Herbicide resistance threats for SNSW and economics of impact mills

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Take home message

- Growers are urged to restrict annual ryegrass population densities to help mitigate the ongoing and widespread evolution of herbicide resistance in this weed species
- Annual ryegrass and sowthistle are at high risk for the evolution of herbicide resistance and a range of weed control strategies are required for the effective management of these species
- Efficient harvester setup and operation can potentially be used to offset the increased costs of using impact mills during the harvest of high yielding crops.

Background

The NSW crop production region covers a diverse range of growing season conditions. Rainfall patterns vary markedly across the region, from summer dominant in the north to winter dominant in the south. Accordingly, the winter growing seasons are longer and cooler in the south, supported primarily by in-season rainfall and shorter and warmer in the north with greater crop reliance on stored soil moisture (Figure 1). As production practices are adapted to changing climates, regional variability in production practices can provide insights into future weed problems. For example, in southern NSW with an apparent shift in focus on soil moisture storage during summer fallow phases for use by subsequent winter crops, summer weed control will become increasingly important along with the need to avoid resistance evolution in summer weed species.

The use of herbicides to successfully control crop weed infestations has been integral to the success of conservation cropping systems in southern NSW and elsewhere in Australia. But over reliance on herbicides has led to the widespread evolution of herbicide resistant weed populations, particularly in annual ryegrass that is by far the most dominant weed of this region (Broster *et al.* 2019). As demonstrated by high frequencies of multiple resistant annual ryegrass populations across many Australian cropping regions (Boutsalis *et al.* 2012; Owen and Powles 2018) this weed is especially prone to resistance evolution. Multiple resistance means the loss of multiple herbicides for the control of annual ryegrass and as this weed is by far the most prolific weed in southern NSW cropping, this means the loss of these herbicides for use on other weeds also. The introduction of harvest weed seed control has helped to reduce the reliance on herbicides, however there are several constraints that prevent the use of these systems in every crop.

Methods

Weed species and herbicide resistance surveys

Over the five-year period from 2013 to 2017, approximately 1,000 cropping paddocks across New South Wales were surveyed at winter crop maturity (Nov. and Dec.) (Figure 1). Each year 75 to 150 paddocks depending on the size of the cropping region were surveyed, with weed species and density data recorded and seed samples collected for subsequent screening.

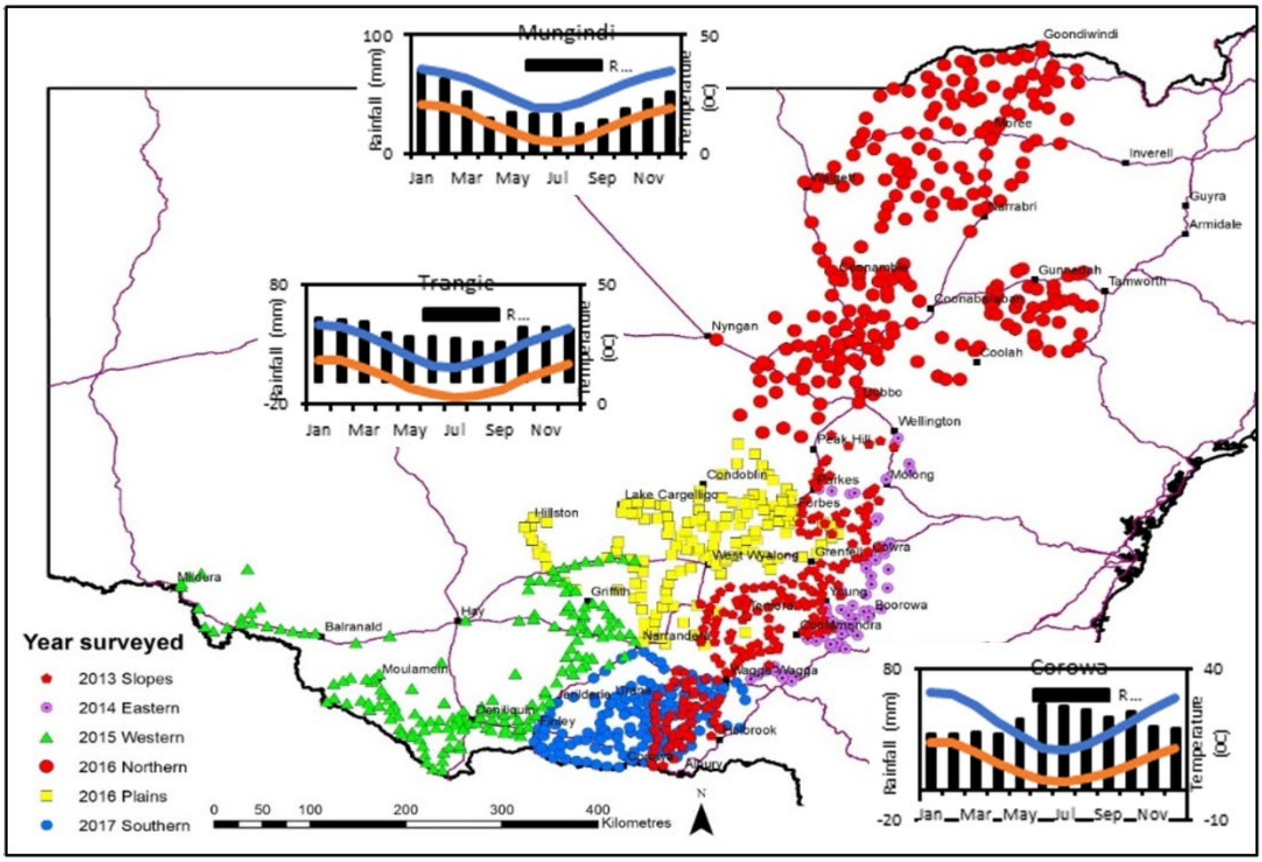

Figure 1. Location of cropping paddocks surveyed in each of the NSW cropping regions during random weed seed collection surveys conducted at the end of each growing season from 2013 to 2017. Embedded line and bar graphs depict long-term (60+ years) monthly average rainfall and temperature data for three representative locations that indicate growing season differences across the cropping region (Bureau of Meteorology 2021).

Herbicide resistance screening

When weed seedlings had reached the three to five leaf stage, herbicide treatments were applied at the upper recommended label rate for each herbicide to the weed species being screened. Herbicides were applied together with appropriate adjuvants (if required) using a twin-nozzle (TeeJet XR110015, Springfield, IL, USA) cabinet sprayer calibrated to deliver 85 L water ha^{-1} at 250 kPa.

Plant mortality was assessed 21 days after treatment, by determining whether the growing point was chlorotic or new growth was visible, as well as comparing with the known susceptible populations. Known susceptible and resistant plant biotypes were used as controls in all experiments, with 100% control of the known susceptible population and high survival (e.g., >90%) of the known resistant populations. In cases where the seed quantity for a population was low, some herbicides were omitted and not all herbicide treatments were repeated. Herbicide resistance screening was conducted under 'ideal' conditions for plant seedling growth, herbicide treatment and treatment effects thus, herbicide efficacy in the field may be lower than was observed in this survey.

Populations were classified as herbicide resistant when >20% of plants survived the upper recommended rate.

Economics of impact mill systems

The costs of using impact mills were compared using the calculator developed by Peter Newman, a farm business consultant with Planfarm. Three scenarios were compared using this calculator and defined cost parameters (Table 1).

- **Scenario one:** influence of higher yielding crops (wheat 5.0 t/ha, legume 3.0 t/ha and canola 3.0 t/ha) on impact mill costs
- **Scenario two:** influence of harvester operation (chaff yield as a % of grain = 0.1) on impact mill costs.
- **Scenario three**: influence of the doubling of nitrogen fertiliser prices on HWSC system use costs.

Table 1. Economic and agronomic parameters used when comparing the influence of harvest scenarios on the operation costs of impact mill systems.

Crops	**Area (ha)**	**Yield (t/ha)**
Cereal	1500	2.5
Legume	750	1.5
Canola	750	1.5
		total tonnes of grain
Total crop area (ha)	3000	6000
Number of harvesters	1	those fitted with HWSC tool
Chaff yield as % of grain yield	0.33	
Fertiliser		$/unit
Urea price ($/t)	500	1.00 N
Muriate of potash price ($/t)	600	1.21 K
MAP price ($/t)	685	2.66 P
Ammonium sulphate ($/t)	280	0.29 S
Operating costs		
Depreciation %	10	
Interest %	4	
Harvest cost $/hour	400	per harvester and chaser bin
Harvest rate ha/hour	10	
Harvest cost $/ha	40	
On farm fuel cost ($/L)	1.10	
Extra fuel due to impact mill (L /t grain harvested)	1	
% reduction in harvest capacity	10	
Wearing parts cost ($/per t grain)	1	$ per t grain
Impact mill	Fitted cost ($)	
Vertical iHSD ®	90,000	
Seed Terminator	120,000	
Redekop™	110,000	

Results and discussion

Weed species occurrence

In SNSW the frequency of occurrence for annual ryegrass (82%) and wild oats (68%) in the weed survey was more than double that of any of the other recorded species.

Sowthistle (25%) was the next most prolific weed of SNSW recorded during these surveys as mature plants at the end of the winter growing season (Table 2). This species is also summer growing and where soil moisture is adequate can be expected to emerge and establish at any stage during summer and winter growing seasons. As sowthistle is prolific, resistance prone and favoured by no-till cropping systems, this will continue to become increasingly difficult to manage in SNSW cropping systems (Chauhan *et al.* 2006; Widderick *et al*. 2010; Werth *et al.* 2017).

Table 2. Five most commonly observed winter annual weed species of the NSW cropping regions as recoded at winter crop harvest during annual random surveys conducted over a five-year period, 2013 to 2017 (number in brackets represent percentage of occurrence in surveyed fields)

Ranking	NSW average 2013 to 2017	Southern NSW 2017
1	Ryegrass (68.5)	**Ryegrass (81.5)**
2	Wild oats (59.9)	**Wild oats (67.9)**
3	Sow thistle (34.2)	**Sow thistle (25.3)**
4	Barley grass (17.0)	**Brome grass (13.6)**
5	Wireweed (15.4)	**Barley grass (8.6)**

Herbicide resistance in southern NSW

Annual ryegrass and wild oats

The very high potential for herbicide resistance evolution in annual ryegrass populations ensures that this species will continue to dictate weed management programs in southern NSW. Very high frequencies of Group 1 (A) (fop only) and 2 (B) (su and imi) herbicide resistant annual ryegrass populations were present throughout the southern NSW cropping region (Table 3). These high levels of resistance to post-emergence selective herbicides, has led to increased reliance on residual herbicides for control of annual ryegrass. There were also significant levels of Group 1 (fop only) resistance found in wild oat populations (Table 3). As annual ryegrass is the most frequently occurring weed across the region then resistance in annual ryegrass must often be first considered before strategies to manage other weeds can be formulated. This can complicate the strategies needed to control populations where multiple weeds are present.

Table 3. Frequency of resistance to commonly used herbicides in randomly collected annual ryegrass and wild oat populations collected from the 2017 winter crop survey of southern NSW cropping paddocks (Resistant = >20% survival)

Herbicide group		Herbicide[a]	Annual ryegrass	Wild oats
Old	New		Resistant populations (%)	
A (fop)	1 (fop)	Diclofop /clodinafop	85	30
A (dim)	1 (dim)	Clethodim	3	0
B (SU)	2 (SU)	Sulfometuron / iodosulfuron	74	0
B (Imi)	2 (Imi)	Imazamox + imazapyr	75	-
D	3	Trifluralin	1	-
J	15	Triallate	-	0
J/K	15	Prosulfocarb + s-metolachlor	0	-
K	15	Pyroxasulfone	0	-
M	9	Glyphosate	7	0

[a]Herbicides applied at the upper recommended rate; - indicates not screened with this herbicide

Sowthistle

There is a very high frequency of chlorsulfuron resistance in NSW populations of sowthistle (94%) Resistant populations were found to be uniformly distributed throughout the NSW and Qld cropping regions (Figure 2A). In contrast, few if any chlorsulfuron susceptible sowthistle populations were found outside of the southern NSW cropping region.

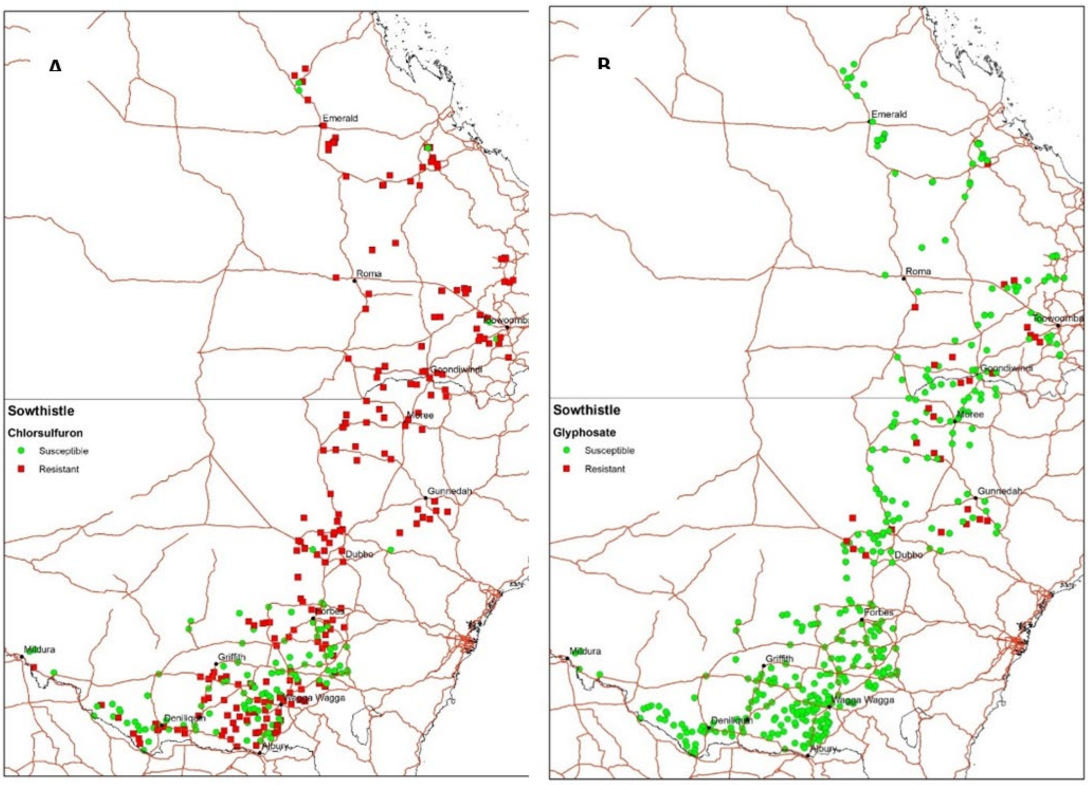

Figure 2. Maps showing (A) chlorsulfuron resistant and susceptible and (B) glyphosate resistant and susceptible populations of sowthistle that were randomly collected during an end-of-season random surveys of the northern grain's region in 2016.

A concerningly high frequency of glyphosate resistance was identified in randomly collected sowthistle (14%) populations (Figure 2B). The majority of the resistant populations were collected from the northern areas of the survey region where there has been an intense selection pressure for glyphosate resistance due to the reliance on this herbicide for summer fallow weed control over many years. As sowthistle is prolific throughout southern NSW, the concern is that an increasing focus on summer fallow weed control will result in similar levels of resistance in this region.

Economic considerations of impact mill systems

Influence of crop harvest program

When grain yields are increased (doubled) as occurred in many areas this last harvest, the costs of running impact mills are estimated to have increased by $4 to $5/ha (Table 4). This cost is related to the increased time taken to harvest a hectare which translates to greater fuel use and wear per unit area. Consequently, the cost of using an impact mill is estimated to increase from around $14 to $18/ha.

Table 4. Predicted influence of high crop yields on the operating costs of impact mills during grain crop harvest

Impact mill	Average yield	High yield
	Cost ($/ha)	
Vertical iHSD	13	18
Seed Terminator	15	19
Redekop	14	18

Harvester setup and operation is becoming increasingly important for improving the efficiency of grain harvest. The original estimate of a 1:3 chaff to grain ratio used as a standard parameter here was based on research conducted several years ago prior to the current understanding of harvester setup and operation (Broster *et al.* 2016). More recently collected data suggests that chaff ratios are much lower when there is a focus on harvester setup (Broster *pers. Comm.*). The impact of reduced chaff production during a more efficient harvest operation results in an estimated $3/ha reduction in impact mill operation costs (Table 5).

Table 5. Predicted influence of harvester setup on the operating costs of impact mills during grain crop harvest

Impact mill	Standard chaff:grain ratio (0.33)	Low chaff:grain ratio (0.1)
	Cost ($/ha)	
Vertical iHSD	13	10
Seed Terminator	15	12
Redekop	14	11

When fertiliser inputs due to HWSC related nutrient removal (concentration in tramlines or windrows) are included in the cost calculations for HWSC systems, Impact mill systems are economically comparable to the other apparent ’cheaper‘ options such as chaff lining and chaff tramlining. The concentration and removal of harvest residues results in nutrient concentration into small areas (e.g., chaff lining, tramlining) or removal (e.g. baling, burning). As impact mill systems allow all residues and thus all nutrients contained in stubble and chaff to be retained in the paddock, then these systems are more ’nutrient efficient’. To compare the impact of increasing fertiliser prices on HWSC costs, a doubling of nitrogen fertiliser costs was used in comparison with the standard. In this scenario there was a $5 to $10/ha increase in cost for all but the impact mill HWSC systems. The indication is that nutrient placement costs can have a greater influence on HWSC system economics than operational costs during harvest (Table 6).

Table 6 Predicted Influence of higher nitrogen prices on the costs of using HWSC systems during grain crop harvest

HWSC system	N Unit price $1.00/kg	N Unit price $2.00/kg
	Cost ($/ha)	
Narrow windrow burn	35	45
Chaff line	16	21
Chaff Deck	17	22
Chaff cart	22	27
Bale Direct	73	88
Vertical iHSD	15	15
Seed Terminator	16	16
Redekop	16	16

Conclusion

The widespread distribution of annual ryegrass combined with the high frequencies of resistance in populations ensure that this weed will continue to dominate weed management decisions in southern NSW cropping programs. The ongoing challenge for the region's growers is to maintain very low densities of this weed in their cropping systems to slow the continuing evolution of resistance and loss of herbicide resources for the control of annual ryegrass and other weed species, such as wild oats. With an increasing focus on summer weed control there is increased pressure to select for glyphosate resistance evolution in sowthistle populations that are prolific throughout the region. As observed in other areas, over reliance on glyphosate has already resulted in widespread resistance in sowthistle populations. There are economic constraints to the use of impact mills during the harvest of higher yielding crops. However, there may an opportunity to mitigate this impact through improved harvest setup and operation.

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