Demography of *Anoda cristata* in wide- and narrow-row soyabean

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Summary

The annual weed *Anoda cristata* is recognized as a problem of increasing importance in soyabean crops. As seeds are the only source for the renewal of *A. cristata* populations, knowledge of its seedbank characteristics and seed production is useful in improving weed management decisions. There is a lack of information about the effect of the planting pattern of soyabean on weed population dynamics. The effects of 70-cm and 35-cm soyabean row spacings on *A. cristata* seedbank, seedling recruitment and mortality, plant biomass, seed production and seed shed were determined. Soyabean density was higher in 35-cm row spacings as an increase in planting rate in narrow-row soyabean is recommended for producers in Argentina. The different planting patterns modified *A. cristata* demography through changes in plant biomass and, subsequently, in seed production. Seedling emergence, plant mortality and the pattern and duration of seed shed were similar in both planting patterns and thus independent of crop spatial arrangement and density. Increments in *A. cristata* seedbank can be reduced by planting soyabean at narrower row spacings and by bringing forward soyabean harvest. The first practice reduces *A. cristata* biomass and consequently seed production, and the second practice decreases the amount of seeds contributing to the soil seedbank.

Keywords: seedbank, emerged seedlings, seedling mortality, seed production.

Introduction

The annual weed *Anoda cristata* (L.) Schlecht is recognized as a weed problem of increasing importance in soyabean [*Glycine max* (L.) Merr.] crops in Argentina (Leiva & Ianone, 1994). Weed control should not rely solely on herbicides, and there is an increasing demand for non-chemical methods of weed control (Colbach & Debaeke, 1998). Management of *A. cristata* may improve with an understanding of the effect of cultural practices on the demography of weed population dynamics.

Quantitative studies of the population dynamics of the weed can help to identify changes in important weed life stages and may be useful in disrupting the life cycle at a particular point. As the seedbank is the only source for the renewal of *A. cristata* populations, knowledge of its characteristics is useful in improving weed management decisions (Buhler *et al.*, 1997). Models play a central role in the study of plant population dynamics and may help producers to manage weeds (Maxwell *et al.*, 1988) and to direct future experimental programmes (Cousens & Mortimer, 1995). A key component of these models is seedbank dynamics, including prediction of seedling emergence and the proportion of the seedbank that produces seedlings.

There is a good understanding of the demographic effects of practices such as tillage (Mohler, 1993) or cover crop (Moore *et al.*, 1994) on weed emergence in soyabean. A similar understanding of the effect of soyabean planting pattern is needed. In Argentina, soyabean is generally sown at 70 cm between rows; however, the use of narrow-row soyabean, with a 30% increase in planting rate, is increasing. Greater seeding rate in narrow-row soyabeans is also recommended in the USA, in both traditional cultivars (Nelson & Renner, 1998) and glyphosate-resistant cultivars (Nelson & Renner, 1999). Spatial arrangement between the crop and the weed has been shown to influence competitive relationships (Spitters & Van der Bergh, 1982) in terms of biomass, but information is lacking regarding the effect of planting pattern on weed seed production.

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The objectives of this paper were to determine *A. cristata* seedling recruitment and mortality, plant biomass, seed production and seed shed at crop harvest time in wide- and narrow-row soyabean.

Materials and methods

Experimental site

Experiments were conducted at the University of Rosario Experimental Farm (lat. 33°01′ S; long. 60°53′) in 1997, 1998 and 1999, on a vertic argiudol with a 0–2% slope, 3% organic matter, pH of 5.8 and 5% sand, 70% silt and 25% clay. During the 12 years before initiating this study, the site was disk-harrowed in the spring for soyabean planting. *Anoda cristata* plants had been observed since 1990. Daily rainfall at the site was obtained from a meteorological station located 200 m from the study site. Rainfall during the 3 years of this study was strikingly different although representative of the extremes experienced in the region (Table 1). There was sufficient moisture each year at planting date. Crop emergence was always at 7 days after planting (DAP).

Experimental procedures

Before planting, the field was disk-harrowed to a depth of 12 cm. The demography of *A. cristata* was assessed in 1997, 1998 and 1999 in two planting patterns: soyabean planted at 35 cm between rows (S35) and at 70 cm between rows (S70). Soyabean density was 371 800 plants ha^{-1} in S35 and 280 000 plants ha^{-1} in S70. Soyabean cv. Asgrow RR 640/600 was planted on 4 December 1997, and cv. Asgrow RR 6401 was planted on 23 November 1998 and 9 November 1999 in S35. Plot size was 4 m × 7 m, with three replicates of each of the two planting patterns. Both cultivars are glyphosate resistant and belong to maturity group VI. Planting was done with a Gherardi G100 grain drill and, in S70, with a Gherardi G95 planter. The soil was not fertilized, and there was no inter-row cultivation. Grass weeds were controlled with haloxyfop as 'Galant' (DowElanco) at 120 g a.i. kg^{-1}, and broad-leaved weeds, other than *A. cristata*, were hand weeded.

Table 1 Precipitation (mm) occurring from soyabean sowing to harvest at Zavalla in 1997/98, 1998/99 and 1999/2000

	Year		
DAP	1997/98	1998/99	1999/2000
0–7	6	22	0
8–14	86	15	2
15–35	208	97	55
36–42	30	5	13
43–70	223	134	66
71–126	269	204	175
127–150	47	97	85

Precipitation one month before sowing was 206 mm in 1997, 125 mm in 1998 and 47 mm in 1999.

Measurements

Photosynthetic photon flux (PPF) penetrating through the soyabean canopy was measured at midday beginning 30–40 DAP and continuing every 3 weeks until harvest by placing a bar and a LI-COR line quantum sensor (400–700 nm) (LI-191SA, Lincoln, NE, USA) across the centre plot rows within the S35 and S70 monocultures in three 1 m × 1 m quadrats in each of the row spacings. Percentage light interception was calculated by dividing the measurement made below the soyabean canopy at the soil level by ambient unshaded light.

Seedling emergence before soyabean planting was determined in 10 permanent 1 m × 1 m quadrats placed in the experimental site from early spring (15 September) to crop planting in 1999.

During the soyabean growing season, four 1 m × 1 m quadrats were randomly distributed in each plot and used during the growing season to assess *A. cristata* demography and plant biomass and seed production in 1998 and 1999. In two additional quadrats per plot, seed rain was monitored.

From planting until April (soyabean stage R8), eight recordings of the *A. cristata* populations were made in both row spacings. Individual weed plants were marked with wires of different colours to determine different cohorts and plant mortality in each recording date. Plant mortality on each recording date and each cohort was determined by counting the number of wires of each colour without plants or with dead plants. Average soyabean stages (Fehr & Cavinness, 1977) were determined at each recording date in five plants per plot. Soyabean was harvested in May every year.

Anoda cristata above-ground biomass was determined in 1998 and 1999 at the end of the growing season. In each of the four quadrats, all plants were cut at soil level, separated between cohorts and weighed after drying at 70 °C for 48 h.

Seed production was assessed by periodically collecting mature capsules and counting the seeds. In 1999, the weight of 100 seeds from each cohort was determined. Seed rain was monitored weekly in 1999 from the beginning (15 March) to the end (18 May) of the seed shedding period. Six 8 cm × 20 cm × 10 cm depth aluminium box seed traps were distributed at random within each quadrat. Boxes were taped to small stakes and driven into the soil. Small holes made in the bottom of the boxes allowed drainage of rainwater. On six assessment dates (approximately weekly), seeds were carefully separated from the traps and counted.

To study the seedbank, the experimental area was sampled systematically in 1997, 1998 and 1999. Twenty-eight soil cores per plot were taken with a 5.5-cm diameter soil probe to a depth of 15 cm. The sampling depth was chosen because the disk-harrow buries seed to ≈ 12 cm, and a previous study had shown that *A. cristata* seedlings do not emerge from depths greater than 12 cm (Solano *et al.*, 1976). The 28 samples from each plot were pooled, sieved through a 6-mm-mesh screen and the seeds were separated by hand and counted. To determine viability, seeds were cut and treated with 0.1% (wt/*V*) tetrazolium chloride. The seeds showing a pink to reddish colour after 24 h were considered viable.

Seedling recruitment was calculated as the proportion of the weed seedbank that emerged each year (Mortimer *et al.*, 1980).

Statistical analysis

For each year, PPF, number of *A. cristata* seeds in the seedbank at planting date, number of seedlings emerged during the growing season, recruitment, accumulated emergence during the growing season, mortality during the growing season, percentage mortality, biomass and number of seeds were analysed using a split-plot design, with the effect of year assessed at one level (against the year × replicate residual term) and the remaining main effects and interactions compared at the lower level using the residual mean square to produce an analysis of the effects of year, planting pattern and DAP or cohorts simultaneously. The analysis allows for a main effect of year and of replicates within year, and then for main effects of planting pattern and DAP or cohorts, together with interactions between pairs of treatments (year, planting pattern and DAP or cohorts) and the three-factor interaction. Before statistical analyses were done, weed seedling and seed numbers were square root transformed, recruitment was angle transformed, biomass was natural log transformed and the constant added was 0.375, and plant mortality in percentage was logit transformed to stabilize variances.

Accumulated seed rain and accumulated seed rain after first seed rain (15 March)/total seed production in both planting patterns were compared using a *t*-test.

Results

PPF penetrating through the soyabean canopy

PPF penetrating through the soyabean canopy was lower in the S35 plots relative to the S70 plots from ≈ 30 DAP until canopy closure (Table 2). No differences were detected beyond the canopy closure stage.

Seedbank, seedling emergence, recruitment and mortality

Seedling emergence from early spring (15 September) to soyabean planting was 2.3 plants m^{-2} in 1999. Seedbank density, seedling emergence and seedling recruitment were similar for both row spacings during 1997, 1998 and 1999 (Table 3). Seedling recruitment was similar between years and ranged between 8.5% and 14.7%. Viability of the seeds exhumed from the seedbank each year was virtually 100% (data not presented). Three different cohorts of *A. cristata* were identified each year. The first cohort included the seedlings that emerged during the first 21 DAP, the second from 22 DAP to 42 DAP and the third from 42 DAP to 150 DAP. Emergence was not affected by the planting pattern each year (Table 4), but occurred later in the growing season in 1999 relative to 1997 and 1998.

Mortality was also independent of the planting pattern and was lower in 1997 and 1998 relative to 1999 (Table 5). In all years, mortality was high for the third cohort but, in 1999, it was also high for the first cohort (Table 6). No mortality was observed before 35 DAP. Two mortality events were observed in 1997 and 1998, whereas in 1999, mortality occurred almost throughout the whole growing season.

Table 2 Percentage photosynthetic photon flux (PPF) penetrating through soyabean canopy in S35 and S70 during soyabean growing season in 1997, 1998 and 1999

DAP	Soyabean stage	1997 S35	1997 S70	1998 S35	1998 S70	1999 S35	1999 S70
25–30	V4	28 (32)	52 (46)	35 (36)	60 (51)	40 (39)	75 (60)
50–55	R1	19 (26)	31 (34)	32 (34)	45 (42)	32 (34)	55 (48)
80–90	R5	3 (10)	5 (13)	7 (15)	11 (19)	21 (27)	49 (44)
100–110	R6	2 (8)	3 (10)	5 (13)	5 (13)	8 (16)	12 (20)
120–130	R8	0 (0)	0 (0)	2 (8)	3 (10)	2 (8)	8 (16)

Analyses performed on angle-transformed values shown in parentheses alongside back-transformed means.
SED (54 d.f., for comparison of treatment means within a year) = 2.3.
SED (54 d.f., for comparison of treatment means between years) = 4.3.

Table 3 Number of *A. cristata* seeds m^{-2} in the seedbank at planting date, total number of seedlings m^{-2} emerged during the growing season and percentage recruitment

	Seedbank		Emerged seedlings		Recruitment (emerged seedlings/seedbank × 100)	
Year	S35	S70	S35	S70	S35	S70
1997	224 (14.9)	221 (14.8)	19 (4.4)	20 (4.5)	8 (16.9)	9 (17.5)
1998	157 (12.5)	164 (12.8)	19 (4.4)	17 (4.1)	12 (20.3)	10 (18.6)
1999	163 (12.8)	154 (12.4)	22 (4.7)	23 (4.8)	13 (21.3)	15 (22.5)

Analyses performed on square root-transformed values shown in parentheses alongside back-transformed means for number of seeds and seedlings. Analyses performed on angle-transformed values shown in parentheses alongside back-transformed means for percentage recruitment.
Seedbank
SED (6 d.f., for comparison within a year) = 0.72.
SED (6 d.f., for comparison between years) = 1.09.
Emerged seedlings
SED (6 d.f., for comparison within a year) = 0.19.
SED (6 d.f., for comparison between years) = 1.11.
Recruitment
SED (6 d.f., for comparison within a year) = 0.43.
SED (6 d.f., for comparison between years) = 2.03.

Table 4 *Anoda cristata* emergence in the different cohorts during the soyabean growing season in S35 and S70 in 1997, 1998 and 1999

	Emergence (plants m^{-2})					
	1997		1998		1999	
Cohort	S35	S70	S35	S70	S35	S70
1	5.1 (2.3)	5.4 (2.3)	5.8 (2.4)	6.1 (2.5)	3.7 (1.9)	3.1 (1.8)
2	8.2 (2.9)	6.8 (2.6)	8.9 (3.0)	8.5 (2.9)	0.9 (0.9)	0.0 (0.0)
3	5.5 (2.3)	7.4 (2.7)	3.9 (2.0)	2.4 (1.5)	17.3 (4.2)	19.2 (4.4)

Analyses performed on square root-transformed value, shown in parentheses, alongside back-transformed means.
The first cohort included the seedlings that emerged during the first 21 DAP, the second from 22 DAP to 42 DAP and the third from 42 DAP to 150 DAP.
No *A. cristata* seedlings were observed before 7 DAP in 1997 and 1998 and before 21 DAP in 1999.
SED (30 d.f., for comparison within a year) = 0.31.
SED (30 d.f., for comparison between years) = 0.99.

Table 5 *Anoda cristata* mortality in the different cohorts during the soyabean growing season in S35 and S70 in 1997, 1998 and 1999

	Mortality (plants m^{-2})					
	1997		1998		1999	
Cohort	S35	S70	S35	S70	S35	S70
1	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	2.8 (0.0)	2.1 (0.0)
2	0.2 (0.4)	0.4 (0.6)	1.1 (1.0)	2.2 (1.5)	0.1 (0.3)	0.0 (0.0)
3	2.8 (1.6)	3.0 (1.7)	2.3 (1.5)	2.4 (1.5)	12.3 (3.5)	12.0 (3.5)
Total	3.0 (1.7)	3.4 (1.8)	3.4 (1.8)	4.6 (2.1)	15.2 (3.9)	14.1 (3.7)

Analyses performed on square root-transformed value, shown in parentheses, alongside back-transformed means.
The first cohort included the seedlings that emerged during the first 21 DAP, the second from 22 DAP to 42 DAP and the third from 42 DAP to 150 DAP.
No mortality occurred before 35 DAP.
SED (30 d.f., for comparison within a year) = 0.22.
SED (30 d.f., for comparison between years) = 0.27.
SED (6 d.f., for comparison of total mortality means between years) = 0.44.

Table 6 Percentage mortality of *Anoda cristata* for each cohort in S35 and S70 in 1997, 1998 and 1999

Cohort	1997 S35	1997 S70	1998 S35	1998 S70	1999 S35	1999 S70
1	0.0 (−2.41)	0.0 (−2.47)	0.0 (−2.53)	0.0 (−2.57)	74.3 (0.88)	65.5 (0.56)
2	2.4 (−2.49)	2.9 (−2.32)	13.8 (−1.65)	26.5 (−0.82)	11.1 (−0.77)	47.0 (−0.00)
3	52.0 (0.03)	44.4 (−0.32)	54.1 (0.31)	95.2 (1.36)	70.0 (0.85)	65.6 (0.67)

Analyses performed on logit-transformed values shown in parentheses alongside back-transformed means.
The first cohort included the seedlings that emerged during the first 21 DAP, the second from 22 DAP to 42 DAP and the third from 42 to 150 DAP.
SED (30 d.f., for comparison within a year) = 0.06.
SED (30 d.f., for comparison within a year) = 0.06.

Table 7 *Anoda cristata* biomass (g m^{-2}) and seed production (no. m^{-2}) in the different cohorts at the end of the growing season in S35 and S70 in 1998 and 1999

	Biomass				Seed production			
	1998		1999		1998		1999	
Cohort	S35	S70	S35	S70	S35	S70	S35	S70
1	13 (2.6)	80 (4.4)	8 (2.1)	14 (2.7)	106 (10.3)	487 (22.1)	57 (7.5)	120 (11.0)
2	12 (2.5)	41 (3.7)	12 (2.5)	62 (4.1)	110 (10.5)	344 (18.5)	120 (11.0)	502 (22.4)
3	4 (1.5)	2 (0.9)	0 (−1.0)	0 (−1.0)	17 (4.1)	12 (3.5)	0 (0.0)	0 (0.0)

Analyses performed on log-transformed values for biomass and on square root-transformed values for seed production shown in parentheses alongside back-transformed means.
The first cohort included the seedlings that emerged during the first 21 DAP, the second from 22 to 42 DAP and the third from 42 to 150 DAP.
SED (20 d.f., for comparison of biomass means within a year) = 0.48.
SED (20 d.f., for comparison of biomass means between years) = 1.55.
SED (20 d.f., for comparison of seed production means within a year) = 0.63.
SED (20 d.f., for comparison of seed production between years) = 1.02.

Biomass and seed production

Weed biomass and seed production per unit area were lower on the S35 plots relative to the S70 plots for each cohort (Table 7). Weed biomass decreased progressively from the first to the third cohort in 1998 but, in 1999, the second cohort produced the highest biomass and greatest number of seeds, whereas the third cohort produced no seeds. No differences were detected in seed weight between cohorts and between planting patterns (data not presented).

Seed rain

Accumulated number of seeds shed per unit area was fourfold higher on the S70 plots compared with the S35 plots, but phenology of seed shed was similar in both planting patterns (Fig. 1). Seed shed began in mid-March and continued for ≈65 days in both planting patterns.

Discussion

The *Anoda cristata* seedbank had an average of 173 seeds m^{-2} for the three years of the study. This value is low compared with a previous study made with individual plants of *A. cristata* (Van Gessel *et al.*, 1998). This may result from lower biomass and seed production per plant in Argentina compared with the United States. Evidence of such biological differences pertaining to germination rates, growth rates and morphology among weed populations has been documented previously (Van Gessel *et al.*, 1998).

Anoda cristata is a hard-seeded species and may require high levels of moisture for germination (Forcella *et al.*, 1997). Variation in the seedling emergence pattern

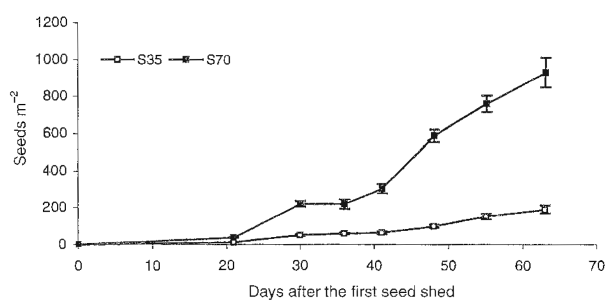

Fig. 1 Accumulated number of seeds shed per unit area in S35 and S70. Bars represent standard errors.

observed in 1997 and 1998 vs. 1999 may be because of different levels of rainfall in each year which modify seed germination. This is supported by observations made in other annual weeds (Stoller & Wax, 1973). Emergence occurred primarily in the first part of the growing season in the humid years (1997 and 1998) in both planting patterns. Rainfall before planting was high enough to explain the differences in the initial amount of emergence of *A. cristata* in soyabean. In the dry year (1999), there was a period of rainfall after planting, which may be associated with the highest emergence flushes. The high rainfall at the end of the growing season did not influence emergence because low temperatures at this time reduced weed germination remarkably (Solano *et al.*, 1976). In the present study, moisture conditions for most of the germinating seeds were satisfied later in the dry than in the humid years. Seasonal variations in the amount of rainfall have also been shown to influence seedling emergence in other species (Stoller & Wax, 1973; Mulugeta & Stoltenberg, 1997).

Anoda cristata seedling emergence was unaffected by the planting pattern. Absence of light requirements for germination in *A. cristata* (Solano *et al.*, 1976) may partially explain this behaviour. Seeds of most species germinate better in light than in darkness (Andersson *et al.*, 1997). The reduction in emergence of *Aegilops cylindrica* Host by higher crop density (Anderson, 1998) and of *Chenopodium album* L. by planting in narrow-row soyabean (Nelson & Renner, 1998) has been attributed to lower solar radiation reaching the soil surface, given that both species are light sensitive. Soil moisture and soil temperature were not measured in the present study, but it was likely that there were no significant differences between planting systems in these critical factors for germination.

Anoda cristata recruitment was relatively stable over the three years of the study and ranged between 8.5% and 14.7% in both planting systems, indicating that it is possible to predict overall emergence of *A. cristata* from the amount of seeds in the seedbank at planting. In most weed species, variability has been reported between seedbank and seedling populations (Ball & Miller, 1989; Forcella *et al.*, 1997). This variability may be caused by a number of factors, for example seedbank sampling size, sample timing and different recruitment patterns in the greenhouse vs. the field (Derksen & Watson, 1998). However, in *Abutilon theophrasti* Medikus, a species with similar characteristics to *A. cristata*, the proportion of seedlings that emerged was also found to be constant (≈ 7%) across cropping systems (Lindquist *et al.*, 1995).

Another biological component required to model seedbank dynamics is an estimate of seedling mortality. Annual mortality in *A. cristata* was similar in both planting patterns, as weeds were able to survive under dense canopies, although their growth rate was much lower under shaded conditions. It was determined that plants with a dry weight of 1 g not only survived, but most of them also produced seeds. However, in barley, mortality in *Avena fatua* L. was greater with increased sowing rate, which promoted the development of a rapid and lasting canopy (Scursoni *et al.*, 1999). High mortality of the first cohort occurred only in 1999 and can be associated with the low precipitation at the beginning of the growing season. Delayed emergence relative to soyabean increased mortality and, in all years, mortality was very high for seedlings emerging in the last cohort. The high percentage of seedling survival from early cohorts during humid years in both planting patterns ensured a high seed return to the seedbank. These results suggest that control measures should be directed to the elimination of these early cohorts. In addition, it has been shown that yield loss in soyabean is also greatest from the early weed cohorts (Dieleman *et al.*, 1996; Cowan *et al.*, 1998), and losses from weed species that emerge after 4–6 weeks (third cohort in the present study) do not reduce crop yield significantly (Zimdahl, 1988).

The different planting patterns modified *A. cristata* demography through changes in plant biomass and, consequently, in seed production. The higher density and narrower row spacing of S35 relative to S70 resulted in a reduction in the number of seeds produced in S35. This reduction may have been because of competition for light, as was observed in studies with other annual weeds (Benvenuti *et al.*, 1994; Lindquist *et al.*, 1995). Reduction in light penetrating through the soyabean canopy at the time of emergence of the third cohort may also account for the low biomass of that cohort. In contrast, the lower biomass of the plants in the first cohort, especially in the dry year, may have been due to competition for water.

Anoda cristata is the most morphologically variable species within the *Anoda* genus (Bates, 1987), and seed weight is lower in most populations in the United States (Van Gessel *et al.*, 1998) compared with the present study in Argentina. However, within the study population, seed weight was a conservative trait and did not differ between cohorts and planting patterns. Seed weight has also been shown not to be significantly affected as a result of shading in *A. theophrasti* (Benvenuti *et al.*, 1994).

Delaying soyabean planting could reduce weed populations and improve weed control (Buhler & Gunsolus, 1996), as tillage can be used to destroy weed seedlings before planting (Ogg & Dawson, 1984). However, emergence of *A. cristata* before normal soyabean planting date was only ≈10% of total seedling emergence during the soyabean growing season and so only a small proportion of the population would be killed during soil preparation. Furthermore, even small delays in soyabean planting are associated with reduction in yields (Sinclair *et al.*, 1992).

The proportion of *A. cristata* seeds that reach the soil is largely determined by harvest timing. *Anoda cristata* has relatively large seeds that are elevated to the tank of the combine. Afterwards, the seeds are separated from the grain and do not return to the field. This practice prevents the shedding of many maturing seeds. Regressions of accumulated seed shedding at days after the date of first seed shedding may help to determine the optimal date to harvest soyabean and optimize weed control. Had the soyabean been harvested in late April in the present experiment, only 30–40% of total seed production would have reached the ground. This percentage may be reduced further by harvesting as soon as leaf senescence occurs (soyabean stage R8) and grain moisture is ≈14% to avoid mechanical damage during the harvesting process (Tekrony *et al.*, 1980). Most soyabean cultivars have not reached maturity until early April and so harvesting cannot be done before this date. Furthermore, it should be noted that harvesting machines are variable in their efficiency of capture of weed seeds (Ballaré *et al.*, 1987).

From this study, it can be concluded that increments in the *A. cristata* seedbank can be severely reduced by two management practices: first, by planting soyabean at narrower row spacings and higher density; secondly, by bringing forward soyabean harvest as much as possible. The first practice reduces *A. cristata* biomass and consequently seed production, and the second practice decreases the amount of seeds reaching the soil. It is also important to target control at the earlier emerging cohorts, particularly during years of high rainfall.

References

Anderson RL (1998) Seedling emergence of winter annual grasses as affected by limited tillage and crop canopy. *Weed Technology* **12,** 262–267.

Andersson L, Milberg P & Noronha A (1997) Germination response of weed seeds to light, light of short duration and darkness after stratification in soil. *Swedish Journal of Agriculture* **27,** 113–120.

Ball DA & Miller SD (1989) A comparison of techniques for estimation of arable soil seedbanks and their relationship to weed flora. *Weed Research* **29,** 365–373.

Ballaré CL, Scopel AL, Ghersa CM & Sánchez RA (1987) The demography of *Datura ferox* (L.) in soybean crops. *Weed Research* **27,** 91–102.

Bates DM (1987) Chromosome numbers and evolution of *Anoda* and *Periptera* (Malvaceae). *Aliso* **11,** 523–553.

Benvenuti S, Macchia M & Stefani A (1994) Effects of shade on reproduction and some morphological characteristics of *Abutilon theophrasti* Medicus, *Datura stramonium* L. and *Sorghum halepense* (L.) Pers. *Weed Research* **34,** 283–288.

Buhler DD & Gunsolus JL (1996) Effect of date of preplant tillage and planting on weed populations and mechanical weed control in soybean (*Glycine max*). *Weed Science* **44,** 373–379.

Buhler DD, Hartzler RG & Forcella F (1997) Implications of weed seedbank dynamics to weed management. *Weed Science* **45,** 329–336.

Colbach N & Debaeke P (1998) Integrating crop management and crop rotation into models of weed populations dynamics: a review. *Weed Science* **46,** 717–728.

Cousens R & Mortimer M (1995) The intrinsic dynamics of population density. In: *Dynamics of Weed Populations*, 135–168. Cambridge University Press, Cambridge, UK.

Cowan P, Weaver SE & Swanton CJ (1998) Interference between pigweed (*Amaranthus* spp.), barnyardgrass (*Echinochloa crus-galli*), and soybean (*Glycine max*). *Weed Science* **46,** 533–539.

Derksen DA & Watson PR (1998) Weed community composition in seedbanks, seedlings, and mature plant communities in a multi-year trial in western Canada. *Aspects of Applied Biology* **51,** 43–50.

Dieleman A, Hamill AS, Fox GC & Swanton CJ (1996) Decision rules for postemergence control of pigweed (*Amaranthus* spp.) interference in soybean (*Glycine max*). *Weed Science* **44,** 126–132.

Fehr W & Cavinness C (1977) *Stage of Soybean Development*. Special Report 80. Iowa State University, Ames, IA, USA.

Forcella F, Wilson RG, Dekker J *et al.* (1997) Weed seed bank emergence across the corn belt. *Weed Science* **45,** 67–76.

Leiva P & Ianone N (1994) *Soja: El Problema de las Malezas y su Control. Segunda Parte. Presencia y Evolución de las Principales Especies.* Información no. 119. Carpeta de Producción Vegetal, Area de Agronomía, EEA Pergamino.

Lindquist JL, Maxwell BD, Buhler DD & Gunsolus JL (1995) Velvetleaf (*Abutilon theophrasti*) recruitment, survival, seed production, and interference in soybean (*Glycine max*). *Weed Science* **43,** 226–232.

Maxwell BD, Wilson MV & Radosevich SR (1988) Population modeling approach for evaluating leafy spurge (*Euphorbia esula*) development and control. *Weed Technology* **2,** 132–138.

Mohler CL (1993) A model of the effects on tillage of emergence of weed seedlings. *Ecology Applied* **3,** 53–73.

Moore MJ, Gillespie TJ & Swanton CJ (1994) Effect of cover crop mulches on weed emergence, weed biomass and soybean (*Glycine max*) development. *Weed Technology* **8,** 512–518.

Mortimer AM, McMahon DJ, Manlove RJ & Putwain PD (1980) The prediction of weed infestations and cost of differing control strategies. In: *Proceedings 1980 British Weed Control Conference – Weeds*, Brighton, UK, 415–422.

Mulugeta D & Stoltenberg DE (1997) Seed bank characterization and emergence of a weed community in a moldboard plow system. *Weed Science* **45,** 54–60.

Nelson KA & Renner KA (1998) Weed control in wide- and narrow-row soybean (*Glycine max*) with imazamox, imazetaphyr, and CGA-277476 plus quizalofop. *Weed Technology* **12,** 137–144.

NELSON KA & RENNER KA (1999) Weed management in wide- and narrow-row glyphosate resistant soybean. *Journal of Production Agriculture* **12,** 460–465.

OGG AG Jr & DAWSON JH (1984) Time of emergence of eight weed species. *Weed Science* **32,** 327–335.

SCURSONI J, BENECH-ARNOLD R & HIRCHOREN H (1999) Demography of wild oat in barley crops: effect of crop, sowing rate, and herbicide treatment. *Agronomy Journal* **91,** 478–485.

SINCLAIR TR, SALADO-NAVARRO L, MORANDI EN & MARTIGNONE RA (1992) Soybean yield in Argentina in response to weather variation among cropping seasons. *Field Crop Research* **30,** 1–11.

SOLANO F, SCHRADER JW & COBLE HD (1976) Germination, growth, and development of spurred anoda. *Weed Science* **24,** 574–578.

SPITTERS CJT & VAN DER BERGH JP (1982) Competition between crop and weeds: a system approach. In: *Biology and Ecology of Weeds* (eds M Holzner & W Numata), 137–148. Junk Publishers, The Hague, The Netherlands.

STOLLER EW & WAX LM (1973) Periodicity of germination and emergence of some annual weeds. *Weed Science* **21,** 574–580.

TEKRONY DM, EGLI DB, BALLES J, PFEIFFER T & FELLOWS RJ (1980) Physiological maturity in soybeans. *Agronomy Journal* **71,** 771–775.

VAN GESSEL MJ, SCHROEDER J & WESTRA P (1998) Comparative growth and development of four spurred anoda (*Anoda cristata*) accessions. *Weed Science* **46,** 91–98.

ZIMDAHL RL (1988) The concept and application of the critical weed-free period. In: *Weed Management in Agroecosystems: Ecological Approaches* (eds MA Altieri & M Liebman), 145–155. CRC Press, Boca Raton, FL, USA.