Interference between maize and *Xanthium strumarium* or *Datura stramonium*

H KARIMMOJENI*†, H RAHIMIAN MASHHADI*, H M ALIZADEH*, R D COUSENS‡ & M BEHESHTIAN MESGARAN*

*Department of Agronomy and Plant Breeding, University of Tehran, Karaj, Iran; † Department of Agronomy and Plant Breeding, College of Agriculture, Isfahan University of Technology, Isfahan, Iran, and ‡Department of Resource Management and Geography, The University of Melbourne, Burnley Campus, Richmond, Victoria, Australia

Summary

Xanthium strumarium and *Datura stramonium* are two of the most important weeds of maize in Iran. Their growth was compared in a field study conducted over 2 years. Relationships were derived between weed density and crop yield, yield components and various growth parameters. Yield, grain number ear^{-1} and grain weight were affected more by *X. strumarium* than by *D. stramonium*. *Xanthium strumarium* followed a pattern of growth resembling that of the maize, whereas *D. stramonium* continued growing for a longer period, mainly affecting maize during the grain-filling period. A large portion of the loss in maize yield caused by *X. strumarium* could be explained by a reduction in grain number ear^{-1}, whereas a greater portion of the maize yield loss from *D. stramonium* was explained by a reduction in grain weight. Weed biomass was greater for *X. strumarium* than for *D. stramonium*, whereas seed production was higher for *D. stramonium*. It is concluded that although *X. strumarium* should be given the highest priority for control in maize on the basis of its superior competitive ability, control of *D. stramonium* is also essential because of both its considerable competitiveness in the current crop and its long-term effects resulting from its greater seed production.

Keywords: Cocklebur, thorn-apple, jimson weed, *Zea mays*, competition, growth, seed production.

Introduction

Maize (*Zea mays* L.) is an important cash crop in Iran, occupying 210 000 ha and yielding approximately 1.6 million tonnes of grain per year (FAOSTAT, 2007). Other than environmental variables, the most important constraint to maize yield is competition from weeds (Rajcan & Swanton, 2001). Two of the weeds with the greatest effects on maize yield in Iran are *Xanthium strumarium* L. (rough or common cocklebur) and *Datura stramonium* L. (thorn-apple or jimson weed) (Shimi & Termeh, 2004).

Xanthium strumarium (Asteraceae) originated in central or South America and now is widespread throughout North America, Europe, Asia, Africa and parts of Australia (Wesley *et al.*, 1989). It produces a fruit that is a hard, woody bur containing two seeds. One of the seeds is usually non-dormant, whereas the second may not germinate until the next year or even later (Esashi *et al.*, 1983). *D. stramonium* is a widespread summer weed of the Solanaceae, originating from America. It also occurs in most of the world's cropping regions (Holm *et al.*, 1997). It has a capsule containing 200–300 seeds and there may be 100 or more capsules per

plant (Scott *et al.*, 2000). Seeds are dormant at maturity (Reisman *et al.*, 1989) and they may remain viable for 39 years in the soil (Weaver & Warwick, 1984).

Xanthium strumarium and *D. stramonium* are highly competitive because of their rapid growth, leading to high water, light and nutrient requirements (Stoller & Woolley, 1985; Wesley *et al.*, 1989; Cavero *et al.*, 1999). They emerge at the same time as maize, grow together and attain similar heights at maturity. Their maximum heights of 1.6–2 m allow them to compete effectively with maize for light. *X. strumarium* has been studied extensively in soyabean (*Glycine max* (L.) Merr.), cotton (*Gossypium hirsutum* L.) (Buchanan & Burns, 1971; Barrentine, 1974) and maize (Beckett *et al.*, 1988). Klingman and Oliver (1994) stated that *X. strumarium* was the most competitive annual weed in North American soyabean production. Interference from *D. stramonium* has been investigated in maize (Beckett *et al.*, 1988; Zanin *et al.*, 1994; Cavero *et al.*, 1999), soyabean (Hagood *et al.*, 1981; Regnier & Stoller, 1989; Henry & Bauman, 1991) and cotton (Byrd & Coble, 1991a; Scott *et al.*, 2000).

When grown at the same density, competitive abilities vary among species. These differences may result, in part, from contrasting patterns of growth and development, weed and crop emergence dynamics and climatic conditions (Harker *et al.*, 2007). In maize crops, some of the most damaging weeds, such as *Ipomoea* spp. (morning glories), *Amaranthus* spp. (pigweeds) and *D. stramonium*, develop late in the growing season. Although early weed growth is crucial in establishing competitive hierarchies of crop and weeds, much of the direct effect on crop yield results from weed growth late in the season (Horvath *et al.*, 2006). To improve our ability to predict the consequences of weed interference on maize, further research is needed on contrasting patterns of weed growth and development.

Despite the fact that *X. strumarium* and *D. stramonium* are the most troublesome weeds in maize, there is only one direct comparative study of the two weeds in this crop (Beckett *et al.*, 1988). Moreover, the majority of studies record only yield and biomass at crop maturity. Therefore, the objectives of the study were to examine the dynamics of growth in mixtures of these species in an Iranian cropping system and to use the data to interpret differences in maize yield losses and yield components resulting from interference from these two weeds.

Materials and methods

A field experiment was conducted in 2006 and repeated in 2007 at the research farm of the College of Agriculture, University of Tehran, Karaj, Iran. The soil type was a loam (pH 5.7 and 0.61% organic matter in 2006

and 1.67% organic matter in 2007). Air temperatures for each year are shown in Table 1. Tillage in both years consisted of autumn mouldboard ploughing to a depth of 20–25 cm, followed by spring disking and harrowing. The experimental site was in fallow for the preceding year of study. Maize (hybrid S.C.704) was planted on 5 May 2006 and 2007 at 6.06 plants m^{-2} with 75 cm between rows and 22 cm between plants within a row. Plots consisted of four rows, 10 m in length. Weed seeds were collected from Karaj maize fields in the year prior to sowing and stored in a cold room at 5°C (± 2) until sowing. They were hand-sown simultaneously with maize on both sides of the crop rows, at a distance of 15 cm from the crop.

The soil was fertilised at planting, at rates of 250 kg ha^{-1} diammonium phosphate (18–46–0 N–P–K) and 150 kg ha^{-1} urea. Additional nitrogen (200 kg ha^{-1} urea) was added to plots through irrigation water at the 6–8 leaf stage of the maize. Chlorpyrifos [1.5 L ha^{-1} as (Dursban EC®; Ghazal chemistry, Babol, Iran, http://www.ghazalshimi.com), 40.8% active ingredient; Dow AgroSciences] was applied twice during the early season to protect maize and weeds against *Agrotis* sp. Plots were furrow irrigated immediately after planting to ensure uniform germination. Irrigation was carried out at 1-week intervals until crop maturity, so that water was not limiting for growth.

Xanthium strumarium or *D. stramonium* were planted at densities of 0, 4, 8, 12 and 16 plants m^{-2}. The experimental design was a randomised complete block with nine treatments and three replicates. In both years, maize and *X. strumarium* emerged together, whereas *D. stramonium* emerged about 3 days later than the other two species. Maize and weed seedlings were thinned to the target densities at their 2–4 leaf stages. All other weeds were removed by hand frequently throughout the growing season.

Biomass and height data were collected 5 weeks after planting (WAP) and again every 15–30 days during the growing season. At each sampling date, four consecutive weed plants (*X. strumarium* or *D. stramonium*) and maize plants from the two middle rows of the plots were cut at ground level. Plants were then divided into leaf,

Table 1 Average monthly air temperatures (°C) during the maize growing season in 2006 and 2007

Month	Mean		Maximum		Minimum	
	2006	2007	2006	2007	2006	2007
May	20.8	20.3	28.3	27.5	13.4	13.0
June	27.0	24.3	35.3	33.5	18.7	16.1
July	27.2	27.0	35.8	34.9	18.5	18.7
August	28.3	27.3	35.7	34.9	20.9	19.8
September	23.1	23.7	30.5	31.4	15.7	16.1

stem and reproductive parts (ear and tassel in corn; flower and fruit in the weeds). The areas of green leaves were measured using a Delta-T leaf area meter (Delta-T Devices, Cambridge, England). All plant parts were oven-dried at 80°C for 48–72 h until a constant weight was reached. Leaf area index (LAI) and crop growth rate (CGR) were calculated according to Hunt (1990):

$$LAI = LA/GA \qquad (1)$$

$$CGR = (W_2 - W_1)/[GA(T_2 - T_1)] \qquad (2)$$

where LA is leaf area, GA is ground area, W_1 is dry weight per plant at a given sampling date, W_2 is dry weight at the next consecutive sampling date, and T_2–T_1 is the number of days between the two sampling dates. Although CGR implies that the focus of study is the crop, the same equation can be applied to the weeds; for consistency with the established literature, we will use the term 'CGR' for all species.
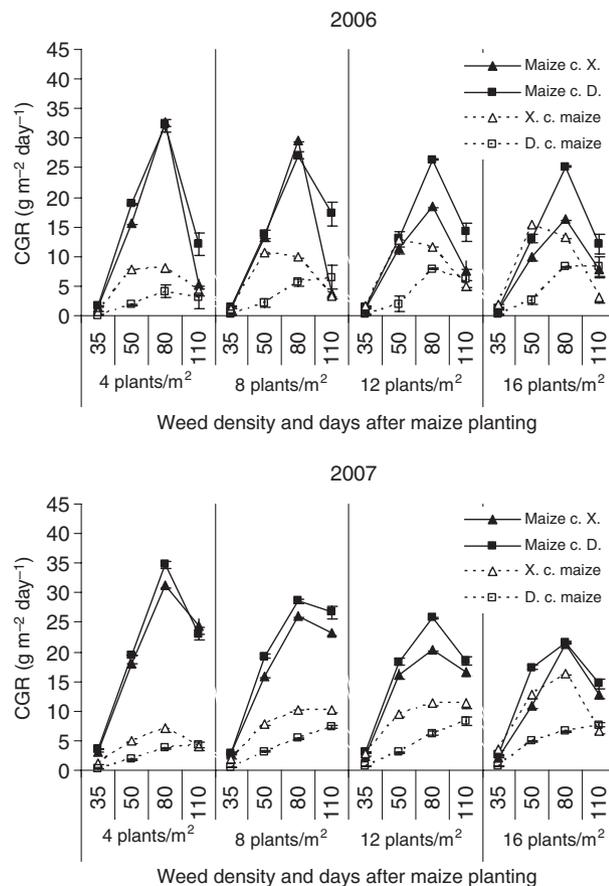
At the end of the experiment, 12 consecutive maize plants and the weeds associated with them were hand-harvested from the last 2 m of each plot, oven-dried at 80°C for 72 h and then weighed. The number of maize ears per plant, the numbers of grains per ear, 100-grain weight and grain yield were measured. For *X. strumarium*, the number of burs per plant and 100-bur weights were recorded, whereas for *D. stramonium* the number of seeds per plant and the 100-seed weight were measured.

Data on plant growth parameters were subjected to ANOVA. Means were examined separately for each year, using the least significant difference, because the interaction of year by sampling times was significant ($P < 0.05$). Linear and non-linear regressions were used to describe the relationships between *X. strumarium* or *D. stramonium* density, weed seed and biomass production and maize yield and yield components (Sigmaplot® version 10.0: Sigmaplot, 2004). Where the relationships were clearly curvilinear, a hyperbolic model (Cousens, 1985) was fitted:

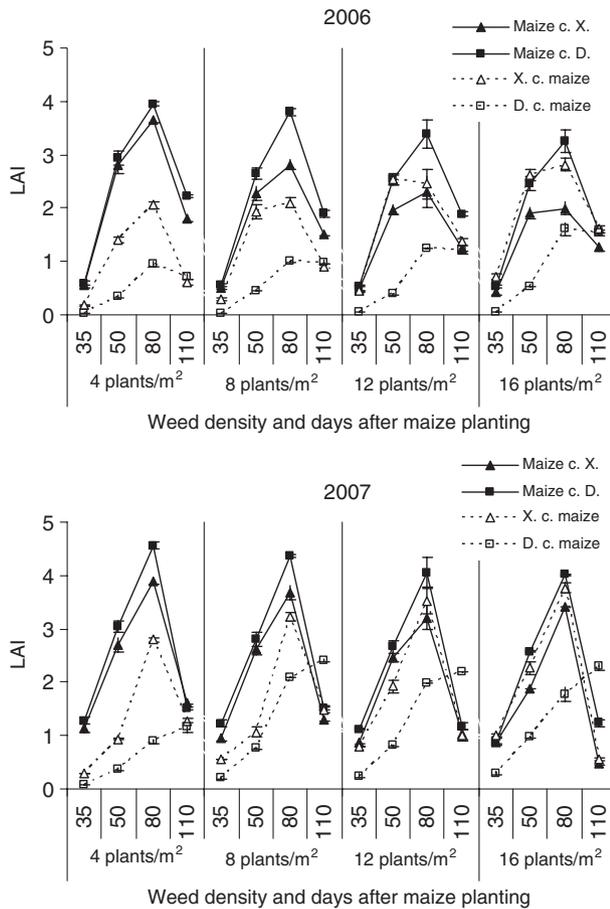$$Y = Y_{WF}\left[1 - \frac{ID}{100(1 + ID/A)}\right] \qquad (3)$$

where Y is yield (or some other crop quantity) per unit area, Y_{WF} is the estimated weed-free yield, D is weed density, I is % yield loss per weed plant m^{-2} as density approaches zero, and A is % yield loss as density approaches infinity. Curves were compared using parallel curve analysis and appropriate F-tests (Maximum Likelihood Program: Ross, 1987).

Results

Weed and crop growth

With a few minor exceptions, maize CGR and LAI were greater than those of the weeds at all densities during both growing seasons. *D. stramonium* CGR and LAI values were the lowest, but increased considerably late in the season (Figs 1 and 2). It reached its maximum CGR and LAI at the later stages of growth [110 days after planting (DAP)] in both years, whereas the highest CGR and LAI for *X. strumarium* and maize were obtained earlier in the season. Maize and *X. strumarium* CGR decreased late in the season. However, that of *D. stramonium* remained constant or increased (Fig. 1).
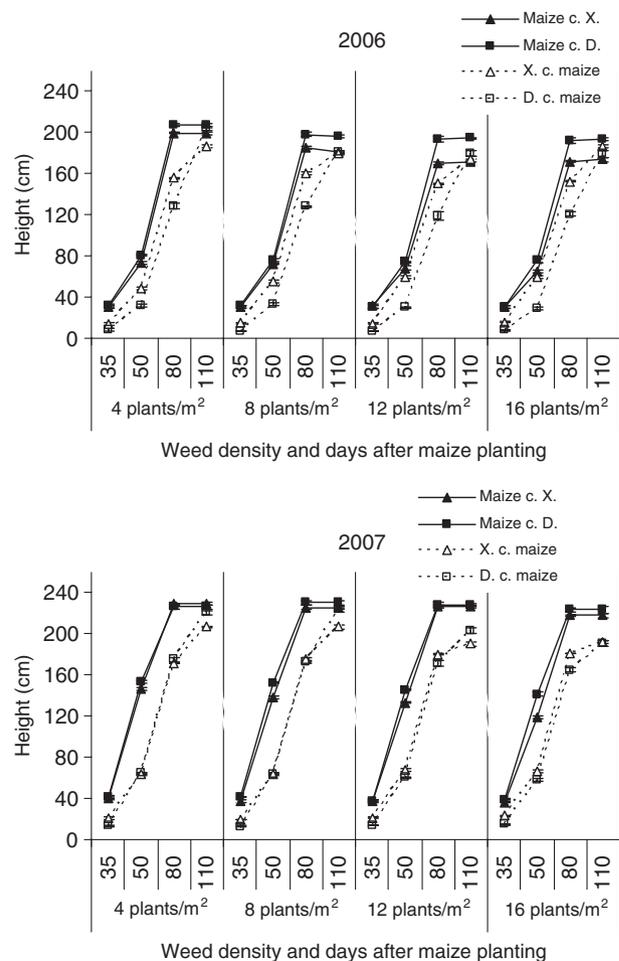
In both years of study, weed CGR and LAI increased with density. Competition from either weed significantly reduced CGR and LAI of maize (Figs 1 and 2). The maximum CGR of maize was reduced by 50% (2006) and 32% (2007), respectively, when density of *X. strumarium* increased from 4 to 16 plants m^{-2}. The same increase in weed density of *D. stramonium* resulted in reductions of 22% (2006) or 38% (2007). Hence, on

Fig. 1 Seasonal changes in CGR of maize, *X. strumarium* and *D. stramonium* in competition in 2006 and 2007. Error bars represent the standard errors for each species for each sampling interval. Letters c. X. and D. are abbreviations for competition, *X. strumarium* and *D. stramonium* respectively (e.g. maize c. X. = maize in competition with *X. strumarium*).

Fig. 2 Seasonal changes in LAI of maize, *X. strumarium* and *D. stramonium* in competition in 2006 and 2007. Error bars represent the standard errors for each species for each sampling interval. See Fig. 1 for abbreviations.


Fig. 3 Seasonal changes in plant height of maize, *X. strumarium* and *D. stramonium* in competition in 2006 and 2007. Error bars represent the standard errors for each species for each sampling interval. See Fig. 1 for abbreviations.

average, the negative effect of *X. strumarium* on maize CGR was greater than from *D. stramonium* in 2006, whereas in 2007 the influence of D. *stramonium* was slightly greater than *X. strumarium*. *X. strumarium* had greater effects than *D. stramonium* in reducing maize maximum LAI at high densities. In 2006, for example, maize competing with 16 plant m^{-2} of *X. strumarium* produced a maximum LAI of 1.99, while at a similar density of *D. stramonium,* maize maximum LAI was 3.25 (Fig. 2).

In both years, the crop was taller than the weeds throughout most of the season, while both weeds and maize were taller in 2007 than in 2006. However, later in the season, *D. stramonium* at some densities (at four plants m^{-2} in both years and at eight plants m^{-2} in 2007) reached the same final height as maize (Fig. 3). In 2006, *X. strumarium* was taller than *D. stramonium* early on, but not by the end of the season. In 2007, *D. stramonium* and *X. strumarium* grew to approximately the same height. Although weed height was still increasing at the end of growing season (Fig. 3), the rate of increase in

plant height at that time was greater in *D. stramonium* than *X. strumarium*.

Biomass, weed seed production and maize yield

Above-ground biomass of both weeds declined approximately linearly with density, with *X. strumarium* producing a greater biomass for a given weed density than *D. stramonium* (Fig. 4) ($P < 0.01$). In case of *X. strumarium,* there was no significant difference between years, whereas for *D. stramonium* plants were larger in 2007 (Fig. 4 and Table 2). Weed seed production per plant also declined linearly with weed density and was greater for *D. stramonium* than for *X. strumarium*. While *D. stramonium* seed production did not vary with year, *X. strumarium* produced more seeds per plant in 2007 (Fig. 4 and Table 2).

Xanthium strumarium was the more competitive weed with the crop, causing a greater reduction in maize yield at any given weed density (Fig. 5). Regression analysis
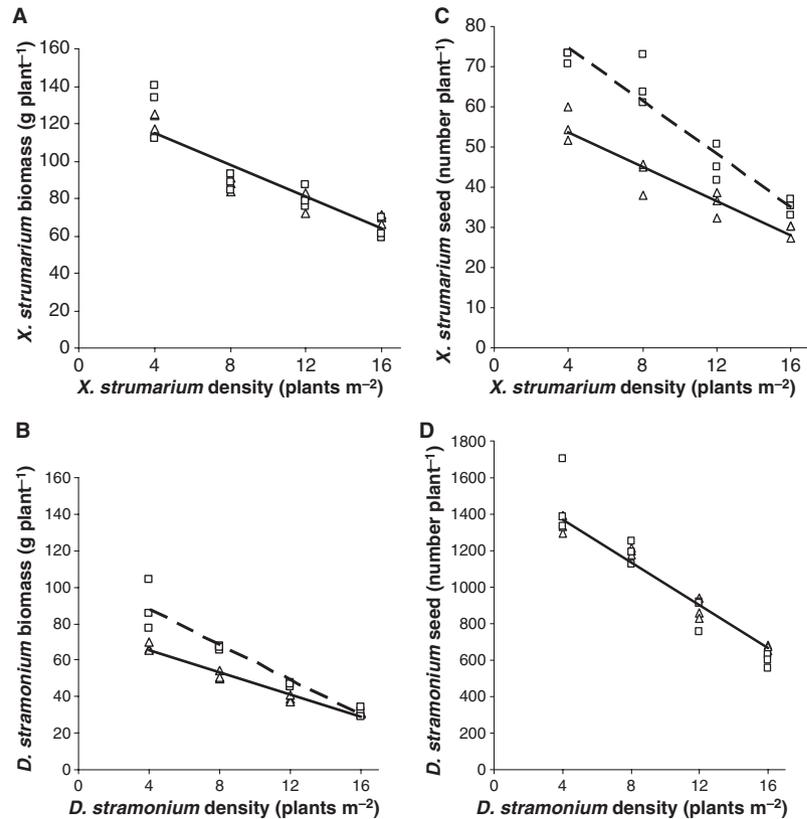
Fig. 4 Responses of *X. strumarium* and *D. stramonium* growing in maize: A,B biomass; C,D seed number per plant; in 2006 (△) and 2007 (□). Solid lines are the fitted linear regressions for pooled (2006 and 2007) or 2006 data and dashed lines are for 2007. Equations are: (A) pooled $y = 136.36 - 4.65x$ ($R^2 = 0.83$); (B) 2006 $y = 77.45 - 3.02x$ ($R^2 = 0.97$); 2007 $y = 106.96 - 4.80x$ ($R^2 = 0.92$); (C) 2006 $y = 62.18 - 2.12x$ ($R^2 = 0.89$); 2007 $y = 87.85 - 3.30x$ ($R^2 = 0.92$); (D) pooled $y = 1989 - 66.35x$ ($R^2 = 0.92$).

indicated a non-linear crop yield response to *X. strumarium* density in both years and a non-linear yield response and linear yield response to *D. stramonium* densities in 2006 and 2007 respectively (Fig. 5). There was a significant interaction between weed species and year: estimated *I* values for *X. strumarium* were 10.32 in 2006 and 9.37 in 2007, whereas for *D. stramonium* the respective values were 6.53 and 3.56 (Table 3).

Both *X. strumarium* and *D. stramonium* reduced maize grain number per ear (GNE) ($P < 0.01$). Reductions were greater from *X. strumarium* than from *D. stramonium*. The decline in GNE with weed density was linear in all cases, except for *D. stramonium* in 2006 (Fig. 6). The GNE was lower in 2006 than in 2007, as

was the case for maize grain yield. *X. strumarium* and *D. stramonium* also reduced maize 100 grain weight (Fig. 7) ($P < 0.01$). Once again, losses were greater from *X. strumarium* than *D. stramonium*. In 2006 and 2007, the decrease in grain weight caused by *D. stramonium* density was linear, whereas the response to *X. strumarium* was curvilinear (Fig. 7). Weed competition did not affect maize ear number per plant ($P > 0.05$).

Discussion

Xanthium strumarium was more competitive than *D. stramonium*, causing a greater yield loss in maize at both low and high weed densities. Rapid development of

Table 2 Results of the parallel curve analysis, testing for differences in the regressions between the two years of the experiment (2006 and 2007)

	Weed biomass (g m⁻²)		Weed seed number plant⁻¹		Maize grain yield (g m⁻²)		Maize grain number ear⁻¹		Maize 100 grain weight (g)	
	F	*P*-value	*F*	*P*-value	*F*	*P*-value	*F*	*P*-value	*F*	*P*-value
Xanthium c. maize	3.25	NS	32.27	**	–	–	–	–	–	–
Datura c. maize	45.93	**	6.15	NS	–	–	–	–	–	–
Maize c. *Xanthium*	–	–	–	–	73.31	**	47.88	**	35.96	**
Maize c. *Datura*	–	–	–	–	NA	NA	NA	NA	11.52	**

Comparisons between years followed by ** indicate differences ($P < 0.01$). NA indicates that no comparison was made because of using different models. For abbreviations see Fig. 1.
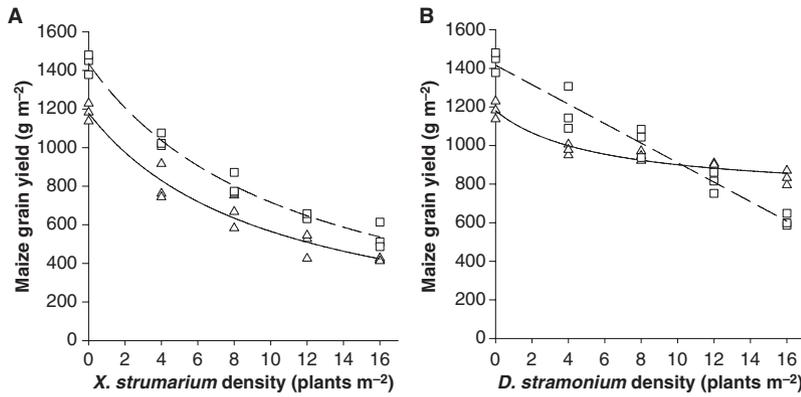
Fig. 5 Relationship between maize grain yield and weed density in 2006 ($\triangle$) and 2007 ($\square$). The solid and dashed lines are the fitted equations for 2006 and 2007 respectively. (A) *X. strumarium*, (b) *D. stramonium*. See Table 3 for regression equations.

Table 3 Parameters for the relationships between crop yield or yield components and weed density (see Eqn 3)

Crop yield or yield component	Year	Weed	Observed weed-free mean	Fitted parameter			RMSE	R^2
				Y_{wf}	I	A		
Yield (g m^{-2})	2006	*X. strumarium*	1183 (15.5)	1179 (137.1)	10.32 (2.112)	100 (16.86)	4207.92	0.95
	2006	*D. stramonium*	1183 (15.5)	1180 (120.7)	6.53 (1.191)	37.2 (5.16)	1297.10	0.92
	2007	*X. strumarium*	1437 (17.5)	1436 (25.8)	9.37 (1.112)	100 (11.14)	2031.48	0.98
	2007*	*D. stramonium*	1437 (17.5)	1416 (29.4)	3.56 (0.157)	–	4307.48	0.95
GNE (no. ear^{-1})	2006*	*X. strumarium*	821 (14.3)	830 (22.8)	3.58 (0.208)	–	2606.05	0.92
	2006	*D. stramonium*	821 (14.3)	847 (16.4)	9.24 (4.803)	24.1 (3.62)	798.01	0.84
	2007*	*X. strumarium*	907 (39.2)	910 (16.4)	2.20 (0.153)	–	1349.85	0.91
	2007*	*D. stramonium*	907 (39.2)	899 (12.8)	1.59 (0.127)	–	818.73	0.90
100 grain weight (g)	2006	*X. strumarium*	26.2 (7.40)	26.27 (8.203)	11.95 (5.661)	40.7 (6.48)	2.02	0.84
	2006*	*D. stramonium*	26.2 (7.40)	26.27 (3.721)	1.52 (0.105)	–	1.01	0.90
	2007	*X strumarium*	25.7 (5.30)	26.54 (7.621)	6.22 (1.913)	66.7 (16.15)	1.77	0.89
	2007*	*D. stramonium*	25.7 (5.30)	25.50 (2.701)	2.35 (0.206)	–	1.07	0.78

Standard errors are given in parentheses. *Linear model $Y = Y_{wf}(1 - ID/100)$ was fitted to data.

leaf area in *X. strumarium* during early growth contributed to its greater competitiveness by increasing its CGR, which in turn resulted in rapid biomass accumulation for this weed. The greater biomass of *X. strumarium* compared with *D. stramonium* at a given density would result in a greater demand for resources, reducing the availability for maize. Other studies have also shown that weeds with a large crop impact, such as *X. strumarium* and *Amaranthus retroflexus,* have a

greater plant weight than species causing less yield loss (Aguyoh & Masiunas, 2003; Lee & Owen, 2003). Our results are in general agreement with those recorded previously for the two weeds in our study. *X. strumarium* was more competitive in soyabeans than *D. stramonium* or *Abutilon theophrasti* Medicus (Regnier & Stoller, 1989; Regnier & Harrison, 1993). *X. strumarium* reduced cotton yield by 1.5–2 times more than *Anoda cristata* L. (spurred anoda), *Digitaria sanguinalis* (L.) Scop. (large
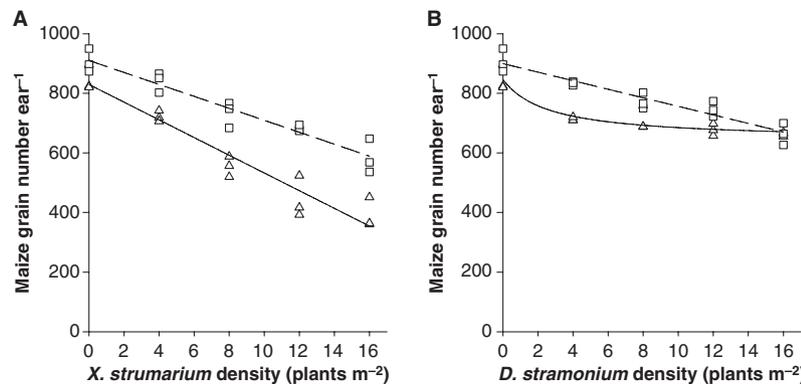
Fig. 6 Relationship between maize grain number ear^{-1} and (A) *X. strumarium* density and (B) *D. stramonium* density in 2006 ($\triangle$) and 2007 ($\square$). The solid and dashed lines are the fitted equations for 2006 and 2007 respectively. See Table 3 for regression equations.

Fig. 7 Relationship between maize 100 grain weight and (A) *X. strumarium* density (B) *D. stramonium* density in 2006 (△) and 2007 (□). The solid and dashed lines are the fitted equations for 2006 and 2007 respectively. See Table 3 for regression equations.
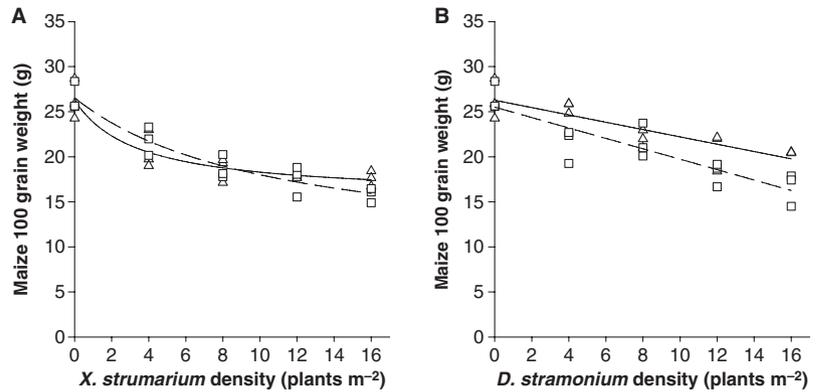
crabgrass), *D. stramonium*, *Chenopodium album* L. (fat-hen), *Ambrosia artemisiifolia* L. (common ragweed), *Cassia obtusifolia* L. (sicklepod) or *Sida spinosa* L. (prickly sida) (Byrd & Coble, 1991b).

Differences in height between crops and weeds are one of the most important determinants of crop yield reduction (Teasdale, 1998). Maize plants had greater height, CGR and LAI than the two weeds. Greater height gain and leaf area expansion rates at early growth stages would favour maize plants in competition for light. For either of the two weed species, the amount of intercepted PAR would have been reduced because both weeds were overtopped by the crop. Shading has been shown elsewhere to drastically reduce *D. stramonium* growth (Benvenuti *et al.*, 1994), whereas *X. strumarium* is more shade tolerant than soyabean and its associated weeds *D. stramonium* and *A. theophrasti* (Regnier *et al.*, 1988).

Higher weed densities increased LAI and CGR of both weeds and consequently led to increased crop yield reductions. Another important consequence of increased density was the reduction of the height of both weeds and crop, which has also been reported in cotton (Scott *et al.*, 2000). One of the main factors that provided some advantage for *X. strumarium* in competition with maize (in comparison with *D. stramonium*) could be its similarity in height to maize, especially at early and mid-growing season.

Both *X. strumarium* and *D. stramonium* reduced maize grain number per ear (GNE) and grain weight. Comparison of the effects of *X. strumarium* and *D. stramonium* on maize yield components shows that when maize competed with *X. strumarium*, a large portion of the maize yield loss could be explained by a reduction in GNE, whereas a greater portion of the maize yield loss resulting from *D. stramonium* could be explained by a reduction in grain weight. At the maximum density (16 plants m^{-2}) *X. strumarium* caused 54% and 45% reduction in maize GNE in 2006 and 2007, respectively, whereas grain weight was reduced by 33% and 40%. In

comparison, *D. stramonium* at the same density caused 21% and 26% reduction in maize GNE in 2006 and 2007, and 22% and 37% reductions in grain weight respectively. These differences in maize yield components are likely to be the result of the difference in weed development: whereas *X. strumarium* followed a pattern that resembles the growth of the maize, *D. stramonium* continued to grow for a longer period and may thus have had a larger impact on grain filling. *D. stramonium* has an indeterminate growth form and continues to grow until the first hard frost (Weaver & Warwick, 1984), after *X. strumarium* has begun to lose its leaves. This growth pattern may be one of the main reasons for the continued presence of *D. stramonium* in maize. *D. stramonium* competition late in the season has also been reported in soyabean (Henry & Bauman, 1991).

In our study, *D. stramonium* emerged about 3 days after the maize and *X. strumarium*. Delay in emergence may contribute to lower yield losses caused by *D. stramonium*, as small early differences in growth can be transformed into large differences in competition much later (Cousens *et al.*, 1987; Fu & Ashley, 2006). For example, maize yield loss decreased as the time between maize and *D. stramonium* emergence increased (Cavero *et al.*, 1999). The higher optimal temperature for *D. stramonium* germination (25–30°C) (Weaver & Warwick, 1984) is likely to delay emergence of the weed.

Xanthium strumarium seed production was much less than *D. stramonium* in both years. At low density, *D. stramonium* seed production was 27 (2006) and 20 (2007)-fold more than *X. strumarium*, whereas these values decreased slightly to 22 (2006) and 18 (2007) at high density. The two weed species have a different life history strategy, with *D. stramonium* producing more, smaller seeds and *X. strumarium* producing fewer but larger seeds. Our study supports previous research showing that *D. stramonium* has a prolific seed production, with > 2000 seeds m^{-2} being produced and added to the soil seed bank, even at low weed density (Scott *et al.*, 2000).

Average monthly air temperatures in 2007 were slightly lower than in 2006, but it is unlikely that weather differences would have been sufficient to explain the differences in crop and weed production between the 2 years. The organic matter content of the soil was lower at the site used in 2006 than 2007. Irrigation was weekly in both years, designed to minimise water stress. The lower organic matter content of the soil in 2006 may, however, have resulted in some soil moisture deficit. This effect appeared as a rolling of maize leaves during the critical reproductive development stages and especially in plots with a heavy infestation of weeds. Water is often the most limiting resource in weed–crop competition in rain-fed crops (Massinga *et al.*, 2003), but this should not be the case in a well-managed irrigated crop and particularly where weeds have been controlled.

In summary, this study used a number of weed and crop growth parameters to identify the potential causes for differential crop losses imposed by two major weeds of maize. Information from such investigations is likely to lead to an improved understanding of weed management systems of maize. As a result of the high seed production of *D. stramonium* and its ability to reduce yield of adjacent crop plants, especially late in the growing season, control of *D. stramonium* around the mid- to late-maize growth period might improve yields, if early control has not been carried out or is ineffective. However, in practice, this would mean hand-weeding, a very expensive option that would not be cost-effective. Although *X. strumarium* should be given a greater priority for in-crop weed control than *D. stramonium*, the latter should not be overlooked as a problem weed, because severe crop losses can be incurred both in the present and future crops.

Acknowledgements

References

Aguyoh JN & Masiunas JB (2003) Interference of large crabgrass (*Digitaria sanguinalis*) with snap beans. *Weed Science* **51,** 171–176.

Barrentine WL (1974) Common cocklebur competition in soybean. *Weed Science* **22,** 600–603.

Beckett TH, Stoller EW & Wax LM (1988) Interference of four annual weeds in maize (*Zea mays*). *Weed Science* **36,** 764–769.

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.

Buchanan GA & Burns ER (1971) Influence of weed competition on cotton, sicklepod and tall morning glory. *Weed Science* **19,** 576–579.

Byrd JDJ & Coble HD (1991a) Interference of common cocklebur (*Xanthium strumarium*) and cotton (*Gossypium hirsutum*). *Weed Technology* **5,** 270–278.

Byrd JDJ & Coble HD (1991b) Interference of selected weeds in cotton (*Gossypium hirsutum*). *Weed Technology* **5,** 263–269.

Cavero J, Zaragoza C, Suso ML & Pardo A (1999) Competition between maize and *Datura stramonium* in an irrigated field under semi-arid conditions. *Weed Research* **39,** 225–240.

Cousens R (1985) A simple model relating yield loss to weed density. *Annals of Applied Biology* **107,** 239–252.

Cousens R, Brain P, O'donovan JT & O'sullivan PA (1987) The use of biologically realistic equations to describe the effects of weed density and relative time of emergence on yield. *Weed Science* **35,** 720–725.

Esashi Y, Ishihara N, Kuraishi R & Kodama H (1983) Light actions in the germination of cocklebur seeds, I: differences in the light responses of the upper and lower seeds. *Journal of Experimental Botany* **34,** 903–914.

FAOSTAT Agriculture Data, 2007. Available at: http://faostat.fao.org/site/567/default.aspx#ancor (last accessed 10 December 2008).

Fu R & Ashley RA (2006) Interference of large crabgrass (*Digitaria sanguinalis*), redroot pigweed (*Amaranthus retroflexus*) and hairy galinsoga (*Galinsoga ciliata*) with bell pepper. *Weed Science* **54,** 364–372.

Hagood ES, Bauman TT, Williams JL & Schreiber MM (1981) Growth analysis of soybean (*Glycine max*) in competition with jimsonweed (*Datura stramonium*). *Weed Science* **29,** 500–504.

Harker KN, Blackshaw RE & Clayton GW (2007) Wild oat (*Avena fatua*) vs redstem filaree (*Erodium cicutarium*) interference in dry pea. *Weed Technology* **21,** 235–240.

Henry WT & Bauman TT (1991) Interference between soybean (*Glycine max*) and jimsonweed (*Datura stramonium*) in India. *Weed Technology* **5,** 759–764.

Holm L, Doll J, Holm E, Pancho J & Herberger J (1997) *World Weeds: Natural Histories and Distribution*. John Wiley, New York.

Horvath DP, Gulden R & Clay SH. A (2006) Microarray analysis of late-season velvetleaf (*Abutilon theophrasti*) effect on corn. *Weed Science* **54,** 983–994.

Hunt R (1990) *Basic Growth Analysis*. Unwin-Hyman, London.

Klingman TE & Oliver LR (1994) Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). *Weed Science* **42,** 523–527.

Lee JM & Owen MDK (2003) Dry matter yield difference of five common cocklebur (*Xanthium strumarium*) biotypes grown at a common site. *Weed Science* **51,** 186–190.

Massinga RA, Currie RS & Trooien TP (2003) Water use and light interaction under Palmer amaranth (*Amaranthus palmeri*) and maize competition. *Weed Science* **51,** 523–531.

Rajcan I & Swanton CJ (2001) Understanding maize-weed competition: resource competition, light quality and the whole plant. *Field Crops Research* **71,** 139–150.

Regnier EE & Harrison SK (1993) Compensatory responses of common cocklebur (*Xanthium strumarium*) and velvetleaf (*Abutilon theophrasti*) to partial shading. *Weed Science* **41,** 541–547.

Regnier EE & Stoller EW (1989) The effects of soybean (*Glycine max*) interference on the canopy architecture of common cocklebur (*Xanthium strumarium*), jimsonweed (*Datura stramonium*), and velvetleaf (*Abutilon theophrasti*). *Weed Science* **37,** 187–195.

Regnier EE, Salvucci ME & Stoller EW (1988) Photosynthesis and growth responses to irradiance in soybean (*Glycine max*) and three broadleaf weeds. *Weed Science* **36,** 487–496.

Reisman BO, Kigel J & Rubin B (1989) Short soaking in water inhibits germination of *Datura ferox* L. and *Datura stramonium* L. seeds. *Weed Research* **29,** 357–363.

Ross GJS (1987) *Maximum Likelihood Program 3.08*. Numerical Algorithms Group, Oxford.

Scott GH, Askew SD, Wilcut JW & Brownie C (2000) *Datura stramonium* interference and seed rain in *Gossypium hirsutum*. *Weed Science* **48,** 613–617.

Shimi P & Termeh F (2004) *Weeds of Iran*. Agricultural Teaching Press, Karaj, Iran.

Sigmaplot (2004) *Sigmaplot, Version 10 for Windows, Release 10.0.* Systat Software, Inc., Richmond, CA.

Stoller EW & Woolley JT (1985) Competition for light by broadleaf weeds in soybean (*Glycine max*). *Weed Science* **33,** 199–200.

Teasdale JR (1998) Influence of maize (*Zea mays*) population and row spacing on maize and velvetleaf (*Abutilon theophrasti*) yield. *Weed Science* **46,** 447–453.

Weaver SE & Warwick SI (1984) The biology of Canadian weeds. 64. Datura stramonium L. *Canadian Journal of Plant Science* **64,** 979–991.

Wesley RAJ, Shaw DR & Barrentine WL (1989) Incorporation depths of imazaquin, metribuzin, and chlorimuron for common cocklebur (*Xanthium strumarium*) control in soybeans (*Glycine max*). *Weed Science* **37,** 596–599.

Zanin G, Berti A & Sattin M (1994) Estimation of economic thresholds for weed control in maize in northern Italy. In: Proceeding 5th EWRS Mediterranean Symposium, Perugia, Italy, pp 51–58.