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Narrow Rows and High Maize Densities Decrease Maize Grain Yield but Suppress Weeds under Dryland Conditions in Zimbabwe

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Abstract: Two experiments were conducted during the 2002/03 and 2003/04 seasons at two sites in Chinyika Resettlement Area in Zimbabwe to determine the effects of maize density (30,000, 36,000 and 42,000 plants ha^{-1}, inter-row spacing (60, 75 and 90 cm) and weeding regime {weeding once at 3 Weeks after Emergence (WAE), twice at 3 and 6 WAE and thrice at 3, 6 and 9 WAE} on maize grain yield and weed biomass and seed production under dryland conditions. The first experiment was organized as a 3×3 factorial testing the effect of the first two factors. The second experiment was designed to test the effect of increasing frequency of weeding in the maize densities and inter-row spacing used in the first experiment. A significant decrease ($p<0.05$) in maize grain yield, by 16-35%, was observed with an increase in maize density from 30 000 to 42 000 plants ha^{-1} at Site 1 in both seasons and Site 2 in the 2002/03 season. There was a significant ($p<0.05$) maize density and weeding regime interaction on weed biomass at 9 WAE at the two sites in the 2002/03 season. At 30,000 plants ha^{-1}, a second weeding was required to reduce weed biomass to that attained in the higher maize densities weeded once. There was a consistent decrease, across sites and seasons, in weed biomass by 61-83 and 50-94% when inter-row spacing was reduced from 90 to 60 cm at 6 and 9 WAE, respectively. The results of this study suggest that there is increased risk of a reduction in maize grain yield from competition for moisture and nutrients when row spacing is reduced below 90 cm and maize density increased above 30 000 plants ha^{-1}, making it difficult to integrate these cultural practices for weed suppression, under semi-arid conditions.

Key words: Maize density, inter-row spacing, weeding regime

INTRODUCTION

Weed suppression through the augmentation of the competitive ability of the crop is one of the cheapest and most useful methods of weed control that is also technically feasible for smallholder farmers (Klingman, 1961). Crops can be favoured in the dynamic process of competition against weeds by use of narrow rows and higher planting rates or densities (Stoller *et al*., 1987; Teasdale, 1995). Narrow row planting and high plant densities reduce weed emergence and growth by decreasing and changing the spectral qualities of incoming radiation incident on weed seeds on the soil surface and weed seedlings under the crop canopy (Zimdahl, 1999; Swanton and Weise, 1991; Tollenaar *et al*., 1994). High plant densities and narrow rows achieve full ground cover earlier in the season than low plant densities and wide rows. Since the critical weed free period coincides with the time it takes for a crop to produce a closed canopy (Zimdahl, 1999), we hypothesize that narrow planting and high plant densities should reduce this period and, therefore, the number of times a maize crop needs to be hoe weeded by smallholder farmers to avert yield loss.

Despite the potential shown by narrow row planting and high maize densities for weed suppression, research on maize plant densities and spatial arrangements has concentrated on their effects on lodging and maize grain yield under high rainfall conditions in Zimbabwe (Macrobert, 1986). Using different combinations of crop densities and row widths in weed management is yet to be fully exploited in a systematic and widespread manner (Murphy *et al*., 1996). There are numerous studies in the literature that have demonstrated the beneficial effect of narrow rows and/or high plant densities in suppressing weeds (Teasdale, 1995, 1998; Murphy *et al*., 1996; Weil, 1982; Begna *et al*., 2001; Tharp and Kells, 2001). No studies have addressed this subject in the context of the

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conditions prevailing in the smallholder farming system characterized by poor soil fertility and low and poorly distributed rainfall. The objective of this study was to determine the effect of reducing row spacing and increasing maize density on maize grain yield, weed growth and fecundity, under smallholder farming conditions, in a semi-arid area of Zimbabwe.

MATERIALS AND METHODS

Two experiments were conducted on farmers' fields during the 2002/03 and 2003/04 seasons at two sites (Village 40 [site 1] and Village 42 [site 2]) in Chinyika Resettlement Area, Zimbabwe. The sites used were characterized by sandy soils, belonging to the fersiallitic group and the dominant clay mineral in these soils is kaolinite (Nyamapfeni, 1991). The soils were well drained with good permeability, with an effective depth of 80 cm, which is ideal for maize. They were generally acidic, with pH ranging from 4.2 to 5.3 on the $CaCl_2$ scale.

The first experiment was organized as a 3×3 factorial in a Randomized Complete Block Design (RCBD) replicated three times to determine the effects of maize density (30,000, 36,000 and 42,000 plants ha^{-1}), inter-row spacing (60, 75 and 90 cm) on weed biomass and maize grain yield. All treatments were weeded three times at 3, 6 and 9 Weeks after Emergence (WAE). Experiment 2 was organized as a 3×3×3 factorial in a RCBD to investigate the effect of maize density and row spacing on the critical weed free period to avert yield loss in maize. The first two factors were as in Experiment 1, while the third factor was weeding regime at three levels (maize weeded once at 3 WAE; twice at 3 and 6 WAE and thrice at 3, 6 and 9 WAE).

The gross plot was 5 m wide and 5 m long having 6, 7 and 9 rows for the 90, 75 and 60 cm row spacing respectively. The net plot was 3 m wide and 3 m long for the 60 and 75 cm rows and 2.7 m wide by 3 m long for the 90 cm rows. Total weed biomass was assessed prior to weeding at 3, 6 and 9 WAE and at maize physiological maturity in both experiments. Weeds were counted by species in three 30×30 cm quadrants randomly thrown in each plot. Weeds were cut at ground level, oven dried to a constant weight at 80°C and weighed. Weed seed capsule production m^{-2} and capsule weight were also determined at maize physiological maturity using the same procedure as for weed numbers.

Both experiments were researcher managed. The land was ploughed using ox-drawn mouldboard ploughs by individual farmers. A medium season maize variety SC 513® was planted in the 2002/2003 season and an early season maize variety SC407® was planted in the 2003/2004 season. Compound D (7% N, 14% P_2O_5, 7% K_2O), at 300 kg ha^{-1}, was applied at each planting station before planting. Two seeds were placed per planting station and the maize was thinned to o ne plant per station at 2 WAE. Ammonium Nitrate (34.5% N) was applied as a topdressing fertilizer at 250 kg ha^{-1} at 5 WAE.

All weed seed capsule density data was (square root + 0.5) transformed (Steel and Torrie, 1984) and maize grain yield was standardized to 12.5% moisture content before statistical analysis. Data from the experiments was subjected to analysis of variance using the Minitab Version 12 (1998) statistical package.

RESULTS

Weed biomass and weed seed production: At both sites and in both seasons, the widest (90 cm) row spacing consistently had the highest weed biomass and there was no significant difference in the weeds biomass in the narrow inter-row spacing of 75 and 60 cm (Table 1). At 6 and 9 WAE, weed biomass significantly decreased by between 61 and 83% when inter-row spacing was decreased from 90 to 60 cm, at the two sites and in both seasons (Table 1). However, there was no difference in weed biomass between the 60 and 75 cm inter-row spacing at 6 WAE. Similar results were evident at 9 WAE, with weed biomass decreasing by an average of 50 to 94% when row width was decreased from 90 to 60 cm (Table 2).

There was a significant inter-row spacing × weeding regime interaction ($p<0.05$) on weed biomass at 9 WAE at Village 40 in the 2002/2003 season (Table 3). The interaction shows that when maize was planted in wide rows (90 cm) it required to be weeded twice at 3 and 6 WAE to attain the same weed biomass as maize weeded once, at 3 WAE, when planted in narrow rows (75 and 60 cm inter-row spacing) (Table 4). Weeding twice resulted in weed biomass that was not significantly different from weeding once in the higher maize densities of 36 000 and 42 000 plants ha^{-1}. In contrast, in the low maize density of 30 000 plant ha^{-1}, weeding twice significantly reduced weed biomass by about 58% compared to weeding once at the two sites in the 2002/2003 season (Table 4). It is also noticeable (Table 4) that the low density of 30 000 plants ha^{-1} maize had to be weeded twice to attain a similar weed biomass as higher maize densities weeded once.

There was a significant maize density × weeding regime ($p<0.05$) interaction on weed seed capsules produced at site 1 in the 2002/2003 season (Table 5). At 30,000 and 36,000 plants ha $^{-1}$ there was no difference in the number of seed capsules produced whether the maize was weeded twice or thrice and the highest number of

Table 1: Effect of inter-row spacing on weed biomass at 6 WAE (SED = 0.58, 52 df)

	Weed biomass ($g\ m^{-2}$)			
	Site 1		Site 2	
Inter-row spacing (cm)	2002/3	2003/4	2002/3	2003/4
60	1.69	6.61	0.90	4.07
75	1.91	9.36	2.16	5.70
90	4.68	17.16	5.29	10.88

Table 2: Effect of inter-row spacing on weed biomass at 9 WAE (SED = 0.55, 52 df)

	Weed biomass ($g\ m^{-2}$)			
	Site 1		Site 2	
Inter-row spacing (cm)	2002/3	2003/4	2002/3	2003/4
60	1.51	5.06	0.17	2.92
75	2.42	6.69	0.94	5.05
90	3.47	11.60	3.01	5.87

Table 3: Inter-row spacing × weeding regime interaction ($p<0.05$) on weed biomass (g) at site 1 at 9 WAE (SED = 1.73, 52 df)

	Inter-row spacing		
Weeding frequency	60 cm	75 cm	90 cm
Once at 3 WAE	5.77	5.19	6.73
Twice at 3 and 6 WAE	4.41	4.89	3.57

Table 4: Maize density × weeding regime interaction on weed biomass ($g\ m^{-2}$) at site 1 at 9 WAE (SED = 1.41, 52 df)

	Plant population		
Weeding frequency	30000	36000	42000
Weeded once	6.35	3.86	3.65
Weeded twice	2.65	2.56	3.62

Table 5: Maize density × weeding regime interaction on weed seed capsules produced (numbers m^{-2}) at site 1 in the 2002/2003 season (SED = 1.68, 52 df)

	Plant density (plants ha^{-1})		
Weeding frequency	30000	36000	42000
Once at 3 WAE	8.82	11.86	7.35
Twice at 3 and 6 WAE	4.85	3.71	8.69
Thrice at 3, 6 and 9 WAE	3.42	2.70	3.58

Table 6: Effect of inter-row spacing on grain yield (SED = 0.64, 52 df)

	Grain yield (t ha^{-1})			
	Site 1		Site 2	
Inter-row spacing (cm)	2002/3	2003/4	2002/3	2003/4
60	3.23	5.08	3.64	5.63
75	4.69	4.56	4.45	5.14
90	5.98	5.86	5.78	3.26

Table 7: Effect of maize density on grain yield (SED = 0.64, 52 df)

	Grain yield (t ha^{-1})			
	Site 1		Site 2	
Population density (plants ha^{-1})	2002/3	2003/4	2002/3	2003/4
30,000	5.62	6.13	5.32	4.11
36,000	5.67	4.83	4.33	4.86
42,000	4.30	3.96	3.98	4.78

Table 8: Effect of weeding frequency on grain yield (SED = 0.33, 52 df)

	Grain yield (t ha^{-1})			
	Site 1		Site 2	
Weeding regime	2002/3	2003/4	2002/3	2003/4
Once at 3 WAE	4.01	4.54	3.44	2.43
Twice at 3 and 6 WAE	5.40	4.16	3.68	3.51
Thrice at 3, 6 and 9 WAE	5.22	5.32	4.47	3.41

Table 9: Inter-row spacing × weeding regime interaction on grain yield at Site 1 in the 2003/4 season (SED = 0.42, 52 df)

	Row spacing		
Weeding regime	60 cm	75 cm	90 cm
Once at 3 WAE	2.56	4.27	4.89
Twice at 3 and 6 WAE	3.17	4.42	5.20
Thrice AT 3, 6 and 9 WAE	4.05	6.72	6.81

capsules were produced when the maize was weeded once. At the highest maize density of 42,000 plants ha $^{-1}$, the maize crop could be weeded only once (rather than twice) with no increase in the number of seed capsules produced, although weeding thrice resulted in the least number of capsules produced (Table 5).

Grain yield: Inter-row spacing significantly ($p<0.05$) affected maize grain yield at the two sites in both seasons (Table 6). Grain yield significantly decreased with a reduction in row width. At Site 1, in the 2003/2004 season and at Site 2 in both seasons, the highest grain yield was obtained from the 90 cm row spacing while there was no difference in the yield from the 60 and 75 cm rows. At Site 1 in the 2003/2004 season there was a progressive decrease in grain yield with decreasing spacing between rows (Table 6).

Maize grain yield significantly decreased ($p<0.05$) with an increase in maize density at Site 1 in both seasons and at Site 2 in the 2002/2003 season (Table 7). At Site 2 in the 2003/2004 season, the general trend was reversed, with a slight increase in maize grain yield as maize density was increased from 30,000 to 36,000 plants ha^{-1} (Table 7).

The effect of weeding frequency on maize grain yield depended on season and site. At site 1 in the 2002/2003 season and site 2 in both seasons, there was no significant maize yield increment derived from weeding thrice as compared to weeding twice. At Site 1 in the 2003/2004 season, maize grain yield significantly benefited when weeding was carried out three times and there were no significant yield differences recorded when maize was weeded once or twice (Table 8).

There was a row spacing × weeding regime interaction ($p<0.05$) on maize grain yield at Site 1 in the 2003/4 season. The interaction shows that maize grain yield was less sensitive to the intensity of weeding in the narrowest (60 cm) inter-row spacing when compared to wider (75 and 90 cm) inter-row spacing (Table 9). Although maize grain yield increased with increased intensity of weeding in the 60 cm inter-row spacing, the yield increases were not statistically significant. In the wider (75 and 90 cm) rows, maize grain yield significantly increased when the maize was weeded thrice compared to once and twice (Table 9).

DISCUSSION

Maize grain yield: The decreases in maize grain yield that were observed in this study with increase in maize density beyond 30 000 plants ha^{-1} and narrowing of row spacing below 90 cm is most likely attributable to higher levels of intra-specific competition for water at higher maize densities and narrow row spacing. Both seasons were characterized by early season droughts and maize plants were observed wilted at during day for most of the vegetative stage, from 1-5 weeks after planting. In the 2003/2004 season, early season rainfall from October to end of January was only 235 mm while February alone received 300 mm. A similar rainfall distribution occurred in the 2004/05 season. Whingwiri *et al.* (1992) recommended a maize population of 32,000 to 36,000 plants ha^{-1} for optimum yields of early maturing varieties under marginal rainfall conditions and 40,000 to 48,000 plants ha^{-1} under conditions of adequate moisture for higher optimum yields in Zimbabwe. Plant population trials conducted by the Agronomy Institute of Zimbabwe showed that a maize population of 37,000 plants ha^{-1} yielded higher in good rainfall seasons while a lower population of about 25,000 plants ha^{-1} was more appropriate in drought seasons (Shumba, 1984). Present results confirm that under semi-arid conditions, with low and poorly distributed rainfall mean of 500-600 mm, it is risky to increase maize density beyond 30,000 plants ha^{-1} and reduce row spacing below 90 cm.

Results of this study contradict those of Mashingaidze *et al.* (2004) in which maize density was maintained at 37 000 plants ha^{-1} and row spacing narrowed from the normal farmer practice of planting at 90×30 cm. Narrow row spatial arrangements (60×45 and 75×36 cm) significantly out yielded the wide row spatial arrangement (90×30 cm) in a high rainfall area (800-1000 mm) on heavy red soils with a high water holding capacity. The yield increases observed were correlated to greater radiation interception by the narrow row spatial arrangements than the wide row spatial arrangement (Mashingaidze *et al.*, 2004). Similar results have been found by Barbieri *et al.* (2000) and Andrade *et al.* (2002). The results of the current study clearly indicate that in nutrient-deficient and water-stressed conditions, the plant growth and yield advantages conferred by narrow rows intercepting more radiation than wide rows become nullified by the effects of greater levels of moisture and nutrient stress at high plant density and narrow rows. In the context of smallholder farmers producing maize in semi-arid areas of annual rainfall of 500-600 mm per annum with frequent mid-season droughts, it would be imprudent to recommend that they increase their maize densities beyond the 30 000 plants ha^{-1} and reduce the row spacing below 90 cm. The results of this study have shown that this will decrease maize grain yields and put smallholder farmer livelihoods at risk.

Weed growth and fecundity: The suppression of weed growth at high maize densities and/or narrow rows observed in this study is similar to what has been reported in a number of studies (Teasdale, 1995; Teasdale, 1998; Murphy *et al.*, 1996; Weil, 1982; Begna *et al.*, 2001; Shrestha *et al.*, 2001). Weed growth is suppressed by high maize density and narrow rows as a result of reduced PAR transmittance to the weeds under the maize canopy (Teasdale, 1995; Tollenaar *et al.*, 1994; Begna *et al.*, 2001; Tharp and Kells, 2001). Teasdale (1995) showed that narrow row and high density maize canopies closed a week earlier than wide row and low maize density canopies. Westgate *et al.* (1997) showed that increasing the maize density increased the total amount of radiation intercepted by the canopy and caused the canopy to close earlier in the season. Present results also show that narrow rows and higher plant densities reduced weed seed production. There is a linear relationship between the biomass of weeds at the end of the season and the amount of weed seeds produced (Thompson, 1991). The results show that high plant densities and narrow rows could be useful cultural weed control measures to restrict the size and activity of the weed seed bank. Restricting the weed seed rain that is added to the soil seed bank by planting high maize density and narrow rows has potential to reduce the weeding burden of small holder farmers in the long term.

The critical weed free period coincides with the time it takes for a crop to produce a closed canopy (Zimdahl, 1999) and any cultural weed management technique that results in earlier canopy closure than normal farmer practice will potentially reduce the critical weed free period to avert yield loss (Mashingaidze *et al.*, 2004). In this study, there was an interaction between row spacing and maize density on one hand and weeding frequency on weed biomass and seed production. The interaction showed that high maize densities (45,000 and 60,000 plants ha^{-1}) and narrow rows (60 and 75 cm) weeded once were equally effective in reducing weed biomass and seed production as low maize density (30,000 plants ha^{-1}) and wide row (90 cm) spacing maize weeded twice. These results suggest that farmers that use the high maize densities and narrow planting may benefit by halving their weeding requirements but still attain the same weed biomass and seed production as farmers who plant at low maize densities and wide row spacing and weed twice.

Synthesis: The results of this study indicate that while high plant densities and narrow rows may be effective cultural practices to suppress weed growth and seed production, they will result in reduced maize grain yield under semi-arid conditions. It is counter-productive to recommend these cultural weed management techniques to risk-averse small holder farmers in semi-arid areas since small holder farmers in southern Africa prioritize maize grain yield to secure their staple food security (Mashingaidze, 2004). The trade off between the potential to reduce weeding burden with the concomitant loss in maize grain yield when farmers use high maize densities and narrow rows require economic quantification in future studies.

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