Long term impact of harvest weed seed destruction on annual ryegrass

Catherine P.D. Borger[1] and Glen P. Riethmuller[2]
[1] Department of Agriculture and Food Western Australia, 75 York Road, Northam, Western Australia 6401, Australia
[2] Department of Agriculture and Food Western Australia, PO Box 432, Merredin, Western Australia 6415, Australia
(catherine.borger@agric.wa.gov.au)

Summary A long term trial (2003 to 2013) investigated annual ryegrass seed production in a crop rotation in Merredin, WA. The weed control methods in the trial included herbicides, or herbicides combined with weed seed destruction at harvest. Data from this trial was used to investigate varying scenarios of harvest weed seed destruction using the Weed Seed Wizard (WSW) model. The WSW demonstrated that herbicides plus weed seed destruction at harvest could reduce the annual ryegrass seedbank to very low levels over eight years. Use of herbicides alone did not reduce the seedbank to the same extent over the entire 11 year span of the trial. Harvest weed seed destruction in alternate years reduced the annual ryegrass seedbank to very low levels compared to use of herbicides alone.

Keywords *Lolium rigidum*, Weed Seed Wizard, model, seed production, residue burning, seedbank.

INTRODUCTION

Herbicide resistance is an increasingly severe problem throughout the world and successful weed control relies on the implementation of integrated weed management (IWM) programs. However, there is a general perception that IWM is difficult and expensive in the short term, compared to chemical weed control. It is important to present growers with IWM programs that are simple to implement and inexpensive in the short term, as well as financially rewarding in the long term.

A good example of a simple and inexpensive IWM technique is weed seed destruction at harvest, which can be achieved using a harvest seed destructor or chaff cart, or through residue burning (Walsh and Newman 2007, Walsh *et al.* 2013). Harvest weed seed destruction can destroy up to 85% of annual ryegrass (*Lolium rigidum* L.Gaud.) seed present at harvest time (Walsh *et al.* 2013, Walsh and Powles 2014). However, in a farm business it may not be possible to use harvest weed seed destruction in every year. Weed seed destruction using a seed destructor or chaff cart causes a delay to harvest, which may be unacceptable in those years where weather conditions will cause damage to the grain. Windrow burning may fail to effectively destroy weed seeds in some years, due to low residue levels or poor burning conditions (Walsh and Newman 2007).

A recent paper demonstrated that annual seed destruction at harvest can eradicate annual ryegrass over an 11 year period (Borger *et al.* 2016). However, the long term impact of occasional weed seed destruction at harvest has not been investigated. Computer simulations of weed growth under varying agronomic scenarios are an excellent way to formulate IWM programs, and demonstrate their long term efficiency and financial viability to growers. A useful model to assess IWM programs is the Weed Seed Wizard (WSW) (Department of Agriculture and Food Western Australia 2016). This model uses site specific soil type, weather records, and farm management records to simulate how different agronomic practices can affect density and seed production of a range of weed species. The current research utilised field data from the study by Borger *et al.* (2016) in the WSW model to investigate harvest weed seed destruction. We hypothesised that a standard crop rotation using herbicides alone would not adequately control annual ryegrass over an 11 year period, a system utilising herbicides plus weed seed destruction at harvest would eradicate annual ryegrass, and a system utilising weed seed destruction in alternate years would reduce but not eradicate annual ryegrass.

MATERIALS AND METHODS

The Weed Seed Wizard model The WSW is a computer simulation tool that allows the user to set weed species, crop and soil parameters, climate conditions from weather records and agronomic management events. The output interface produces results that include (but are not limited to) crop yield, size of the weed seedbank, and an economic analysis of the system. Full details of the model are included in Renton *et al.* (2008).

Field trial data to parameterise the model A trial was conducted from 1987 to 2013 at the Department of Agriculture and Food Western Australia (DAFWA)

Merredin Research Station (Borger *et al.* 2016). Crop species were sown at row spacings of 9, 18, 27 or 36 cm, and the crop residue was burnt or retained at the end of each winter annual growing season. Non-selective, pre-emergent and in crop herbicides were applied to control weeds, which predominately included annual ryegrass and Indian hedge mustard (*Sisymbrium orientale* L.). A chaff cart was used in 2003 to 2006. The herbicides successfully controlled wild mustard but the annual ryegrass remained in crop. Annual ryegrass seed production was assessed from 2003 to 2013. Full details of the results of this experiment from 2003 to 2013 are found in Borger *et al.* (2016).

Scenarios in the model The scenarios in the WSW model were based on the results of the field trial. Scenario 1 in the WSW model used data from the crop residue retained treatments and Scenario 2 used data from the residue burnt treatments. Both Scenarios assumed a row spacing of 18 cm.

The initial parameters loaded into the model were 'Southern WA grain region'. Under 'Scenario Setup' tab, the timeframe was 1 December 2002 to 31 December 2013. The initial annual ryegrass seedbank was set to 1500 seeds for Scenario 1 and 500 seeds for Scenario 2. This was because the annual ryegrass seedbank had reached higher levels in the plots where residue was retained (the seedbank had built up from 1987 to 2002). The soil type was 'Southern region – Silty clay loam', as the closest approximation to the actual soil type of the field trial, which was a mottled eutrophic red chromosol (Borger *et al.* 2016). A weather record was created from data generated by the DAFWA Merredin Research Station weather station (Department of Science Information Technology and Innovation 2016).

Each agronomic event (seeding, harvest etc.) and herbicide spray event that occurred in the field trial in Borger *et al.* (2016) was added to the WSW scenarios (Table 1).

Each harvest event in the WSW included date, crop species and harvest type. For Scenario 1, the harvest type was 'Chaff cart' for 2003 to 2006. However, the percent of weed seeds dropped in the field peas (in 2005) was increased from the default value of 20% to 80%, as Matthews *et al.* (1996) found that only 20% of the annual ryegrass seed was captured by a chaff cart in a pea crop. From 2007 to 2013, the harvest selected was 'All chaff spread/normal harvest'. However, crop lifters were used to lift/harvest a greater proportion of annual ryegrass seed heads, and so the percent of annual ryegrass seed dropped was adjusted from 99% to 96% in cereal and canola crops and left as 99% in the chickpea crop, based on the data in Borger *et al.* (2016). For Scenario 2, the harvest type was 'Narrow windrow and burning', as the closest approximation to burning all crop residue that was done in the initial field trial (Borger *et al.* 2016). However, the seed dropped was altered to 35% in the shorter field pea and chickpea crops. This was again based on the field pea data in Matthews *et al.* (1996), where only 65% of the annual ryegrass seed entered the harvester. 'Advanced Events' and 'Seed Drop' were selected in the WSW to indicate abscission of annual ryegrass seeds in the fallow of 2008.

Scenario 3 was used to investigate weed seed destruction at harvest in alternate years. Scenario 3 was the same as Scenario 2, but in every second year, 'Narrow windrow and burning' was replaced with 'All chaff spread/normal harvest'.

RESULTS

Over the 11 year span, the number of annual ryegrass seeds in the seedbank after harvest was greatest under Scenario 1, followed by Scenario 3 and Scenario 2 (Table 2). The number of seeds predicted by the WSW was similar, but not identical to the actual number of seeds observed by Borger *et al.* (2016). However, it should be noted that the WSW reports the total number of seeds in the soil seedbank, whereas the seeds observed in Borger *et al.* (2016) was only the annual ryegrass seed produced at harvest each year.

The income (and potential income) generated by each cropping system was greatest in Scenario 1 (Table 3). Income was similar in Scenario 2 and 3. The annual and total cost of weeds was greatest in Scenario 1, followed by Scenario 3 and 2 (total weed cost of \$104, \$35 and \$28 ha^{-1} over 11 years).

DISCUSSION

The prior research by Borger *et al.* (2016) noted that residue burning in each year (plus herbicide use) reduced annual ryegrass seed production to 0 seeds m^{-2} by 2011 (Table 2). The result from Scenario 2 in the WSW was similar, with the annual ryegrass seedbank reduced to 2 seeds m^{-2}. Again, it should be noted that the WSW accounts for all the seeds in the seedbank, not just the seeds added to the seedbank at harvest. Therefore, it is reasonable that the WSW seed number should be slightly higher than that observed by Borger *et al.* (2016). By comparison, herbicide use alone (no residue burning) did not reduce annual ryegrass seed production to zero, which was confirmed by Scenario 1 in the WSW. However, the WSW predicted a 'blow out' at the end of Scenario 1 (500 seeds in the 2013 seedbank) due to no in-crop herbicide. In reality, the Sakura herbicide used in 2013 was highly effective

Table 1. The crop sowing details, herbicide options and harvest date entered into the model, based on the agronomic events that occurred in the field trial detailed in Borger *et al.* (2016).

Sowing date, crop species (and number of viable seeds sown)	Herbicide, date of application (and percent annual ryegrass kill rate, residual kill rate and half-life of the herbicide at the first mention of each product)	Harvest date
4/6/03: wheat (*Triticum aestivum* L.) (255 seeds m^{-2})	1/5/03: Glyphosate 450 (85%, 0%, 0 days)	5/12/03
	28/5/03: Glyphosate 450	
	4/6/03: SpraySeed/Trifluralin (85%, 90%, 20 days)	
	29/7/03: Spear (80%, 0%, 0 days)	
3/6/04: wheat (218 seeds m^{-2})	2/6/04: Spray.Seed/Trifluralin	17/12/04
	20/7/04: Spear	
2/6/05: field pea (*Pisum sativum* L.) (62 seeds m^{-2})	15/4/05: SpraySeed (85%, 0%, 0 days)	11/11/05
	2/6/05: SpraySeed/Trifluralin	
	25/7/05: Select (80%, 0%, 0 days)	
8/6/06: wheat (280 seeds m^{-2})	25/1/06: Glyphosate + Hammer (85%, 0%, 0 days)	9/11/06
	10/5/06: Glyphosate + Hammer	
	8/6/06: SpraySeed/Trifluralin	
	8/6/06: Dual Gold/Atrazine (50%, 90%, 30 days)	
	21/8/06: Decision (80%, 0%, 0 days)	
26/6/07: barley (*Hordeum vulgare* L.) (247 seeds m^{-2})	26/6/07: SpraySeed/Trifluralin	6/11/07
	13/8/07: Decision	
5/5/08: chemical fallow	5/5/08: SpraySeed	1/12/08
	29/6/08: Glyphosate 450	
	26/8/08: Glyphosate 450	
	1/9/08: SpraySeed	
15/6/09: oilseed (*Brassica napus* L.) rape (129 seeds m^{-2})	15/6/09: SpraySeed/Trifluralin	9/11/09
3/6/10: wheat (217 seeds m^{-2})	3/6/10: SpraySeed/Trifluralin	9/11/10
	2/8/10: Achieve (80%, 0%, 0 days)	
7/7/11: wheat (198 seeds m^{-2})	7/7/11: Glyphosate + Hammer	30/11/11
	7/7/11: Boxer Gold (20%, 95%, 30 days)	
	26/7/11: Achieve	
18/6/12: chickpea (*Cicer arietinum* L.) (55 seeds m^{-2})	15/6/12: SpraySeed/Simazine (85%, 50%, 20 days)	10/12/12
	24/7/12: Select	
28/5/13: wheat (240 seeds m^{-2})	13/5/13: Glyphosate 450	26/11/13
	28/5/13: SpraySeed	
	28/5/13: Sakura (40%, 95%, 30 days)	

and annual ryegrass seed production did not increase (Table 2). However, the WSW confirmed the findings of Borger *et al.* (2016) that herbicides cannot eradicate annual ryegrass, whereas herbicides combined with harvest weed seed destruction can reduce annual ryegrass seed production to very low levels in eight years. These results indicate that the WSW is an excellent tool for modelling IWM programs, to help growers explore methods to eradicate annual ryegrass.

The total cost of weeds over the 11 year span was \$28 ha^{-1} in Scenario 2 (residue burnt). The weeds reduced the income (compared to the potential income) by less than \$1 ha^{-1} over the last four years of the trial. The total cost of the weeds was \$104 ha^{-1} in Scenario 1 where annual ryegrass seed production at harvest was not reduced to 0 seeds m^{-2}. Actual income (and potential income) was greater in Scenario 1 in spite of the higher weed burden, because residue burning reduced yield (Borger *et al.* 2016). However, on an actual farm, residue burning could be replaced with other methods of weed seed destruction at harvest that do not reduce yield (Walsh *et al.* 2013).

Scenario 3 demonstrated that the annual ryegrass seedbank could be reduced to very low levels even where it is not possible to utilise harvest weed seed

Table 2. The actual number of annual ryegrass seeds m^{-2} produced at harvest in Scenario 1 and 2 from Borger *et al.* (2016), and the number of seeds m^{-2} in the seedbank after harvest predicted by the WSW in Scenario 1, 2 and 3.

	Scenario 1		Scenario 2		Scenario 3
Year	Actual seeds	WSW seeds	Actual seeds	WSW seeds	WSW seeds
2003	296	394	117	152	152
2004	312	288	117	119	147
2005	558	586	221	129	151
2006	18	105	5	29	52
2007	54	23	23	5	8
2008	0	33	0	8	13
2009	319	121	152	17	49
2010	24	37	1	3	8
2011	162	41	0	2	8
2012	50	81	0	4	17
2013	1	500	5	9	85

Table 3. The year, grain price, potential income (income from the potential yield that could be achieved in the absence of weeds), actual income, weed cost (i.e. the difference between the actual income and the potential income), and the total income or weed cost over the 11 year span, for each Scenario.

		Scenario 1			Scenario 2			Scenario 3		
Year	Price (\$ t^{-1})	Potential income (\$ ha^{-1})	Actual income (\$ ha^{-1})	Weed cost (\$ ha^{-1})	Potential income (\$ ha^{-1})	Actual income (\$ ha^{-1})	Weed cost (\$ ha^{-1})	Potential income (\$ ha^{-1})	Actual income (\$ ha^{-1})	Weed cost (\$ ha^{-1})
2003	216	800	783	16.9	655	650	4.7	655	650	4.7
2004	197	377	372	5.2	349	347	1.8	349	347	1.8
2005	407	848	808	40.1	856	839	16.9	859	839	19.3
2006	242	644	635	9.9	641	639	2.2	642	639	2.6
2007	347	154	153	0.7	114	114	0.1	114	114	0.3
2008	*	*	*	*	*	*	*	*	*	*
2009	433	387	382	4.4	383	382	1.0	384	382	1.8
2010	257	278	276	1.9	278	278	0.3	278	278	0.8
2011	227	502	501	1.1	434	434	0.1	434	434	0.2
2012	393	53	53	0.3	63	63	0.0	63	63	0.1
2013	316	727	703	23.7	575	574	0.9	578	574	4.0
Total (\$ ha^{-1})		**4770**	**4666**	**104**	**4348**	**4320**	**28**	**4356**	**4320**	**35**

* Data not available as no crop was sown in 2008.

destruction in every year. Further, there was little change to the total cost of weeds ($35 ha^{-1} over 11 years) compared to Scenario 2.

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