Voraxor® Herbicide: An Alternative to Paraquat in Fallow Double-Knock - Managing Glyphosate and Paraquat Resistant Weeds.

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Summary Glyphosate resistant weeds pose a significant risk, threatening the sustainability of conservation farming systems in Australia. To counter glyphosate resistance, the 'double-knock' herbicide technique has been developed for fallow control of problematic weeds. The double-knock strategy refers to the sequential herbicide approach, in which different herbicide groups are applied with at least a one-week interval between the application of the first and second sprays. Predominantly glyphosate (Group 9) is followed by paraquat (Group 22).

A combination of field and pot trials were conducted to test the hypothesis that the Group 14 herbicide Voraxor® is a viable alternative to paraquat in the fallow double-knock system. Results from these trials indicated that Voraxor at 37.5 g ai ha^{-1} is equivalent or superior to paraquat at 1320 g ai ha^{-1} for control of several problematic fallow weeds when applied using the double-knock method following glyphosate at 855 g ai ha^{-1}.

Keywords Voraxor®, fallow, weeds, knockdown, double-knock, residual control, resistance management.

INTRODUCTION

Worldwide, thirty-eight weed species have now evolved resistance to glyphosate, distributed across 37 countries and in 34 different crops and six non-crop situations (Heap *et al*. 2018).

Since 2007, 76 populations of *Echinochloa colona*, 57 populations of *Conyza bonariensis*, 10 populations of *Chloris truncata* R.Br. and 3 populations *Urochloa panicoides* P. Beauv. have been identified as glyphosate-resistant (group 9) in Australia (Preston 2010 & Cook *et al*. 2008 - 2018). There are also 7 recorded cases of paraquat (group 22) resistance in *Conyza spp*. in Australia (Chauhan *et al.* 2018).

The double-knock method relies on the sequential herbicide application to control any survivors following the initial glyphosate application. The technique seeks to optimise glyphosate efficacy and acts as a means of combating increasing glyphosate resistance.

A limitation of the current double-knock strategy is the reliance on a single herbicide group – group 22. This trial work sought to evaluate the addition of an alternate mode of action (MOA), Group 14, into the double-knock strategy as the use of a different herbicide MOA can delay the evolution of herbicide resistance (Beckie & Reboud, 2009).

Voraxor® herbicide contains a combination of trifludimoxazin plus saflufenacil (Tirexor® and Kixor®) - two potent protoporphyrinogen IX oxidase (PPO or Protox) inhibiting herbicides that provide complimentary activity. This combination has demonstrated high levels of knockdown and residual activity against grass and broadleaf weeds in comparison to other Group 14 chemistry (Witschel *et al.* 2018 & Armel e*t al.* 2020). Also, notably against Group 14 resistant broadleaf weeds (Porri *et al.* 2022).

This paper outlines the results from a series of field and pot experiments that examined an alternate use pattern for Voraxor® as a paraquat replacement in the double-knock weed control system.

MATERIALS AND METHODS

Herbicide evaluation Experiments were performed on several weed species (Table 1) that are known to be tolerant or resistant to glyphosate at the BASF CropSolutions Research Farm, Loomberah, NSW, Australia (-31.1814, 151.063), which is located near Tamworth.

Field trials Between 2019 - 2022, 18 field trials took over place several soil types, ranging in timing from September to February. The field trial sites were managed to encourage populations of weeds that are known to be tolerant to glyphosate as a solo application.

Table 1. Weeds evaluated

Common Name	Species
Flaxleaf fleabane	*C. bonariensis*
Feathertop Rhodes grass	*C. virgata*
Windmill grass	*C. truncata*
Barnyard grass	*E. colona*
Liverseed grass	*U. panicoides*

Trial weed populations ranged between 58 and 89 plants per m². Site management ensured an even growth stage of each weed species was present at the time of application. Individual trials were conducted using a complete randomised block design of four replications, plot size was 20 m². Data for this paper was drawn from the relevant treatments that pertain to this hypothesis.

Pot trials Between 2019 and 2022, five randomised pot experiments tested both Group 9 resistant and susceptible biotypes of *C. virgata* and *E. colona.* The resistant biotypes were collected from Northern NSW and Southern QLD. The biotypes are known to be Group 9 resistant though resistance testing and screening. Seeds where pre-germinated and then four replicates of each biotype planted into commercially available potting mix.

Application Occurred when weed species were at the 4-6 leaf stage. Pot and field experiments were each subjected to the double-knock sequential herbicide strategy, see Table 2. Herbicides were applied at a 7-day interval, using a hand boom operating at 3 BAR, utilising AIXR110015 nozzles, applying a coarse droplet in 100 L ha^{-1} total volume.

Experimental design – Treatments Data was extracted from the relevant treatments of the 23 trials then, the percentage weed control from both double-knock treatments and a single application of glyphosate compared relative to the unsprayed control.

Table 2. Trial treatments

glyphosate 570 g/L	Single	855.0 g ai ha^{-1}
glyphosate 570 g/L *fb* paraquat 360 g/L	Sequential	855.0 g ai ha^{-1} *fb* 1320.0 g ai ha^{-1}
glyphosate 570 g/L *fb* Voraxor® 375 g/L	Sequential	855.0 g ai ha^{-1} *fb* 37.5 g ai ha^{-1} (+ 1% v/v MSO)

fb = followed by
MSO -Methylated seed oil

Assessment Visual assessment of herbicide efficacy using a scale of 0-100% relative to the untreated control. Results presented are at 14 days after the sequential application occurred.

Statistical analysis conducted using a one-way analysis of variance (ANOVA) at the 95% confidence level utilising ARM software, Revision 2020.2 (GDM Solutions). Where significant treatment effects occurred (p=0.05) a LSD / Tukey's HSD mean separation test was conducted to determine treatment differences.

RESULTS

The subset data from field experiments involving the species listed in Table 1 demonstrated that applying the current industry standard, for difficult to control grasses - glyphosate followed by paraquat, provided between 83.2 – 97.7 % control of the weed species listed in table 1. The *C. truncata* data is a notable exception, where the industry standard, whilst a significant improvement in comparison with a solo glyphosate application, resulted in suppression only (84.3% control).

In the same series of subset data from field trials, results indicated that applying glyphosate followed by Voraxor® + MSO provided 94.6 – 98.3 % control of all grass species listed in Table 1 when applied at the 4-6 leaf stage.

The pot trial data which evaluated control of Group 9 susceptible and resistant species demonstrated the validity of the double-knock methodology with a significant increase in the control of these glyphosate resistant grasses.

Pot trial data demonstrated applying glyphosate followed by Voraxor® + MSO provided 94.6 – 94.8 % control of glyphosate resistant grasses. The level of group 9 resistant grass weed control of glyphosate followed by Voraxor® + MSO was statistically equivalent to the current industry standard of glyphosate followed by paraquat. (83.2 – 96.0 %).

Table 3. Effect of herbicide treatments on percentage control of glyphosate-susceptible and glyphosate resistant weed biotypes at 14 days after application (relative to the untreated control, UTC = 0%).

	% Weed control						
Treatment	***E. colona***		***C .virgata***		***C. truncata***	***C. bonariensis***	***U. panicoides***
	Susceptible	**Resistant**	**Susceptible**	**Resistant**	**Susceptible**	**Susceptible**	**Susceptible**
glyphosate	91.1 b	13.8 b	60.6 b	3.5 b	19.8 b	3.3 c	91.2 a
glyphosate *fb* paraquat	97.7 a	83.2 a	93.9 a	96.0 a	84.3 a	45.8 b	95.6 a
glyphosate *fb* Voraxor® + MSO	98.3 a	94.8 a	97.5 a	94.6 a	98.6 a	97.9 a	98.2 a

Compendium of data collected from the following: *C. bonariensis* – 18 field trials, *C. virgata* – 9 field & 5 pot trials, *C. truncata* - 18 field trials, *E. colona* – 18 field & 5 pot trials, *U. panicoides* – 18 field trials

The current industry standard for *C. bonariensis* control in fallows is glyphosate + 2,4-D followed by paraquat. The use of 2,4-D can lead to off-target vapour drift and damage of highly susceptible crops such as tomatoes, cotton, sunflowers, soybeans, and grapes. (https://www.dpi.nsw.gov.au/biosecurity/weeds/weed-control/herbicides/spray-drift)

This trial work also sought to evaluate the potential of removing 2,4-D in situations where *C. bonariensis* is a target species.

Glyphosate followed by paraquat has been identified as an effective control tactic for *Conyza spp*. (Werth *et al*. 2010; Widderick *et al*. 2014).

The subset data extracted from field trials indicated that glyphosate followed by Voraxor® + MSO provided statistically superior control of C. bonariensis compared to glyphosate followed by paraquat (97.9 compared to 45.8 % control).

The combination of glyphosate followed by Voraxor® + MSO provided a statistically significant increase in control of *C. bonariensis* when compared to glyphosate followed by paraquat. (Table 3).

DISCUSSION

These experiments indicate Voraxor® 375 g/L when applied 7 days after an initial application of glyphosate, at a rate of 37.5 g ai ha^{-1} + 1% v/v of MSO, is a viable alternative to paraquat 360 g/L at a rate of 1320.0 g ai ha^{-1} when applied as the sequential partner in a double-knock scenario, for the control of glyphosate tolerant and resistant weed species.

These experiments validate this new use pattern and suggest Voraxor® is a robust option for weed control and as a herbicide resistance management tool in cropping fallows targeting the weeds listed in Table 1. The use of Voraxor® as the partner to glyphosate in double-knock can also negate the risk to highly susceptible crops in areas where this use pattern can be adopted to control *C. bonariensis.*

ACKNOWLEDGMENTS

Tony Cook. Department of Primary Industries, Tamworth Agricultural Institute, 4 Marsden Park Road, Calala, NSW 2340, Australia, for the provision of glyphosate resistant weed seed.

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