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The Harrington Seed Destructor: Its role and value in farming systems facing the challenge of herbicide-resistant weeds

A. Jacobs [a], R. Kingwell [a,b,*]

[a] School of Agricultural and Resource Economics, University of Western Australia, Crawley, Western Australia, Australia
[b] Australian Export Grains Innovation Centre, Australia

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ABSTRACT

Herbicide-resistant weeds are an increasing global problem in crop production systems. To lessen the incidence of herbicide resistance and to prevent the spread of herbicide-resistant weeds many farmers in Australia have adopted weed seed control measures at grain harvest. One new option is known as the Harrington Seed Destructor (HSD). It is a machine that intercepts crop residue from the harvester and then mechanically destroys embedded weed seeds. In this study, the RIM (Ryegrass Integrated Management) model was used to investigate the economic worth of the HSD within integrated weed management strategies applicable to different weed environments, rotations, sizes of cropping programmes and crop yields. Use of the HSD generated increased returns compared to many other weed management strategies in several scenarios, but especially when non-selective herbicide resistance occurred and large areas of high-yielding crops were grown. Emerging trends in grain farming that include larger areas sown to crops, a greater incidence of herbicide-resistant weeds and higher crop yields, when combined with further manufacturing improvement of the HSD, will only further favour the use of the HSD as a key component of integrated weed management.

1. Introduction

In March 2015, the International Survey of Herbicide-Resistant Weeds recorded instances of 245 weed species displaying herbicide resistance. Resistance to 22 of the 25 known herbicide modes of action and resistance to 156 different herbicides were displayed. Herbicide-resistant weeds in 86 crops in 66 countries were reported in early 2015 (Weed Science Organisation, 2015).

Heap (2014) and Powles and Yu (2010) discuss the spread and extent of herbicide resistance in agricultural weed species, Australia being highlighted as a country where herbicide resistance problems were most severe (Harker and Clayton, 2004). Australia's early adoption of zero tillage, no-tillage and direct drilling (Edwards et al., 2012) helped boost crop productivity and made farming systems more crop-dominant (Planfarm Bankwest, 2015). However, reduced areas of pasture and less tillage removed some traditional weed control such as grazing and cultivation, and led to a high selection pressure for resistance (Monjardino et al., 2005). These changes in farming systems, when combined with no-till farming's great reliance on herbicides, the high densities of ryegrass and the genotypic plasticity of ryegrass, have facilitated the emergence of herbicide-resistant weed populations.

Some populations of annual ryegrass (*Lolium rigidum*), Australia's most economically damaging crop weed (Yu et al., 2007), have developed multi-herbicide resistance (Walsh et al., 2004; Llewellyn and Powles, 2001). This means that the weed populations have evolved resistance to more than one herbicide through separate selection processes. The emergence of herbicide-resistant ryegrass has led farmers to adopt a number of integrated weed management practices (Monjardino et al., 2005). Integrated weed management involves a range of weed control methods that combine non-herbicide techniques with changes in herbicide usage (Llewellyn and Pannell, 2009). Non-herbicidal methods include actions such as higher seeding rates, heavy grazing by sheep of weed plants just prior to crop sowing, green manuring and swathing (McGillon and Storrie, 2006).

The most common non-herbicidal weed control practice in Australia is the collection of weed seeds during harvest (Edwards et al., 2012). Harvest weed seed control (HWSC) involves collecting crop residues laden with weed seeds in either a chaff cart or in a narrow windrow behind the harvester. Narrow windrowing involves adding on the back of the harvester a chute which allows the crop residues to be concentrated into narrow rows placed on the remaining stubble. In autumn, several weeks after harvest, these rows are then burned which kills almost all the weed seeds embedded in the windrows. Another option is the Bale Direct System (BDS) that is a large square baler directly attached to the grain harvester. Weed seeds in the chaff are trapped in the bales that are subsequently sold and/or used as animal feed.

* Corresponding author at: School of Agricultural and Resource Economics, University of Western Australia, Crawley, Western Australia, Australia.
E-mail addresses: ashleyjjacobs@outlook.com (A. Jacobs), ross.kingwell@aegic.org.au (R. Kingwell).

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Another new technology for controlling weed seeds is known as the Harrington Seed Destructor (HSD). The HSD collects the crop residue from the rear of the harvester and processes it in a rolling cage mill that crushes or damages the weed seeds rendering them unviable (Walsh and Harrington, 2011; Harrington and Powles, 2012).

Previous studies have determined the operational costs of different HWSC options (Douglas et al., 2013; Newman, 2012) and the economic case for integrated weed management practices has been the subject of much research (Gorddard et al., 1995; Schmidt and Pannell, 1996; Jones et al., 2006; McGillon and Storrie, 2006; Monjardino et al., 2003, 2004, 2005; Pannell et al., 2004; Smith et al., 2006; Chikowo et al., 2009; Doole and Pannell, 2008; Doole et al., 2009). These studies report a wide range of values of the economic benefit of HWSC. However, the four most common HWSC options (HSD, chaff carts, narrow windrow burning, BDS) are yet to be jointly subject to any economic comparison in the setting of practical farm management. To evaluate the economic worth of the HSD requires the value of its use to be compared against other HWSC options.

This study uses the bio-economic simulation model RIM (Ryegrass integrated management) (Lacoste and Powles, 2013) to evaluate the value of the HSD against the other HWSC options with various herbicide resistance levels and weed burdens. Using a wide-ranging scenario analysis the long-term financial value of these options is appraised and the situations in which the HSD is economically preferred are identified. In addition the magnitude of this economic superiority is outlined.

The next section gives an overview of the bio-economic simulation model RIM and how the HSD was incorporated within RIM. A subsequent section gives modelling results.

2. Bio-economic modelling

The RIM model is a deterministic dynamic simulation model that evaluates the profitability of ryegrass control methods in rainfed mixed enterprise agricultural land-use over 10 years with 7 types of crops and 3 types of pastures (Lacoste and Powles, 2013; Pannell et al., 2004). The model includes 43 operational options (chemical, mechanical and cultural methods) to control ryegrass at different stages of its growth. The model captures the dynamics of weed populations and their susceptibility to different control methods, whilst accounting for the financial costs and revenues associated with different land-use sequences (Pannell et al., 2004). The biological outputs include each year's ryegrass plant and seed density that affects crop competition and the ryegrass seed set each year. The model's financial output is the equivalent annual value of the time series of the annual gross margins ($/hectare/year) generated by the particular land-use sequence, given a particular weed control strategy.

RIM is a 1.3 MB Excel® file, constructed using VBA macros, formulae and parameter values provided from a range of scientific and technical sources. Validation of RIM is described by Monjardino et al. (2003). The main outputs of the model are weed density and financial net returns. More detail about RIM is provided by Monjardino et al. (2003) and Pannell et al. (2004). As an illustration of key relationships considered in RIM, a crop's yield depends on its competitive ability in comparison to weeds and the densities of each. In RIM, a crop's yield (as a proportion of the weed-free yield) is specified as PY (plant crop yield) in the following equation:

$$PY = \frac{(1+a)}{P_o} \cdot \frac{PD.M}{a + PD + f_{RC} + G_{RES}} + (1-M)$$

where a represents the background competition factor, P_O is the standard crop density (plants m^{-2}), PD represents the actual plant density, f_{RC} is the ryegrass competition factor and G_{RES} is the ryegrass numbers in early spring (plants$\cdot m^{-2}$). M represents the maximum proportion of crop yield lost at high densities of ryegrass. Hence, integrated weed management with non-herbicide treatments and changes in herbicides alters key variables in the above equation, leading to crop yields being less affected by weeds.

Examples of options in RIM to control annual ryegrass are listed in Table 1.

2.1. Adjustments to parameters and assumptions of RIM

For this study many parameters and assumptions in RIM were updated, drawing on the latest research and current industry sources. Updated yield and price data (see Table 2) came from ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences) (Valle et al., 2013). The purchase and installation costs of HWSC systems were obtained from various suppliers (see Table 3) and were then included in RIM. In addition, the running or operational costs (including nutrient loss costs) of various HWSC systems were gleaned from existing research.

The inclusion of machinery ownership costs associated with the various HWSC options meant that RIM's financial output became the equivalent annual value of the flow of annual net margins ($/hectare/year), rather than gross margin, generated by each particular land-use sequence and HWSC option under consideration.

The costs of nutrient removal were based on the findings of Newman et al. (2013) and Brennan (2006). These costs were based on a nutrient analysis of wheat and lupin straw and chaff by Newman (2012). He found wheat crop residue contained 10 kg of potassium and 6 kg of nitrogen per tonne of residue, and lupin crop residue contained 14 kg of potassium and 14 kg of nitrogen per tonne of residue. Assuming a harvest index of 0.4 and that 60% of the stubble goes through the harvester, then there are 2.1 tonnes of crop residue for every 2 tonnes per hectare of wheat crop. Assuming the cost of nitrogen is $1.15/kg and potassium is $1.30/kg, then the cost of nutrient loss is $22.40/tonne of wheat. However, only 50% of the crop residue nutrients are available to next year's crop due to the rate of crop residue decomposition and the tie-up of nutrients by soil organisms. Therefore, the cost of nutrient loss becomes $11.20/tonne of wheat. As the BDS and narrow windrow burning remove 100% of residue put through the harvester, $11.20/tonne of wheat is the cost of replacing those lost nutrients. Chaff carts only remove chaff residue, which is 15% of the crop residue and so costs

Table 1
Examples of options in RIM for controlling annual ryegrass.

Category	The timing of the control option	Options considered
Enterprises subject to weed control		
Crops		Wheat, barley, canola, and generic legume
Pastures		Sub-clover, Cadiz, and volunteer pasture
Weed control operations		
Seeding timing	1, 2, 3[b]	Dry, wet, delayed and + delayed
Soil preparation	2, 3	Tickle and mouldboard ploughing
Tillage system	1, 2, 3	Full cut and knife point
Crop seeding rates	2, 3	Standard and high
Knockdown herbicides	2, 3	Paraquat and glyphosate
Pre-emergent herbicides	2, 3, 4	Sakura®, trifluralin, Boxer Gold®, Group B[a] and triazine
Post-emergence herbicides	4	Group A, triazine + Group A, triazine, Group B, glyphosate
Crop sacrifice	5	Green manure, brown manure, mow + spray, hay + spray, and silage + spray
Spraying/swathing	5	Topping, swathing and swathing with spray
Grazing	5	Standard and high intensity
Harvest weed seed control	6	HSD, BDS, narrow windrow, chaff carts and tramlining

[a] This nomenclature of herbicides is used in Australia (see GRDC, 2008).
[b] 1. Before break of season. 2. 0–10 days after break. 3. 10–20 days after break. 4. Early crop growth. 5. Early spring. 6. During harvest. For more details, see Lacoste (2013, 2014).