Integrated control of wild oat in wheat using time of sowing, seeding rate, and herbicides

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Abstract
Delay sowing of wheat is practiced in weedy paddocks of Australia to maximize weed control before sowing. However, it often caused a grain yield penalty. This research was conducted to investigate the integrated effect of the sowing time of wheat (7th May: timely-planted and 7th June: late-planted) and the seeding rate (100 and 200 seeds m^{-2}) on the control of wild oat (*Avena ludoviciana*) with pre-emergent herbicides (unweeded, pyroxasulfone 100 g ha^{-1}, triallate 800 g ha^{-1}, trifluralin 600 g ha^{-1} and prosulfocarb + s-metolachlor 300 g ha^{-1}). Grain yield was lowest (1.8 t ha^{-1}) in the unweeded plot of timely-planted wheat sown at a seeding rate of 100 plants m^{-2}. For timely-planted wheat, grain yield was highest in the plot treated with pyroxasulfone (6.5 t ha^{-1}) sown at 100 seeds m^{-2}. The high seeding rate of wheat (200 seeds m^{-2}) in timely and late-planted crops did not influence grain yield when plots were treated with pyroxasulfone or triallate. However, in timely-planted wheat plots, where weed control was poor (unweeded, trifluralin, and prosulfocarb + s-metolachlor), the high seeding rate of wheat resulted in improved yield. The high seeding rate in late-planted wheat did not influence grain yield. Averaged over weed control treatments, weed biomass was reduced significantly with the higher seeding rate (490 g m^{-2}) compared with the lower seeding rate (230 g m^{-2}) in timely-planted wheat. The high seeding rate did not influence weed biomass in late-planted wheat; however, weed biomass in all plots of late-planted wheat was lower than in the plots of timely-planted wheat at 100 seeds m^{-2}. Weed seed production was higher in timely-planted (1,870-3,330 seeds m^{-2}) than late-planted wheat (630-730 seeds m^{-2}); however, weed seed production in timely-planted wheat was reduced 44% with the high seeding rate compared with the low seeding rate. For late-planted wheat, weed seed production remained similar in all weed control treatments. Applications of pyroxasulfone and triallate in timely-planted wheat reduced weed seed production significantly compared with other weed control treatments. These results suggest that timely sowing of wheat with effective pre-emergent herbicides (pyroxasulfone and triallate) can provide effective control of wild oat and limit the weed seed production.

Keywords: *Avena* species, integrated weed management, timely sowing, weed biomass.

Introduction
Wild oat is a very competitive weed in wheat. A previous study in Australia revealed that wild oat caused a yield reduction of 78% in a wheat crop (Martin et al. 1987). Wild oat caused an annual revenue loss of AU$ 28 million to Australian agriculture when assessed in terms of loss of crop yield and cost of control (Llewellyn et al. 2016). In general, when paddocks are highly infested with weeds, delayed sowing of wheat is advised for maximizing weed control and attaining high yield (Cussans and Wilson 1976; Singh et al. 1995). However, delayed sowing of wheat often caused a yield penalty due to slower early growth (Sharma et al. 2008).

Recent research in Australia has revealed that early cohorts (i.e., emergence in May) of wild oat in Australia are prolific seed producers and are very competitive (Mahajan and Chauhan 2021). By delaying the sowing date of wheat, early cohorts of wild oat can be removed by cultivation (Cussans and Wilson 1976). On the other hand, early-planted no-till wheat in Australia gets a better opportunity to take the advantage of stored moisture (Derpsch et al. 2010). Moreover, early-planted wheat grows more vigorously in warmer soil, and the vigorous nature of the crop in early sowing offers intense competition to weeds (Mahajan and Brar 2002; Gomez-Macpherson and Richards 1995). Wild oat in Australia emerges in multiple cohorts from March to October (Mahajan and Chauhan 2021). If wild oat emergence is low, there may be less advantage in delaying the sowing of wheat for wild oat control. Benefits of increased seed rate for weed competition have been documented in Australia (Radford et al. 1980; Martin et al. 1987; Walker et al. 2002). We hypothesized that crop competitiveness of late sown wheat might increase by using a high seeding rate, and it may help in suppressing late cohorts of wild oat. Wild oat has evolved resistance to acetolactate synthase inhibitor herbicides, which are widely used for wild oat control in Australia (Storrie 2007). This means that the use of pre-emergent herbicides could be an alternative method of wild oat control in wheat in Australia. New pre-emergent herbicide options could provide better flexibility for wild oat control in wheat, especially when integrated with optimum sowing time and seeding rate. This research was aimed at investigating the integrated effects of sowing time of wheat and seeding rate on the control of wild oat with pre-emergent herbicides.

Methods

Experiment design and herbicide treatments

A field experiment was conducted at the Gatton research farm of the University of Queensland, Australia, in the winter season of 2020. The field was prepared with two passes using a disc-harrow followed by a rotavator. The wheat variety "Spitfire" was sown at a row spacing of 35 cm using a cone planter. The experiment was conducted in a split-split plot design with two sowing times in the main plots (7th May and 7th June), two seeding rates (100 and 200 seeds m^{-2}) in sub-plots, and five weed control treatments (unweeded, pyroxasulfone 100 g ha^{-1}, triallate 800 g ha^{-1}, trifluralin 600 g ha^{-1} and prosulfocarb + s-metolachlor 300 g ha^{-1}) in sub-sub plots. All treatments were replicated thrice, and the individual plot size was 4.5 m x 1.4 m.

To ensure even distribution of wild oat plants across the experimental site, wild oat seeds were broadcasted before wheat sowing at a rate of 40 kg ha^{-1}. Pre-emergent herbicides were incorporated by sowing (IBS) for both sowing dates. Herbicide spray was done with a CO_2 backpack sprayer with 160 L of water ha^{-1}. Wild oat control (plant biomass and seed number) and wheat grain yield were assessed at harvest.

Statistical analysis

Data were analyzed using three-way ANOVA with the time of sowing, seeding rate, and weed control treatments as factors. Means were separated using Fishers protected LSD.

Results and Discussion

For timely-planted wheat, grain yield was highest in the plots treated with pyroxasulfone (6.5 t ha^{-1}) sown at 100 seeds m^{-2} (Table 1). The high seeding rate of wheat (200 seeds m^{-2}) in timely and late-planted crops did not influence grain yield when plots were treated with pyroxasulfone or triallate. However, in timely-planted plots, where weed control was not effective (unweeded, trifluralin, and prosulfocarb + s-metolachlor), the high seeding rate of wheat resulted in improved yield (43 to 61%). These results suggest that when weed control was poor in the timely-planted crop, a high seeding rate helped in smothering the weed flora. This was also evident by the weed biomass and weed seed production data in Table 2. It was found that in the timely planted crop, averaged over weed control treatments, weed biomass and seed production of wild oat was reduced by 53 and 44%, respectively, by using a high seeding rate compared with the low seeding rate. The high seeding rate did not influence weed biomass in late-planted wheat; however, weed biomass in all plots of late-planted wheat was lower than in the plots of timely-planted wheat at 100 seeds m^{-2}. This suggests that at a low seeding rate (100 seeds m-^{2}), wild oat can be controlled by delaying the planting of wheat.

Table 1. Interaction effect of sowing time, seeding rate, and weed control treatments on grain yield

Weed control treatments	Grain yield (t ha^{-1})			
	7th May		7th June	
	100 seeds m^{-2}	200 seeds m^{-2}	100 seeds m^{-2}	200 seeds m^{-2}
Unweeded	1.8	2.9	3.5	3.4
Pyroxasulfone 100 g ha^{-1}	6.5	5.6	4.0	4.1
Triallate 800 g ha^{-1}	5.0	5.1	3.9	4.0
Trifluralin 600 g ha^{-1}	2.3	3.3	3.1	3.1

Prosulfocarb + S-metolachlor 300 g ha^{-1}	2.2	3.4	3.5	3.1
LSD (P=0.05)			0.9	

Table 2. Interaction effect of sowing time and seeding rate of wheat on wild oat biomass and seed number

Seeding rate (seeds m^{-2})	Sowing time	
	7th May	7th June
	Weed biomass (g m^{-2})	
100	491.8	251.2
200	229.5	210.6
LSD (P=0.05)	45.3	
	Wild oat seeds (number m^{-2})	
100	3325	727
200	1867	628
LSD (P=0.05)	600	

Weed seed production was higher in timely-planted (1,870-3,330 seeds m^{-2}) than late-planted wheat (630-730 seeds m^{-2}); however, weed seed production in timely-planted wheat was reduced by 44% with the high seeding rate compared with the low seeding rate (Table 2). Such results suggest that in the timely planted crop, a high seeding rate of wheat could reduce the seed number of wild oat. For late-planted wheat, weed seed production remained similar in all weed control treatments. Applications of pyroxasulfone and triallate in timely-planted wheat reduced weed seed production significantly compared with other weed control treatments (Table 3). These results suggest that in the timely planted crop, wild oat seed production can be minimized by using pre-emergent herbicides viz, pyroxasulfone and triallate. Weed seed production is a crucial measure for the integrated management of wild oat. Seeds produced at the end of the season generally top up the weed seed bank for future years (Kleemann et al. 2016). Our results suggest that the weed seed bank of wild oat can be effectively reduced by delaying the planting of wheat.

Table 3. Interaction effect of sowing time and weed control treatments on seed production of wild oat

Weed control treatment	Wild oat seeds (number m^{-2})	
	7th May	7th June
Unweeded	3692	895
Pyroxasulfone 100 g ha^{-1}	1231	528
Tri-allate 800 g ha^{-1}	1750	331
Trifluralin 600 g ha^{-1}	3534	997
Prosulfocarb + s-Metolachlor 300 g ha^{-1}	2772	637
LSD (P=0.05)	896	

Conclusions

Wild oat in the early-planted wheat crop had vigorous growth and high seed production. The high seeding rate in early-planted wheat suppressed the growth of wild oat and decreased weed seed production. In early-planted wheat, pyroxasulfone and triallate were effective pre-emergent herbicides against wild oat and helped to improve grain yield. In conclusion, early sowing with effective pre-emergent herbicides, like pyroxasulfone and triallate, may increase wheat yield without compromising wild oat control.

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