# Control of windmill grass over the summer fallow increases wheat yield

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**Summary** Windmill grass is a summer active, native species found throughout Australia. This research found that growth of windmill grass over summer significantly reduced the growth and yield of the following wheat crop (wheat yield of 0.9 t ha$^{-1}$ with no summer weed control, 1.2 t ha$^{-1}$ with summer weed control). Controlling windmill grass is desirable to maximise crop yield, but there are few registered herbicides available. Mature windmill grass in field conditions was successfully killed by glyphosate 540–1080 g a.i. ha$^{-1}$ (Roundup Power Max®), glyphosate 540 g a.i. ha$^{-1}$ followed by paraquat 135 g a.i./diquat 115 g a.i. ha$^{-1}$ (Spray.Seed®), or haloxyfop 208 g a.i. ha$^{-1}$ (Verdict®). Young plants (in the glasshouse) were also controlled pre-seeding by diuron 990 g a.i. ha$^{-1}$ (Diuron®) and trifluralin 500 g a.i. ha$^{-1}$ (Triflur Xcel®). However, further research is required to identify a broader range of herbicide options for windmill grass control.

**Keywords** *Chloris truncata*, windmill grass, summer, weed, control, herbicide.

## INTRODUCTION

*Chloris truncata* R.Br. (windmill grass) is a tufted, native, annual species found throughout Australia (Australia's Virtual Herbarium 2009). As a summer active ($C_4$) grass, windmill grass may reduce potential yield of winter crops by utilising moisture and nutrients that would otherwise be available to the following crop, or delay sowing due to the time taken removing weeds in autumn (Osten *et al.* 2006). Further, windmill grass is a common host for the cereal leaf disease *Barley yellow dwarf virus* (Hawkes and Jones 2005).

Unfortunately, there are few registered herbicides available to control windmill grass (Moore and Moore 2007). This research aimed to determine the extent to which crop yield was impacted by windmill grass and identify effective herbicide control options.

## MATERIALS AND METHODS

**Impact of windmill grass on wheat growth** A site was identified at the Department of Agriculture and Food WA Merredin Research Station (616448 mE, 6515155 mN, Zone 50). The site had previously been un-grazed ley pasture, where windmill grass was the dominant summer grass species.

A trial (plots 4.5 m by 20 m) commenced in December 2008 (field trial A). The trial design included four treatments: summer weed control or no summer weed control, followed by wheat sown at 18 or 36 cm row spacing, replicated four times. A succession of cohorts emerged in the summer of 2008/2009. To establish the summer weed control treatments, glyphosate at 1080 g a.i. ha$^{-1}$ was sprayed during October and December 2008, to remove all windmill grass plants. It was not necessary to remove other summer weed species, as density of other species was very low. Wheat (cv. Wyalkatchem) was sown in July 2009 at 70 kg ha$^{-1}$ to a depth of 3 cm and 115 kg ha$^{-1}$ Agras® fertiliser was placed at 4 cm, using 50 mm wide bolt-on combine dart points. Glyphosate at 810 g a.i. ha$^{-1}$ with carfentrazone-ethyl at 96 g a.i. ha$^{-1}$ (Hammer®) was applied 1 week prior to sowing to remove winter annual weeds (windmill grass had naturally senesced prior to this). No other in-crop herbicides were applied, as other weed species (and windmill grass) were very sparse within the crop. The crop was harvested on 30 November 2009. Within the crop, four permanent quadrats per plot were established to measure windmill grass density prior to seeding (i.e. density during the prior spring and summer), wheat and windmill grass density following crop emergence, as well as windmill grass density, wheat head number and wheat biomass at the milk grain fill stage of the crop. Crop yield was assessed at harvest.

Residual plots were used to confirm that the data were normally distributed. ANOVA was used to assess the impact of the weed control and row spacing factors on the measured variables, as well as the interaction between weed control and row spacing. Least significant differences were used to separate means (GENSTAT Version 12.1 2009).

**Windmill grass control – glasshouse trial** Seeds were collected from an area adjoining field trial A. In October 2009, 99 pots (40 cm long by 16.5 cm wide by 14.5 cm tall) were filled with potting mix to within 2 cm of the top. Thirty windmill grass seeds per pot were planted by individually placing seeds on the surface of the potting mix. Pots were maintained in an open glasshouse (no temperature control). Water and fertiliser were applied as necessary to ensure healthy growth.

Herbicide treatments (replicated three times, Table 2) were applied with an overhead compressed air belt driven glasshouse boom sprayer calibrated to deliver 96 L ha$^{-1}$ at 200 kPa. Treatments of trifluralin, diuron and tri-allate were applied directly to the soil surface, 2 days after the seeds were planted (4 September 2009). The remaining 15 herbicide treatments were applied to a set of plants at the 2 to 4 leaf stage (13 October 2009), and a second set of plants at seed maturity stage (1 December 2009). Plants were not watered for 2 days after herbicide application, to ensure the herbicide did not wash off. Percent survival was assessed as the number of plants surviving 3 weeks after herbicide application, compared to the number of plants prior to herbicide application. Residual plots were used to confirm that the data were normally distributed. ANOVA was used to assess percent weed control, using herbicide and plant age (application time) as a factor. Least significant differences were used to separate means (GENSTAT Version 12.1 2009).

**Windmill grass control – field trial** A trial was established (field trial B) in the site directly to the east of field trial A in November 2009 (plots 2.5 m by 10 m). Windmill grass plants were evenly distributed within the site. The ten herbicide treatments (replicated four times in a randomised block design) shown in Table 3 were sprayed using a spray boom mounted on four wheel motorbike, on 17 November 2009 (following rainfall). The boom was 40 cm above ground level. The bike was driven at 11 km h$^{-1}$, applying 80 L ha$^{-1}$ of spray with four Turbo Teejet nozzles (TT11002-VP yellow) spaced 34 cm apart along the boom.

The number of surviving plants was assessed in five quadrats per plot (50 cm by 100 cm), on 15 December 2009. Residual plots were used to confirm that the data were normally distributed. ANOVA was used to investigate differences between average plant survival using herbicide treatment as the factor. Least significant differences were used to separate means (GENSTAT Version 12.1 2009).

## RESULTS

**Impact of windmill grass on wheat growth** Windmill grass cohorts grew from October 2008 to February 2009 where growth was not prevented by summer weed control treatments. Cohorts declined naturally (presumably due to lack of moisture) in February 2009, and no further weed cohorts emerged during summer. Average weed density over spring and summer was significantly greater in the no weed control plots, and was not affected by row spacing (Table 1).

Most windmill grass plants senesced naturally in February 2009. However, a few plants emerged during July 2009. As a result, windmill grass density following sowing was still slightly greater in the no weed control plots compared to the weed control plots. Row spacing did not affect windmill grass density in the crop. Initial wheat density was not affected by weed control, but was greater in the narrow row plots. At the milk grain filling stage of crop development, windmill grass density was still slightly greater in the no weed control plots, and was unaffected by row spacing. Wheat biomass, head number and yield were significantly greater in the weed control plots, compared to no weed control plots. Biomass, head number and yield

**Table 1.** The mean density of windmill grass (plants m$^{-2}$) from October 2008 to February 2009 (i.e. the months in which windmill grass cohorts grew), wheat and windmill grass density (plants m$^{-2}$) following crop emergence, wheat biomass (g m$^{-2}$), wheat heads (no. m$^{-2}$) and windmill grass density (plants m$^{-2}$) at the milk grain fill stage of crop development and wheat yield (t ha$^{-1}$) averaged over the no summer weed control or summer weed control treatments, and the 18 cm or 36 cm row spacing treatments. The P and LSD values indicate where means were significantly different.

| Crop stage | Oct 08–Feb 09 | Post-seeding | | | Milk grain fill | | Harvest |
|---|---|---|---|---|---|---|---|
| Measurement | Weed density | Wheat density | Windmill grass density | Wheat biomass | Wheat heads | Windmill grass density | Yield |
| No weed control | 11.4 | 144 | 2.4 | 311 | 187 | 0.9 | 0.9 |
| Weed control | 0.0 | 143 | 0.5 | 370 | 210 | 0.1 | 1.2 |
| LSD | 3.0 | 7.5 | 0.8 | 16.6 | 7.5 | 0.5 | 0.1 |
| P | 0.001 | 0.757 | 0.001 | <0.001 | <0.001 | 0.003 | 0.001 |
| 18 cm row | 6.3 | 162 | 1.1 | 360 | 209 | 0.3 | 1.1 |
| 36 cm row | 5.2 | 125 | 1.8 | 321 | 188 | 0.6 | 0.9 |
| LSD | 3.0 | 7.5 | 0.8 | 16.6 | 7.5 | 0.5 | 0.1 |
| P | 0.46 | <0.001 | 0.072 | <0.001 | <0.001 | 0.141 | 0.007 |

were also greater under narrow row spacing. For all of these variables, the interaction between weed control and row spacing was not significant.

**Control – glasshouse trial** When windmill grass plants were at the 2–4 leaf stage, glyphosate 1080 g a.i. or paraquat 270 g a.i./diquat 230 g a.i. ha$^{-1}$ killed all plants, as did glyphosate followed by paraquat/diquat. Paraquat 135 g a.i./diquat 115 g a.i. or glyphosate 540 g a.i. ha$^{-1}$ killed 89 to 90% of plants. Haloxyfop was also effective (92% control), as were diuron and trifluralin (100% control, Table 2). When mature plants were sprayed, none of the herbicides were effective (data not presented). Herbicide damage was clearly

**Table 2.** Average windmill grass plant survival, as a percent of the number of weeds present directly before spraying herbicide treatments, at the 2 to 4 leaf stage or pre-seeding in the glasshouse trial. Note: + indicates a second herbicide treatment 1 week after the first herbicide.

| Herbicide treatment (ha$^{-1}$) | Windmill grass (%) |
|---|---|
| 2 to 4 leaf stage | |
| Control | 107 |
| Glyphosate 540 g a.i. (Roundup Power Max®) | 10 |
| Glyphosate 1080 g a.i. | 0 |
| Paraquat 135 g a.i./diquat 115 g a.i. (Spray.Seed®) | 11 |
| Paraquat 270 g a.i./diquat 230 g a.i. | 0 |
| Glyphosate 540 g a.i. + paraquat 135 g a.i./diquat 115 g a.i. | 0 |
| Glyphosate 1080 g a.i. + paraquat 270 g a.i./diquat 230 g a.i. | 0 |
| Haloxyfop 208 g a.i. (Verdict®) | 8 |
| Diclofop-methyl 200 g a.i./sethoxydim 20 g a.i. (Decision®) | 34 |
| Metribuzin 210 g a.i. (Lexone®) | 34 |
| Tralkoxydim 172 g a.i. (Achieve®) | 69 |
| 100 g/L Pinoxaden 25 g a.i./cloquintocet-mexyl 6.35 g a.i. (Axial®) | 95 |
| Fluazifop-P 211.2 g a.i. (Fusilade®) | 41 |
| Imazamox 24.75 g a.i./imazapyr 11.25 g a.i. (Intervix®) | 106 |
| Sulfosulfuron 18.75 g a.i. (Monza®) | 91 |
| Pre-seeding herbicides | |
| Diuron 990 g a.i. (Diuron®) | 0 |
| Tri-allate 800 g a.i. (Avadex Xtra®) | 98 |
| Trifluralin 500 g a.i. (Triflur Xcel®) | 0 |
| LSD (P <0.001) | 23.04 |

**Table 3.** Average number of windmill grass plants surviving herbicide treatment in field trial B. Herbicides were sprayed onto a population of windmill grass consisting of plants at a range of growth stages. Note: + indicates a second herbicide treatment 1 week after the first herbicide.

| Herbicide treatment (ha$^{-1}$) | Windmill grass (plants m$^{-2}$) |
|---|---|
| Control | 11 |
| Glyphosate 540 g a.i. | 2 |
| Glyphosate 1080 g a.i. | 1 |
| Paraquat 135 g a.i./diquat 115 g a.i. | 12 |
| Paraquat 270 g a.i./diquat 230 g a.i. | 9 |
| Glyphosate 540 g a.i. + paraquat 135 g a.i./diquat 115 g a.i. | 1 |
| Haloxyfop 208 g a.i. | 3 |
| Diclofop-methyl 200 g a.i./sethoxydim 20 g a.i. | 11 |
| Metribuzin 210 g a.i. | 14 |
| Diuron 990 g a.i. | 13 |
| LSD (P <0.001) | 2.9 |

apparent, but plants recovered or re-sprouted, and produced new seed heads. As a result, the final surviving plant number was not significantly different to the control, for all treatments.

**Control – field trial** All treatments with glyphosate were highly effective. The surviving plants were very small and few had produced seed heads. Haloxyfop was also highly effective. Paraquat 270 g a.i./diquat 230 g a.i. ha$^{-1}$ killed vegetative growth, but most plants re-sprouted and visual assessment indicated that seed head production was reduced but not prevented. Other herbicide treatments had very little impact on the windmill grass (Table 3).

## DISCUSSION

Growth of windmill grass over summer reduced crop biomass, head production and yield, indicating that control of this weed is beneficial to maximise production. The windmill grass within the crop may also have had an impact on crop growth. However, the impact was probably minimal, given the low density of windmill grass within the growing season. Crop growth (initial plant density, biomass, head production and yield) was greater under narrow rows. This has been found previously in wheat crops (Amjad and Anderson 2006). Initial plant density is probably reduced in wide rows due to increased plant competition within the row, and subsequent crop yield is reduced (Amjad and Anderson 2006). Even though weed density was significantly lower in the narrow row spacing (within the cropping season), it is unlikely that density of windmill grass in either row spacing treatment was high enough to influence crop development.

Control of windmill grass could be achieved with glyphosate, or glyphosate followed by paraquat/diquat, over the summer fallow. Diuron or trifluralin (pre-seeding) successfully controlled this weed, but were only tested in glasshouse conditions. Haloxyfop can be used to control this weed if it germinates within broad leaf crops. However, these herbicides are not registered for windmill grass control.

In this trial, several herbicides were effective in the field, but did not kill a significant number of mature windmill grass in glasshouse conditions. This indicates that windmill grass has an impressive ability to recover from herbicide damage in the presence of adequate water and fertiliser. Therefore, when spraying mature plants in the field, it is important to ensure that rain will not follow the herbicide event to allow recovery and re-growth.

It should be noted that in this paper, specific herbicide products were referred to (rather than active ingredients). It has previously been found that windmill grass can have different reactions to different formulations of the same herbicide (Stewart 2002).

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