Wild radish (*Raphanus raphanistrum* L.) development and seed production in response to time of emergence, crop-topping and sowing rate of wheat

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Summary

To determine if increasing crop sowing rates suppresses the competition effects of wild radish, field trials were conducted in 2000 at Avondale and Goomalling, Western Australia. Higher wheat sowing rates, whilst increasing wheat biomass and grain yield, were found to have a limited impact on the biomass and plant density of wild radish. However, wild radish seed production was reduced by 35 and 33% at Avondale and Goomalling respectively when the conventional wheat sowing rate of 60 kg ha^{-1} was tripled to 180 kg ha^{-1}. Similar reductions in wild radish seed production were achieved by removing the early wild radish cohort at Goomalling. When two wild radish cohorts were removed at Avondale there was a 77% reduction in seed production. These studies determined that the biggest impact on wild radish growth and development was due to early cohort removal whilst higher wheat sowing rates produced substantial reductions in wild radish seed production only.

Keywords: Sowing rates, crop competition, weed suppression.

Introduction

Wild radish (*Raphanus raphanistrum* L.) originated in the Mediterranean region (Rollins 1981) but is now a significant weed throughout many of the worlds cropping zones, including those of southern Australian (Cheam and Code 1995). It is one of the most problematic dicotyledonous weeds of dryland cropping systems across this vast region (Alemseged *et al.* 2001). The importance of this weed is attributed to its ability to reduce crop yields (Panetta *et al.* 1988, Cousens *et al.* 2001, Blackshaw *et al.* 2002, Hashem and Wilkins 2002, Eslami *et al.* 2004). The difficulty in controlling wild radish arises from its flexible germination requirements (Cheam and Code 1995), high reproductive capacity (Reeves *et al.* 1981, Panetta *et al.* 1988, Cheam and Code 1995) and longevity of seeds in the soil (Reeves *et al.* 1981). Added to this, wild radish has considerable genetic diversity and can evolve resistance to commonly applied herbicides (Hashem *et al.* 2001a, Hashem *et al.* 2001b, Walsh *et al.* 2001) displaying multiple herbicide resistance mechanisms (Walsh *et al.* 2004).

Crop yield losses can be substantial due to the competitive effects of even low densities of wild radish, depending on the time of emergence. Densities of 7 and 200 plants m^{-2} reduced wheat yields by 10 and 50%, respectively (Code *et al.* 1978, Code and Reeves 1981). Dellow and Milne (1987) showed that 160 wild radish plants per square metre reduced wheat yields by 70 to 80%. Similarly, Hashem and Wilkins (2002) found that wild radish densities of between 10–75 plants m^{-2} at crop anthesis reduced wheat yields by 7–56%. This study also determined that the same wild radish densities reduced lupin (*Lupinus angustifolius* L.) grain yields by 28–92%. Blackshaw *et al.* (2002) found that a wild radish density as low as four plants per square metre reduced canola (*Brassica napus* L.) yields by nine percent. These studies also determined that competition was substantially lower from later emerging cohorts of wild radish. At a density of 64 wild radish plants per square metre, canola yields were reduced, respectively, by 77, 54, 33, 19 and 0% when wild radish emerged 0, 2, 4, 7 and 10 weeks after canola. In a similar study by Cousens *et al*. (2001), wild radish cohorts emerging four weeks after wheat had no effect on crop biomass.

The evolution of herbicide resistance in wild radish is widespread in cropping regions of Western Australia (Walsh *et al.* 2001). The difficulty in controlling resistant annual ryegrass (*Lolium rigidum* Gaud.) and wild radish biotypes has led to the development of alternate weed control practices. For example higher crop sowing rates are used to create a higher crop:weed seedling ratio effectively suppressing weed growth during the critical early post emergence phase (Harper 1977). High crop sowing rates have been shown to suppress the growth and seed production of annual ryegrass (Medd *et al.* 1985, Martin *et al.* 1987, Lemerle *et al.* 1996), wild oat (*Avena ludoviciana* Durieu., *Avena fatua* L.) (Radford *et al.* 1980, Martin *et al*. 1987, Walker *et al.* 2002, Xue and Stougaard 2002) and phalaris (*Paradoxa minor* L.) (Walker *et al.* 2002). To date there have been no studies that have specifically examined the effects of increased crop sowing rates on the growth, development and seed production of wild radish.

Increased crop competition may enhance the efficacy of late season non-selective herbicide application (crop-topping) that targets seed production of wild radish. Within wheat crops, wild radish infestations can produce large quantities of viable seed, for example, 45 000 seed m^{-2} Reeves *et al*. (1981). This prolific seed production allows wild radish to establish a large seed bank in one growing season. A technique that aims to reduce the seed production of weeds within cropping systems is crop-topping, which is the practice of applying reduced rates of non-selective herbicides (typically glyphosate or paraquat plus diquat) at crop maturity (Stanton and Pratley 2004). The effectiveness of this practice relies on the crop reaching maturity before the weed. However, wild radish is an indeterminant plant species and in the Mediterranean environment of southern Australia seed production typically commences before crop maturity and continues for a prolonged period afterwards, depending on available soil moisture. It is hypothesized that increased competition from higher sowing rates will delay the reproductive development of wild radish thereby increasing the efficacy of crop-topping in reducing wild radish seed production. This paper reports on field experiments conducted in the central wheat belt of Western Australia examining the effects of increasing wheat sowing rates, cohort removal and crop-topping on wild radish growth and seed yield.

Materials and methods

Crop sowing and site management

Field trials were established in 2000 at Goomalling (31.28°S, 116.8°E.) and Avondale (32.0°S, 116.39°E.) by sowing wheat into fields with existing wild radish seedbanks. Emerged weeds were controlled at both sites with 450 g ha^{-1} glyphosate applied two to three weeks before sowing and with 270 g ha^{-1} paraquat plus 230 g ha^{-1} diquat immediately prior to sowing. Wheat (*Triticum aestivum* cv. Callingiri) was sown at Goomalling on 25 May and at Avondale on 6 June with a tyned plot seeder fitted with knife points and press wheels on a 20 cm row spacing and 4 cm sowing depth. Fertilizer was incorporated in the soil below the seed at 17.5, 7.6 and 16 kg ha^{-1} of N, P, and S respectively. Three wheat sowing rates (60, 120 and 180 kg ha^{-1}) were used at both sites in plots measuring 2 × 20 m at Goomalling and 2 × 15 m at Avondale.

Wild radish cohorts
Three wild radish cohorts emerged during the growing season at Avondale while two cohorts emerged at Goomalling. The all cohorts treatments consisted of all wild radish emerging throughout the growing season. Cohorts 2+3 treatments were established by removing the first cohort that emerged. Similarly, the cohort 3 treatment was established by removing the first and second cohorts. Wild radish plants were removed by applying MCPA at 250 g ha^{-1} to control any wild radish plants present at the time of spraying. This herbicide treatment was applied using a hand held boom equipped with flat fan nozzles delivering an application rate of 105 L ha^{-1}.

The three wild radish emergence treatments at Avondale were: i) all cohorts – all wild radish seedlings emerging throughout the growing season, ii) cohorts 2+3 – wild radish seedlings emerging after spraying on 19 July, 43 days after sowing (DAS) and iii) cohort 3 – all wild radish seedlings emerging after second herbicide treatment on 15 September, 101 DAS. The two cohort treatments at Goomalling were: i) all cohorts – all wild radish seedlings emerging throughout the growing season and ii) cohort two – wild radish seedlings emerging after spraying on 12 July 2000, 48 DAS.

Crop-topping treatment
A paraquat (203 g ha^{-1}) plus diquat (173 g ha^{-1}) mixture was applied in a strip across half of all plots when wheat reached maturity. At this time wild radish plant maturities ranged from late flowering through pod development stages 7.0–8.0 (Madafiglio *et al.* 1999). Herbicides were applied on 3 November at Avondale and on 1 November at Goomalling using a vehicle mounted sprayer equipped with flat fan nozzles delivering 70 L ha^{-1}.

Data collection procedures
Wild radish and wheat plant samples were collected for the determination of total biomass at crop anthesis at Avondale on 24 October and Goomalling on 20 October. Wheat samples were collected from 5 × 1.0 m rows and wild radish plants were harvested from adjacent 5 × 0.1 m^2 quadrats in each plot. Final wild radish plant densities were determined by counting all plants in each plot immediately prior to harvest at Goomalling on 10 December and at Avondale on 15 December. At this time wild radish plants were collected from a 1.0 m^2 area in each plot to determine the number of seeds retained on plants at harvest. These quadrats were vacuumed to collect wild radish pod segments shed prior to harvest. Samples of 100 pod segments were randomly collected from five treatments and hand dissected to remove seeds. Viability was determined by placing seeds on agar plates in a germination cabinet at 25°C under lights for 12 h and at 15°C in the dark for 12 hours. After four weeks any seeds that had either germinated or did not decay were deemed to be viable. Pod segments for each plot were counted and counts converted to seed number for analysis. A plot harvester was used to determine wheat yields at Goomalling on 11 December and at Avondale on 16 December.

Experimental Design and Analysis
Each experiment was a randomized block design where main treatments of sowing rate and cohorts were randomized within each of three blocks (replicates). For analysis the crop topping was treated as a subplot treatment. Results were analysed using analysis of variance and means were separated using Fisher's protected LSD at = 0.05 level of significance.

Results and discussion

Sowing rate effects on wheat
A threefold increase in wheat sowing rates increased wheat grain yields at both Avondale and Goomalling in the 2000 growing season by 0.4 t ha^{-1} above those recorded for the conventionally used rate of 60 kg ha^{-1} (Figure 1). These results support those reported in other studies conducted in the WA wheatbelt (Anderson and Sawkins 1997, Anderson *et al.* 2004). Wheat biomass yields were also increased by 0.3 t ha^{-1} at Avondale and Goomalling by increasing sowing rates above 60 kg ha^{-1} (Figure 1). Wheat grain and biomass yields increased ($P <0.05$) when sowing rates were raised from 60 to 120 kg ha^{-1} at Goomalling (Figure 1) but, a further increase from 120 to 180 kg ha^{-1} did not produce additional responses ($P >0.05$). At Avondale, wheat biomass increased when sowing rates were increased from 60 to 120 kg ha^{-1}, however, grain yield was only increased ($P <0.05$) at the highest sowing rate (Figure 1). Anderson *et al.* (2004) found that soil type and climatic conditions produced differing responses to increased sowing rates at different sites. The large differences in growing season (May–September) rainfall between Goomalling (193 mm) and Avondale (260 mm) in 2000 may account for the variations observed here (Figure 2).

Sowing rate effects on wild radish

The highly competitive nature of wild radish was indicated in these studies by the marginal effect that increased wheat crop competition had on wild radish plant densities and biomass levels. Despite higher wheat biomass, and therefore, crop competition at higher sowing rates, the only significant effect ($P <0.05$) of increased sowing rates on wild radish was a reduction in biomass at Goomalling (Figure 3). At Avondale there was no effects ($P >0.05$) of sowing rates on wild radish. However, the observed declines in wild radish biomass and plant density as sowing rates increased indicated that higher sowing rates may have resulted in a significant response. At Goomalling there was a small (0.2 t ha^{-1}) but significant ($P <0.05$) reduction in wild radish biomass when sowing rates were increased from 60 to 180 kg ha^{-1} (Figure 3).

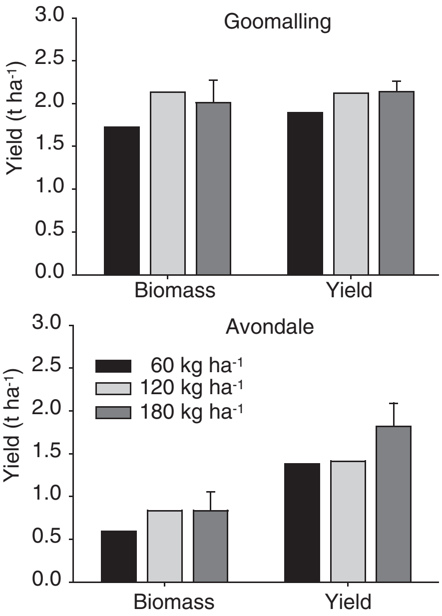

Figure 1. Effect of increasing sowing rates on the yield and biomass of wheat at grown two locations in 2000. Bars indicate LSD values at P = 0.05.

The average wild radish plant density at Avondale (38 plants m^{-2}) was 3.5 fold greater than the average density at Goomalling (11 plants m^{-2}) corresponding to average biomass levels of 0.4 t ha^{-1} and 0.23 t ha^{-1} at Avondale and Goomalling respectively. Therefore, in these studies, wild radish biomass reductions only occurred at low plant densities and higher sowing rates (Goomalling). Similar effects in other weed species have been observed previously where there were reductions in biomass and plant density of ryegrass (Medd *et al*. 1985) and wild oats (Radford *et al*. 1980) only occurred at high crop sowing rates.

Wild radish cohort effects on wheat
Preventing the establishment of wild radish during the early post-emergence phase of the crop increased wheat yields (Figure 4). Previous studies have shown that there is a reduced impact on wheat biomass and grain yield from later-emerging wild radish cohorts (Cheam and Code 1995, Cousens *et al*. 2001). Similarly, reduced effects on yields and biomass from later emerging wild radish have been reported in lupin (Panetta *et al*. 1988) and canola crops (Blackshaw *et al*. 2002).

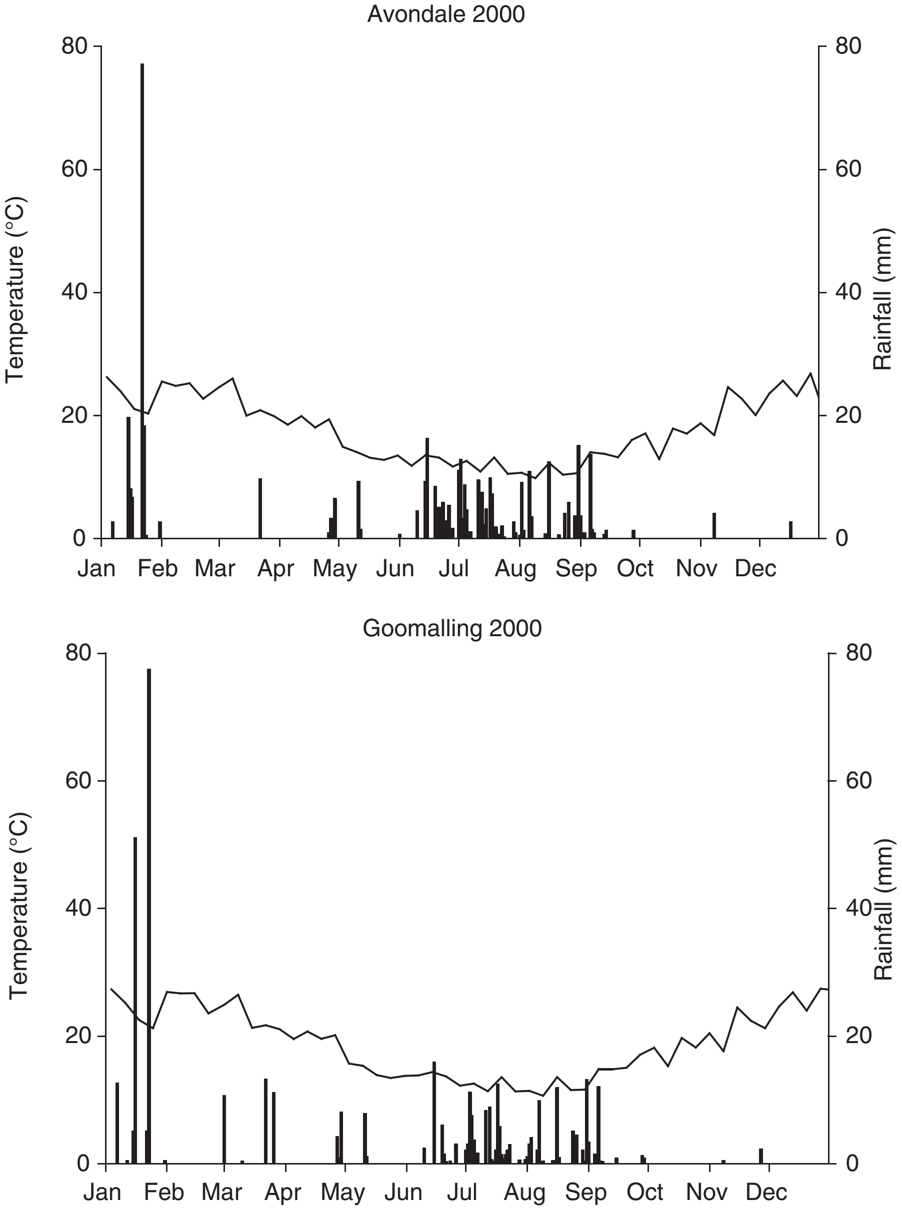

Figure 2. Daily rainfall and seven day average temperature data at (a) Avondale and (b) Goomalling 2000.

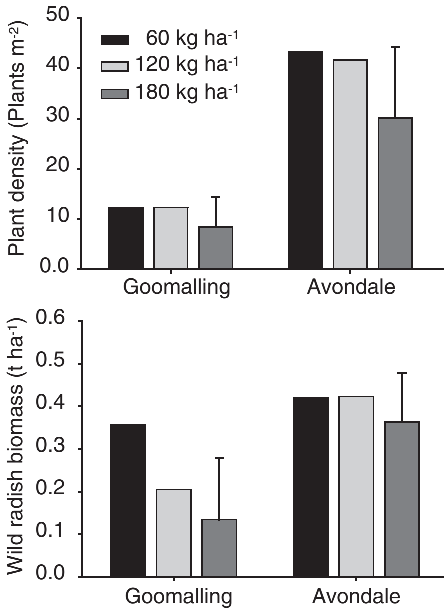

Figure 3. Effect of increasing sowing rates on the plant density (a) and biomass (b) of wild radish emerging in wheat crops grown two locations in 2000. Bars indicate LSD values at P = 0.05.

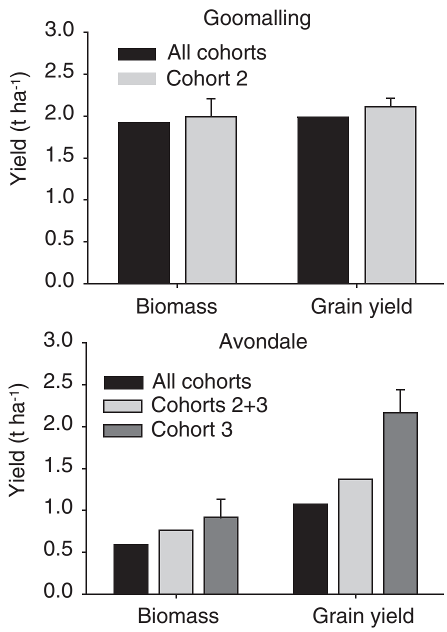

Figure 4. Influence of wild radish cohorts on the biomass (a) and grain yield (b) of wheat grown at two locations in 2000. Bars indicate LSD values at P = 0.05.

Wild radish densities were higher at Avondale resulting in an increased potential for gains in wheat yield following the removal of wild radish cohorts. At Avondale, each time a cohort of wild radish was removed there was an increase ($P < 0.05$) in grain yield but it was only when cohorts 1 and 2 were removed (Cohort 3 treatment) that an increase in wheat biomass was observed (Figure 4). The removal of the first cohort produced a 28% wheat yield increase while the removal of the first two cohorts produced a 102% yield increase. At Goomalling the removal of the initial wild radish cohort had a lower impact on wheat grain yield due to the lower average plant densities that established in the wheat crop at this site (Figure 4). Lower wild radish plant densities have a reduced capacity for restricting wheat yields (Code and Reeves 1981, Cheam and Code 1995, Hashem and Wilkins 2002), therefore, the yield loss due to wild radish competition was much lower at Goomalling.

Wild radish cohort growth and development

Higher wheat sowing rates did not reduce plant establishment and dry matter production of later emerging wild radish plants. There were no reductions in wild radish plant densities or biomass of the last emerging cohorts at Avondale or Goomalling when wheat sowing rates were increased from 60, to 120 and 180 kg ha^{-1} (specific cohort data not presented). Later emerging wild radish plants did, however, establish at lower densities and produced lower levels of biomass as has been previously observed (Panetta *et al.* 1988, Cousens *et al.* 2001). At Avondale, there were significantly lower ($P < 0.05$) wild radish plant densities within the wheat crop at the end of the growing season for cohort treatments 2+3 and cohort 3 respectively than for the all cohorts treatment (Figure

5). Average wild radish plant densities establishing from cohorts 2+3 (39 plants m^{-2}) and cohort 3 (7 plants m^{-2}) were 50% and 10% of the wild radish density that established in the all cohort treatment (68 plants m^{-2}). Similar patterns were observed in wild radish biomass levels for later establishing wild radish plants where there was a 40% reduction for cohorts 2+3 and a 90% reduction in cohort 3 at Avondale. At Goomalling wild radish biomass was significantly lower ($P < 0.05$) for cohorts 2+3 than the all cohort treatment where the removal of the initial cohort reduced biomass by 44%. However, there was no difference in wild radish plant density between these two cohort treatments.

It was only within the cohort all treatment that higher sowing rates significantly ($P < 0.05$) reduced plant density and biomass levels at both the Avondale and Goomalling sites. When sowing rates were increased from 60 to 180 kg ha^{-1} wild radish plant density and biomass levels were reduced ($P < 0.05$) in the cohort all treatment by 24 plants m^{-2} and 0.25 t ha^{-1} respectively at Avondale. Similarly, at Goomalling the same increase in sowing rates resulted in wild radish biomass being reduced ($P < 0.05$) by 0.3 t ha^{-1} between cohort all and cohort 2+3 treatments.

Wild radish seed production

The largest reduction in wild radish seed production and, therefore, the greatest restriction on the ability of this weed to maintain a viable seedbank within cropping systems, occurred following the removal of the initial cohort (Figure 6b). Total seed production for later emerging cohorts was substantially reduced at both Avondale and Goomalling (Figure 6b). At Goomalling the amount of seed produced by the cohort 2 treatment was 35% lower than the all cohort treatment while at Avondale it was only when the first two cohorts were removed that a significant ($P < 0.05$) reduction (77%) occurred (Figure 6). Reduced seed production of in-crop wild radish plants emerging later in the growing season has been demonstrated previously (Reeves *et al*. 1981, Blackshaw 2002).

Despite higher sowing rates of wheat reducing wild radish seed production they did not prevent the establishment of an effective seed bank. At Avondale the 180 kg ha^{-1} sowing rate reduced ($P < 0.05$) wild radish seed production by 33% below that of the 60 kg ha^{-1} rate, while at Goomalling the same comparison produced a 34% reduction ($P < 0.05$) in wild radish seed production (Figure 6a). These reductions equated to decreases in total seed production of 1969 and 988 seed m^{-2} respectively for Avondale and Goomalling. Despite this reduction wild radish seed production was sufficient at both Avondale (3605 seed m^{-2}) and Goomalling (1985 seed m^{-2}) to establish a large seed bank. Higher wheat sowing rates produced more effective reductions in seed production in wild oats (Radford *et al*. 1980, Walker *et al*. 2002, Xue and Stougaard 2002) and phalaris (Walker *et al*. 2002).

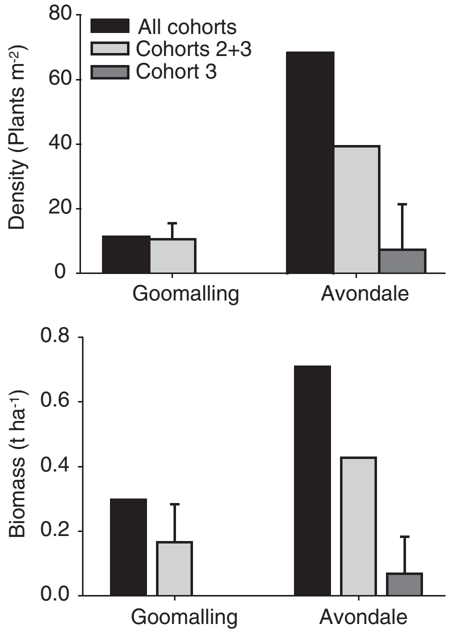

Figure 5. Wild radish cohort effects on plant density (a) and biomass (b) of wild radish emerging in wheat crops grown two locations in 2000. Bars indicate LSD values at P = 0.05.

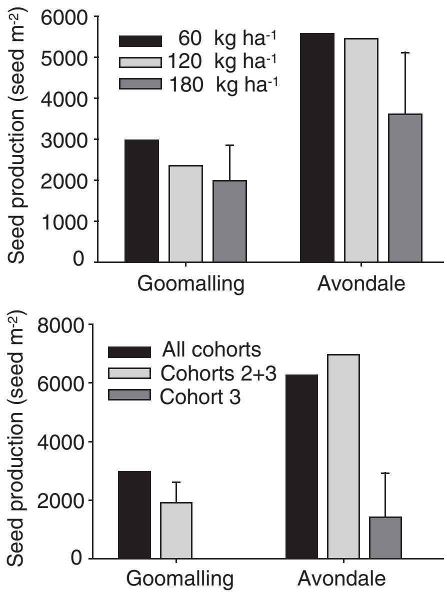

Figure 6. Effect of sowing rate (a) and cohort (b) on the production of viable seed by wild radish plants growing in wheat crops at two locations in 2000. Bars indicate LSD values at P = 0.05.

Crop topping had a minimal impact on the total viable seed production of wild radish growing in wheat crops at Avondale or Goomalling (Figure 7). The amount of seed retained on the plants at harvest was significantly ($P < 0.05$) reduced at the Avondale site by the crop topping treatment. Paraquat and diquat are desiccants that cause treated plants to become brittle increasing the amount of seed shed prior to harvest. This has significance for seed catching at harvest, practised by farmers to restrict the input of seeds into the seedbank. Lower seed retention on wild radish plants at harvest leads to a reduced collection efficiency. The poor result of crop-topping was likely due to the majority of wild radish seed being mature at the time of treatment. The timing of the application of crop topping treatments is constrained by the development stages of the crop and the weed species where weed seed maturity ideally occurs after crop maturity.

Conclusion

In the Mediterranean environment of southern Australia, reducing the impact of competition from wild radish on wheat crops is essential for avoiding substantial yield losses. The results from these studies were that a three-fold increase in wheat sowing rates had a minimal impact on the establishment and growth of wild radish. Additionally, the indications were that higher sowing rates than those used in these studies were needed to impact on

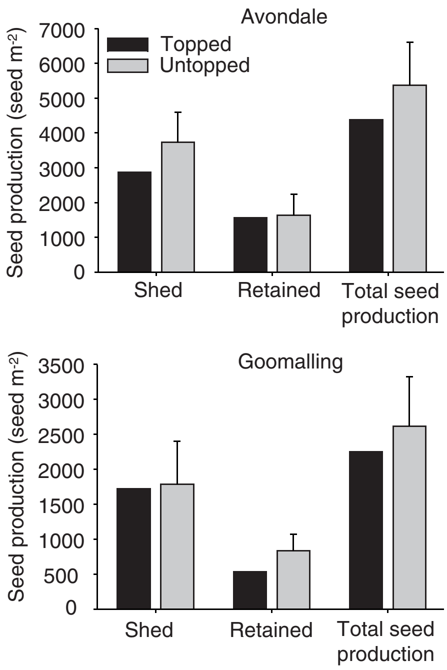

Figure 7. Effect of crop topping on the amount of viable wild radish seed shed, retained and total production at maturity of wheat crops grown at two locations in 2000. Bars indicate LSD values at P = 0.05.

wild radish and only when it was present at high densities. The greatest impact on wild radish growth and seed yield was achieved by controlling the initial cohorts early in the growing season and this consistently produced large increases in wheat yields. Despite there being no effect on wild radish growth higher wheat sowing rates did, however, consistently reduce wild radish seed production and was more effective than crop topping. These results clearly demonstrate the difficulty in restricting the competition effects of wild radish within cropping systems.

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