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Weed Seed Wizard: A tool that demonstrates the value of integrated weed management tactics such as harvest weed seed destruction

Catherine P.D. Borger[a,*], Glen P. Riethmuller[b], Michael Renton[c]

[a] Department of Primary Industries and Regional Development, 75 York Rd (PO Box 483), Northam, Western Australia 6401, Australia
[b] Department of Primary Industries and Regional Development, PO Box 432, Merredin, Western Australia 6415, Australia
[c] School of Biological Sciences and School of Agriculture and Environment, The University of Western Australia, Crawley, Western Australia 6009, Australia

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ABSTRACT

Harvest weed seed destruction (HWSD) can be included in an integrated weed management (IWM) program to help control weed populations and combat herbicide resistance. However, it may not be possible or practical to use this technique in every year. This research utilised a computer model, the Weed Seed Wizard, to investigate the impact of employing HWSD every second year. Data from a long term trial in Merredin Western Australia demonstrated the value of residue burning (an early method of HWSD) compared to residue retention on the destruction of *Lolium rigidum* seed from 2003 to 2013. The agronomic practices utilised in this trial, soil type and rainfall at the field site, and crop yield data were used to parametrise two scenarios in the model. Scenario 1 was based on data from the field trial plots where residue was retained and scenario 2 was based on data from the plots where residue was burnt (i.e. HWSD). A third hypothetical scenario was based on scenario 2, but only incorporated HWSD in every second year. The model gave reasonable predictions of *L. rigidum* seed production each year (when compared to the actual seed production in the field trial), and accurately predicted when *L. rigidum* seed numbers would reach very low levels in scenario 2, due to annual HWSD. Scenario 3 indicated that HWSD in every second year could not reduce *L. rigidum* seeds to the same extent as annual HWSD, but the *L. rigidum* population was reduced to and maintained at less than one plant m^{-2} at harvest within four years. The model indicated that the total cost of weeds ranged from \$85 ha^{-1} in scenario 1 to \$32 and \$27 ha^{-1} in scenario 3 and 2. However, income was greatest in scenario 1 as HWSD via burning residue caused a yield reduction in scenario 2 and 3. The results highlight both the benefits of HWSD as a weed management tactic and the value of the Weed Seed Wizard as a tool to investigate different IWM programs.

1. Introduction

Integrated weed management (IWM) programs are necessary in grain cropping systems to combat herbicide resistance (Llewellyn et al., 2004). A potential technique to add to an IWM program is harvest weed seed destruction (HWSD), which can be achieved using a harvest seed destructor or chaff cart, or through windrow burning (Walsh and Newman, 2007; Walsh et al., 2013). Up to 85% of *Lolium rigidum* L. Gaud. (annual ryegrass) seed present at harvest time is collected by the harvester, and up to 99% of this seed can be destroyed by burning or mechanical weed seed destruction (Walsh et al., 2013; Walsh and Powles, 2014). A recent paper by Borger et al. (2016) demonstrated that residue burning could reduce *L. rigidum* seed production at harvest to zero over an 11 year period. However, in a farm business it may not be possible or practical to destroy weeds at harvest in every year. Weeds may lodge or shed seed prior to harvest (Walsh et al., 2013). Windrow burning may fail to effectively destroy weed seeds due to poor burning conditions (i.e. wind drives the fire too quickly to allow an effective burn), or low residue levels (which prevent the fire burning hot enough to destroy all seeds) (Walsh and Newman, 2007).

Long term data on weed seed destruction in every year compared to seed destruction in alternate years is required to investigate the practicality of this weed control technique in the broad scale grain cropping system. Computer simulations (models) of weed growth under varying agronomic scenarios are a way to generate this data, and analyse and demonstrate the long term efficiency and financial viability of an IWM program (Lacoste and Powles, 2014; Lawes and Renton, 2010; Renton and Chauhan, 2017). However, many models do not take into account seasonal variability, which impacts the efficacy of weed control options. For example, in a dry year herbicide performance is compromised when weeds are moisture stressed (Storrie, 2014). At the same time, weed growth and seed production are affected both by the dry conditions,

* Corresponding author.
E-mail addresses: catherine.borger@dpird.wa.gov.au (C.P.D. Borger), glen.riethmuller@dpird.wa.gov.au (G.P. Riethmuller), michael.renton@uwa.edu.au (M. Renton).

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and by reduced competition from the moisture stressed crop (Storrie, 2014; Zimdahl, 2004).

The value of a model is influenced by biological accuracy, quality of recommendations and ease of use (Wilkerson et al., 2002). For biological accuracy and high quality recommendations, a weed population model needs to accurately represent how seasonal conditions impact weed growth and population dynamics. One such model that takes seasonal variability into account is the Weed Seed Wizard (Agriculture and Food Western Australia, 2016; Peltzer et al., 2012b; Renton et al., 2008; Renton et al., 2006). This freely available model is applicable to all Australian grain cropping regions, and uses site-specific soil type, weather records, and farm management records to simulate how different agronomic practices can affect density, seed production and long-term population dynamics of a range of weed species.

Lolium rigidum is Australia's most problematic dryland cropping weed, and widespread herbicide resistance has made it necessary to apply IWM tactics to control this species (Llewellyn et al., 2016). Harvest weed seed destruction is a new paradigm for IWM in Australia and is particularly advocated for the control of *L. rigidum* (Walsh et al., 2013). When combined with herbicide use, harvest weed seed destruction can eradicate *L. rigidum* (Borger et al., 2016). The current research aims to test the hypothesis that the Weed Seed Wizard model can predict *L. rigidum* seed production in a standard crop rotation (utilising herbicides) in the region of Merredin, Western Australia (WA). The research further aims to investigate the impact of different frequencies of harvest weed seed destruction on *L. rigidum*. This would test the secondary hypotheses that a crop rotation using herbicides alone would not adequately control *L. rigidum*, a system utilising weed seed destruction at harvest every year would eradicate *L. rigidum*, and a system utilising weed seed destruction in alternate years would maintain *L. rigidum* at low levels.

2. Materials and methods

2.1. The Weed Seed Wizard model

The Weed Seed Wizard (WSW) is an agricultural decision support tool based on a computer simulation of how long-term weed population dynamics within a field interact with management activities and environment. The WSW, implemented using an object-oriented approach in the Java programming language, includes an input interface, data lists, data editors, an event queue, a dynamic representation of the state of the system and an output interface. Within the input interface, the user can set or modify weed parameters, crop parameters, soil parameters, weather records and agronomic management events. All required parameters can be read from standardised xml files by parsers to create data list structures that can then be used by the simulation. Weather data can similarly be read in from standardised csv files. Different versions of the data files are available to represent different locations, or users can provide their own. Once read in, parameter values can be modified and adapted to better represent local conditions as required, and then resaved if desired. The simulation runs using an event queue, i.e. a list of events ordered by scheduled date and time, including agronomic management events, rainfall and climate events from the weather records, plant germination, plant senescence and seed abscission. The state of the system includes various submodules which represent different objects within the natural system, including the weed seedbank in the soil, the living population of weed plants, any residual herbicides acting in the soil, and the moisture within the soil. As each event occurs, the state of the system is updated, taking into account the climatic conditions (including temperature and rainfall), the soil type (consisting of soil layers at multiple depths), and the seedbank and plant population (consisting of individual seed/plant cohorts). To simulate the dynamics of the system, the events are applied to the state sequentially, using the parameters specified in the data lists. The state also maintains a record of some aspects of the evolving state of the system. Each individual object within the system is linked to associated data, and communicates with other objects and their data as required. For example, a seed cohort has a defined species, age, level of dormancy, germination status, moisture content, accumulated degree days and position within the soil. A particular soil layer has a temperature and moisture level. Germination of the seed cohort within the soil layer will depend on the characteristics of each. The output interface uses the records generated by the state to produce a series of results displays, including annual crop yield and yield loss to weeds, as well as daily weed plant and seed numbers, rainfall and temperature, soil moisture and temperature, and degree days (indicating degree days after ripening, minimum after-ripening requirements, acquired dormancy degree days, and proportion of germinable seed).

2.2. Model parameters

A long-term experiment was conducted from 1987 to 2013 at the Department of Primary Industries and Regional Development (DPIRD) Merredin Research Station, WA (Borger et al., 2016). Crop species (chosen to reflect the standard rotation choices of the region) were sown at row spacings of 9, 18, 27 or 36 cm, and the crop residue from the prior crop was either burnt or retained at the beginning of each winter annual growing season. Non-selective, pre-emergent and in crop herbicides were applied to control weeds (predominately *L. rigidum* and *Sisymbrium orientale* L.). A chaff cart was used from 2003 to 2006 to catch and remove crop residue and weed seeds that were caught by the harvester. The herbicides successfully controlled *S. orientale* but the *L. rigidum* remained in crop. *Lolium rigidum* seed production at harvest was assessed from 2003 to 2013 (although actual *L. rigidum* plant number was not assessed), and fecundity was significantly lower in crops with narrow row spacings, and also in the plots where crop residue was burnt (Borger et al., 2016). The model parameters used in the current study are based on this experiment, with the two primary scenarios utilising data from the crop residue retained (scenario 1) or crop residue burnt (scenario 2) plots at a row spacing of 18 cm. The 18 cm spacing was selected because it is common to the region and the model does not directly simulate varied row spacing.

The initial parameters loaded into the model were 'Southern WA grain region', as this region incorporates the district of Merredin. Exact parameter values can be seen by downloading the model and loading this parameter set, from https://www.agric.wa.gov.au/weed-seed-wizard-0. Under 'Scenario Setup' tab, the timeframe was set to 1 December 2002 to 31 December 2013. The initial *L. rigidum* seed bank was set to 1500 for scenario 1 and 500 seeds for scenario 2, as the *L. rigidum* seed bank had reached higher levels in the unburnt plots of scenario 1 from 1987 to 2002. The soil type was 'Southern region – Silty clay loam', as the closest approximation to the actual soil type of the experiment, which was a mottled eutrophic red chromosol (Borger et al., 2016; Isbell, 2002). A weather record (including daily rainfall, maximum and minimum temperature and evaporation from 1889 to 2016) was created from data generated by the Merredin Research Station weather station (site number 010093) (Department of Science Information Technology and Innovation, 2016).

Under 'Event Management', events were created to match the experiment details specified in Borger et al. (2016). Agronomic events that were selected from the model options for each year are detailed in Table 1. For each 'Sow Event', the date of sowing and crop species were specified and the 'Till type' was set to knifepoint seeding. The 'seeds/m^2' data was specified to be the known viable seed sowing density and the '%viable' option was set to 100%. For each spray in Borger et al. (2016), a 'Spray Event' was created using the herbicide option in the model that most closely matched the herbicide used in the original experiment. For example, glyphosate 450 g a.i. ha^{-1}, RoundupCT® Extra, 450 g a.i. L^{-1}, SC, Nufarm Ltd. specified in Borger et al. (2016) was entered into the model by selecting 'Glyphosate 450'. The herbicide 'Spear' was not available in the model (diclofop-methyl/fenoxaprop-p-