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Full Length Research Paper

Reduced dosages of atrazine and narrow rows can provide adequate weed control in smallholder irrigated maize (*Zea mays* L.) production in South Africa

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An on-farm experiment was conducted in Zanyokwe irrigation scheme to investigate the effects of row spacing (45 and 90 cm) and atrazine dosage (33, 67 and 100% of the label recommended dosage) on weed density and biomass and on maize yield. Overall percent kill of weeds increased with increase in atrazine dosage and with reduction in row spacing. Percent kill varied according to weed species with a 100% kill of broad leaf weeds such as *Amaranthus hybridus*, *Nicandra physaloides* and *Bidens pilosa* regardless of herbicide dosage while *Digitaria sanguinalis*, *Cyperus esculentus, Cynodon dactylon and Oxalis latifolia* could not be controlled even at the LRD. Weed density at maize physiological maturity decreased by 11% when row spacing was decreased from 90 to 45 cm. Atrazine dosage and row spacing did not have significant interactive effects and their main effects did not significantly affect weight of green cobs, cob length or grain yield. The study demonstrated the possibility of incorporation of reduced herbicide dosages and narrow rows to achieve adequate weed control and optimise on yields in smallholder farming systems.

Key words: Row spacing, reduced atrazine dosages, weed density, weed biomass, maize yield.

INTRODUCTION

Inadequate weed control is one of the major causes of poor yields on smallholder farms in South Africa (SA) (Marais, 1992; Bembridge, 2000; Machethe et al., 2004; Fanadzo, 2007). Most smallholder farmers are aware of the detrimental effects of weeds but do not have the means to control them, especially where tractor mechanisation has resulted in an increased area of land being cultivated (Steyn, 1988). Weed control using hand hoeing is the major contributor to the total labour input in the production of crops in smallholder irrigation in SA (van Averbeke et al., 1998). The efficacy of hand hoeing is often compromised by continual wet conditions characteristic of the beginning of the rainy season. Hoe-weeding under wet conditions often causes weeds to re-root and re-establish, necessitating several rounds of weeding to keep the crop weed-free and avert yield losses (Mashingaidze and Chivinge, 1995; Mashingaidze, 2004). Effective hoe weeding in maize requires 460 h ha^{-1} in SA (Auerbach, 1993) and this becomes impractical given the large areas planted to the crop and the general shortage of labour on small farms.

It was observed in Zanyokwe irrigation scheme (ZIS) that farmers tended to abandon crops to weeds after failing to meet the labour requirement for hoe weeding (Fanadzo, 2007). The labour shortages for weeding are being worsened by the increase in morbidity wreaked by the AIDS pandemic that is sweeping sub-Saharan Africa (Sibuga, 1999). The ability of smallholder farmers to effectively control weeds is not only threatened by the HIV/AIDS subtracting the able-bodied weeders from the households, but also by farmers neglecting their weeding

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Abbreviations: RHDs, Reduced herbicide dosages; **LRDs,** label recommended dosages; **WAE,** weeks after emergence; **a.i,** active ingredient; **ZIS,** Zanyokwe irrigation scheme; **SA,** South Africa.

chores to tend to the sick and attend funerals (Mashingaidze, 2004).

Incorporation of herbicides in smallholder farming has been shown to minimise labour requirements and increase profitability (Auerbach, 1993). However, adoption of herbicide technology in the smallholder sector has traditionally been low because of lack of technical knowledge of the farmers and extension agents, lack of funds to purchase herbicides, fear of crop phytotoxicity and lack of equipment (Johnson and Adesina, 1993). It has long been recognised that application of reduced herbicide dosages (RHDs) can provide similar levels of weed control as label recommended dosages (LRDs) (Salonen, 1992; O'Sullivan and Bouw, 1993; Alm et al., 2000; Duchense et al., 2004; Mashingaidze, 2004). RHDs reduce crop injury, risk of contamination in the ecosystem, herbicide carryover phytotoxicity problems and the escalating problem of herbicide-resistant weeds (Blackshaw et al., 2006; Pannacci and Covarelli, 2009), thus enhancing sustainability in the long run. Use of RHDs costs a fraction of the LRD and is therefore more attractive to resource-poor smallholder farmers.

Cultural management techniques, such as reduced crop row spacing, that provide supplemental weed control when herbicide inputs are reduced can help reduce production costs (Grichar et al., 2004). Narrow rows are thought to increase weed control by increasing the competitiveness of a crop with weeds and by reducing light transmittance to the soil surface (Tharp and Kells, 2001). The reduction of competition among crop plants while favouring competition against weeds (Acciaresi and Zuluaga, 2006) through the use of narrow rows may be more favourable to the use of RHDs (Johnson and Hoverstad, 2002). It was hypothesised that integration of narrow rows with RHDs will be more effective in controlling weeds and averting yield losses compared to the use of narrow rows or RHDs in isolation. The objective of this study was therefore to investigate the effects of row spacing and herbicide dosage on weed growth and on green and grain maize yield.

MATERIALS AND METHODS

The experiment was established at three farmers' fields; Nofemele in 2006/07 and Bantubantu and Kalawe in 2007/08 in ZIS (32°45´S, 27°03´E) in the Eastern Cape Province of South Africa. The area has a warm temperate climate with mean annual rainfall of about 575 mm of which about 445 mm is received in summer, necessitating supplementary irrigation (van Averbeke et al., 1998). Soils at Nofemele and Kalawe consisted of deep dark coloured soils of the Oakleaf form, while Bantubantu consisted of dark coloured heavy-textured soils of the Valsrivier form (Soil Classification Working Group, 1991). Nofemele was planted on the 28th November 2006 while at Bantubantu and Kalawe planting was done on the 4th and 6th December 2007, respectively.

The experiment was laid out as a split plot in a randomised complete block design replicated three times, with row spacing as the main plot and atrazine dosage as the sub plot. Row spacing was at two levels: 45 and 90 cm, while atrazine dosage was at three levels; 750, 1500 and 2250 g active ingredient (a.i.) atrazine ha^{-1}, representing 33, 67 and 100% of the LRD of atrazine for a sandy clay loam/sandy clay (31 - 40% clay content). The herbicide was applied using a knapsack sprayer calibrated to apply 200 L of herbicide spray mixture per hectare. The herbicide treatments were applied when the majority of the weeds were at the 2 - 3 leaf stage at 2 weeks after emergence (WAE). In-row spacing was 27 and 54 cm for the 90 and 45 cm rows, respectively, to give a target population of 41,152 plants ha^{-1}. Gross plots were 9.9 × 8 m and the corresponding net plot size was 3.6 × 6 m each for the green and grain yield assessments.

Land was ploughed and disked once using a tractor-drawn plough and disc harrow, respectively, before the plots were marked. Fertilizer was applied at a rate of 250 kg N ha^{-1}, a third of which was applied as a basal application at planting as compound fertilizer 2: 3: 4 (30) and the other two thirds were applied as lime ammonium nitrate (28% N) topdressing in two equal splits at 5 and 7 WAE. Supplementary irrigation was done using the sprinkler system with a gross application of 6 mmh^{-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. Maize for green cobs was harvested at the soft dough stage. Marketable cobs were considered to have a length equal to or above 33 cm and showing a health grain set suitable for commercialisation.

Data were collected on weed density and biomass, percent weed kill and green and grain maize yield. Weeds were counted by species in five randomly placed 30 cm × 30 cm quadrants just before herbicide application. Four wire pegs with a red flag marker were placed at the corners of each quadrant to enable subsequent counts at the same locations. Two weeks after herbicide application, surviving weeds within the marked quadrants were counted by species. At 6 WAE and at maize physiological maturity, another five 30 cm × 30 cm quadrants were randomly placed into the net plots and weed biomass recorded. Green maize yield was evaluated by cob length and the weight of marketable cobs.

All weed density and biomass data were expressed per square metre and weed density data were square-root transformed (Steel and Torrie, 1984) before statistical analysis. Percent weed kill data were transformed using the arc-sine square root transformation (Steel and Torrie, 1984); however, actual percentages are presented. Grain yield was standardised to 12.5% moisture content before analysis of variance (ANOVA) on a per site basis. Bartlett's test (Gomez and Gomez, 1984) was carried out to determine homogeneity of error variances before combining data across sites. Due to the homogeneity of error variances, data was combined for ANOVA. ANOVA was performed using Genstat Release 7.22 DE. Least significant difference (LSD) was calculated at 5% confidence level to compare treatment means using Student's t-test (Ott, 1998).

RESULTS

Weed density prior to herbicide treatments

The initial weed species and density, before herbicide spraying varied across the three sites (Table 2). *Cyperus esculentus* L. was present at moderate density at all the three sites. *Cynodon dactylon* was present at Nofemele and Bantubantu but not at Kalawe, whilst *Eleusine indica* was recorded at Kalawe but not at Nofemele and Bantubantu. *Ageratum conyzoides* was present at high

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

Month	2006/07 (mm)			2007/08 (mm)			Temperatures (°C)	
	Rainfall	Irrigation	Total	Rainfall	Irrigation	Total	2006/07	2007/08
November	45.3	48.0	93.3	38.0	48.0	86.0	19.1	19.0
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	0.0	90.7	65.2	0.0	65.2	20.0	20.8
April	26.3	0.0	26.3	48.0	0.0	48.0	19.0	16.9
Total	328.2	293	621	477.1	138.0	615.1	-	-

Table 2. Weed species and their densities per square metre prior to herbicide application.

Weed species	Nofemele	Bantubantu	Kalawe
Grasses			
C. dactylon	24	34	-
Setaria pumila	2	6	-
Setaria verticilata	-	2	-
E. indica	-	-	24
Urochloa panicoides	-	-	-
D. sanguinalis	-	-	52
Sedges			
Cyperus esculentus	90	34	39
Broad leaves			
N. physaloides	28	2	6
O. latifolia	70	64	2
D. stramonium	2	28	-
A. conyzoides	144	108	-
P. major	82	4	-
I. purpurea	28	16	-
B. pilosa	2	10	2
Commelina benghalensis	2	2	23
Tagetes minuta	-	4	7
Argemone Mexicana	-	20	-
Ciclospermum leptophyllum	-	68	-
Chenopodium album	-	7	-
A. hybridus	-	-	12
Total	474	409	191

densities at Nofemele and Bantubantu farms, but was not recorded at Kalawe. *Nicandra physaloides* was present at moderate density at Nofemele farm, but at low densities at Bantubantu and Kalawe. Whilst *Oxalis latifolia* was present at relatively high density at Nofemele and Bantubantu, its density at Kalawe was low. *Plantago major* was the third most important weed at Nofemele after *A. conyzoides* and *C. esculentus*, but the weed was not important at the other two sites. With 16 different weed species, Bantubantu had the most diverse weed spectrum while Kalawe had the least number of weed species totalling nine. Nofemele had the highest weed density overall and the density was more than twice the density recorded at Kalawe (Table 2).

Weed density at 6 WAE and at maize physiological maturity

There were no significant interactions among factors on weed density at 6 WAE and at maize physiological maturity. The main effect of row spacing was significant ($p < 0.05$) at physiological maturity but not at 6 WAE. The main effects of site and herbicide dosage were not significant ($p > 0.05$) both at 6 WAE and at physiological maturity. At physiological maturity, weed density decreased by 11% from 12.73 to 11.30 weeds m^{-2} when row spacing was decreased from 90 to 45 cm.

Weed mortality

There were no significant interactions among the factors on percent kill of weeds. Atrazine dosage ($p < 0.01$), row spacing ($p < 0.05$) and site ($p < 0.05$) had significant effects on overall percent weed kill. There was a consistent increase in percent weed kill with increase in atrazine dosage. Percent kill increased from 46.2 to 58.8 to 70.6% when dosage was increased from 33 to 67 to 100% of the LRD. Percent kill increased by 8.2% from 54.4 to 62.6% when row spacing was reduced from 90 to 45 cm. Kalawe had the least percent weed kill of 50.1% whilst weed mortality at Nofemele (63.9%) and Bantubantu (61.6%) was similar.

Percent weed kill varied according to weed species. There was a 100% kill of broad leaf weeds *A.conyzoides, D. stramonium, P. major, Amaranthus hybridus*, *N. physaloides* and *Bidens pilosa* regardless of the herbicide dosage used; no survivors could be counted at three weeks after herbicide application. *Digitaria sanguinalis*, *C. esculentus, C. dactylon and O. latifolia were* the most tolerant weed species; the herbicide appeared to have temporarily scotched their foliage but they were observed re-growing from underground rhizomes later on, even at the LRD.

Weed biomass at 6WAE

There was a significant ($p < 0.01$) interaction between row spacing and site on weed biomass at 6 WAE. The main effects of atrazine dosage, row spacing and site were significant ($p < 0.01$). The row spacing × site interaction showed a significant decrease in weed biomass at the 45 cm row spacing at Nofemele and Bantubantu, but weed biomass at Kalawe was similar regardless of row spacing used (Table 3). There was a significant decrease in weed biomass with increased herbicide dosage. Weed biomass decreased by 22% from 123 to 95.7 g m^{-2} when dosage was increased from 33 to 67% of the LRD, while increasing dosage from 67 to 100% of the LRD resulted in a 19% decrease in weed biomass from 95.7 to 77.9 g m^{-2}.

Weed biomass at maize physiological maturity

There was a significant ($p < 0.05$) atrazine dosage × site interaction on weed biomass at maize physiological maturity. The main effects of atrazine dosage ($p < 0.01$), row spacing ($p < 0.05$) and site ($p < 0.01$) were significant. The dosage × site interaction showed that at Nofemele and Bantubantu, similar weed biomass was obtained regardless of herbicide dosage. However, at Kalawe there was a significant decrease in weed biomass when herbicide dosage was increased beyond 33% of the LRD, but there was no difference between 67 and 100% of the LRD (Table 4). Weed biomass decreased by 22% from 141.5 to 109.0 g m^{-2} when 45 cm rows were used instead of 90 cm rows.

Maize yield and yield components

Data on grain yield is only available from Nofemele and Kalawe. The farmer at Bantubantu harvested the remainder of the maize in the absence of the researcher after green maize data was collected. There were no significant interactions among factors on green maize yield, length of green cobs, grain yield and grains cob^{-1}. There was a significant ($p < 0.05$) interaction between atrazine dosage and site on 1000 grain weight. The only significant ($p < 0.01$) main effect on green cob weight, cob length and grain yield was site. The number of grains cob^{-1} was not affected by any of the factors tested and row spacing had no effect on any of the parameters measured.

The atrazine dosage × site interaction showed that similar 1000 grain weight was obtained at Kalawe regardless of herbicide dosage, while at Nofemele the full LRD resulted in significantly bigger grains than 33 and 67% of the LRD which produced similar 1000 grain weight (Table 5). Nofemele produced the highest weight of green cobs whilst Kalawe had the least. Nofemele and Bantubantu produced cobs of similar length while Kalawe produced shorter cobs. Nofemele produced 2,176 kg ha^{-1} more grain yield than Kalawe (Table 5).

DISCUSSION

Results of this study indicated that whilst reduced dosages of atrazine can be used successfully; this depends on the main weed species in an area. If more tolerant weed species such as *D. sanguinalis* and *C. esculentus* are the main weed species, then RHDs may not achieve adequate weed control as demonstrated by the study. The reduction in grain yield at Kalawe may be attributed to the increased weed pressure at that site. The dominant weed present at that site was the grass weed *D. sanguinalis*, which proved very difficult to control even at the recommended dosage. This is also supported by the fact that this site recorded the least percent weed kill. Our results conform to findings by Shrestha et al. (2001) who reported that the effectiveness of narrow rows in reducing weed biomass was influenced by weed spectrum and weed density among other factors.

Table 3: Weed biomass (g m^{-2}) obtained at 6 WAE at different row spacings at the three sites

Row spacing (cm)	Site		
	Nofemele	Bantubantu	Kalawe
90	135.4	96.2	118.9
45	68.3	54.3	120.2
LSD (0.05)	20.4		

Table 4. Weed biomass (g m^{-2}) obtained at varying atrazine dosages at the three sites at maize physiological maturity

Site	Atrazine dosage (g a.i. ha^{-1})		
	750g	1500g	2250g
Nofemele	164.3	144.2	129.1
Bantubantu	79.6	65.2	54.0
Kalawe	249.0	135.8	106.3
LSD (0.05)	53.5		

Table 5. Green and grain maize yield and yield components at two levels of row spacing and three levels of atrazine dosage at Nofemele, Kalawe and Bantubantu farms.

Treatment	Green cob weight (kg ha^{-1})	Cob length (cm)	Grain yield (kg ha^{-1})	1000 grain weight (g)	Number of grains cob^{-1}
Atrazine dosage [AD] (g a.i. ha^{-1})					
750	21 066	40.0	7 757	525	558
500	21 213	39.1	7 800	512	564
2250	21 671	39.2	7 964	541	562
Significance	NS	NS	NS	*	NS
Row spacing [RS] (cm)					
45	21 651	39.6	7 860	526	563
90	20 982	39.3	7 820	526	560
Significance	NS	NS	NS	NS	NS
Site [S]					
Nofemele	25 218	40.0	8 928	660	567
Bantubantu	23 776	39.7	-	-	-
Kalawe	17 956	38.6	6 752	392	556
Significance	**	*	**	**	NS
Interactions					
AD×RS	NS	NS	NS	NS	NS
AD×S	NS	NS	NS	*	NS
RS×S	NS	NS	NS	NS	NS
AD×RS×S	NS	NS	NS	NS	NS

NS, *, **Non-significant, significant at 5% and significant at 1%, respectively.

Findings by Mashingaidze (2004) indicated that mixing reduced dosages of atrazine and nicosulfuron provided better weed control compared to similar or higher doses of each individual herbicide. This means that application of reduced doses of mixtures of complementary herbicides in terms of target species spectrum (nicosulfuron is mainly a grass herbicide while atrazine controls mainly broadleaf weeds), rather than individual herbicides, may reduce the need to follow up application of reduced dosages with weed control tillage to remove weed escapes. Results of this study indicate that a RHD strategy applied over a number of seasons may increasingly select for the moderately tolerant weed species to the herbicides being applied. In the case of atrazine as used in the study, the moderately tolerant weeds *C. esculentus, C. dactylon* and *D. sanguinalis* and the broad leaf weed *O. latifolia* would be selected for by the strategy as more of these weeds species escaped the herbicide treatments at low doses. The RHD strategy, therefore, needs to be integrated with other weed control tactics that will remove herbicide escapes and prevent them from producing seed (Mashingaidze, 2004).

Numerous studies have indicated the importance of competitive cropping systems to attain long-term weed management (Mohler, 2001; Nazarko et al., 2005). Similar results of reduction in weed biomass with narrow rows as obtained in this study for Nofemele and Bantubantu were reported by Blackshaw et al. (2006). Results of this study are in conformity with findings by Johnson et al. (1998) who reported little benefit in maize to narrow row spacings as a method for reducing herbicide inputs. Although our findings largely showed no interaction between herbicide dosage and row spacing, research indicates that there is good potential to reduce both herbicide use and the number of herbicide applications when they are utilised within competitive cropping systems such as use of narrow rows (Blackshaw et al., 2006). Forcella et al. (1992) and Teasedale (1995) found that weed control from RHDs in maize was increased in narrow compared to wide rows. Weed populations are reduced over time and existing weeds are suppressed in those systems employing good agronomic and competitive crops. Herbicide coverage, uptake and efficacy can be greater with low weed densities (Winkie et al., 1981) and therefore, any crop production practice that reduces weed competition over time is important to the successful use of RHDs. Jordan et al. (1995) suggested that management aimed at increasing seed mortality can be more effective than management aimed solely at killing weed seedlings.

Successful and sustainable long-term weed management will require a shift away from simply controlling problem weeds to systems that restrict weed repro-duction, reduce weed emergence and minimize weed competition with crops. Research has shown that compe-titive crop production practices can contribute to the development of more sustainable weed management systems (Mohler, 2001). In the context of smallholder farmers, the RHD can be followed up by mechanical or hoe cultivation to remove the herbicide escapes. Since weed escapes will be rendered uncompetitive to the crop by the RHD (as shown by no yield effect in this study), before full ground cover, the timing of the following hand hoeing or mechanical cultivation becomes less critical. This can be a potential advantage given the general shortage of labour for hoe weeding in smallholder agriculture and specifically in the study area.

Conclusions

The study has demonstrated the possibility of incorporation of RHDs and narrow rows in smallholder farming systems. However, this will depend largely on the weed spectrum in a particular locality. Planting maize in narrower rows than the traditional 0.9 m reduced weed growth and fecundity compared to wider rows. Integration of narrow rows with reduced herbicide dosages did not result in superior weed control compared to the use of narrow rows or reduced herbicide dosages in isolation. The results of this study suggest the possibility of developing a weed management system based on the use of RHDs, to slow down or stop weed growth soon after application. This strategy will reduce the competitiveness of weeds, without necessarily killing them, before full ground cover by the crop canopy.

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