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Full Length Research Paper

Effect of inter-row spacing and plant population on weed dynamics and maize (*Zea mays* L.) yield at Zanyokwe irrigation scheme, Eastern Cape, South Africa

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A study was conducted to determine the effects of inter-row spacing (45 and 90 cm) and plant population (40000 and 60000 plants ha^{-1}) on weed biomass and the yield of both green and grain materials of maize plants. The experiment was set up as 2 × 2 factorial in a randomised complete block design with three replications. Plant population had no significant effects and interaction among factors was not significant on weed biomass. Narrow rows of 45 cm reduced weed biomass by 58%. Growing maize at 40000 plants ha^{-1} resulted in similar green cob weight regardless of inter-row spacing. Cob length decreased with increase in plant population and with wider rows. Similar grain yield was obtained regardless of inter-row spacing when maize was grown at 40000 plants ha^{-1}, but at 60000 plants ha^{-1}, 45 cm rows resulted in 11% higher grain yield than 90 cm rows. Increasing plant population from 40000 to 60000 plants ha^{-1} resulted in a 30% grain yield increase. The study demonstrated that growers could obtain higher green and/or grain yield by increasing plant population from the current practice of 40000 to 60000 plants ha^{-1} and through use of narrow rows.

Key words: Row spacing, plant population, weed density, weed biomass, maize yield.

INTRODUCTION

Maize (*Zea mays* L.) is the most important grain crop in South Africa (SA) and is produced throughout the country under diverse environments. It is an important grain crop under irrigation, which produces high yields and is one of the most efficient grain crops in terms of water utilisation (Department of Agriculture, 2003). However, grain yields obtained by most smallholder irrigation farmers, are far below potential with an average of less than 3 t ha^{-1} being common (Bembridge, 1996; Averbeke et al., 1998; Machethe et al., 2004; Fanadzo, 2007). For example, the average grain yield achieved by farmers at Zanyokwe irrigation scheme (ZIS) in the Eastern Cape was found to be 1.8 t ha^{-1} (Fanadzo, 2007).

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Weed competition has been reported as one of the major causes of poor yields in smallholder irrigation schemes in SA and specific reference to the Eastern Cape Province is made by Marais (1992), Bembridge (1996), van Averbeke et al. (1998) and Fanadzo (2007). In this context, competition from weeds early in the development of maize remains one of the most serious and widespread production problems (Vernon and Parker, 1983: Low and Waddington, 1990; Waddington and Karigwindi, 1996; Mashingaidze, 2004).

Provided nutrients and moisture are not limiting, successful cultivation of maize depends largely on the efficacy of weed control. Weed induced losses are highest in smallholder farming and can be as high as 99% in maize (Fanadzo, 2007). Poor weed control decreases water and nitrogen use efficiency, the two most important inputs to achieving high yields under irrigation (Thomson et al., 2000). Most smallholder farmers are

are aware of the detrimental effects of weeds, but do not have the time or the means to control them, especially where tractor mechanisation has resulted in an increased area of cultivated land (Steyn, 1988). In smallholder irrigation schemes such as ZIS, many farmers rely on hoe weeding which is highly labour intensive, cumbersome and ineffective. Shortage of labour means that smallholder farmers invariably weed a large proportion of the crop late, after the crop has already suffered significant yield damage (Chivinge, 1990; Mashingaidze, 2004).

Crops can be favoured in competition against weeds by use of narrow rows and/or higher population densities. Use of narrow rows and/or higher population densities hastens the rapidity of closure of the canopy and enhances canopy radiation interception, thereby increasing crop growth rates and yields (Andrade et al., 2002) and suppressing weed growth and competitiveness (Murphy et al., 1996; Zimdahl, 1999; Mashingaidze, 2004). Therefore, the use of narrow rows and/or higher population densities could be used by smallholder irrigation farmers as means of weed control through achieving full ground cover earlier in the season, thereby reducing the impact of weeds on maize yield.

Optimum maize population is known to vary according to level of soil fertility, moisture status, cultivar grown and planting time (Sangoi, 2000). Generally, under irrigation, the practice in SA is to grow short season cultivars at a population of 80000 to 90000 plants ha^{-1} whereas medium to long season cultivars can be grown at populations of 45000 to 65000 plants ha^{-1} (Department of Agriculture, 2003). However, observations in ZIS indicated that farmers used a standard population of 40000 plants ha^{-1} for all their maize production, and may as a result be compromising on yield and income. Farmers in ZIS sell some of their maize as green cobs and price is charged as per cob. Therefore, a higher plant population with acceptable cob size would mean higher income per given unit of land. The objective of this study was to determine the relationship between inter-row spacing and plant population on weed biomass and maize yield.

MATERIALS AND METHODS

Location

The experiment was carried out in three sites at ZIS located in the central part of the Eastern Cape. The three sites were Nofemele and Bantubantu farms (32°45´S, 27°03´E) and Booi farm (32°45´S, 27°04´E). Soils at Nofemele consisted of deep dark-coloured soils of the Oakleaf form, while Bantubantu consisted of dark-coloured heavy-textured clay soils of the Valsrivier form. Soils at Booi were of the Hutton form (Soil Working Group, 1991). All sites have a warm temperate climate with mean annual rainfall of about 575 mm of which about 445 mm is received in summer, necessitating supplementary irrigation (Averbeke et al., 1998). The trial was planted on the 16 and 17 December, 2006 for Booi and Bantubantu farms, respectively. Nofemele farm was planted on 20 December, 2007.

Site preparation

Land was ploughed and disked once using a tractor-drawn plough and disc harrow, respectively, before the plots were marked. Maize cultivar SC 701 (Seed-CO®, South Africa) was used. Three seeds were planted per hole and the crop was thinned to one plant per station at 2 weeks after emergence (WAE) to give the desired population. Fertilizer was applied at a rate of 220 kg N ha^{-1} to all plots. A third of the N was applied as a basal application at planting as compound fertilizer 2:3:4 (30) [6.7% N, 10% P, 13.3% K] and two thirds as lime ammonium nitrate (with 28% N) topdressing in two equal splits at 5 and 7 WAE. Weed control was done by hand hoeing once at 3 WAE. Supplementary irrigation was done using the sprinkler system with a gross application of 6 mm hr^{-1}. Irrigation water was applied to meet the crop water requirements and the amount applied varied with weather conditions and crop growth stage (Table 1). Maize stalk borer (*Buseola fusca* Fuller) was controlled by applying Bulldock® (active ingredient: pyrethroid) granules in the maize funnel at 4 WAE.

Plant sampling and data collection

Weeds were counted in five randomly placed 30 × 30 cm quadrants per net plot prior to weeding at 3 and at 8 WAE. Counted weeds were cut at ground level, oven dried to a constant weight at 80°c and weighed. At harvest, data on green cob weight, cob length and grain yield were collected for each site. Green maize yield was evaluated by total weight and cob length. Marketable cobs were considered to have a length equal to or above 33 cm, and showing a health grain set suitable for commercialisation.

Experimental design and statistical procedures

The experiment was laid out in a randomised complete block design with three replicates. The treatment design was a 2 × 2 factorial with two inter-row spacing, 45 and 90 cm and two population levels, 40000 and 60000 plants ha^{-1}. At 40000 plants ha^{-1}, intra-row spacing was 56 cm for the 45 cm inter-row spacing whilst at 90 cm, intra-row spacing was 28 cm. At 60000 plants ha^{-1}, intra-row spacing for 45 cm rows was 38 cm whilst that for the 90 cm rows was 19 cm. Gross plot size was 9.9 x 8 m and the corresponding net plot size was 3.6 x 6 m each for green (corn on the cob) and grain yield assessments.

Weed density and biomass, green and grain maize yield and yield parameters were subjected to analysis of variance. Statistical analysis was performed using Genstat Release 7.22 DE on a per site basis and Bartlett's test (Gomez and Gomez, 1984) carried out to test for homogeneity of error variances before combining across sites. Grain yield was standardised to 12.5% moisture content before statistical analysis. Unless otherwise stated, differences referred to in the text are significant at $p<0.05$.

RESULTS

Weed density

Weed density (numbers m^{-2}) prior to weeding at 3 WAE varied among sites. The main weed species present at the three sites were *Setaria verticilata, Setaria pumila*, *Cyperus esculentus*, *Nichandra physaloides*, *Oxalis latifolia* and *Galinsoga parviflora. S. verticilata* had a density of 100 m^{-2} at Booi and 17 m^{-2} at Bantubantu, while Nofemele had none. *S. pumila* was present at a

Table 1. Rainfall, irrigation and mean temperatures during crop growth.

Month	2006/2007 (mm)			2007/2008 (mm)			Temperature (°C)	
	Rainfall	Irrigation	Total	Rainfall	Irrigation	Total	2006/2007	2007/2008
December	43.4	59.0	102.4	124.7	36.0	160.7	20.0	21.6
January	48.3	64.0	112.3	104.7	36.0	140.7	22.8	22.1
February	74.2	122.0	196.2	96.5	18.0	114.5	23.2	22.6
March	90.7	48.0	138.7	65.2	48.0	113.2	20.0	20.8
April	26.3	0.0	26.3	48.0	0.0	48.0	19.0	16.9
Total	282.9	293.0	575.9	477.1	138.0	615.1	-	-

high density of 298 m^{-2} at Booi but the weed was not present at Bantubantu and Nofemele. *C. esculentus* was present at low densities of less than 30 m^{-2} at all sites. *N. physaloides* was present at the highest density of 140 m^{-2} at Booi, but the weed was not present at Nofemele and present at a very low density of 4 m^{-2} at Bantubantu. The density of *O. latifolia* was 138 m^{-2} at Nofemele and 32 m^{-2} at Bantubantu, but Booi had none. In total, Bantubantu had three grass species and 10 broadleaf species, Nofemele had no grass species and three broadleaf species, while Booi had four grass species and three broadleaf species. With 14 different species, Bantubantu had the most diverse weed spectrum while Nofemele and Booi had four and eight different species, respectively. At 8 WAE, there were no significant interactions among factors and no main effects were significant.

Weed biomass

There were no significant interactions among factors at 3 and 8 WAE with regard to weed biomass. Plant population and site had no significant effects at both 3 and 8 WAE. Row spacing had a significant ($p<0.01$) effect on weed biomass at 8 WAE, but not at 3 WAE. Weed biomass decreased from 312.2 to 130.7 g m^{-2} when 45 cm rows were used instead of 90 cm rows at 8 WAE.

Green cob weight

The site × plant population × inter-row spacing interaction was significant. The main effects of row spacing and plant population were significant ($p<0.01$). Main effect of site was not significant ($p>0.05$). The site × plant population × inter-row spacing interaction showed that maize grown at 40 000 plants ha^{-1} had similar green cob weight regardless of row spacing across the three sites (Table 2). However, at 60000 plants ha^{-1}, cob weight obtained at Nofemele and Bantubantu was higher in 45 cm rows compared to 90 cm rows, while there was no difference in cob weight at Booi regardless of inter-row spacing. At 40000 plants ha^{-1}, Booi and Bantubantu had similar and significantly lower yield than Nofemele when maize was grown in 90 cm rows. At the same plant population, the cob weight obtained from Booi and Bantubantu was similar, while cob weight at Nofemele was similar to that of Bantubantu, but significantly higher than at Booi when maize was grown in 45 cm rows. At 60000 plants ha^{-1}, similar yield was obtained across the three sites when maize was grown in 90 cm rows. At the same population, similar yield was obtained at Booi and Bantubantu while cob weight at Nofemele was similar to that of Bantubantu, but significantly higher than at Booi when maize was grown in 45 cm rows (Table 2).

Cob length

There were no significant interactions among factors with respect to cob length. The main effects of plant population and inter-row spacing were significant ($p<0.01$), while the effect of site was not significant. Cob length decreased from 39.9 to 37.2 cm when plant population was increased from 40000 to 60000 plants ha^{-1}. Cob length increased from 37.9 to 39.2 cm when inter-row spacing was decreased from 90 to 45 cm.

Grain yield

There was a significant ($p<0.01$) interaction between plant population and inter-row spacing on grain yield. The main effects of plant population and inter-row spacing were significant ($p<0.01$), while the main effect of site was not significant. Similar yield was obtained regardless of inter-row spacing when maize was grown at 40000 plants ha^{-1}. At 60000 plants ha^{-1}, growing maize in narrow rows of 45 cm resulted in significantly higher yield than in 90 cm rows. Yield obtained at 60000 plants ha^{-1} was significantly higher than at 40000 plants ha^{-1} (Table 3).

Grains cob^{-1}

There were no significant interactions among factors with respect to number of grains per cob. Plant population had a significant effect while the effect of inter-row spacing was not significant. Number of grains cob^{-1} decreased

Table 2. Green cob weight (kg ha^{-1}) at varying levels of plant population and inter-row spacing.

	40000 plants ha^{-1}		60000 plants ha^{-1}	
Site	**45 cm rows**	**90 cm rows**	**45 cm rows**	**90 cm rows**
Booi	22 300^{e}	22 250^{e}	31 417^{b}	30 599^{bc}
Nofemele	25 463^{d}	24 143^{d}	33 460^{a}	31 607^{b}
Bantubantu	23 885d^{e}	22 255^{e}	32 948^{ab}	31 089^{bc}
LSD (0.05)		1817.6		

Table 3. Grain yield at varying levels of plant population and row spacing.

	Grain yield (kg ha^{-1})	
Plants ha^{-1}	**45 cm rows**	**90 cm rows**
40000	9 653	9 650
60000	12 547	11 288
LSD(0.05)	469.2	

from 504 to 464 when plant population was increased from 40000 to 60000 plants ha^{-1}.

DISCUSSION

Weed density and biomass

Results of this study indicated that both inter-row spacing and plant population had no significant effects on weed density and/or biomass at 3 WAE and that the effect of plant population on both weed density and biomass was not significant. At 3 WAE, maize at both row spacings had not developed a canopy to shade the weeds growing beneath, hence the failure to affect weed biomass. Both inter-row spacing and plant population had no significant effects on weed density at all growth stages of the maize crop. The possible explanation for this could be that weed density is not a good measure of weed growth and fecundity. Weed biomass (dry weight) is a better measure since such values combine weed density and size. Weed numbers can be halved, but if their weight is doubled, crop/weed competitive relationships may be unaltered (Klingman, 1971). Reduction in weed biomass with narrow rows at 8 WAE is most likely a result of quicker and complete canopy cover with the narrow spacing, thereby depriving the weeds of photosynthetically active radiation. One theory for reduced weed growth in narrow rows is quicker row closure, which reduces light penetration to the weeds emerging below the crop canopy (Alford et al., 2004). The suppression of growth (dry weight) of weeds by narrow rows has been reported in a number of studies (Teasdale, 1995; Begna et al., 2001; Tharp and Kells, 2001; Alford et al., 2004). Weed growth suppression by narrow rows is mainly due to increased shading of the inter-row rather than the in-row. This probably explains why plant population had no effect on weed biomass as observed in this study. However, some studies (Mashingaidze, 2004; Singh and Singh, 2006) have reported weed suppression with high plant populations.

Maize yield

This study indicated that all green cobs obtained were marketable regardless of plant population or row spacing, while total green cob weight and grain yield depended on inter-row spacing and population used. Grain yield was significantly higher at 60000 plants ha^{-1} while the yield advantage from narrow rows was only observed at the higher population but not at 40000 plants ha^{-1}. Maize is the agronomic grass species that is most sensitive to variations in plant density, such that for each production system, there is a population that maximises the utilisation of available resources, allowing the expression of maximum attainable yield in that environment (Sangoi, 2000). Maize yield is known to increase with increased plant population until the increase in yield attributable to the addition of plants is less than the decline in mean yield per plant due to increased inter-plant competition (Tollenaar and Wu, 1999; Mashingaidze, 2004). The results suggest that the population of 40000 plants ha^{-1} used by the ZIS farmers is not high enough to optimise on both green and grain maize production under irrigation. Farmers would obtain higher yields and profits by increasing plant population to 60000 plants ha^{-1} without necessarily having to change their inter-row spacing, although narrow rows would result in slightly higher yields and would help in weed suppression. In maize production, plant population per unit area is more important than specific row width (Department of Agriculture, 2003) and this is especially true if production is done under irrigated conditions.

Many studies conducted to test the effect of row spacing on maize grown under rainfed conditions have reported grain yield increases with decrease in spacing between rows (Barbieri et al., 2000; Andrade et al., 2002; Mashingaidze, 2004). Most of the yield response of maize to reduction in row spacing was related to improvements in radiation interception at the critical flowering stage (Bullock et al., 1988; Andrade et al., 2002). However, Ottman and Welch (1989) and Westgate et al. (1997) found no effects of row spacing on PAR interception at flowering, with all row spacings having full or nearly full radiation interception at flowering. The results of this study have shown that the use of narrow rows does not result in superior yields when maize is grown at 40000 plants ha^{-1}, although this plant population compromises yield and income. A possible reason for this is that at this population, there is lower intra-specific competition for limiting resources as compared to the higher population of 60000 plants ha^{-1}. The spatial arrangement and maize density that was closest to square planting geometry (45 × 38 cm) at 60000 plants ha^{-1} had the highest green and grain yield, suggesting that it had lower intra-specific competition compared to wider rows at the same population. The results also suggest that the greatest intra-specific competition occurred in the plant density and spatial arrangement that resulted in the closest spacing of plants within the row (90 × 19 cm) for the 60000 plants ha^{-1} density as evidenced by the significant difference in yield with row spacing at the higher plant population.

In this study, yield increased by 11% when maize grown at 60000 plants ha^{-1} and planted in 45 cm rows rather that 90 cm rows. Results of this study are in conformity with findings by Barbieri et al. (2000) who reported a 10% yield response to narrow rows. Greater responses to decreases in row spacing are expected in those crop species whose plants are closer together within the row (Andrade et al., 2002), such as soybean. Similarly, the response of maize to narrow rows is low or null at low plant densities (Fulton, 1970). This possibly explains the similarity in yield regardless of row spacing when maize was grown at the lower density of 40000 plants ha^{-1} in this study.

Conclusion

The study showed that increasing plant population from farmers' practice of about 40000 plants ha^{-1} to 60000 plants ha^{-1} resulted in more marketable green cobs and increased grain yield by up to 30%. Maize yield response to narrow rows could only be realised when maize is grown at the higher population of 60000 plants ha^{-1}, but not at 40000 plants ha^{-1}. Narrow rows reduced above ground weed dry matter and hence competition through earlier canopy closure. It was recommended that farmers at ZIS should plant their maize at 60000 plants ha^{-1} in narrow rows of 45 cm to reduce weed competition and optimise on maize yield.

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