Crop safety and broadleaf weed control implications for various herbicides and combinations in lentil

***Jordan Bruce*[1]*, Navneet Aggarwal*[2]*, Stuart Sherriff*[1]*, Sam Trengove*[1] *and Penny Roberts*[2].**
[1]*Trengove Consulting;* [2]*SARDI.*

SAGIT project codes: TC121, TC116, TC119; **GRDC Project Codes:** UOA2105-013RTX

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

Take home messages
- Lentil crop safety varied significantly between acidic and alkaline sands in 2021 trials, with the use of Reflex®, diuron, metribuzin and terbuthylazine herbicides, with alkaline sand sites incurring more herbicide damage than acidic sand sites.
- Crop damage with Reflex® herbicide on alkaline sands was rate responsive, with yield loss in a trial at Bute increasing from 17% when applied at 0.5L/ha to 54% when applied at 1L/ha.
- Crop damage on alkaline sands was cumulative where Reflex® was applied in combination with a group 5 herbicide, such as diuron. In a trial at Alford on an alkaline sand, yield loss to either diuron or Reflex® was 20%, increasing to 52% yield loss when applied in combination.
- Seasonal variation, including higher rainfall post-seeding in 2021 may have been a contributing factor in higher level of crop damage in alkaline sandy soils.
- Effective control of broadleaf weeds such as bifora, common sow thistle, Indian hedge mustard, wild turnip and capeweed, including populations resistant to Group 2 imidazolinone herbicides, was achieved with Reflex® (Group 14 herbicide).
- Control of various broadleaf weeds was achieved in lentil using Reflex® in combination with other registered herbicides including Group 2, 5 and 12 herbicides. However, crop safety to these combinations varied between herbicides and their doses, and soil type.
- Herbicide strategies on high-risk alkaline sandy soil types needs careful planning to balance between avoiding crop damage and achieving adequate weed control. Rate of Reflex may need to be adjusted near the middle of the rate range in some soil types to find the right balance of crop safety and weed control.

Background
Reflex® (fomesafen 240g/L) herbicide has been recently registered for use in chickpea, narrow leaf lupin, lentil, field pea, faba bean and vetch. Of all the pulse species with a Reflex® registration, lentil is the most sensitive, with a maximum rate of 1L/ha incorporated by sowing (IBS) only, whilst other legume species have a maximum rate of 1.25L/ha post-sowing and pre-emergence (PSPE) (except vetch, maximum 0.9L/ha PSPE) or 1.5L/ha IBS. Reflex® is registered for control of broadleaf weeds, including wild radish, Indian hedge mustard, sow thistle, prickly lettuce and bifora when used at 0.75-1L/ha in lentils. A new mode of action registered in lentils will provide herbicide rotation options and will be particularly useful where herbicide resistance is developing.

Effective broadleaf weed management is a major constraint to achieving 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 (previously B). The increased reliance on Group 2 imidazolinone (IMI) herbicides carries the risk of the development of herbicide resistant weeds, and therefore raises concerns for the long-term efficacy of this mode of action. The availability of a new mode of action herbicide in Reflex® (Group 14, previously Group G) has increased the broadleaf weed control options for both conventional and herbicide tolerant cultivars of pulse crops.

Previous SAGIT projects (TC116, TC119) have investigated crop safety and weed control on sandy soils of the northern Yorke Peninsula for Group 2, Group 5 (previously C) and Group 12 (previously F) 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). SAGIT project TC121 has continued this work, including Reflex®, investigating herbicide crop safety on a range of soil types, including differences in soil texture and pH, with 2021 results presented here.

Method

A total of four trial sites were established in 2021 to assess herbicide tolerance and weed control on imidazolinone (IMI) tolerant lentils.

Two of these four trials 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 (Table 1). Weeds were removed by hand from all plots in these trials to determine herbicide effects in the absence of weeds.

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	OC (%)	Texture	Weeds assessed
Alford	Alkaline herbicide tolerance	7.7	8.4	11.7	0.94	Sand	Indian hedge mustard (*Sisymbrium orientale)*, burr medic (*Medicago polymorpha)*, common sow thistle *(Sonchus oleraceus)*, and wild turnip (*Brassica tournefortii)*
Bute 1	Acidic herbicide tolerance	4.7	5.8	3.09	0.76	Sand	As above + Cape weed (*Arctotheca calendula)*
Bute 2	Loam weed control	7.5	8.1	Not available	1.33	Loam	Bifora (*Bifora testiculata)*, Indian hedge mustard and common sow thistle
Bute 3	Sand weed control	6.8	8.1	Not available	0.82	Loamy sand	Indian hedge mustard

The remaining two trials were established at Bute (2 & 3) to develop strategies for controlling broadleaf weeds (including bifora, Indian hedge mustard and common sow thistle) on loamy soil, and sandy alkaline soils (Table 1). The treatments comprised of herbicide combinations from Group 2, 5 and 14 in a randomised complete block design with three replicates. The background population of broadleaf weeds in the paddock was used for this study.

Rainfall conditions in 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 (Table 4). A total of 278mm was received between seeding and harvest (Figure 4).

Trial establishment

Trials were sown using knife points and press wheels between 26 May and 4 June and were sown to PBA Hurricane XT[A]. Herbicides were applied using hand boom equipment delivering 100L/ha water volume at a pressure of 200kPa. Plots at the herbicide tolerance sites were rolled post-emergent compared to the weed control trials which were rolled immediately post-seeding.

Herbicide properties and application details

The herbicides used in the trials are described in Tables 2 and 3.

Table 2: Pre-emergent herbicide properties for products used in the herbicide tolerance trials in 2021(source: GRDC pre-emergent herbicide fact sheet).

Herbicide (Group)	**Solubility (mg/L @ 20°C)**		**Adsorption coefficient, Koc value**	
Diuron (5)	36	Low solubility	813	Slightly mobile
Terbuthylazine (5)	7	Low solubility	230	Moderately mobile
Metribuzin (5)	1165	High solubility	60	Mobile
Reflex® (14)	50	Moderate solubility	228	Moderately mobile

Table 3: Herbicide products and application timing/method for the alkaline (Alford) and acidic sand (Bute 1) herbicide tolerance trials in 2021.

Herbicide product	**Trial application**	**Trial rate (product)**	**Registered use pattern**
Diuron (900g/kg)	IBS	830g/ha	830g – 1100g/ha PSPE
Metribuzin (750g/kg)	IBS	180g/ha	180g PSPE
Terbyne® (terbuthylazine 750g/kg)	IBS	750g/ha	1.0 – 1.4kg/ha IBS
Reflex® (fomesafen 240g/L)	IBS	1000mL/ha	500 – 1000mL/ha IBS
Intercept® (imazamox 33g/L + imazapyr 15g/L)	Post-emergent	500mL/ha	500 – 750mL/ha Post
Diflufenican (500g/L)	Post-emergent	150mL/ha	100 – 200mL/ha Post

Results and discussion

Crop safety

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

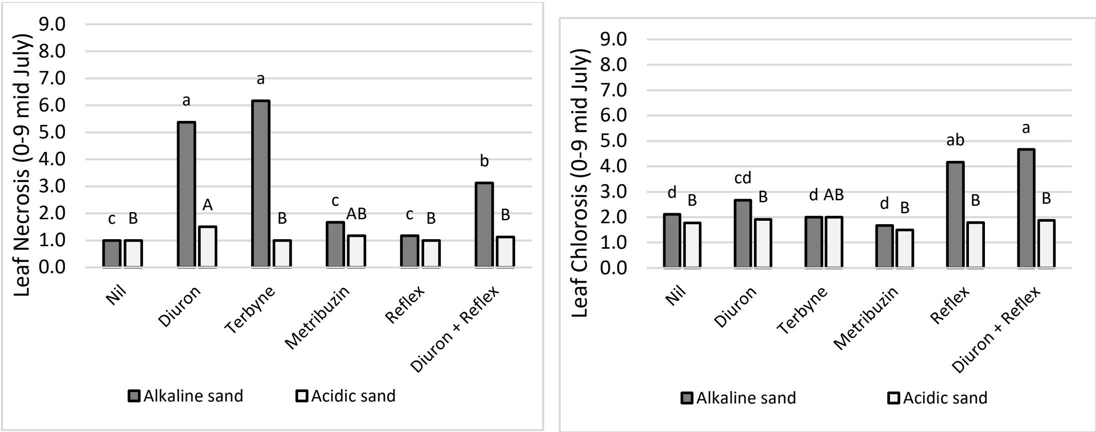

Figure 1. Early season leaf necrosis (left) and chlorosis (right), scored 13 July at Alford (alkaline sand) and 20 July at Bute (acidic sand) (0 = no chlorosis, 9 = death) of PBA Hurricane XT^A for the herbicide tolerance trials in 2021. Lower case letters and upper-case letters denote significant differences for each site, P values = <0.001.

At both sites, there was a reduction in leaf necrosis associated with combining diuron and Reflex® compared with diuron alone, this requires further investigation.

Previous trial work has shown that on these sandy soil types, there is a strong relationship between NDVI (where NDVI is correlated to biomass) and yield for lentil, and this is also the case for the 2021 alkaline sand herbicide tolerance trial (Figure 2). Herbicide damage on this sandy soil resulted in growth and biomass reduction (Figure 1) and led to decreased yields (Figure 2).

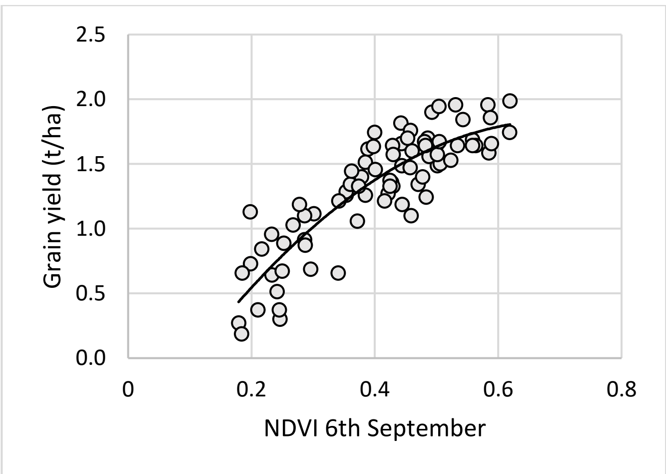

Figure 2. Relationship for Greenseeker NDVI of PBA Hurricane XT^A (recorded on 06-09-2021) and grain yield for the alkaline sand herbicide tolerance trial at Alford in 2021 ($y = -5.2444x^2 + 7.3026x – 0.706$, $R^2 = 0.77$).

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 (Figure 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.

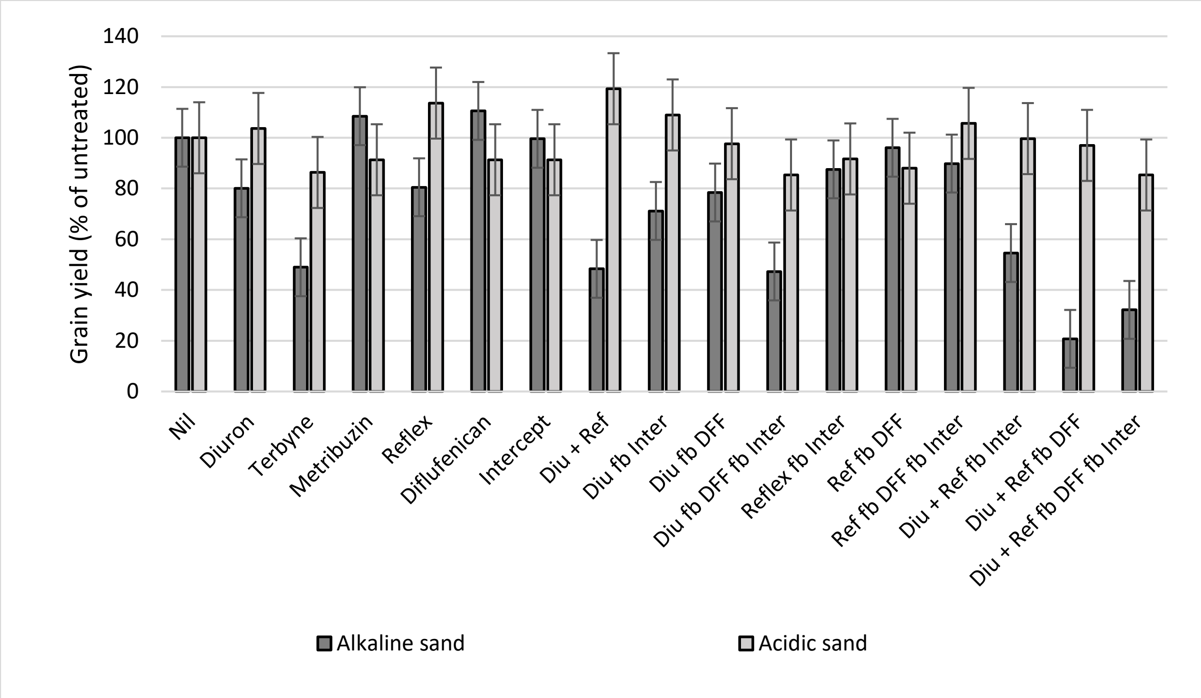

Figure 3. Grain yield presented as per cent of untreated for individual herbicide treatments at the acidic (Bute 1) and alkaline sand (Alford) herbicide tolerance sites in 2021, Diu = diuron, Ref = Reflex®, DFF = diflufenican, Inter = Intercept®, fb = followed by. Bars represent LSD at P=0.05

Where diuron and Reflex® were applied in combination, yield loss increased to a 52% reduction in grain yield 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 the combination of diuron plus Reflex® applied IBS followed by DFF post-emergent. This treatment resulted in a grain yield reduction of 79%. The addition of Intercept® to this treatment did not increase the level of damage further.

Reflex® application rates in the herbicide tolerance trials (Alford, Bute 1) were set at 1000mL/ha for all treatments. However, in the weed control trials (Bute 2 & 3), rates of 500mL/ha, 750mL/ha and 1000mL/ha were applied. Grain yield loss at the alkaline sand trial (Bute 3) varied depending on the rate applied with the 500, 750 and 1000mL/ha rates yielding 83%, 76% and 46% of the untreated, respectively (Pr(>F) = <0.001). This indicates that if rates can be reduced and weed control is still maintained, the crop safety margin can be improved.

Seasonal effect of crop safety

It is important to note that season and rainfall patterns are likely to influence herbicide movement and activity in soil and the effect this has on the crop. All the above crop safety data is from the 2021 season. Reflex® was also included in 2020 trials 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, with June 2021 rainfall receiving

56mm compared to 19mm in June 2020 (Figure 4). Bute sites received 63 mm rainfall in June 2021 (Table 4). Greater spring rainfall in 2020 is also likely to have contributed to better crop recovery.

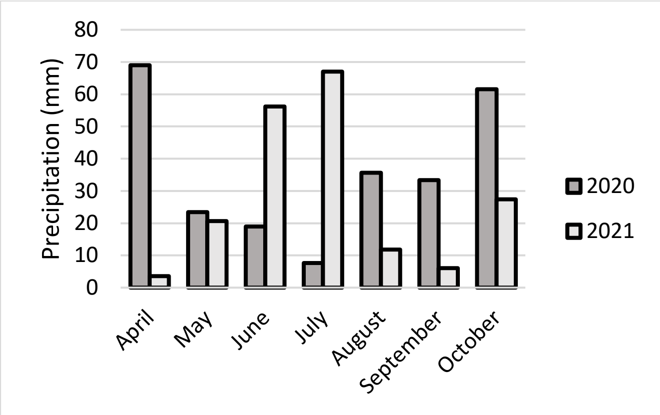

Figure 4. Growing season rainfall recorded at the Alford community weather station.

Table 4. Daily rainfall received at Bute sites after sowing till June 30, 2021.

Date	Rainfall received (mm)	Date	Rainfall received (mm)
7/06/2021	3.3	18/06/2021	1.8
8/06/2021	19.5	19/06/2021	1.1
9/06/2021	3.3	20/06/2021	0.1
10/06/2021	0.3	23/06/2021	1.0
11/06/2021	1.2	24/06/2021	3.9
13/06/2021	0.7	25/06/2021	4.7
15/06/2021	5.4	26/06/2021	0.2
16/06/2021	0.8	27/06/2021	0.3
17/06/2021	15.3	28/06/2021	0.1

Broadleaf weed control

Reflex® was effective in controlling 94-98% of bifora at rates of between 500 and1000mL/ha (Table 5). Application of 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 sow thistle control at all sites where it was present (Tables 5 and 7).

Intercept® did not provide adequate control of Indian hedge mustard (IHM) and was not significantly different to the untreated control at the clay loam site (Bute 2) (Table 5). Similar results for poor IHM control with Intercept® occurred at the other three sites (Tables 6 and 7). 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. This suggests that strategic use of IMI herbicides in combination with alternative modes of action is needed to delay the increase of resistant broadleaf weeds or to manage already resistant populations.

Table 5. Effect of herbicides on broadleaf weeds and their seed set on clay loam soils at Bute 2, 2021.

Herbicide treatment (commercial product rate)	**Rate (Product)**	**Seed bearing bifora plants/m²**	**Bifora seeds set/m²**	**IHM pod set/m²**	**Common sow thistle plants/m²**	**Common sow thistle pod set/m²**
Intercept®	600 mL/ha (Post)	0.1^{de}	0.4^{c}	731^{a}	1.4^{bc}	4^{de}
Metribuzin 200 g/ha (PSPE)		14.3^{c}	323^{b}	1^{de}	0^{d}	0^{f}
Reflex® 500 ml/ha (IBS)		5.9^{cd}	35^{c}	217^{bc}	2.6^{b}	12^{bcd}
Reflex® 500 ml/ha (IBS) + Intercept® 600 ml/ha (POST)		0^{e}	0^{c}	409^{ab}	0.4^{cd}	1^{ef}
Reflex® 500 ml/ha (IBS) + Metribuzin 200 g/ha (PSPE) + Intercept® 600 ml/ha (POST)		0^{e}	0^{c}	24^{de}	0^{d}	0^{f}
Reflex® 500 ml/ha (IBS) + Terbyne® 1000 g/ha (IBS) + Intercept® 600 ml/ha (POST)		0.1^{de}	0.4^{c}	0^{e}	0^{d}	0^{f}
Reflex® 750 ml/ha (IBS)		2.0^{de}	7^{c}	64^{cde}	3.1^{b}	15^{abc}
Reflex® 750 ml/ha (IBS) + Intercept® 600 ml/ha (POST)		0^{e}	0^{c}	81^{cde}	0.2^{cd}	1^{ef}
Reflex® 750 ml/ha (IBS) + Metribuzin 200 g/ha (PSPE) + Intercept® 600 ml/ha (POST)		0^{e}	0^{c}	0^{e}	0^{d}	0^{f}
Reflex® 750 ml/ha (IBS) + Terbyne® 1000 g/ha (IBS) + Intercept® 600 ml/ha (POST)		0^{e}	0^{c}	10^{de}	0^{d}	0^{f}
Reflex® 1000 ml/ha (IBS)		5.4^{cd}	21^{c}	24^{de}	2.6^{b}	21^{ab}
Terbyne® 1000 g/ha (IBS)		52.7^{b}	1672^{a}	105^{cd}	1.2^{bc}	5^{cde}
Unweeded control		97.2^{a}	1987^{a}	836^{a}	7.3^{a}	29^{a}

Table 6. Effect of herbicides on Indian hedge mustard (IHM) and their seed set on sandy alkaline soils at Bute 3, 2021.

Herbicide treatment (commercial product rate)	IHM/m^2 (120 DAS)	IHM pods/m^2 (135 DAS)
Diuron 550 g/ha (PSPE)	0.2[bc]	1[b]
Intercept® 600 ml/ha (POST)	5.6[a]	118[a]
Metribuzin 180 g/ha (PSPE)	0.6[b]	13[b]
Reflex® 500 ml/ha (IBS)	0.6[b]	5[b]
Reflex® 500 ml/ha (IBS) + Diuron 550 g/ha (PSPE)	0[c]	0[b]
Reflex® 500 ml/ha (IBS) + Diuron 550 g/ha (PSPE) + Intercept® 600 ml/ha (POST)	0[c]	0[b]
Reflex® 500 ml/ha (IBS) + Metribuzin 180 g/ha (PSPE)	0[c]	0[b]
Reflex® 500 ml/ha (IBS) + Metribuzin 180 g/ha (PSPE) + Intercept® 600 ml/ha (POST)	0.2[bc]	5[b]
Reflex® 750 ml/ha (IBS)	0[c]	0[b]
Reflex® 1000 ml/ha (IBS)	0[c]	0[b]
Unweeded control	6.3[a]	154[a]

Reflex® applied at 1000mL/ha IBS was effective at controlling IMI resistant IHM populations at this location. The level of weed control improved with increasing Reflex® rates from 500mL/ha (217 IHM pods/m^2) to 1000mL/ha (24 IHM pods/m^2) (Table 5). Most of the surviving IHM plants in Reflex® treated plots were found in the in-row spaces, from where the applied herbicide was likely moved out by the seeding operation. Where Reflex® was applied IBS and followed by a Group 5 herbicide, metribuzin or Terbyne® as a PSPE application, the surviving weeds in the in-row area were mostly controlled. Reflex® also proved more effective against capeweed (93% control) compared to Intercept® (48% control) (Table 7).

Intercept® application was the stand-out herbicide for achieving medic control in these trials, particularly at the acidic site where the next best treatment only achieved 38% control. Therefore, to achieve the desired level of broadleaf weed control in lentil, it is important to know the likely weed types, population, and resistance status prior to deciding on herbicide treatment.

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 5 and Group 12 herbicides provide broad-spectrum broadleaf weed control in lentil. Group 2 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 IMI herbicides, metribuzin, Terbyne® or diuron, will diversify the selection pressure for broadleaf weed control in lentil and delay the resistance build up to a specific mode of action.

Table 7. Broadleaf weed control with herbicide treatments on an alkaline and acidic sandy soil at Alford and Bute 1, respectively, in 2021.

	Alkaline sand				Acidic sand				
Herbicide treatment (commercial product rate)	**Medic control (%)**	**IHM control (%)**	**Wild turnip control (%)**	**Common sow thistle control (%)**	**Medic control (%)**	**IHM control (%)**	**Wild turnip control (%)**	**Common sow thistle control (%)**	**Capeweed control (%)**
Nil	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}	0^{a}
Diuron 830 g/ha (IBS)	63^{b}	93^{cd}	100^{c}	96^{b}	38^{abc}	80^{b}	82^{b}	84^{cd}	76^{bcde}
Terbyne® 750 g/ha (IBS)	78^{bc}	96^{cde}	100^{c}	96^{b}	30^{abc}	87^{bc}	78^{b}	90^{cd}	87^{defg}
Metribuzin 180 g/ha (IBS)	53^{ab}	74^{ab}	98^{b}	48^{a}	4^{ab}	73^{b}	76^{b}	57^{b}	62^{abc}
Intercept® 500 ml/ha (POST)	93^{d}	70^{ab}	98^{b}	85^{b}	80^{ef}	0^{a}	100^{d}	84^{c}	48^{ab}
Diuron 830 g/ha (IBS) + Intercept® 500 ml/ha (POST)	89^{cd}	96^{de}	100^{c}	96^{b}	$70b^{cde}$	70^{b}	99d	97^{ef}	74^{abcd}
Diflufenican 150 ml/ha (POST)	53^{ab}	100^{g}	100^{c}	93^{b}	42^{abcd}	100^{e}	100^{d}	90^{cd}	90^{cdef}
Diuron 830 g/ha (IBS) + Diflufenican 150 ml/ha (POST)	58^{b}	100^{g}	99^{c}	100^{b}	90^{efg}	100^{e}	100^{d}	100^{f}	99^{gh}
Diuron 830 g/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept® 500 ml/ha (POST)	91^{d}	100^{g}	100^{c}	96^{b}	98^{fg}	100^{e}	100^{d}	100^{f}	99^{gh}
Reflex® 1000 ml/ha (IBS)	54^{ab}	96^{de}	99^{c}	93^{b}	0^{a}	93^{cd}	94c	94^{de}	93^{efgh}
Reflex® 1000 ml/ha (IBS) + Intercept® 500 ml/ha (POST)	88^{cd}	$96e^{fg}$	100^{c}	100^{b}	80^{cde}	97^{d}	100^{d}	100^{f}	91^{efgh}
Reflex® 1000 ml/ha (IBS) + Diflufenican 150 (POST)	57^{b}	100^{g}	100^{c}	100^{b}	78^{def}	100^{e}	100^{d}	100^{f}	98^{fgh}
Reflex® 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept® 500 ml/ha (POST)	93^{d}	100^{g}	100^{c}	100^{b}	100^{g}	100^{e}	100^{d}	100^{f}	100^{h}
Diuron 830 g/ha (IBS) + Reflex® 1000 ml/ha (IBS)	72^{bc}	97^{def}	99^{c}	93^{b}	18^{ab}	96^{d}	97c	91^{cd}	95^{efgh}
Diuron 830 g/ha (IBS) + Reflex® 1000 ml/ha (IBS) + Intercept® 500 ml/ha (POST)	87^{cd}	96^{de}	100^{c}	96^{b}	88^{efg}	97^{d}	100^{d}	100^{f}	91^{defg}

Diuron 830 g/ha (IBS)+ Reflex® 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST)	75^{bc}	100g	100^{c}	100^{b}	66^{cde}	100^{e}	100^{d}	100^{f}	99^{gh}
Diuron 830 g/ha (IBS) + Reflex® 1000 ml/ha (IBS) + Diflufenican 150 ml/ha (POST) + Intercept® 500 ml/ha (POST)	93^{d}	100^{fg}	100^{c}	100^{b}	86^{efg}	100^{e}	100^{d}	100^{f}	100^{h}
Weed density in nil (weeds/plot)	159	91	56	9	16	119	87	22	39
Weed density in nil (weeds/m^2)	10.6	6.1	3.7	0.6	1.1	7.9	5.8	1.5	2.6

Acknowledgements
The research undertaken as part of this project is made possible by the significant contributions of growers through both trial cooperation and the support of the GRDC, the authors would like to thank them for their continued support. The authors also thank SAGIT for their support. The help received from SARDI Clare team in the field work is greatly appreciated. Authors also thank Jason Sabeeney for making available the herbicide Reflex® for the current research studies.

References
Trengove S, Sherriff S, Bruce J (2021) Increasing reliability of lentil production on sandy soils. Proceedings GRDC Grains Research Update, Adelaide, February 2021, pp. 99-106.

Contact details
Jordan Bruce
Trengove Consulting
jordanpbruce@gmail.com