Getting the best out of Imidazolinone (IMI) herbicides in tight Group B tolerant break and cereal crop rotations

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Abstract
The increased availability of Group B tolerant break crop and cereal crops has resulted in high usage for imidazolinone (IMI) herbicides in continuous cropping systems. Over-reliance on IMI herbicides has increased the risk of shifting weed flora, and resistance build-up in weeds. To develop sustainable use patters for IMI chemistries, multiple herbicide strategies were investigated in a lentil-canola-wheat-barley system in South Australia's Mid-North, and a lentil-wheat-lentil-wheat system in Yorke Peninsula, during 2018 and 2019. The greatest benefit from IMI herbicides to manage broadleaf weeds in a systems approach were obtained by their usage in the break crop phase, with the succeeding cereal crop getting advantages of imazapyr, imazamox and imazapic residues remaining from previous season. Use of IMI herbicides in two consecutive years, i.e. in break crop phase and the subsequent cereal crop, did not provide additional benefit for broadleaf weed control. Rotating herbicides with alternative modes of action in the cereal phase – such as LVE MCPA (Group I), Clopyralid (Group I), Bromoxynil + Dicamba (Group C and I), MCPA Amine (Group I), Affinity (Group G), and Paradigm (Group I + B) – improved bifora, bedstraw and vetch control in tight Group B tolerant break and cereal crop rotations. Use of chlorsulfuron in wheat (on label) instead of lentil (off-label industry practice) provided extra benefits for bifora control in the lentil-wheat sequence. Rotating IMI herbicides with other modes of action in a system approach will reduce the selection pressure and sustain these chemistries as a valuable broadleaf and grass weed management tool.

Key words: Broadleaf weeds, canola, lentil, wheat, barley

Introduction
The availability of Group B imidazolinone (IMI) herbicide tolerant break crop options including XT lentil, Clearfield® canola, and PBA Bendoc faba bean have broadened weed control options, especially for hard to control grass weeds such as brome grass and multiple broadleaf weeds (Boutsalis *et al*, 2016). This, coupled with better economic returns and improved harvest efficiency, has increased their adoption by South Australian (SA) growers. Traditionally, break crops were included once every three to six years in the crop rotation, however their frequency has now increased and, in some regions, has become equal to cereal crops or even greater in some cases.
The increased adoption of IMI herbicide tolerant break crops has resulted in over-reliance on IMI herbicides. Moreover, availability of multiple Clearfield® resistant cereal crops (wheat and barley), and now an IMI-tolerant oaten hay crop, has provided multiple IMI tolerant crop options across both cereal and break crop phases. The increased reliance on IMI herbicide tolerant break crops and recurrent use of IMI herbicides for broadleaf weed control has increased the risk of resistance build-up to these important herbicides in weeds. This is well supported by the findings of Boutsalis *et al* (2016) from their random surveys in different regions of SA that recorded 33% of surveyed paddocks with resistant wild turnip in the SA Mallee region and 13-14% paddocks with Indian Hedge Mustard resistant to the IMI herbicide Intervix®. Similarly, common sowthistle has been reported to develop resistance to imazamox + imazapyr, and imazapic in 65 and 88% respectively of the high break crop intensity (HBCI) paddocks (paddocks with at least two break crops in last 5-6 years) in SA (Aggarwal *et al*, 2019).

Another key concern is the development of cross-resistance within a group of herbicides having the same mode of action. A weed population that is resistant to sulfonylureas can be cross-resistant to IMI herbicides, even if the population has never been exposed to IMIs (Boutsalis and Powles, 1995). It has been observed that 50% of the common sowthistle populations resistant to sulfonylureas were cross-resistant to IMI herbicides from the paddocks where IMI herbicides were not used in last 5-6 years (Aggarwal *et al*, 2019). This suggests a need to develop sustainable methods for use of IMI-crops in HBCI systems with tight Group B tolerant break and cereal crop rotations that involve the regular use of different IMI herbicides. The judicious inclusion of diverse mode of action herbicides along with reduced use of AHAS chemistries in crop rotations has the potential to increase the heterogeneity of the selection pressure and reduce or delay the build-up of IMI-herbicide resistant weeds (Boutsalis *et al*, 2016).

In the GRDC-SARDI funded project DAS00168BA, research was undertaken to develop strategies for sustainable use of IMI chemistries in HBCI systems. The research investigated whether to use IMI herbicides in the break crop phase or cereal phase, the frequency of IMI use in a crop rotation, and the carryover effect on following cereal or break crops with respect to impact on broadleaf weeds.

Methods

A canola-wheat-barley-lentil system-based trial was established at the Hart field site (Mid-North) in 2017, to investigate sustainable use of IMI herbicides in tight Group B tolerant break and cereal crop rotations. Vetch and bedstraw seeds were sown in 2017 to build up the weed population at the trial site, with treatments initiated from 2018. Another lentil-wheat-lentil-wheat system-based trial was established in 2018 at farmer's paddock in Bute (Yorke Peninsula) having a background population of bifora. The trials were sown by using a no-till plot seeder fitted with knife-point tines and press wheels. Plots were 10 m long and contained 12 crop rows spaced 22.5 cm apart. The experiments were laid out in a split plot design at Hart and split-split plot design at Bute with four replications. Sowing at Hart was done on June 5, 2018 and May 30, 2019, and at Bute on June 19, 2018 and May 8. The crop season rainfall at Hart was 129 mm and 132 mm and at Bute was 142 mm and 182 mm in 2018 and 2019, respectively.

Herbicides used at Hart in 2018 and 2019:

a) Canola: Lontrel (Group I) post sowing (POST) ± OnDuty (Group B) POST
b) Wheat: Eclipse (Group B) POST + LVE MCPA (Group I) POST + Clopyralid (Group I) POST ± OnDuty (Group B) POST
c) Barley: Bromoxynil + Dicamba (Group C and I) POST ± Imazamox + imazapyr (Group B) POST
d) Lentil: Metribuzin (Group C) post sowing, post emergence (PSPE) + Broadstrike (Group B) or Imazamox + imazapyr (Group B) POST

Herbicides used at Bute in 2018:

a) Wheat: {MCPA Amine (I) POST + Affinity (G) POST} ± {Paradigm (I + B) + LVE-MCPA (I)} ± OnDuty (B) POST
b) Lentil: Metribuzin (C) PSPE + Broadstrike (B) or Imazamox + imazapyr (B) POST ± chlorsulfuron incorporated by sowing (IBS)

Herbicides used at Bute in 2019:

a) Wheat: {MCPA Amine (I) POST + Affinity (G) POST} ± chlorsulfuron ± OnDuty (B) POST
b) Lentil: Metribuzin (C) PSPE + Broadstrike (B) or Imazamox + imazapyr (B) POST ± chlorsulfuron (IBS)

IMI herbicide residue testing in the soil:

Soil samples were taken from three random spots in each plot before sowing of the second year crop and bulked depth wise at 0-10 cm, 10-30 cm, and 30-50 cm of the soil layer to study the residues of imazapyr, imazamox and imazapic from the previous season.

Results and discussion

At Hart, the use of non-IMI herbicides LVE MCPA (Group I) POST + Clopyralid (Group I) POST + Eclipse (Group B) POST in wheat, and Bromoxynil + Dicamba (Group C and I) POST in the barley phase resulted in similar levels of vetch and bedstraw bifora control as achieved with both non-IMI + IMI herbicides (OnDuty POST in wheat, and Imazamox + imazapyr POST in barley) in the lentil-canola-wheat-barley system in 2018 and 2019 (Tables 1 and 2). Furthermore, non-IMI herbicides alone provided a similar level of vetch control in canola, and bedstraw control in the lentil phase, compared to the use of both non-IMI + IMI herbicides. The use of IMI-herbicides was essential for control of vetch in the lentil phase and bedstraw in the canola phase in 2018. The results were similar in 2019, with the exception that non-IMI herbicides provided effective for control of vetch in lentil and bedstraw in canola (Table 2). A very low rainfall (35 mm) from POST herbicide application until harvest in 2019 may have resulted in lower seed set on stressed vetch and bedstraw plants in non-IMI treatments as well. There was no added benefit in controlling vetch and bedstraw with the additional use of an IMI herbicide in the 2019 cereal crop that followed an IMI herbicide used in the 2018 break crop phase. This might be due to residues of imazapyr and imazapic up to 2.3 and 6.3 ng/g of soil, respectively detected in top 0-10 cm layer at sowing of cereal plots in 2019 from their usage in 2018 break crop plots.

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Table 1. Vetch and bedstraw seed set as affected by different herbicide treatments in lentil-canola-wheat-barley system at Hart in 2018

Crop	Vetch seed set/m^2		Bedstraw seed set/m^2	
	IMI frequency			
	Only non-IMI herbicides	IMI herbicides + non-IMI herbicides	Only non-IMI herbicides	IMI herbicides + non-IMI herbicides
Canola	0[b]	0[b]	78[a]	0[b]
Wheat	0[b]	0[b]	0[b]	0[b]
Barley	0[b]	0[b]	0[b]	0[b]
Lentil	122[a]	11[b]	0[b]	0[b]

Table 2. Vetch and bedstraw seed set as affected by different herbicide treatments in lentil-canola-wheat-barley system at Hart in 2019

Crop	Vetch seed set/m^2			Bedstraw seed set/m^2		
	Only non-IMI herbicides in two years	IMI herbicides only in 2018 + non-IMI herbicides (2018 and 2019)	IMI herbicides twice in two years (2018, 2019) + non-IMI herbicides (2018 and 2019)	Only non-IMI herbicides in two years	IMI herbicides only in 2018 + non-IMI herbicides (2018 and 2019)	IMI herbicides twice in two years (2018, 2019) + non-IMI herbicides (2018 and 2019)
Canola	0	0	0	0	0	0
Wheat	1.4	0	0	0.5	2.5	0
Barley	0.1	0.7	0	0	0.1	1.0
Lentil	0	0.3	0	0	0	0
LSD 5%	NS			NS		

In a lentil-wheat-lentil-wheat system trial at Bute in 2018, the use of non-IMI herbicides (MCPA Amine (I) POST + Affinity (G) POST, and Paradigm (I + B) + LVE-MCPA (I)) in wheat was the best option for controlling bifora, and provided a similar level of weed control to the use of both non-IMI + IMI herbicides (OnDuty POST) (Figure 1). Further, MCPA Amine POST + Affinity POST combination proved equally effective for bifora control (8 bifora seeds/m^2) in wheat as the same treatment with additional sprays of Paradigm + LVE-MCPA POST (17 bifora seeds/m^2). On the other hand, IMI herbicide was essential for bifora control in lentil. Further, use of Imazamox + imazapyr (POST) achieved a similar level of bifora control (107 bifora seeds/m^2) compared to the common off-label industry practice of chlorsulfuron (IBS) + Imazamox + imazapyr (POST) (158 bifora seeds/m^2).

In 2019, again non-IMI herbicides alone were as effective as non-IMI + IMI herbicides in wheat (Table 3). Additional application of chlorsulfuron along with MCPA Amine + Affinity proved a more effective broadleaf weed control strategy in wheat that followed the IMI lentil phase compared to wheat that followed a non-IMI lentil phase. Similarly, there was improved bifora control in lentil that followed a wheat crop with IMI herbicide used in the previous season compared to lentil that followed a wheat crop without IMI herbicide, although overall level of bifora control was higher in wheat plots.

Further, in a lentil-wheat sequence, use of IMI herbicides once in two years in the lentil phase and no-IMI herbicides in succeeding wheat proved as effective as IMI herbicides used both in lentil and wheat crops consecutively (Table 3). This might be due to residues of imazapyr and imazamox up to 1.8 and 1.5 ng/g of soil, respectively detected in top 0-10 cm layer at sowing of wheat plots in 2019 from their usage in 2018 lentil plots. Therefore, using IMI herbicides in the break crop phase and saving it in cereal phase proved a better strategy, and using chlorsulfuron in wheat (on label) instead of lentil (off-label industry practice) provided extra benefits for bifora control in the lentil-wheat sequence.

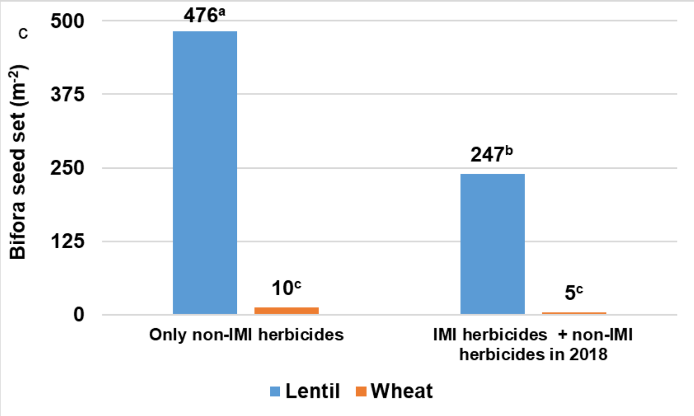

Figure 1. Bifora seed set in wheat and lentil as affected by IMI and non-IMI herbicides at Bute in 2018

Table 3. Effect of herbicides on bifora management in wheat and lentil at Bute in 2019

Crop	Strategy	Bifora seed set/m^2		
		IMI frequency		
		Twice in two years (2018 and 2019)	Used only in 2018	No IMI use
Lentil	S1 (without chlorsulfuron)	362^c	940^b	2458^a
	S2 (with chlorsulfuron)	1^e	0^e	0^e
Wheat	S1 (with chlorsulfuron)	0^e	2^e	23de
	S2 (without chlorsulfuron)	16de	47de	122^{cd}

Conclusion

The developing resistance to imidazolinone (IMI) herbicides to broadleaf weeds is an emerging challenge for the grains industry. The selection pressure imposed by the frequent use of IMI herbicides for broadleaf weed control in high break crop intensity systems, has made the current weed management practices non-sustainable in the long term. A holistic approach of using multiple IMI tolerant crops (wheat, barley, oaten hay, canola, lentil, faba bean) in a judicious and sustainable manner in the cropping rotation is essential to maintain this herbicide tolerance technology as an effective broadleaf management tool. Adopting improved weed management practices by rotating IMI herbicides with other modes of action in a systems approach will reduce the selection pressure on broadleaf weeds, especially for Group B herbicides. This will allow the industry to continue achieving break crop benefits in terms of N-fixation from pulses, a subsequent yield increase in the following rotational crops, disease breaks for cereal crops, and higher monetary returns depending on market prices.

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