Anoda cristata control with glyphosate in narrow- and wide-row soyabean

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Received 13 December 2002
Revised version accepted 6 January 2004

Summary

Experiments evaluated the effect of glyphosate rate and *Anoda cristata* density, on crop and weed biomass and weed seed production in wide (70 cm) and narrow rows (35 cm) glyphosate-resistant soyabean (*Glycine max*). Soyabean density was higher at 35 cm row spacing as an increase in planting rate in narrow-row soyabean is recommended for producers in Argentina. Soyabean biomass at growth stage V4 (four nodes on the main stem with fully developed leaves beginning with the unifoliate leaves) was higher when grown on narrow than in wide-rows but was not affected by the presence of *A. cristata*. At growth stage R5 (seed initiation – seed 3 mm long in a pod at one of the four uppermost nodes on the main stem, with a fully developed leaf and full canopy development), crop biomass was greater in narrow rows compared with wide rows with 12 plants m^{-2} of *A. cristata*. In narrow-row soyabean, a single application of a reduced rate of glyphosate maintained soyabean biomass at R5 and provided excellent weed control regardless of weed density. In wide-row soyabean control was reduced at the high weed density. Regardless of row spacing, *A. cristata* biomass and seed production were severely reduced by half of the recommended dose rate of glyphosate but the relationship between biomass and seed production was not altered. Glyphosate rates as low as 67.5 g a.e. ha^{-1} in narrow rows or 540 g a.e. ha^{-1} in wide rows provided excellent control of *A. cristata*. To minimize glyphosate use, planting narrow-row soyabean are effective where *A. cristata* density is low.

Keywords: crop and weed biomass, weed density, row spacing, seed production, *Anoda cristata*, glyphosate.

Introduction

Soyabean [*Glycine max* (L.) Merr.] is a major crop in Argentina and the annual broad-leaved weed *Anoda cristata* (L.) Schlecht. has become a problem of increasing importance (Mattioli, 1984; Leiva & Ianone, 1994). Before the introduction of glyphosate-resistant soyabean, glyphosate was primarily applied at planting or pre-emergence in non-tillage systems. In recent years almost 90% of the soyabean area in Argentina is planted with glyphosate-resistant soyabean (Vitta *et al.*, 2000) and consequently post-emergence applications of the herbicide have increased significantly. Information is available on the efficacy of post-emergence applications of glyphosate to control summer annual weeds in soyabean (e.g. Krausz *et al.*, 1996; Wait *et al.*, 1999; Mulugueta & Boerboom, 2000).

Current economic, environmental and management concerns have provided incentive to investigate means of reducing the use of herbicides for weed management. Reduced-rate technology is an approach to lower costs that can provide effective control of susceptible species and decrease weed seedling vigour of less susceptible species to give the crop a competitive growth advantage (Vangessel & Westra, 1997). The performance of reduced glyphosate rates is dependent on weed species and weed size (Vanlieshout & Loux, 2000) but little information exists on the effect of reduced rates of glyphosate at different weed densities.

Herbicides applied at reduced rates can decrease seed production (Taylor & Oliver, 1997). It is important to find the most appropriate rate because weed plants that escape control often produce abundant seeds (Defelice *et al.*, 1989). *Anoda cristata* produces a high number of

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persistent seeds that emerge throughout the soyabean growing season (Faccini *et al.*, 1992).

Crop spatial arrangement may modify the competitive relationships between the crop and the weed (Spitters & van der Bergh, 1982) and there is a trend towards reducing row width as a means of increasing crop competition to suppress weeds (Johnson *et al.*, 1997). In Argentina, soyabean is usually planted at a row distance of 70 cm but the adoption of narrower planting patterns is increasing. Soyabean density was higher in 35 cm row spacings as an increase in planting rate in narrow-row soyabean is recommended in Argentina (Puricelli *et al.*, 2002). Control of weeds was consistently higher when herbicides were applied in narrow-row compared with wide-row soyabean (Mickelson & Renner, 1997; Ateh & Harvey, 1999). In the presence of annual broadleaved weeds, soyabean yield improved in narrow- compared with wide-row soyabean (Elmore, 1987; Bauer *et al.*, 1991). It is important to compare *A. cristata* management in wide- and narrow-row soyabean and to evaluate its interaction with reduced glyphosate dose rates to optimize weed control and the objective of this study was to investigate the effect of glyphosate rate and *A. cristata* density on crop and weed biomass and weed seed production in wide- (70 cm) and narrow-row (35 cm) glyphosate-resistant soyabean.

Materials and methods

Field experiments were conducted at the University of Rosario Experimental Farm at Zavalla (Lat. 33°01′S Long 60°53′), Argentina in 1997–98 and 1998–99. The soil was a vertic argiudol with 3% organic matter, a pH of 5.8, and an inorganic fraction consisting of 5% sand, 70% silt and 25% clay. During the previous 15 years, the crop rotation on the experimental site was with wheat, maize and soyabean. Rainfall during the experiment was 753 mm from November 1997 to February 1998 and 443 mm from November 1998 to February 1999. There was adequate moisture each year to plant soyabean at normal planting times.

Experimental procedure

The plot was disced and harrowed and the cultivar Asgrow 640/600 was planted on 4 December 1997 and 23 November 1998 and harvested in April of the following year. Soyabean was planted at 514 800 plants ha^{-1} in 35 cm rows with a Gherardi G100 grain drill (Casilda, Argentina) and at 375 000 plants ha^{-1} in 70 cm rows with a Gherardi G95 planter. A 30% increase in planting rate in narrow-row soyabean is recommended in Argentina (Baigorri & Croatto, 2000). Higher seeding rate in narrow-soyabean is also recommended in USA in both traditional cultivars (Nelson & Renner, 1998) and in glyphosate-resistant cultivars (Nelson & Renner, 1999). The soil was not fertilized and there was no inter-row cultivation. During the whole experiment, all weeds other than *A. cristata* were controlled with haloxyfop (Galant, 240 g a.e. L^{-1}, Dow AgroSciences) applied at 0.24 kg a.e. ha^{-1} and hand-weeding. Glyphosate (Roundup, 360 g a.e. L^{-1}, Monsanto) applications were made with CO_2 backpack sprayer. Spray solutions were applied using 8003 flat-fan nozzles at a pressure of 270 kPa in a water volume of 187 L ha^{-1}. The recommended rate of glyphosate for *A. cristata* is 1080 g a.e. ha^{-1} for plants with seven to eight leaves as those present at the time of application in the experiments (CASAFE, 1997). A natural infestation of *A. cristata* was thinned to 0, 2 and 12 plants m^{-2} on the day of glyphosate application *c.* 35 days after planting (DAP). Application time was chosen considering that an earlier application can result in new *A. cristata* emergence that may compete with the crop and produce seeds, while later control could result in important crop yield reductions due to plants beyond the critical period of competition. The critical period of weed control in soyabean was found to be 30–45 DAP (Chhokar & Balyan, 1999). Crop and *A. cristata* above-ground biomass was determined at soyabean growth stages V4 (four nodes on the main stem with fully developed leaves beginning with the unifoliate leaves) at *c.* 35 DAP and at soyabean growth stage R5 (seed initiation – seed 3 mm long in a pod at one of the four uppermost nodes on the main stem with a fully developed leaf and full canopy development) by cutting plants at the surface soil in 1 m^2 sub sample per plot (Fehr & Cavinness, 1977). Biomass at the later growth stage was found to be positively correlated with grain yield (Board *et al.*, 1996). Biomass was recorded after drying for 48 h at 70°C. *Anoda cristata* seeds m^{-2} were determined by removing capsules from one 1 m^2 subplot per plot as they matured, till the end of the weed growing season.

Experimental design

Three separate experiments were conducted simultaneously. In the first experiment the effect of planting pattern, glyphosate rate and *A. cristata* density on crop and weed biomass was determined. The experiment design was a split-split plot with three replications. Soyabean planting pattern was the main plot (narrow and wide rows), with glyphosate rate (1080, 540 g a.e. ha^{-1} and control) as the subplot. Finally, density of *A. cristata* (0, 2 and 12 plants m^{-2}) was the sub-subplot factor. Sub-subplots measured 3 m × 7 m. In both years control of *A. cristata* with 540 g a.e. ha^{-1} glyphosate, expressed relative to the corresponding control treatments with 2 and 12 plants m^{-2} of *A. cristata* in narrow and wide rows, was determined at the R5 growth stage.

In the second experiment the effect of planting pattern, glyphosate dose rate and *A. cristata* density on weed seed production was determined. The experimental design was a split-split-plot with three replications and subplot size was 3 m × 7 m. The main plot was planting pattern (narrow and wide rows) with glyphosate dose rate as subplot factor (1080, 540 g a.e. ha^{-1} and control) and *A. cristata* density as sub-subplot factor (2, 4, 7, 12 and 30 plants m^{-2}). Additionally, in three plots per block soyabean was removed and *A. cristata* was grown in monoculture. *Anoda cristata* seed production per area was determined in narrow and wide rows at a glyphosate dose rate of 540 g a.e. ha^{-1} and without glyphosate at all weed densities. Finally, in 1997–98 individual plant weights and seed weights of 1000 seeds were assessed for 50 plants of contrasting weights taken from the wide-row control plots.

In the third experiment the effect of planting pattern on glyphosate dose–response relationships was determined. The experimental design was a split-plot with three replications where the main plot was planting pattern (narrow and wide rows) and the subplot factor was glyphosate rate (1080, 540, 270, 135, 67.5 and 0 g a.e. ha^{-1}). The subplot size was 3 m × 7 m. Weed density was four plants m^{-2}. Weed biomass and seed production were determined at R5 growth stage.

Statistical analysis

Biomass dry weights were log-transformed ($\log(x + 1)$), seed number square root-transformed ($\sqrt{x + 0.5}$), and percentage data arcsine-transformed ($\sin^{-1}\sqrt{x + 0.5}$), where x is the fractional conversion of the percentage value before analysis to reduce variance and improve normality.

Soyabean and *A. cristata* biomass was analysed using ANOVA to test the effect of year, herbicide rate, planting pattern, and *A. cristata* density and possible interactions. Mean values were separated by Fisher's protected LSD ($P = 0.05$) or a *t*-test ($P = 0.05$). SED values in the tables are for transformed data.

The relationships between *A. cristata* biomass and seed production per unit area of *A. cristata*, weed seed production and weed density, and biomass and seed production of *A. cristata* and glyphosate rate were determined using regression analyses. Rectangular hyperbolic models related *A. cristata* density and seed production per area in all treatments González Andújar & Fernández-Quintanilla, 1991). Log-logistic models related herbicide dose rate to *A. cristata* biomass and seed production per area (Seefeldt *et al.*, 1995). A linear model related *A. cristata* biomass and seed production per unit area without glyphosate application in narrow rows and wide rows. Coefficients of determination, residual mean squares, sum of squares, and residuals were evaluated to determine best-fit models. Estimated parameters were compared using *t*-tests.

Results and discussion

Soyabean biomass at V4 was higher in narrow than in wide rows (Table 1) but the presence of *A. cristata* did not affect crop biomass. In contrast, *A. cristata* biomass at V4 was affected by weed density, but not by crop row spacing (Table 2).

At R5, crop biomass was greater in narrow row compared with wide rows with 12 plants m^{-2} of *A. cristata*. There was no difference in soyabean biomass where 0 or 2 plants m^{-2} of *A. cristata* were present (Table 3). The difference imposed by the planting pattern on soyabean biomass at V4 disappeared at R5 at low weed density. Higher precipitation in the 1997–98 than in the 1998–99 growing season can account for the higher soyabean biomass produced during the first growing season. *Anoda cristata* at 12 plants m^{-2}

Table 1 Soyabean biomass prior to glyphosate application at soyabean growth stage V4 as affected by the interaction between herbicide dose, density and planting pattern. Analyses performed on log-transformed values for biomass shown in parentheses, alongside back-transformed mean

	Glyphosate dose (g a.e. ha^{-1})	Weed density (plants m^{-2})	Row spacing ($g\ m^{-2}$) Narrow row	Wide row
1997–98	0	0	108 (4.7)	79 (4.6)
		2	113 (4.7)	77 (4.7)
		12	112 (4.7)	69 (4.7)
	540	0	105 (4.7)	66 (4.4)
		2	113 (4.8)	79 (4.3)
		12	110 (4.7)	72 (4.2)
	1080	0	114 (4.1)	64 (4.2)
		2	121 (4.3)	72 (4.3)
		12	107 (4.3)	78 (4.4)
1998–99	0	0	84 (4.4)	58 (4.3)
		2	74 (4.3)	65 (4.4)
		12	80 (4.4)	60 (2.9)
	540	0	75 (4.4)	58 (4.1)
		2	81 (4.3)	61 (4.2)
		12	83 (4.5)	63 (4.1)
	1080	0	84 (4.1)	63 (4.1)
		2	75 (4.1)	57 (4.0)
		12	87 (4.1)	62 (2.8)

SED (transformed data) (72 d.f., for comparison of biomass means within a year) = 0.24.
SED (transformed data) (72 d.f., for comparison of biomass means between years) = 0.25.

Table 2 *Anoda cristata* biomass prior to glyphosate application at soyabean growth stage V4 as affected by the interaction between herbicide dose, weed density and planting pattern. Analyses performed on log-transformed values for biomass shown in parentheses, alongside back-transformed mean

	Glyphosate dose (g a.e. ha^{-1})	Weed density (plants m^{-2})	Row spacing (g m^{-2})	
			Narrow row	Wide row
1997–98	0	2	1.7 (0.6)	2.0 (0.0)
		12	9.1 (2.2)	10.5 (0.0)
	540	2	1.8 (0.6)	2.2 (0.0)
		12	12.3 (2.5)	9.5 (0.0)
	1080	2	1.8 (0.6)	2.0 (0.0)
		12	8.9 (2.2)	10.9 (0.0)
1998–99	0	2	1.6 (0.5)	1.9 (0.5)
		12	8.7 (0.0)	9.5 (0.0)
	540	2	1.5 (0.4)	1.4 (0.4)
		12	8.6 (0.0)	7.2 (0.0)
	1080	2	1.3 (0.3)	1.5 (0.4)
		12	8.5 (0.0)	9.5 (0.0)

SED (transformed data) (46 d.f., for comparison of biomass means within a year) = 0.07.
SED (transformed data) (46 d.f., for comparison of biomass means between years) = 0.12.

Table 3 Soyabean biomass at soyabean growth stage R5 as affected by the interaction between herbicide dose, weed density and planting pattern. Analyses performed on log-transformed values for biomass shown in parentheses, alongside back-transformed mean

	Glyphosate dose (g a.e. ha^{-1})	Weed density (plants m^{-2})	Row spacing (g m^{-2})	
			Narrow row	Wide row
1997–98	0	0	1110 (7.0)	1163 (7.1)
		2	1033 (6.9)	1005 (6.9)
		12	860 (6.8)	680 (6.5)
	540	0	1110 (7.0)	1150 (7.0)
		2	1113 (6.9)	1099 (7.0)
		12	950 (6.9)	781 (6.9)
	1080	0	1107 (7.0)	995 (6.9)
		2	1006 (6.9)	1010 (6.9)
		12	998 (6.9)	1114 (7.0)
1998–99	0	0	814 (6.7)	782 (6.7)
		2	795 (6.7)	667 (6.5)
		12	681 (6.5)	468 (6.1)
	540	0	813 (6.7)	805 (6.7)
		2	786 (6.7)	801 (6.7)
		12	766 (6.6)	547 (6.3)
	1080	0	839 (6.7)	823 (6.7)
		2	763 (6.6)	779 (6.7)
		12	697 (6.6)	725 (6.7)

SED (transformed data) (72 d.f., for comparison of biomass means within a year) = 0.20.
SED (transformed data) (72 d.f., for comparison of biomass means between years) = 0.20.

reduced soyabean biomass. Without glyphosate, the reduction in soyabean biomass was lower in the narrow rows than wide rows. At 540 g a.e. ha^{-1} glyphosate the reduction in soyabean biomass was only significant for wide rows.

Table 4 *Anoda cristata* biomass at soyabean R5 growth stage as affected by the interaction between herbicide dose, density and planting pattern. Analyses performed on log-transformed values for biomass shown in parentheses, alongside back-transformed mean

	Glyphosate dose (g a.e. ha^{-1})	Weed density (plants m^{-2})	Row spacing (g m^{-2})	
			Narrow row	Wide row
1997–98	0	2	28.4 (3.4)	45.1 (3.8)
		12	55.4 (4.0)	86.2 (4.5)
	540	2	0.1 (0.0)	8.3 (2.2)
		12	0.8 (0.6)	46.2 (3.9)
	1080	2	0.0 (0.0)	0.0 (0.0)
		12	0.0 (0.0)	0.0 (0.0)
1998–99	0	2	29.7 (3.4)	52.8 (4.0)
		12	69.2 (4.3)	144.1 (5.0)
	540	2	0.0 (0.0)	5.6 (2.3)
		12	0.0 (0.0)	62.6 (4.1)
	1080	2	0.0 (0.0)	0.0 (0.0)
		12	0.0 (0.0)	0.0 (0.0)

SED (transformed data) (46 d.f., for comparison of biomass means within a year) = 0.09.
SED (transformed data) (46 d.f., for comparison of biomass means between years) = 0.09.

Weed density did not affect soyabean biomass where 1080 g a.e. ha^{-1} glyphosate was applied and provided complete control of *A. cristata* (Table 4). The application of 540 g a.e. ha^{-1} glyphosate in narrow rows killed all *A. cristata* plants present in 1998–99 and most of the weed plants in 1997–98. In wide rows, control with this dose rate was lower than in narrow rows. The reduction in *A. cristata* biomass was greater for densities of 2 plants m^{-2} than 12 plants m^{-2}.

Recommended herbicide rates are usually based on high weed density and may therefore be an overestimation of the amount required at lower densities (Hamill *et al.*, 1994). At 540 g a.e. ha^{-1} glyphosate control of *A. cristata* was lower for 12 vs. 2 plants m^{-2} in wide rows but in narrow rows control was excellent at low and high weed density (Table 5). The effectiveness of combining reduced rates and narrow crop spacing was remarkably good (Table 6). Reducing row distance had the same effect on seed production of *A. cristata* as applying 540 g a.e. ha^{-1} glyphosate in wide-row soyabeans. Greater control with low than with high densities was also observed by Dieleman *et al.* (1999) for *Abutilon theophrasti* Medik. in sunflower (*Helianthus annuus* L.).

Biomass and seed production per unit area of *A. cristata* without glyphosate application in narrow rows and wide rows were associated by a linear model (Fig. 1) in which data were combined over planting patterns because parameters did not differ ($P > 0.05$).

Table 5 Percentage control of *Anoda cristata* with application of 540 g a.e. ha^{-1} glyphosate relative to the corresponding untreated controls (two and 12 plants m^{-2} of *Anoda cristata* in narrow- and wide-row soyabean in 1997–98 and 1998–99). Application was at soyabean growth stage V4 and biomass evaluation at growth stage R5. Analyses performed on angle-transformed values shown in parentheses, alongside back-transformed mean

Anoda cristata density (plants m^{-2})	1997–98 (%)		1998–99 (%)	
	Wide-row	Narrow-row	Wide-row	Narrow-row
2	82 (64.9)	100 (90.0)	85 (67.2)	100 (90.0)
12	47 (43.2)	100 (90.0)	57 (48.9)	100 (90.0)

SED (transformed data) (12 d.f., for comparison of biomass means within a year) = 1.62.
SED (transformed data) (12 d.f., for comparison of biomass means between years) = 1.89.

At 540 g a.e. ha^{-1} glyphosate, weed biomass was reduced but the relationship between biomass and seed production was similar to that of untreated plants although the magnitude of variation in biomass was less than that for untreated plants. Seed production of *A. cristata* plants with the same biomass was similar for plants surviving the application and untreated plants, and this was also observed for *Chenopodium album* L. (Rasmussen, 1993). A linear relationship between weed biomass and seed production was also observed in other studies (Thompson *et al.*, 1991; Wright, 1993). However, in a study with diclofop-methyl on *Avena fatua*, plants with the same biomass had higher reproductive output without, than with, application of the herbicide (Scursoni *et al.*, 1999).

Individual *A. cristata* dry weights at R5 ranged from 0.9 to 48.1 g $plant^{-1}$. Plants, as small as 0.9 g, produced at least two seeds. Seed weight of 1000 seeds for individual plants weighing from 4.6 g (SE ± 0.23) to 28.5 g (SE ± 0.31) was 12.3 g (SE ± 0.20) and 12.5 g (SE ± 0.14) respectively. Thus, *A. cristata* seed weight was independent of plant weight. These results concur with another study showing that most *Amaranthus retroflexus* L. plants of small size can produce seeds (Knezevic & Horak, 1998). A similar plasticity pattern in seed production was found in *Diplotaxis erucoides* (L.) DC. (Sans & Masalles, 1993).

The relationships between glyphosate rate and weed biomass (Fig. 2A) and seed production (Fig. 2B) fitted to a log-logistic model in wide rows. The glyphosate dose rates causing 50% reduction in biomass and seed production were 135.9 and 101.8 g a.e. ha^{-1} in 1997–98 and 133.4 and 138.5 g a.e. ha^{-1} in 1998–99. In contrast, in narrow rows, rates higher than 67.5 g a.e. ha^{-1} glyphosate provide complete weed control and, consequently, dose–response relationships could not be calculated. Glyphosate rates as low as 67.5 g a.e. ha^{-1} in narrow rows or 540 g a.e. ha^{-1} in wide rows provided excellent control of *A. cristata*. In another soyabean study planted in 76 cm rows, reduced rates of herbicides other than glyphosate did not reduce *A. theophrasti* biomass and seeds, as much as the recommended rate (Bussan *et al.*, 2001).

Before the appearance of glyphosate-resistant soyabean, *A. cristata* was difficult to control with the available herbicides (Mattioli, 1984). The results of this study show that control using glyphosate below the label-recommended rate is adequate to maintain reliable weed control and adequate soyabean growth when *A. cristata* densities are low or when soyabean are sown

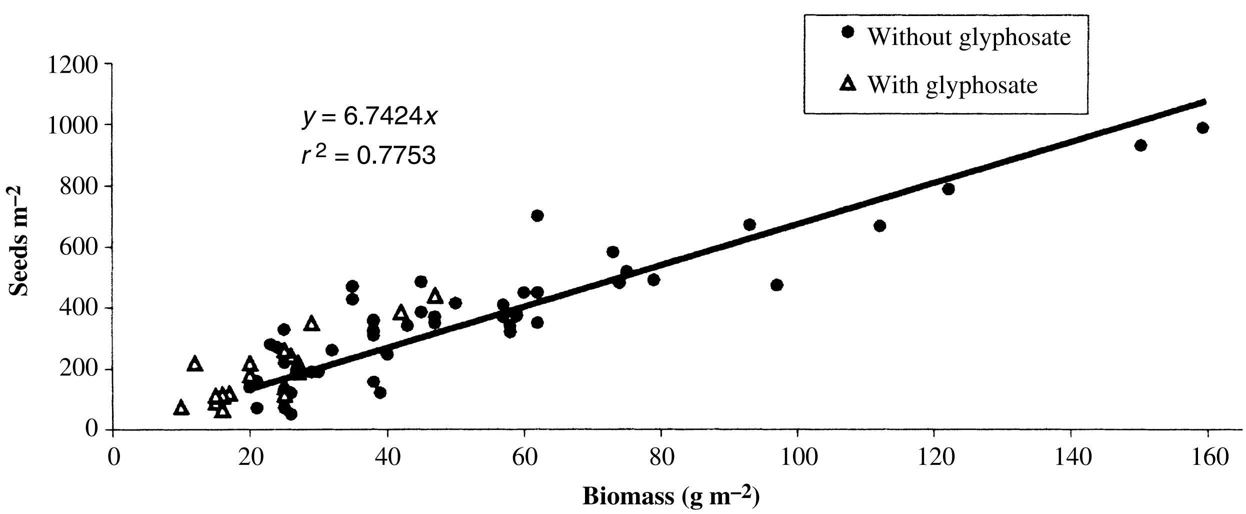

Fig. 1 Relationship between biomass and seed production of *A. cristata* per area in narrow and wide rows with 0 and 540 g a.e. ha^{-1} glyphosate. Symbols represent observed values.

Table 6 Parameter estimates of the regression analysis for predicting the relationship between *Anoda cristata* density and seeds per unit area in narrow- and wide-row soyabean, in wide row with the 540 g a.e. ha^{-1} glyphosate and in weed monoculture without glyphosate application; $S = ID/[1 + (ID/A)]$; where D is *A. cristata* density, S is seeds per unit area, I is the initial slope parameter and A is the asymptotic seed production per unit area at high *A. cristata* densities

Year		I (no. m^{-2})	A (no. m^{-2})	r^2
1997–98	Narrow row with no glyphosate	75.4 (8.7)	492.8 (22.1)	0.91
	Wide row with no glyphosate	166.3 (12.9)	851.4 (29.1)	0.96
	Wide row with 540 g a.e. ha^{-1} glyphosate	83.2 (9.1)	712.6 (26.7)	0.77
	Weed monoculture	178.2 (13.3)	951.2 (30.8)	0.95
1998–99	Narrow row with no glyphosate	158.3 (12.6)	790.5 (28.1)	0.96
	Wide row with no glyphosate	372.2 (19.3)	998.9 (31.6)	0.90
	Wide row with 540 g a.e. ha^{-1} glyphosate	95.9 (9.8)	789.2 (28.1)	0.77
	Weed monoculture	440.4 (20.9)	1007.6 (31.7)	0.83

Analyses performed on square-root transformed values for seed production shown in parentheses, alongside back-transformed mean.

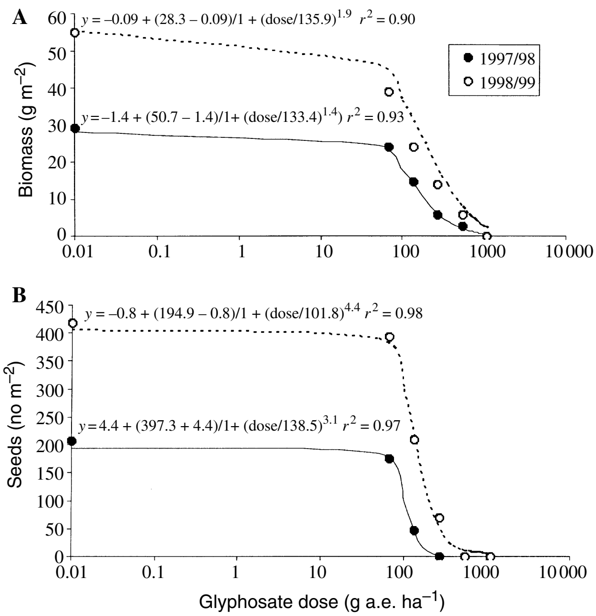

Fig. 2 Relationship between glyphosate dose rate and biomass (A) and seed production (B) of *Anoda cristata* in wide rows. Symbols represent mean values.

on narrow rows at a high density. In other studies it has been shown that, depending on weed spectrum and the degree of early season weed competition, control programmes with glyphosate alone are viable options in glyphosate-resistant soyabean (Corrigan & Harvey, 2000; Payne & Oliver, 2000).

It is evident from this study that *A. cristata* biomass production may be reduced through increased crop competitiveness by optimizing soyabean planting density and spatial arrangement to minimize seed production of *A. cristata* in soyabean crops when managed carefully.

Acknowledgement

The authors thank M. Sc. Alicia González for providing excellent statistical advice.

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