Getting the most out of herbicides and combinations for lentil (*Lens culinaris*) crop safety and broadleaf weed control on light to medium textured soils

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Summary: Crop safety and effective weed control with Reflex® (fomesafen 240 g L^{-1}), Group 14 herbicide and its combination with other registered herbicides was assessed in lentil on different soil types at four sites in South Australia. Lentil crop safety varied between acidic and alkaline sands with the use of Reflex®, diuron, metribuzin and terbuthylazine herbicides, with alkaline sand sites incurring more herbicide damage than the acidic sand site. Crop damage with Reflex® on alkaline sands was rate responsive, with yield loss increasing from 17% when applied at 0.5L ha^{-1} to 54% when applied at 1L ha^{-1}. Crop damage on alkaline sands was cumulative when Reflex® was applied in combination with a Group 5 herbicide, such as diuron. Effective control of Bifora (*Bifora testiculata*), common sowthistle (*Sonchus oleraceus*), Indian hedge mustard (*Sisymbrium orientale*) and wild turnip (*Brassica tournefortii*), including populations resistant to imidazolinone herbicides, was achieved with Reflex®. Wide-spectrum broadleaf weed control was achieved using Reflex® in combination with other registered Group 2, 5 and 12 herbicides.

Keywords: herbicide efficacy, herbicide tolerance,
lentil, sandy soils.

INTRODUCTION

Effective broadleaf weed control is a major constraint to achieving full yield potential in pulse crops. The adoption of herbicide tolerant pulse crops has improved broadleaf weed control options. However, it has resulted in over-reliance on a few modes of action, particularly Group 2 imidazolinone (IMI) herbicides. Reflex® (fomesafen) herbicide has been recently registered for chickpea, narrow leaf lupin, lentil, field pea, faba bean and vetch to control range of broadleaf weeds. Of all the pulses with a Reflex® registration, lentil is the most sensitive, with a maximum rate of 1L ha^{-1} incorporated by sowing (IBS) only, whilst other legume species have a maximum rate of 1.25 L ha^{-1} post-sowing and pre-emergence (PSPE) (except vetch, maximum 0.9L ha^{-1} PSPE) or 1.5L ha^{-1} IBS. A new mode of action registered in lentils will provide herbicide rotation options for both conventional and herbicide tolerant cultivars, and will be particularly useful where herbicide resistance is developing or already present for Group 2 herbicides.

Previous research studies have investigated lentil crop safety and weed control on sandy soils of the Northern Yorke Peninsula for Group 2, Group 5 and Group 12 herbicides. This work highlighted the heightened risk of crop damage from soil residual herbicides on these soil types, in particular the Group 2 and 5 herbicides (Trengove et al. 2021). The current research studies have extended this work, including Reflex®, investigating herbicide crop safety on a range of soil types, including differences in soil texture and pH.

MATERIALS AND METHODS

A total of four experiments were established in 2021 to assess herbicide tolerance and broadleaf weed control on imidazolinone (IMI) tolerant lentils (Table 1). Two of these four experiments were established at Alford and Bute 1 (Northern Yorke Peninsula) on sandy soils with either high or low soil pH to assess crop safety when using Group 2, 5, 12 and 14 pre-emergent and/or post-emergent herbicides. Other two experiments were established at Bute (2 & 3) to develop strategies for controlling broadleaf weeds on loamy soils, and sandy alkaline soils. The treatments included combinations from Group 2 (Intercept®), 5 (metribuzin, diuron and Terbyne®) and 14 (Reflex®) in a randomised complete block design with three replicates (Tables 2 and 3).

Experiments were sown to PBA Hurricane XT[A] using knife points and press wheels between 26 May and 4 June, 2021. Two major rainfall events occurred after seeding, with 27.6 mm and 24.0 mm of rainfall received within the first and second week, respectively. A total of 278 mm was received between seeding and harvest at Bute. Post-emergent herbicide treatments were applied at 5-6 crop node stage. Herbicides were applied using hand boom equipment delivering 100 L ha^{-1} water at a pressure of 200 kPa. Plots at the herbicide tolerance sites were rolled post-emergent compared to the weed control experiments which were rolled with seeding. Broadleaf weed counts from herbicide tolerance experiments (Alford and Bute 1) were taken four weeks after post-emergent herbicide treatments and were removed by hand after counting to determine herbicide effects in the absence of weeds. Broadleaf weed pod/seed set counts (Bute 2 and Bute 3) were taken 130 days after herbicide treatments using a 0.25 m^2 quadrat placed at three random locations in each plot.

Table 1: Descriptions for the four trial sites established in 2021.

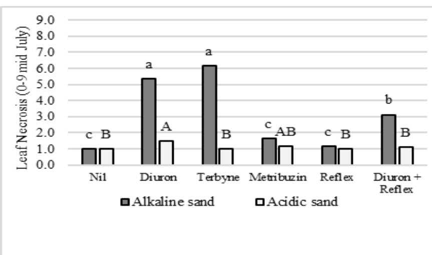
Location	**Site**	**0-10 pH ($CaCl_2$)**	**0-10 pH (H_2O)**	**ECEC Cmol kg^{-1}**	**OC (%)**	**Texture**
Alford	Alkaline herbicide tolerance	7.7	8.4	11.7	0.94	Sand
Bute 1	Acidic herbicide tolerance	4.7	5.8	3.09	0.76	Sand
Bute 2	Loam weed control	7.5	8.1	-	1.33	Loam
Bute 3	Sand weed control	6.8	8.1	-	0.82	Loamy sand

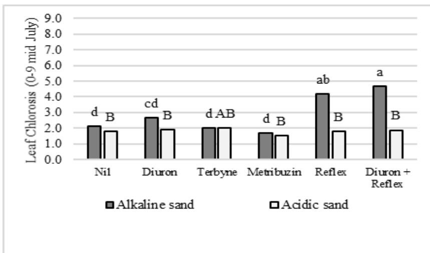
RESULTS AND DISCUSSION

Crop safety

At the alkaline site (Alford), the Group 5 herbicides diuron and Terbyne® caused significant herbicide damage with scores for necrosis reaching 6.2 out of 9 from the application of Terbyne® (Figure 1). Reflex® caused significant damage at this site but in the form of leaf chlorosis. The combination of Group 5 and 14 herbicides did not lead to increased leaf necrosis or chlorosis damage. In contrast, at the acidic site (Bute 1), there were only minor leaf necrosis symptoms evident in association with the application of diuron, and no other herbicide was significantly different from the control treatment. Reflex® caused stunting in lentil as the rate increased from 500 to 1000 mL ha^{-1} in weed control experiments (Bute 2 & 3) (data not shown) and the effect was more pronounced in alkaline sands than in loamy soils.

Figure 1. Leaf necrosis (left) and chlorosis (right), scored 13 July at Alford (alkaline sand) and 20 July at Bute (acidic sand) (0 = no chlorosis, 9 = death) of PBA Hurricane XT^A . Lower case letters and upper-case letters denote significant differences for each site, P values = <0.001.





Herbicide damage on this sandy soil resulted in growth and biomass reduction (data not shown) and led to decreased yields. Grain yield was significantly reduced in response to the application of some herbicide treatments at the alkaline sand trial site, consistent with earlier herbicide damage scores (Table 3). Diuron and Reflex® treatments both reduced grain yields by 20% when applied alone, and Terbyne® reduced yield by 51%. This contrasts with the acidic sand site where no significant yield differences occurred in response to the application of any individual herbicide.

Diuron and Reflex® were applied in combination at the Alford alkaline site increased yield loss to a 52% compared to the untreated control. Post-emergent herbicides Intercept® and diflufenican (DFF) did not cause yield loss at either site, which is consistent with results of Trengove et al. (2021) for similar soil types. Generally, DFF and Intercept® were also safe to apply following application of either diuron or Reflex® IBS. Where these had caused damage at the alkaline sand site, the post-emergent applied herbicides did not exacerbate the damage. However, the most damaging combination of herbicide at the alkaline sand site was diuron plus Reflex® applied IBS followed by DFF post-emergent and reduced grain yield by 79%. Grain yield loss at the alkaline sand trial (Bute 3) varied depending on the Reflex® rate applied with the 500 mL, 750 mL and 1000 mL ha^{-1} rates yielding

83%, 76% and 46% of the untreated plot, respectively. This indicates that if rates can be reduced and weed control is still maintained, the crop safety margin can be improved.

Reflex® was also included in 2020 experiments and, whilst similar herbicide damage symptoms were present on an alkaline sand, this did not translate into any yield loss in 2020. There were no herbicide damage symptoms or yield loss at the acidic sand site in 2020. A reason for the increased herbicide damage in the 2021 season may be due to more rainfall in the weeks following sowing, which may have moved the herbicide further into the soil profile and laterally into the crop row, with June 2021 rainfall recorded at 56 mm compared to 19 mm in June 2020. Greater spring rainfall in 2020 is also likely to have contributed to better crop recovery.

Broadleaf weed control

Reflex® was effective in controlling 94-98% of bifora at rates of between 500 and 1000 mL ha^{-1} (Table 2). Intercept®, on its own or in combination with Reflex®, provided excellent control of bifora, reducing seed set to <1 bifora seed m^{-2} compared to existing pre-emergent herbicide options metribuzin and Terbyne® with 323 and 1672 bifora seeds m^{-2}, respectively. Similarly, the combination of Reflex® + Intercept® provided high levels of common sowthistle control at all sites (Tables 2 and 3). Intercept® did not provide adequate control of Indian hedge mustard (IHM) and was not different to the untreated control at the loam site (Bute 2) (Table 2). Similar results for poor IHM control with Intercept® occurred at Alford and Bute 1 (Table 3), and Bute 3 (data not shown) sites. However, wild turnip was effectively controlled with Intercept®. This poor control of IHM may be explained by the increase of IHM populations resistant to imidazolinone herbicides in this area.

Reflex® was effective at controlling IMI resistant IHM populations. The level of weed control improved with increasing Reflex® rates from 500 ml ha^{-1} (217 IHM pods m^{-2}) to 1000 ml ha^{-1} (24 IHM pods m^{-2}) (Table 2). Most of the surviving IHM plants in Reflex® plots were found in the in-row spaces, from where the applied herbicide was likely moved out by the seeding operation. When Reflex® IBS was followed by a Group 5 herbicide, metribuzin/Terbyne® applied as PSPE, the surviving weeds in the in-row area were mostly controlled. Herbicide combinations by including Intercept® proved effective for medic control (Table 3).

The availability of the new Group 14 herbicide Reflex® has increased the options for achieving improved broadleaf weed control in lentil, including weeds resistant to IMI herbicides. Careful decisions regarding safe dosage rates of Reflex®, governed by the soil type, and a follow-up application of Group 2, 5 and Group 12 herbicides provide broad-spectrum broadleaf weed control in lentil. IMI herbicides will continue to be a valuable tool for broadleaf weed control in lentil, especially for weeds that have not evolved resistance to this mode of action, and the weeds such as medics that are not effectively controlled with other herbicides. Using Reflex® in conjunction with Group 2, 5 and 12 herbicides will diversify the selection pressure for broadleaf weed control in lentil and delay the resistance build up to a specific mode of action.

Table 2. Effect of herbicides on broadleaf weeds and their seed set on loam soils at Bute 2, 2021.

Herbicide treatment (commercial product rate ha^{-1})	Bifora seeds m^{-2}	IHM pods m^{-2}	Common sowthistle pods m^{-2}
1. Intercept® 600 mL (POST)	0.4^{c}	731^{a}	4^{de}
2. Metribuzin 200 g (PSPE)	323^{b}	1^{de}	0^{f}
3. Reflex® 500 mL (IBS)	35^{c}	217^{bc}	12^{bcd}
4. Reflex® 500 mL (IBS) + Intercept® 600 mL (POST)	0^{c}	409^{ab}	1^{ef}
5. Reflex® 500 mL (IBS) + Metribuzin 200 g (PSPE) + Intercept® 600 mL (POST)	0^{c}	24^{de}	0^{f}
6. Reflex® 500 mL (IBS) + Terbyne® 1000 g (IBS) + Intercept® 600 mL (POST)	0.4^{c}	0^{e}	0^{f}
7. Reflex® 750 mL (IBS)	7^{c}	64^{cde}	15^{abc}
8. Reflex® 750 mL (IBS) + Intercept® 600 mL (POST)	0^{c}	81^{cde}	1^{ef}
9. Reflex® 750 mL (IBS) + Metribuzin 200 g (PSPE) + Intercept® 600 mL (POST)	0^{c}	0^{e}	0^{f}
10. Reflex® 750 mL (IBS) + Terbyne® 1000 g (IBS) + Intercept® 600 mL (POST)	0^{c}	10^{de}	0^{f}
11. Reflex® 1000 mL (IBS)	21^{c}	24^{de}	21^{ab}
12. Terbyne® 1000 g (IBS)	1672^{a}	105^{cd}	5^{cde}
13. Unweeded control	1987^{a}	836^{a}	29^{a}

Table 3. Broadleaf weed control on an alkaline and acidic sandy soil at Alford and Bute 1, respectively, in 2021.

Herbicide (commercial product rate ha^{-1})	Alkaline sand at Alford % weed control				Grain yield (t ha^{-1})	Acidic sand at Bute 1 % weed control				Grain yield (t ha^{-1})
	Medic	IHM	Wild turnip	Common sowthistle		Medic	IHM	Wild turnip	Common sowthistle	
1. Nil	0^{a}	0^{a}	0^{a}	0^{a}	1.61^{abc}	0^{a}	0^{a}	0^{a}	0^{a}	1.0^{abc}
2. Diuron 830 g (IBS)	63^{b}	93^{cd}	100^{c}	96^{b}	1.29^{cd}	38^{abc}	80^{b}	82^{b}	84^{cd}	1.04^{abc}
3. Terbyne® 750 g (IBS)	78^{bc}	96^{cde}	100^{c}	96^{b}	0.79^{ef}	30^{abc}	87^{bc}	78^{b}	90^{cd}	0.86^{bc}
4. Metribuzin 180 g (IBS)	53^{ab}	74^{ab}	98^{b}	48^{a}	1.74^{ab}	4^{ab}	73^{b}	76^{b}	57^{b}	0.91^{abc}
5. Intercept® 500 mL (POST)	93^{d}	70^{ab}	98^{b}	85^{b}	1.60^{abc}	80^{ef}	0^{a}	100^{d}	84^{c}	0.91^{abc}
6. Diuron 830 g (IBS) + Intercept® 500 mL (POST)	89^{cd}	96de	100^{c}	96^{b}	1.14^{de}	70^{bcde}	70^{b}	99d	97^{ef}	1.09^{abc}
7. Diflufenican 150 mL (POST)	53^{ab}	100^{g}	100^{c}	93^{b}	1.78^{a}	42^{abcd}	100^{e}	100^{d}	90^{cd}	0.91^{abc}
8. Diuron 830 g (IBS) + Diflufenican 150 mL (POST)	58^{b}	100^{g}	99^{c}	100^{b}	1.26^{cd}	90^{efg}	100^{e}	100^{d}	100^{f}	0.98^{abc}
9. Diuron 830 g (IBS) + Diflufenican 150 mL (POST) + Intercept® 500 mL (POST)	91^{d}	100^{g}	100^{c}	96^{b}	0.76^{f}	98^{fg}	100^{e}	100^{d}	100^{f}	0.85^{c}
10. Reflex® 1000 mL (IBS)	54^{ab}	96de	99^{c}	93^{b}	1.29^{cd}	0^{a}	93^{cd}	94c	94de	1.14^{ab}
11. Reflex® 1000 mL (IBS) + Intercept® 500 mL (POST)	88^{cd}	96e^{fg}	100^{c}	100^{b}	1.41^{bcd}	80^{cde}	97^{d}	100^{d}	100^{f}	0.92^{abc}
12. Reflex® 1000 mL (IBS) + Diflufenican 150 mL (POST)	57^{b}	100^{g}	100^{c}	100^{b}	1.54^{abc}	78^{def}	100^{e}	100^{d}	100^{f}	0.88^{bc}
13. Reflex® 1000 mL (IBS) + Diflufenican 150 mL (POST) + Intercept® 500 mL (POST)	93^{d}	100^{g}	100^{c}	100^{b}	1.44^{abcd}	100^{g}	100^{e}	100^{d}	100^{f}	1.06^{abc}
14. Diuron 830 g (IBS) + Reflex® 1000 mL (IBS)	72^{bc}	97^{def}	99^{c}	93^{b}	0.78^{f}	18^{ab}	96^{d}	97c	91^{cd}	1.19^{a}
15. Diuron 830 g (IBS) + Reflex® 1000 mL (IBS) + Intercept® 500 mL (POST)	87^{cd}	96de	100^{c}	96^{b}	0.88^{ef}	88^{efg}	97^{d}	100^{d}	100^{f}	1.0^{abc}
16. Diuron 830 g (IBS) + Reflex® 1000 mL (IBS) + Diflufenican 150 mL (POST)	75^{bc}	100g	100^{c}	100^{b}	0.33^{g}	66^{cde}	100^{e}	100^{d}	100^{f}	0.97^{abc}
17. Diuron 830 g (IBS) + Reflex® 1000 mL (IBS) + Diflufenican 150 mL (POST) + Intercept® 500 mL (POST)	93^{d}	100^{fg}	100^{c}	100^{b}	0.52f^{g}	86^{efg}	100^{e}	100^{d}	100^{f}	0.85^{c}
Weed density in nil (weeds plot^{-1})	159	91	56	9	-	16	119	87	22	-
Weed density in nil (weeds m^{-2})	10.6	6.1	3.7	0.6	-	1.1	7.9	5.8	1.5	-

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