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RIM, LUSO, PERTH AND THE WIZARD: A COMPLEMENTARY FAMILY OF MODELS FOR SUPPORTING WEED MANAGEMENT DECISIONS IN CROPPING SYSTEMS

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ABSTRACT

This paper presents a number of related models developed to address different weed management questions in Australian cropping systems. The models are compared and contrasted in terms of purpose, application and design, in order to show that the models form a complementary family, with each suitable for addressing a different range of aims and applications.

Key words: Weed, management, model, herbicide, resistance, simulation.

INTRODUCTION

Weeds are an important factor in every agronomic system. They reduce yields through competing with crop for nutrients, water and light, and can also contaminate harvested grain and poison stock. However, in some sense, real problem is not the weeds growing in crop, but the bank of weed seeds lying hidden beneath soil. No matter how many weeds I can kill right now, there will always be more seeds waiting in the ground. The weed seedbank is a serious challenge for three main reasons: it is invisible, it is patient and it is complex. While the weeds can be seen competing with crop above ground by light of day, their seeds lurk hidden beneath ground. While most cropping weeds come and go within a few months, their seeds can often wait happily for months or years until conditions are suitable. And while it may seem that best way to control weeds is simply to kill the plants, the long-term fluctuations in weed numbers will be affected by complex interaction of a large number of factors. These include varying dormancy of a range of different species; competition among crops and different weed species; the effects of herbicides, tillage (or non-tillage), harvesting options and other management techniques on soil, plants and seeds; weather and environment; individual genetic variability within populations that may evolve over time under different

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selection pressures, affecting resistance to herbicides, dormancy and other characteristics; and even seed-eating insects and microbes!
One way to help understand, predict and manage a system that is mostly hidden beneath the soil and dependent on a large number of complex interactions that play out over a relatively long term, is to create a computational model of that system. A computational model can help integrate existing knowledge and hypotheses gained from observations, literature and focussed experiments and trials. By synthesising this information in a model, we can build a reasonable representation of the way things will work in a much wider range of interacting conditions and over a much longer time period than would be possible to address directly in field trials or experiments. The simulation can provide a window into parts of system that are usually hidden (the seedbank and population genetics for example), and look at how they influence and are influenced by parts of system that directly affect us (the weeds) and parts that we can control (management options).

Constructing a model involves making decisions and trade-offs about what underlying processes to include or not include in model, the appropriate level of detail and realism at which to represent these processes, and what temporal and spatial scale to base the model on. There are also choices about how to enable user interaction with model, and what kind of results should be provided by model. In general, like all design decisions, these decisions should be made in light of a clear idea of the purpose for which the model is being built. For example, the best choices for a model intended to be a practical decision-aid tool that can help farmers and consultants manage weed populations in specific agricultural contexts and seasons are likely to be very different to best choices for a model intended to help researchers analyse the efficacy of general long-term management strategies for reducing the risk of evolving herbicide resistance.

This paper briefly presents a number of related models developed to address different weed management questions in Australian cropping systems. The aim is to compare and contrast the models in terms of purpose, application and design, and to show that the models form a complementary family, with each suitable for addressing a different set of aims and applications.

Resistance and Integrated Management (RIM)

RIM (Resistance and Integrated Management or Ryegrass Integrated Management) is a computer package developed in Microsoft Excel that allows users to try out various combinations of weed treatments and observe their predicted impacts on ryegrass populations, crop yields and long-term economic outcomes (Pannell *et al*., 2004). A wide variety of chemical and non-chemical weed treatment options are included, so that as chemicals are lost to herbicide resistance, users can experiment to try to identify the next best substitute. RIM has been used extensively as part of interactive workshops with farmers, agronomists and agricultural science students, and for economic analyses of various weed control options (eg. Monjardino *et al*., 2004).

RIM works on an annual time step and represents a single paddock within a farm. A southern Australian agricultural system is represented, where there is one crop or pasture option possible each winter, and a summer fallow. The model represents an average season within an average paddock; no specific weather or soil data is required, and effects of such specific information cannot be modelled directly. There is therefore no representation of climate variability, and the only way to make model specific to a particular locality, farm or paddock is to change all relevant parameters (such as potential yield) within model. The standard version of RIM represents one species only, ryegrass, although other versions have been constructed for wild radish and poppy (Monjardino *et al*., 2004, Torra *et al*., 2010). The level of biological detail is relatively simple and abstract. For example, only a single seedbank pool is used, with no representation of different soil layers or seed cohorts. Four different weed plant cohorts are included. Herbicide resistance is represented in model in a simple way; it is assumed that only a limited number of uses are available for each herbicide group. There is no representation of individual or population genetics or actual evolution of resistance.

The user enters their proposed crop or pasture options for 10 or 20 years and then their proposed management options within each year, by entering letters or tick marks into an Excel spreadsheet. The model automatically warns if options are not appropriate for land use for which they have been entered. As each option is entered, user is immediately provided with updated output including total number of weeds and weed seed numbers in each year, the gross margin achieved for each year and the 'average' annual profit over the full 10 or 20 years (actually the nominal annuity). More detailed biological and economic results, for more detailed understanding of main outputs, can also be viewed if desired.

The Weed Seed Wizard (WSW)

The development of the Weed Seed Wizard has been funded by Cooperative Research Centre for Australian Weed Management and Grains Research and Development Corporation, with the aim of creating a practical decision-aid tool that can help farmers and consultants manage weed populations in real agricultural contexts. Implemented in the Java programming language, the model uses detailed and specific paddock management and weather records, and simulation of important aspects of seed biology, in order to track and predict the number, ages, soil depth, dormancy levels, viability and germination of seeds in the soil. The model then predicts the amount of weeds appearing each year (Renton *et al.*, 2008).

Some aspects of underlying models within WSW are based on similar models in RIM, although WSW adds much greater temporal resolution and biological detail and realism, as it works on a daily time step. WSW represents a single paddock or section of paddock within a farm and aims to be able to represent any kind of farming system, with crops sown and harvested on any day of the year, although the current version is best suited to simulating a southern Australian agricultural system. Unlike RIM, the model requires detailed daily weather data for the period simulated, and is thus able to simulate the effects of specific variations in such data, such as season-to-season variation in timing of opening rains and differences in weather in different locations. There is also some representation of the effects of different soil types. WSW has been constructed so that new weed species can easily be added to the model and populations including multiple weed species can be simulated without difficulty. The accuracy of these simulations depends of course on the adequacy of the parameterisation of each species included in the model. The level of biological detail in WSW is relatively complex and realistic compared to RIM. For example, multiple seedbank cohorts are represented for different soil layers and age cohorts. Different weed plant cohorts for every separate germination date are also included. Resistance is not explicitly represented in the model at all, although it can be included by assuming a decline in efficacy of a certain herbicide over time.

The user enters all their proposed management options into WSW as ‘events’, specifying the date for the event. Possible management events include herbicide applications, sowing of crops, tillage, grazing and harvest. Various options can be specified for each event, such as the kill-rate achieved by a given herbicide application, although sensible defaults are provided as a guide. Management events can be provided to represent a single year or as many consecutive years as desired, and the user also specifies the start and end date of the simulation. When the user is satisfied with sequence of events entered, the scenario is simulated and the user provided with updated summary output including the total density of weed seeds following each harvest, the crop harvest achieved, and the amount of potential harvest lost to weed competition. Much more detailed biological and economic results can also be viewed if desired, such as seedbank densities for different soil layers and species or weed densities for each species on each day of the simulation. The current version of the model does not provide economic outputs.

Land Use Sequence Optimiser (LUSO)

The development of LUSO has been funded by Grains Research and Development Corporation with the aim of creating a bio-economic model and optimisation framework for analysing drivers of tactical and strategic decisions regarding 'break-crops' and land-use sequencing within agricultural systems. Implemented in the Python programming language, the model simulates the dynamics of weed populations, plants disease loads and soil nitrogen levels over many years, together with their effects on yield and profit (Lawes and Renton, 2010).

The weed model underlying LUSO is based on RIM, with addition of plant disease and soil nitrogen modules and a number of automated bio-economic analysis tools. Like RIM, LUSO works on an annual time step and represents a single paddock within a farm. A southern Australian agricultural system is represented, with one crop or pasture option possible each winter and a summer fallow. The standard version of the model represents an average season within an average paddock; no specific weather or soil data is required, the effects of such specific information cannot be modelled directly and there is therefore no representation of climate variability. The model can be quite easily adapted to a specific locality, farm or paddock by changing all relevant parameters (such as potential yield) within the model, since the number of parameters is relatively small. Moreover, a prototype version of LUSO has been developed to account for seasonal variability and its effects on crop yield, pasture production, plant disease dynamics and weed seed set. The standard version of LUSO represents a single weed species; by default this is parameterised to represent ryegrass, although the model has been designed so that it can easily be adapted to represent any other species of interest or potentially a number of species if necessary. Like RIM, the level of biological detail is relatively simple and abstract. For example, only a single seedbank pool is used, with no representation of different soil layers or seed cohorts. Herbicide resistance can be represented in the model in simple ways, either by assuming a fixed number of available uses for a herbicide or a steady decline in the efficacy of the herbicide.

LUSO requires a list of default parameters for a number of possible land uses. A standard version of the parameter file is provided with the model and can be easily customised by the user using Microsoft Excel as an editor to address a particular question or situation of interest. The analysis framework can then be used in a number of ways. Most simply, a specific sequence of land use options can be specified and the resulting predicted profit calculated, similar to RIM. Alternatively, a number of optimisation algorithms are available, which can be used to determine the best land use sequence or sequences for the given assumptions and their corresponding predicted profits. Automated sensitivity analyses can then be conducted to determine how the optimal land use sequence and the optimal profit change as one or more model parameters vary. For example, this capability could be used to determine what average level of weed seed set control would need to be achieved in a canola crop for canola to be included in a farmer's optimal land use sequence strategy or what increase in wheat competitiveness would be required to achieve a 10% increase in long-term profitability of overall cropping system. The framework allows analysis of both strategic and tactical decisions. For example, it can be used to analyse the drivers and thresholds influencing the decision of whether or not to sacrifice short-term profit for long-term weed management benefits by green-manuring a lupin crop, or it can be used to analyse the drivers and thresholds influencing whether lupins are included in a long-term crop sequencing strategy.

Polygenic Evolution of Resistance To Herbicides (PERTH)

The development of PERTH has been supported by Grains Research and Development Corporation through the Australian Herbicide Resistance Initiative. The PERTH model was created to analyse the effect of different long-term management options on the risk of evolving herbicide resistance in agricultural systems and to account for the effects of weed biology, weed ecology, population dynamics and genetics underlying resistance. Implemented in the Python programming language, the model simulates the dynamics of weed population numbers and genetics over many years, together with their effects on crop yield (Renton *et al.,* 2011).

The model of weed population dynamics underlying PERTH was originally based on RIM, although it has been extended by adding detailed representation of resistance genetics and their interaction with herbicide efficacy, and, more recently, more detailed representation of seedbank density at different soil depths and important aspects of weed biology, such as dormancy and breeding system (level of out-crossing). Like RIM, PERTH works on an annual time step and represents a single paddock within an agricultural system where there is one crop or pasture option possible each year. The standard version of the model represents an average season within an average paddock, with no representation of specific weather or climate variability. There is little need for more specificity, since the model is aimed at evaluating general long-term strategies. However, a prototype version of PERTH is being developed to account for seasonal variability and its effects on risk of herbicide resistance evolution, as affected by weed seed set and variation in crop yield, herbicide efficacy and application timing. The standard version of PERTH represents a single weed species; by default this is parameterised to represent ryegrass, although the model has been designed so that it can easily be adapted to represent any other species of interest. The level of biological detail is intermediate between the simplicity of RIM and LUSO, and the complexity of WSW. For example, the resistance genetics is represented in great detail, with each seed represented separately for this purpose. The seedbank is also divided into a number of soil layers and the weeds into four different cohorts. Cohorts are affected by management in different ways. Herbicide resistance is represented in the model in much greater detail and at a higher level of realism than other three models. Evolution is simulated explicitly and mechanistically, emerging as a result of interaction between population dynamics, individual resistance genetics, differential survival of individuals at different herbicide applications and genetic recombination with breeding.

PERTH requires a list of default parameters specifying weed characteristics, resistance genetics factors, and weed management options. A standard version of parameter file is provided with the model and can be customised by the user using Microsoft Excel as an editor to address a particular question or situation of interest. The model is then run and produces a series of outputs showing the results of the simulation under the given assumptions. These graphical and tabular outputs include weed densities at critical time of the season, levels of resistance specified in various ways, crop yield as a percentage of potential of weed-free yield, and details of genetics, all given for each year of simulation, so their dynamics can be tracked over time. One summary output is also provided, the number of years for which weed numbers remain low enough for system to remain agronomically sustainable. Example Python scripts are also provided that can be used to determine the effects of varying different model parameters on the number of years of the systems' sustainability.

DISCUSSION AND CONCLUSIONS

The list of weed simulation models presented in this paper is not at all intended to be exhaustive. Many other models have been developed to simulate important aspects of weeds in Australian cropping systems. These include the well-established Agricultural Production Systems Simulator (APSIM), which includes modules for simulating the growth of weeds in competition with crops (Keating *et al.,* 2003), and Thornby and Walker's (2009) model that integrates APSIM with a model of weed population dynamics to predict herbicide resistance evolution in northern Australia cropping systems.

The models presented in this paper have different intended purposes, which are reflected in different design choices. RIM and WSW have sophisticated graphical user interfaces, as they are intended to be used by a wide range of non-technical users, while

LUSO and PERTH have simpler user interfaces. RIM's interface can be adapted quickly, allowing it be used easily in interactive workshops, while WSW's interface is more complex and slower to use, because it allows access to a much greater array of underlying biological and management details. The design choices reflect conscious trade-offs. For example, the focus on genetics in PERTH makes PERTH good at predicting long-term evolution of resistance, while seed dormancy mechanisms and specific detailed weather data in WSW make WSW good at predicting temporal germination patterns under actual weather conditions. LUSO and RIM include economics while WSW and PERTH do not. The relative simplicity of LUSO makes it feasible to develop computationally intensive optimisation routines that would not be feasible for WSW. Each model is specialised for its intended purpose.

When new issues arise, it may seem attractive to try to adapt an existing model to which resources and time have already been devoted. While this may sometimes be the case, in practice it will often be more efficient to develop a new model aimed specifically at addressing this new question. As an analogy, rather than adapt your car to travel on the ocean, it may be easier to just build a boat. With a clear goal in mind, appropriate design decisions can be made. The new model will thus contain only those features and processes necessary to address the issue. Useful parts of existing models can be included and less relevant parts left out. Specific purpose models are thus kept as simple as possible, making them easier to maintain and use and minimising computational demands, while models regularly extended to address new demands tend to steadily increase in complexity and thus computational and maintenance requirements. Specialised models can also work together efficiently. For example, instead of trying to build economics into every aspect of WSW or PERTH, their output can be used to identify key parameter values for LUSO, which can then be used efficiently for economic analysis. Instead of trying to build detailed resistance genetics into WSW or include specific weather data in PERTH, WSW can be used to predict the effects of climate on germination variability, and this can then be incorporated into PERTH. If we also want predictions of crop yield variability to include in PERTH, then instead of trying to build a detailed yield prediction model into PERTH itself, we can look for an appropriate model to provide these predictions, which may be APSIM. Instead of trying to make one model that does everything, we can create a family of efficient models that specialise in simulating different aspects of weed dynamics and find ways to allow these models to work together to support weed management decisions.

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