Understanding, predicting and managing weed seedbanks in agricultural systems with the Weed Seed Wizard

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Summary Weeds are an important factor in every agronomic system. The Weed Seed Wizard is a simulation model that has been developed to help co-ordinate management of weed seed within the seedbank. The model uses field management and weather records, and simulation of important aspects of seed biology, to track and predict the number, ages, soil depth, dormancy levels, viability and germination of seeds in the soil, in order to predict the amount of weeds appearing each year. In this paper, we explain the structure of the model and discuss how it can simulate the effect of decisions regarding choice of crop, sowing date, seeding rate, tillage, grazing management and herbicide application on weed germination, weed density, crop yield and the long-term sustainability of the system. We also explain how the seed dormancy, germination requirements, competitiveness, and herbicide resistance of different weed species or populations can strongly affect the dynamics of the system, and thus the choice of an appropriate management strategy.

Keywords Individual-based, seed ecology, simulation model, seedbank dynamics, weed control, weed management.

INTRODUCTION

If you think weeds are a problem, maybe you need to think again! Maybe the real problem is the weed seedbank hidden beneath your feet! Weeds are just a symptom. They compete with crops and pastures to reduce yield, contaminate grain and maybe poison stock. But the seedbank is the underlying disease. If you kill every last weed, your crop will appear to be clean but the weeds will be back next year nonetheless. We need to use long-term strategies for managing the seedbank: starving it of new recruits; exposing seeds to natural enemies; burying them so deeply they can never emerge; and exploiting their dormancy mechanisms to trigger germination in situations where the weeds can be easily killed or will have little effect. In this way we can slowly but surely drive the seedbank towards extinction.

In order to help move towards this long-term view of weed management, the aim of the Weed Seed Wizard project has been to construct computer simulations of weed seedbank dynamics for a number of species. As a national Weeds CRC project, with participants in the states of Western Australia, South Australia, New South Wales and Queensland, it has targeted major in-crop annual weeds from each cropping region. For the southern states, modelled weeds included annual ryegrass (*Lolium rigidum* Gaudin), barley grass (*Hordeum leporinum* Link.), wild radish (*Raphanus raphanistrum* L.), wild oat (*Avena fatua* L.), brome grass (*Bromus* spp.) and silver grass (*Vulpia* spp.). Northern weeds included sweet summer grass (*Brachiaria eruciformis* (Sm.) Griseb), liverseed grass (*Urochloa panicoides* P.Beauv.), awnless barnyard grass (*Echinchloa colona* (L.) Link), native jute (*Corchorus trilocularis* L.), bladder ketmia (*Hibiscus trionum* L.), fleabane (*Conyza* spp.) and sowthistle (*Sonchus oleraceus* L.). Seeds of these different weed species persist in the soil (or seedbank) for different periods. Some species have little or no dormancy and germinate with the opening rains, largely depleting the seed bank. Other species with dormancy require specific environmental (light, moisture, temperature, accumulated degree days) cues for dormancy to be broken and germination to commence. These species can persist for several years. The Wizard has been based on the vast collection of existing documented knowledge about each species, and will be validated against further data collected from a number of trials in each of the participating states.

As seedbank dynamics and weed seed persistence are complicated and often hard to understand, the first objective was to build a modelling framework that could be used for scientific investigation of the complex mix of factors affecting the weed seedbank, and thus contribute to our understanding of seedbank dynamics. This will then lead to a second longer-term objective of constructing a practical decision-aid tool, incorporating current scientific knowledge, that could help farmers and consultants predict and manage weed populations in real agricultural contexts. The plan is that eventually this tool will be self-calibrating (have the capacity to adjust its parameters in response to ongoing observation records to better predict weed populations in a particular field). As part of the Sustainable Cropping Systems program within the CRC for Australian Weed Management, the Weed Seed Wizard project contributes to developing crop and pasture systems for sustained productivity and profitability through these objectives.

THE MODEL

The Weed Seed Wizard takes into account conservation tillage (minimum disturbance) systems combined with strategic use of a range of other techniques, such as soil inversion, autumn tickle, crop competition, selective and nonselective herbicides, crop topping, swathing, seed catching, and burning or grazing for stubble management. It also incorporates recent advances in understanding of the factors that affect germination and death of weed seeds, in order to predict the amount of weeds appearing each year. Currently the model works as a stand-alone interactive software application, but we envisage that eventually the Wizard will operate as an adjunct to field record-keeping software, using farmer records concerning field management decisions, the site, and other observations. Such records might include crop sown, sowing date, seeding rate, tillage and grazing management, herbicide application, crop yield, weed density and rainfall. The idea is that one day the Wizard might be part of a farm management system that integrates farmer record keeping with simulations of biological and physical processes including weed populations, soil water and nutrition, insect pests and diseases.

The Wizard has been designed and implemented in the 'web-friendly' Java programming language, and several versions have been released for testing and use. The model includes representations of the soil, the daily weather, the crop and weed plant populations, and the individual crop and weed seeds within the soil. It simulates the moisture and temperature within the soil; the dormancy, after-ripening and germination of the seeds; the effects of competition between different plant species on seed set; and the effects of management actions on plants and seeds. A graphical user interface (GUI) has been designed for the tool. The GUI is based on scenario windows where the user can add, delete or edit scheduled management actions and view the simulated output regarding the states of the soil seedbank, plant populations and crop yield as tables or graphs of various levels of detail (Figure 1). These scenario windows can be used to compare a number of different management scenarios. There are also options for the user to change the initial seedbank of the simulated field, the weather data files used, the period of simulation, and many other model parameters, using standard interface tools such as menus, buttons and editable tables. Standard xml data formats have been designed for required data on herbicides, plant species, management schedules, seedbank numbers and types of cultivation and then routines have been implemented to read this data into the model and write it back to files as required.

The Weed Seed Wizard is being built using an 'object-oriented' approach that enables different parts of the model's interface and internal structure to be described clearly as separate 'objects' or modules within the program. This will facilitate adaptation of the model and interface for different purposes and users. The primary objects in the model (Figure 2) are an input interface allowing the user to configure the model, set up the initial state of the system and schedule management events; an event queue including all events that effect the modelled agricultural system; data lists including all required model parameters; a representation of the changing state of the modelled system; and an output interface for presenting the output of

(a)

(b)

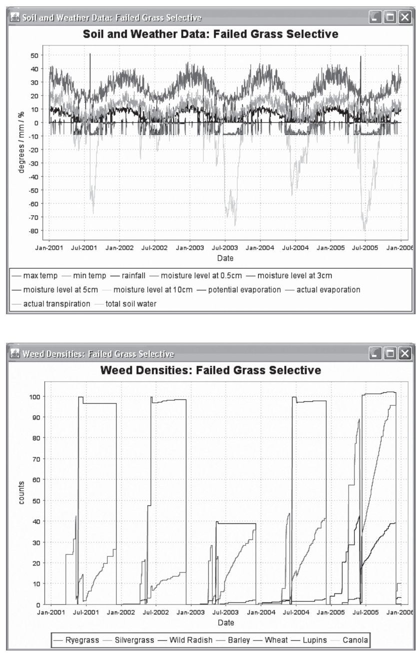

Figure 1. Example output from the Weed Seed Wizard: soil and weather data over five years (a), and corresponding simulated weed and crop numbers for a particular scenario (b).

the model. The state object (Figure 3), the heart of the Wizard, includes sub-objects representing the environment (conditions such as rainfall, potential evaporation and temperature), the soil (consisting of a number of layers), the seedbank (consisting of individual seed cohorts), the plant community (consisting of individual plant cohorts), and a record of important aspects of the evolving state of the system.

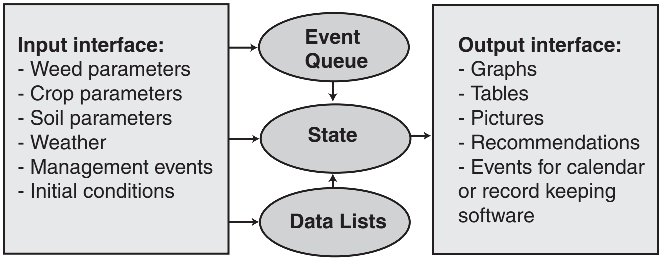

Figure 2. The overall modular structure of the Weed Seed Wizard.

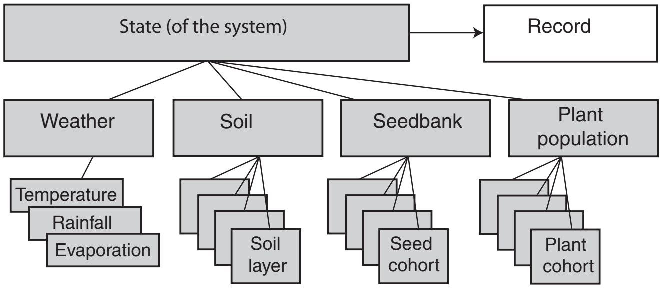

Figure 3. The Weed Seed Wizard's modular representation of the dynamic state of the agronomic system.

RESULTS

The current version of the Wizard is able to produce reasonable simulations of the population dynamics of ryegrass and wild radish for a range of standard integrated management strategies for these species, including knockdown, pre-emergent and post-emergent herbicide applications, 'double-knock' herbicide strategies, variable sowing densities, seed-catching and strategic mouldboard (inversion) and 'tickle' cultivation events. For example, the situation illustrated in Figure 1 is a standard Western Australian wheat-wheat-lupin-wheat-wheat rotation from 2001 to 2005 using actual daily weather records for Northam and assuming an initial ryegrass seedbank of 100 m^{-2}. The base management schedule includes knockdown, at-sowing and in-crop selective herbicide applications in the wheat seasons. The resulting prediction is for weed densities to fall over time. Changing the scenario to assume that resistance to the in-crop selective develops in 2002 changes the prediction so that ryegrass density now rises over time and 'blows out' in the 2005 (this is the result illustrated in Figure 1 bottom). Changing the scenario by using a chaff cart to remove weed seeds in 2002 changes the predictions so that ryegrass densities are much lower in 2003, 2004 and still at manageable levels in 2005. Simulations of the other species also appear reasonable, but have not been tested as well as for ryegrass and wild radish.

CONCLUSIONS

The Weed Seed Wizard will integrate current knowledge of weed biology and the effects of management techniques to simulate and predict annual weed populations. It will allow us to explore how the dormancy, germination requirements, competitiveness, and herbicide resistance of different weed species or populations can affect the dynamics of the system, and thus the choice of an appropriate management strategy. Through incorporating the effects of herbicides and a range of other strategic options, the Wizard will help us design a truly integrated weed management system. By giving deeper insight into the how different factors interact to determine weed seedbank levels and helping farmers manage weeds within their fields, the Wizard will contribute to building the sustainability of Australian crop and pasture systems.

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