Towards a process based emergence model for wild radish

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Summary Sustainable weed management must include the management of the seedbank, which can be implemented through an understanding the dynamics of germination and emergence. This knowledge can be integrated into a mechanistic model that can be used to predict weed seed emergence and applied as a research tool and as an on-farm management tool.

A mechanistic model was developed based on research conducted on the germination/emergence dynamics of wild radish. The modelling framework was DYMEX which allows biologists to model without being mathematicians.

Field validation of the model at one site in Victoria showed close agreement between actual and predicted emergence timing and proportion. Further developments of the model are outlined.

Keywords *Raphanus raphanistrum*, DYMEX, hydrothermal, dormancy cycling, mechanistic model.

INTRODUCTION

Weed management techniques that target both weed seedbanks and seedlings are required to effectively manage weed populations in arable crops. The ability to accurately predict the timing and magnitude of weed seedling emergence allows a farmer to optimise the application of weed management tactics based on seedling mortality or suppression. There have been many successful attempts to develop empirical (descriptive) models of weed germination and emergence, usually based upon a Weibull function. Such models are, however, unsuitable for predicting future emergence patterns. Some process-based models of cumulative emergence proportion, based on the accumulation of effective hydro-thermal time units, have demonstrated that it is possible to make predictions of emergence timing that are sufficiently accurate to aid management. Such models have lacked a demographic component, and so do not predict absolute numbers of emergent seedlings. Knowing the absolute numbers of seedlings can potentially influence the choice of management technique, and its magnitude.

We describe a process-based deterministic model for predicting seedling emergence of wild radish (*Raphanus raphanistrum* L.), named WREM (Wild Radish Emergence Model). WREM is based on laboratory and field-based experiments (Young 2001), and builds on the experience of previous emergence modelling attempts by adding in a demographic component and detailed treatment of dormancy cycling.

MODEL DESCRIPTION

WREM was built using DYMEX (Maywald *et al.* 1999), a user-friendly population modelling program. At the heart of WREM is a lifecycle model of wild radish consisting of three lifestages (dormant seed, germinable seed and emerged seedlings) and four life processes (mortality, dormancy cycling and germination) that lead to seedling emergence (Figure 1). The model is driven by environmental parameters (soil temperature, soil water potential and light conditions experienced), which are derived from air temperature, rainfall, class A pan evaporation and time of cultivation.

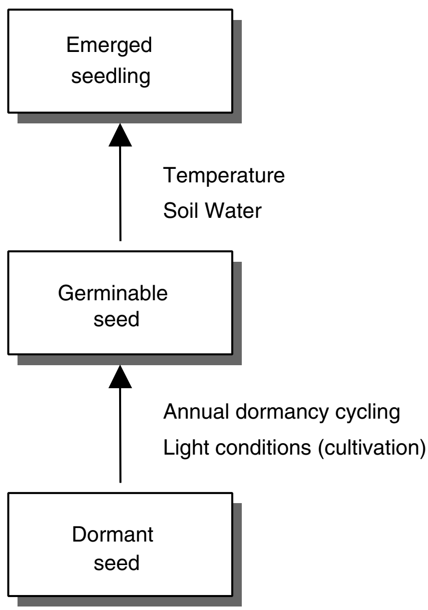

Figure 1. The processes of seedling emergence in WREM.

In the field, seeds move from a dormant state into a germinable state in an annual cycle (Figure 2). This has been described for many species e.g. *Chenopodium album* L. Vleeshouwers and Kropff (2000), *Lamium purpureum* L. Baskin and Baskin (1984), *Polygonum aviculare* Courtney (1968), *Polygonum persicaria* L. Bouwmeester and Karssen (1992) and Vleeshouwers and Kropff (2000), *Raphanus raphanistrum* Young (2001), *Spergula arvensis* L. Vleeshouwers and Kropff (2000), *Veronica hederifolia* L. Roberts and Lockett (1978). For wild radish, the temperature window widens over the winter months and narrows over the summer months, primarily being a change in response to maximum temperature in which germination can occur (Figure 2). Dormancy breakage is also regulated by light, which opens up the temperature window earlier in the year than if the seeds are not exposed to light (Young 2001).

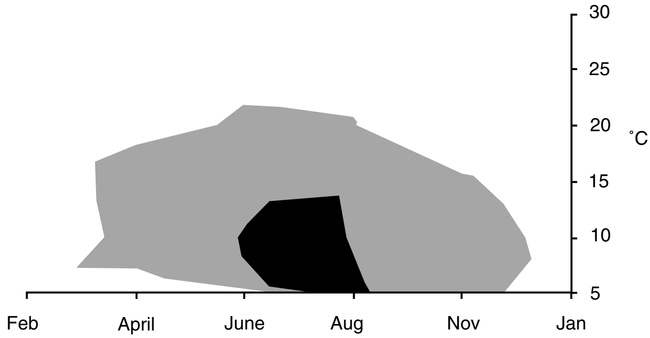

Figure 2. Germination temperature window of wild radish. The grey shaded area is the germination temperature window where seeds have received light and sufficient soil moisture. The black area is the germination temperature window if seeds receive sufficient soil moisture, but do not receive light.

The present version of WREM is designed to explore the emergence of wild radish seedlings one year at a time. As indicated in Figure 1, ungerminated seeds do not currently cycle back from a germinable state to a dormant state. The model includes a separate tillage event module that accounts for time of tillage, allowing a switch in seed response under dark conditions to under light conditions (Figure 2).

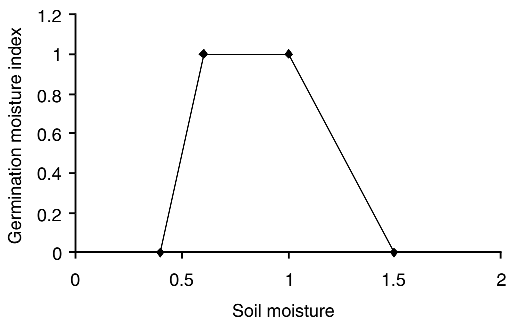

Figure 3. Germination moisture index (MI).

Germination is determined by temperature and soil water levels, and can occur when soil temperatures are within the germination window and suitable soil moisture is available (>-0.4 MPa) (Young 2001).

In WREM, the soil moisture content in the germination zone of the soil profile is simulated using a single bucket model with a shallow moisture-holding capacity (10 mm). Evapotranspiration is set at a constant 80% of class A pan evaporation, reflecting the rapid-drying nature of the soil surface. Hydrothermal time units are calculated from the product of daily values for temperature and soil moisture favourability indices scaled from 0 (totally unfavourable) to 1 (optimal). Both favourability functions are three-segment linear functions that approximate a quadratic function (Figures 3 and 4). The daily germination rate is a linear function of the daily hydro-thermal time units (default 0.03 day^{-1}).

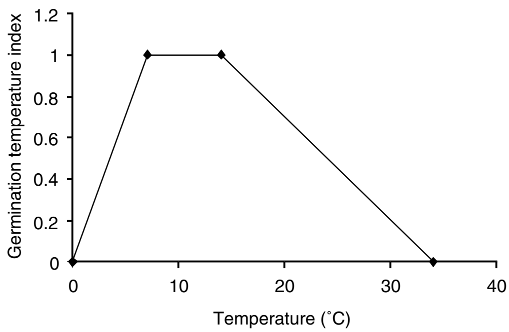

Figure 4. Germination temperature index (TI).

MODEL VALIDATION

Collecting emergence data Wild radish emergence plots were established at Dookie (Victoria), Avondale (West Australia), Roseworthy (South Australia) and Wagga Wagga (New South Wales) in Autumn of 2000 and 2001. Only the results for Dookie are presented here. At Dookie, plots were set up in a barley crop that was sown using minimum tillage practices. The soil type at this location was a clay loam. Emergence plots were 1 m^2 and there were at least five replicates per main plot treatment. Wild radish emergence was sampled destructively at weekly intervals and began with the first flush of emergence that occurred with the onset of the autumn rains. Emergence was evaluated throughout the growing season.

RESULTS

The predicted values closely followed the actual emergence data. In 2000, the break to the season was dramatic, with little rain prior to May. However in 2001, there were sporadic rainfall events in the February to March period, allowing significant emergence of radish prior to any cultivation. The over prediction of emergence in late June may be due to crop establishment having a suppressive effect on weed emergence (Figure 5).

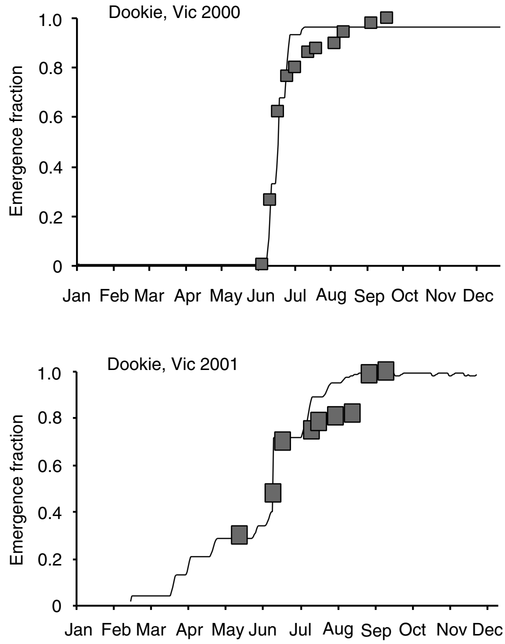

Figure 5. Comparison between recorded and simulated wild radish emergence at Dookie 2000 and Dookie 2001. Solid line is the predicted emergence. The solid boxes are actual emergence proportions.

DISCUSSION

As the results indicate, WREM performs well at Dookie in a minimum tillage situation. As different tillage techniques will place seeds at different depths in the soil profile (Cousens and Moss (1990), Yenish *et al*. (1992)), and seeds at different depths have different germination windows (Young 2001), it may be necessary to include a soil layer module in WREM to account for seeds at different depths.

At present WREM has three life stages: dormant seed, germinable seed and emerged seeds. This does not differentiate between the germination phase and the pre-emergent phase of seedling emergence (Forcella *et al*. (2000), Vleeshouwers and Kropff (2000), Young (2001)). Without this fourth life stage, fatal germination is not accounted for. This fourth life stage is necessary where hard-setting soils occur, or where tillage operations can stimulate germination but also place seed at depths from which seedlings can not emerge.

While WREM uses actual seed numbers, in its present state these numbers are transformed into a proportion of total emergence for the season. This is due to present inaccuracies of seed bank estimation Further work is required to allow in-field estimation of seed bank size in order to estimate density of emerged seedlings.

The modular nature of DYMEX means that WREM can be easily extended to incorporate additional life stages and processes as required to investigate the long-term effects of environmental drivers and management practices on weed dynamics, or the development of herbicide resistance. Similarly, it is possible to add a crop lifecycle and investigate the effects of competition on crop yield. That same flexibility, and simple data requirements, means that it is possible to develop a simplified version of the model to aid decision-support in a similar manner to the Timerite™ model for red-legged earth mite (Lawrence 2001).

WREM can be run in real time using historical data up to the present, and then switched to predicted (modelled) future data or long-term daily averages for predicting future system dynamics. By predicting the timing and size of wild radish seeding emergence, this tool would enable farmers to (a) time the application of herbicides for maximum impact, (b) implement early cultivation to stimulate the seedbank, which can then be followed with more cultivation or other weed management techniques in order to control the emerging seedlings.

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