results also suggest that spot placement maybe risky in water limited environments, where the high concentration of the fertilizer around the root zone the crop may predispose the crop to higher levels of moisture stress and reduce the growth and yield response to the applied fertilizer. Banding of fertilizers below or on the side of the crop row in the soil has been shown not only to reduce weed populations but also to increase crop yields when compared to broadcasting in beans (*Phaseolus vulgaris* L.) (Ottabong *et al*., 1991), soybean (*Glycine max* Merr.) groundnuts (*Arachis hypogaea* L.) (Everaarts, 1992) and wheat (*Triticum aestivum* L.) (Cochran *et al*., 1990). The banding of fertilizer below the seed or to one side of the seed concentrates mineral nutrients in the root zone of the crop. It also restricts access of weeds to the fertilizer by spatial separation and by virtue of the shallow depth of soil exploited by most annual weed roots (DiTomasi, 1995; Ottabong *et al*., 1991; Moody, 1981). Nitrogen uptake and biomass of weeds was lower and wheat yields higher with sub-surface banded or point injected N fertilizer compared to surface broadcast (Blackshaw *et al*., 2004, 2005; O'Donovan *et al*., 2007).

Early growth of the maize in the banding and spot placement treatments was generally greater than in the broadcast treatment, agreeing with results of Tanner (1984), in an experiment on similar soils as in Experiments 2 and 3. However, in all cases in this study, the trend in maize grain yield showed a consistent superiority of banding over spot placement, albeit not statistically significant in Experiments 1. These results may be indicative of the droughty conditions that characterized the two seasons in which these experiments were held. Tanner (1984) explained that spot placement maybe more beneficial in seasons with adequate rainfall than banding and broadcasting but the opposite can be true in dry seasons as high concentrations of fertilizer around the root zone of the crop where fertilizer has been spot placed increases the severity of moisture stress episodes much more than in the broadcast and band treatments. The apparent superior maize grain yield of the banding treatment over the spot placement treatment may be attributable to this phenomenon. This should hold given rainfall totals of 667 mm in 2001/02 season at UZ campus and 450 mm in the 2002/03 season at Rio Tinto, and the fact that rainfall was poorly distributed within the season, at both sites.

To some extent the results of the rate of fertilizer application on maize grain yield in Experiment 1 lend support to the hypothesis that high concentrations of fertilizer were somewhat damaging to maize grain yield. Maize grain yield showed a distinct trend of decreasing from the 150 to the 225 kg ha^{-1} application rate, more so in the spot than in the band fertilizer placement treatments and no response in the broadcast treatment (Table 1). Early maize growth data also displayed similar trends (Table 1). These results suggest that at 225 kg ha^{-1} of compound D fertilizer, the high concentrations of fertilizer in the root zone of the spot and band placed fertilizer probably predisposed the plants to more severe episodes of drought stress.

Broadcasting of fertilizer and its incorporation into the soil mean that the applied mineral nutrients will be distributed more or less uniformly across the soil surface and in the soil depth to which the fertilizer is incorporated. In contrast, with spot and band placement of fertilizer, the fertilizer is placed below the soil surface nearest to the root zone of the crop. The dormancy of some annual weed species is broken by increased levels of nitrates in the soil (DiTomasi, 1995; Agenbag and De Villiers, 1989) and this may explain the higher densities of weeds observed in the broadcasting treatment compared to banding and spot placement treatments. Banding of fertilizer reduced weed density compared to broadcasting in a number of studies (Ottabong *et al*., 1991; Everaarts, 1992; Cochran *et al*., 1990; Kirkland and Beckie, 1998) similar to our results. It would seem, therefore, that weeds tend to emerge in greater number where fertilizers are spread and incorporated throughout the whole soil surface in comparison to more precise placement of fertilizer nearest the crop roots.

Access to applied fertilizer nutrients is promoted for the crop and restricted for the majority of the shallow rooted weeds found in the mid-row area when fertilizer is banded or spot placed nearest the crop seed at planting. The opposite would be true when fertilizer is broadcast and incorporated in the soil. This would explain why higher weed biomass was recorded from the broadcast compared to the spot and band fertilizer placement treatments in this study. Higher levels of nutrient uptake by weeds have been recorded when fertilizer was broadcast compared to more precise fertilizer placement methods into the soil nearest to the crop rooting zone (Blackshaw *et al*., 2002). To some extent this may partly explain the higher rates of growth of weeds in the broadcast treatments recorded in this study and others in the literature. Kirkland and Beckie (1998) reported that broadcast applied fertilizer was more effective than banded fertilizer in promoting wild oat and broadleaf weed emergence and growth over the season in a wheat crop. Weeds are generally more efficient in accumulating soil nutrients than crop plants (Vengris *et al*., 1953; Sibuga and Bandeen, 1980, Moody, 1981; Teyker *et al*., 1991; DiTomasi, 1995;;; Qusem, 1992, 1993; Ampong-Nyarko and De Datta, 1993;). It is, therefore, expected that weeds will win the competition battle with the crop for applied fertilizer nutrients unless access to the nutrients promoted for the crop and discouraged for weeds by precise placement of the fertilizer.

The effects of precise fertilizer placement in denying access of weeds to applied nutrients and, therefore, reducing the competitiveness of weeds against the crop is confounded with its effects in promoting higher rates of crop growth and attainment of earlier canopy closure which achieve the same effect. Results of this study generally showed that band and spot placement of fertilizer increased early maize growth and PAR interception compared to maize grown in the broadcast treatment. Competition for light tends to give an increasing advantage to the plants that have a starting position advantage (bigger and leafier plants at the start of the dynamic process of competition). Weiner *et al*. (1997) observed that larger plants were able to obtain a share of resources that was disproportionate to their relative size and to suppress the growth of smaller individuals. The lower weed biomass attained by weeds in the spot and band placed fertilizer treatments compared to the broadcast treatment in this study is, therefore, partly explainable in terms of these placement methods increasing the size and competitiveness of the maize crop against weeds.

Our results also show that there is likely to be increased weed growth within the row when fertilizer is spot or band placed compared to broadcasting and such weed growth may increase in the row with increased rates of fertilizer application. Munguri (1996) reported similar results in sandy soils. It may, therefore, mean that fertilizer placement should be integrated with weed management tactics that remove weeds within the row soon after crop emergence before they cause crop damage. Weeds that are within the row are nearest to crop plants and if they grow together with the crop, are more damaging than those in the middle of the row especially early on, soon after crop emergence.

The lower seed production by weeds in the band and spot fertilizer placement treatments compared to the broadcast treatments is reflective of the linear relationship between weed biomass and fecundity of annual weeds found in other studies (Thompson *et al*., 1991). The reduction in seed production with precise placement of fertilizer compared with broadcasting means that these methods will not only be potentially beneficially in increasing crop yields and reducing weed competition, but could affect weed propagule numbers in the soil seedbank in the long term.

Results of this study show that the maize crop must be weeded at 3 WAE to achieve maximum yields and that there is no yield advantage to be gained by continuing to weed the crop after 6 WAE. Tanveer *et al*. (2001) found similar results when they tested the effect of weed free periods with side-placement and broadcasting of fertilizer in wheat. These results were consistent for all fertilizer placement methods as there were no interactions between the fertilizer placement methods and weed-free/weedy period in Experiments 2 and 3. It would seem, therefore, that although weed density and biomass were reduced by precise placement of fertilizer in the rooting zone of the crop, the reduction in weed competitiveness was not adequate to effectively reduce the overall weeding requirements of the crop for attainment of maximum yields.

Increased precision in the placement of fertilizer nearest to the rooting zone of the crop had been shown to enhance the competitiveness of the crop against weeds in this study. Weed emergence and growth were reduced and crop growth was enhanced significantly more in the banding and spot placement methods than in the broadcast method of fertilizer application. For smallholder farmers, precise placement of fertilizer makes sure that the little fertilizer that is applied literally ‘goes a long way’ because it produces yields that are similar to those that are obtained with higher fertilizer application rates applied using the broadcasting method (Jonga *et al*., 1996; Munguri, 1996). Chivinge and Mariga (1998) showed that half the recommended fertilizer application rates (44 kg N ha^{-1}) produced maize grain yield similar or higher than full application rates provided that adequate weed control (hoe-weeding at 3 and 5 WAE or application of 1.75 kg a.i. atrazine full cover spray) was carried out in the smallholder sector in a semi-arid area of Zimbabwe. Munguri (1996) showed that the same similar benefits were derived when fertilizer or manure was banded or spot placed in comparison to broadcasting, meaning that precision of placement technology is also available to those farmers with cattle and access to cattle manure.

systems from two fronts, reduced weed competitiveness and increased crop yield, more with band than spot application, in water limited environments, as suggested by results of this study. Our results seem to indicate that high fertilizer application rates and/or spot placement of fertilizer may nullify any expected yield gains from the supply of mineral nutrients by a greater predisposition of the crop to moisture stress in semi-arid regions. The fertilizer placement decisions must, therefore, take into account the soil moisture conditions that are likely to prevail in the particular semi-arid environment, however banding gave consistently high yields in water limited environments in this study.

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Table 1: Effect of fertilizer application rate and placement method on maize grain yield (t ha^{-1}) in Experiment 1

	Fertilizer application rates (kg ha^{-1})			
Fertilizer placement method	75	150	225	Mean
Spot	2. 448	3. 686	2. 858	2. 998
Band	3. 107	3. 748	3. 271	3. 376
Broadcast	2. 436	2. 978	3. 077	2. 831
Mean	2.664a[1]	3.471b	3.069ab	
	P value	SED	Lsd $_{0.05}$	
Effect of fertilizer rate	P<0.05	0.347	0. 736	
Effect of fertilizer placement	P>0.05	0.347	NS	
Rate × placement interaction	P>0.05	0.601	NS	

[1]Means followed by the same letter in a row are not significantly different at P<0.05

Table 2: Effect of fertilizer placement on maize grain yield components in Experiments 2 and 3

Fertilizer placement	Ear length cm ear^{-1}		Ear mass kg ear^{-1}		Number of kernel rows ear^{-1}		Number of kernels row^{-1}	
	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3	Exp 2	Exp 3
Spot	15.4b[1]	13.8b	0.23b	0.17b	15.0a	14.8a	37.3a	30.6b
Band	16.1b	16.1c	0.25b	0.20c	15.0a	15.3ab	37.8a	34.0c
Broadcast	10.1a	10.0a	0.14a	0.11a	14.7a	15.8b	34.9a	23.8a
P-value	P<0.001	P<0.001	P<0.001	P<0.001	P>0.05	P<0.05	P>0.05	P<0.001
Sed	0.481	0.602	0.016	0.011	0.506	0.355	1.253	1.079
Lsd$_{0.05}$	0.998	1.248	0.033	0.023	NS	0.737	NS	2.239

[1]Means followed by the same letter in a column are not significantly different at P<0.05

Table 3: Effect of weeding regime (weeks after emergence, WAE) on maize grain yield components in Experiments 2[1] and 3[2]

Weeding regime	Ear length cm ear^{-1}		Ear mass Kg ear^{-1}		Number of kernel rows ear^{-1}		Number of kernels row^{-1}	
	Exp2	Exp 3	Exp 2	Exp 3	Exp2	Exp 3	Exp 2	Exp 3
3 WAE	13.8a[3]	15.9c	0.20a	0.22d	15.1a	15.1a	36.0a	33.9c
6 WAE	13.6a	15.0c	0.20a	0.19c	14.9a	15.6a	37.2a	31.6c
9 WAE	14.3a	12.1b	0.23a	0.14b	15.1a	15.3a	37.6a	28.1b
12 WAE	13.8a	10.3a	0.19a	0.10a	14.4a	15.3a	35.9a	24.3a
P-value	P>0.05	P<0.001	P>0.05	P<0.001	P>0.05	P>0.05	P>0.05	P<0.001
Sed	0.556	0.695	0.018	0.013	0.584	0.410	1.447	1.246
Lsd$_{0.05}$	NS	1.441	NS	0.026	NS	NS	NS	2.585

[1] Weeding regime refers to duration of weed free and then weedy period in Experiment 2 in Table 2.

[2] Weeding regime refers to duration of weedy period and then weed free in Experiment 3 in Table 2.

[3]Means followed by the same letter in a column are not significantly different at P < 0.05

Table 4: Interaction between fertilizer application rate and method of placement on weed biomass (g m^{-2}) in the row in Experiment 1

Placement method	Fertilizer applications rates in kg ha^{-1}		
	75	150	225
Spot	16.52a[1]	23.31a	25.32a
Band	16.43a	14.52a	32.54b
Broadcast	30.43b	18.72ab	14.31a

	P-value	Sed	$Lsd_{0.05}$
Effect of fertilizer placement method	$P>0.05$	3.440	NS
Effect of rate of fertilizer application	$P>0.05$	3.440	NS
Rate × placement interaction	$P<0.01$	5.985	12.305

[1] Means followed by the same letter in a row are not significantly different at $P < 0.05$.

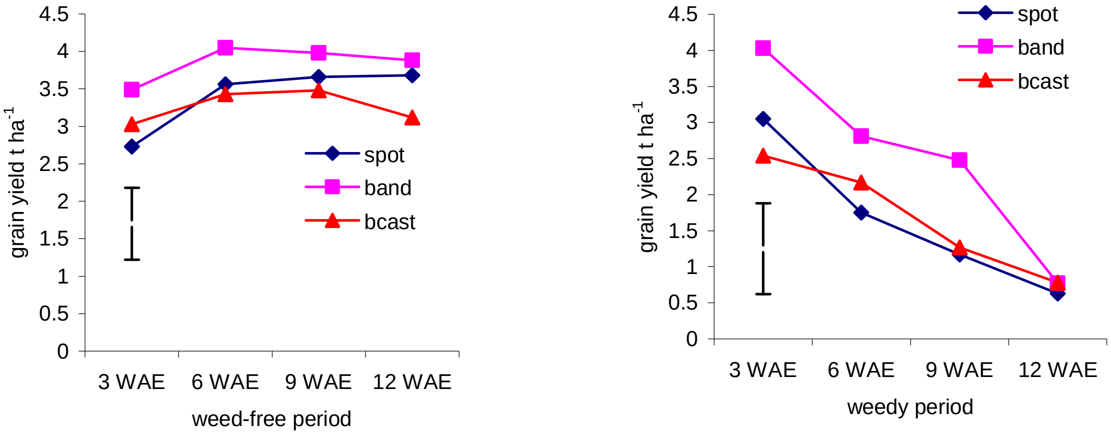

Figure 1: (A) Effect of weed free period (then weedy) and fertilizer placement method on maize grain yield in Experiment 2. (B) Effect of weedy period (then weed-free) and fertilizer placement method on maize grain yield in Experiment 3. Error bars within each figure represent ± standard error of the difference (22df) for the comparison of grain yield means within and between fertilizer placement treatments

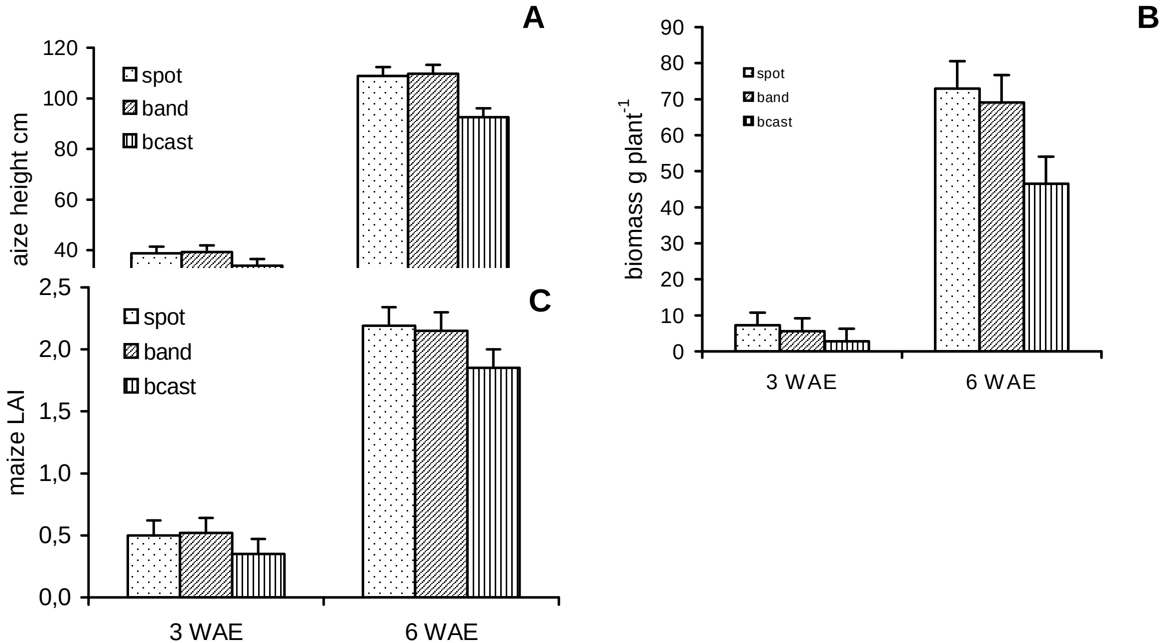

Figure 2: Effect of fertilizer placement on (A) maize plant height (in cm); (B) plant biomass (in g), and (C) leaf area index (LAI) at 3 and 6 WAE in Experiment 2. Error bars within each figure represent + standard error of the difference for the comparison of fertilizer placement means at 3 WAE (4df) and 6 WAE (10df) when maize plants were harvested

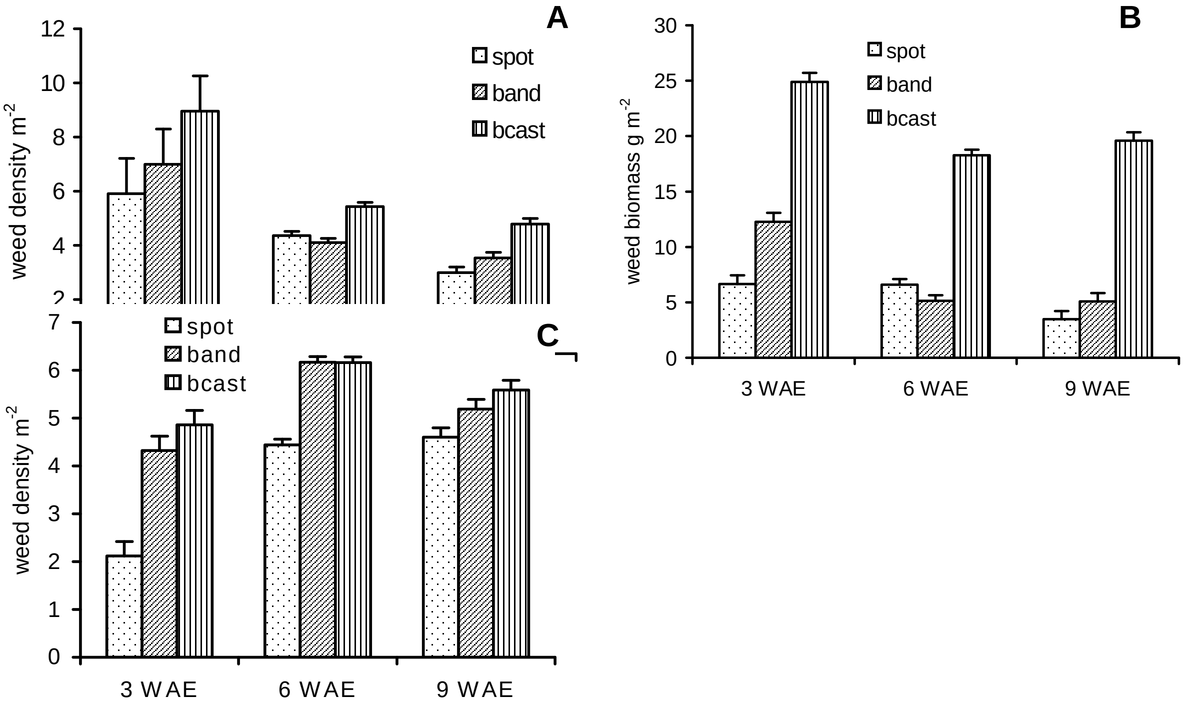

Figure 3: Effect of fertilizer placement on (A) weed density, (B) weed biomass in Experiment 2 and (C) weed density in Experiment 3. Error bars within each figure represent +standard error of the difference for the comparison of fertilizer placement means at 3 WAE (4df), 6 WAE (10df) and 9 WAE (16df) of weed measurement

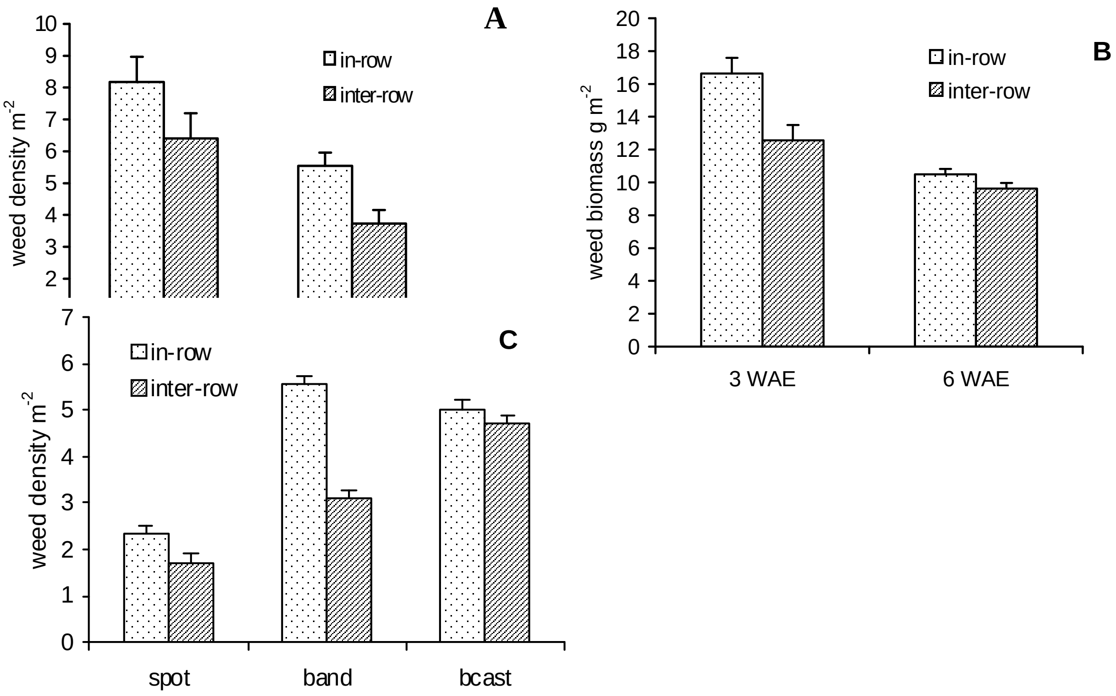

Figure 4: Weed density (A) and biomass (B) in the maize row and in the middle of the maize inter-rows in Experiment 2. (C) The effect of fertilizer placement on weed density in the row and in the middle of maize inter-rows at 6 WAE in Experiment 3. Error bars in each figure represent +standard error of the difference for the comparison of in-row and between- row means at 3 WAE (4df) and at 6WAE (10df) of measurement (A and B) and for each placement method (10df) (C)

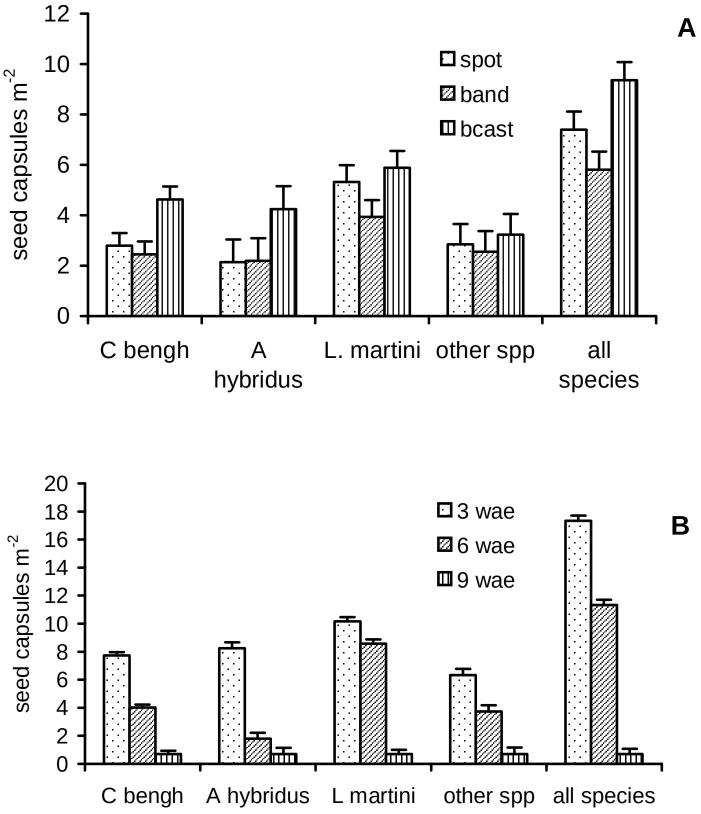

Figure 5: (A) Effect of fertilizer placement on weed seed capsule production in Experiment 2. (B) Effect of weeding regime on weed seed capsule production in Experiment 2. Error bars represent +standard error of the difference (16df) for the comparison of (A) fertilizer placement and (B) weed regime means within each species

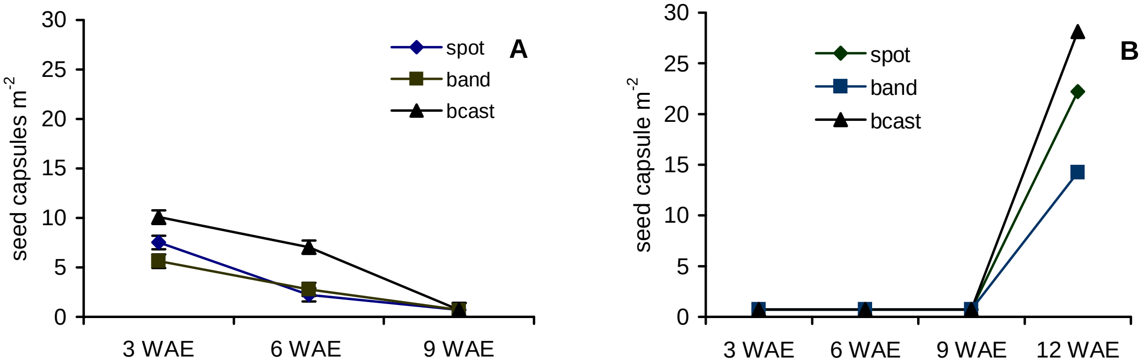

Figure 6: (A) Interaction between fertilizer placement method and weeding regime on C. benghalensis weed seed capsule production in Experiment 2. (B) Weed seed capsule production in Experiment 3. Error bars are ± interaction standard error of the difference {(A) 16df} and {(B) 22df) for the comparison of seed capsule number means within and between fertilizer placement methods