Computer model for simulating the long-term dynamics of annual weeds under different cultivation practices

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Abstract

A model is being developed which describes the population dynamics of annual weeds and how it is affected by crop rotation, cultivation practices and weed control. The model aims to predict the development of a certain weed species in order to plan crop rotation and cultivation practices to minimize the risk of proliferation. The model does not predict the exact number of weeds expected to be found in a certain year or crop, but rather the general development over a number of years. The model includes documented knowledge, as well as informal expert knowledge, on seed survival in the soil, seed placement in soil after tillage, seed germination with respect to placement in soil, time of year and tillage, weed development in response to crop competitiveness and seed production of the weeds. The model is at present only accounting for the development of one weed species at a time, and only a few weed species are parameterised. However, the model can easily be extended with more weed species, crops and cultivation practices. Model predictions should match what knowledgeable weed scientists already know, perhaps with a little new insight.

Introduction

Weed control alone is not always enough to prevent proliferation of a certain weed species. This is particularly the case in organic farming, where the efficacy of mechanical weed control often is low. Because of this, many preventive methods including tillage, crop rotation, augmentation of the competitiveness of the crop against the weed, sowing time and harvest time etc. are included in the weed control strategy – particularly in organic farming (Kropff et al. 2000; Rasmussen et al. 2000).

A diversified crop rotation can prevent proliferation of a single weed species, since the demands of most weed species in terms of germination, growth and propagation cannot be met if sowing time, crop growth and harvest time are varied between years. An example is that winter annual species germinate primarily in the fall and their establishment is less successful in spring-sown crops than in crops sown in the fall. Experiments have shown that some of the problems with grass weeds, which can arise in crop rotations dominated by winter cereals, can be alleviated by incorporating larger proportions of spring cereals in the rotation (Melander 1993).

The competitiveness of the crop against the weeds is a very important parameter for the growth and propagation of the weeds. Choice of cultivar, seed rate, quality of the seedbed, row distance and geometrical arrangement, fertiliser level and fertiliser application/placement are among the most important factors influencing crop competitiveness (Espeby 1989; Kropff & van Laar 1993; Christensen & Rasmussen 1996; Weiner et al. 2001).

There are many possibilities to prevent weed problems, but they have to be planned well in advance. Optimally, for a certain crop rotation, there would be a strategy for the utilisation of preventive methods within that crop rotation. The need for direct control should be restricted to as little as possible. However, it is quite complicated to characterize the way the different methods interact in the crop rotation and how the crop rotation itself may influence the weed proliferation.

In order to illustrate this, a computer model has been developed which describes the development of different annual weed species under different scenarios. The purpose of the model is to define the development in order to choose the best management to avoid proliferation of a certain weed. The model does not attempt to predict the exact number of weeds likely to germinate in any certain year, but to predict a general trend in the development over a course of several years. As such, it is not a decision support system to plan control in a given crop, but a management support system to plan crop rotation and other cultural measures to decrease reliance on high control efficacy.

Materials and Methods

Modelling approach

Several models have been published, which describe the proliferation of field weeds (Cousens & Mortimer 1995). The system components and processes incorporated in these models reflect the interest of the modeller and the purpose of the model and include soil seed bank, germination, establishment, growth, competition, and seed production. Most of these models work in time steps of one year and under the common assumption that all individuals of a weed species germinate and shed seeds at the same time. Such models are well suited to describe the proliferation of a weed under uniform cropping conditions, such as grass weed propagation in no-till, continuous winter cereals. In contrast, models with a finer time step can capture the variation within a year. Most weed species emerge and shed seeds unevenly through the year; for example, new emergence is often seen after rain or tillage. Within a competitive crop, latecomers will suffer a high mortality thus depleting the soil seed bank, whereas in less competitive crops, plants are more likely to thrive and eventually contribute to the seed bank. To grasp such within-year processes, models with a time step finer than one year are needed. Thus Christensen et al. (1999), based upon the matrix model approach of Silvertown (1987), developed a model that operated in time steps of 14 days. This facilitated the modelling of weed cohorts, having emerged at different times through the year, and the effect of various control measures in different crop rotations could be predicted based upon the knowledge put into the model.

The model presented here is a continuation of this line of work. As a guideline for model design, we wish to keep it simple so that it can easily be extended with additional weed species, crops and cultivation practices. At the same time, we wish to maintain the overall realism so that the model can offer guidance on weed management through targeted planning of cropping cycle and cultivation practices. Model predictions should match what knowledgeable weeds scientists already know, perhaps with a little surprise and new insight now and then.

Weed life stages

Our weed model is stage-structured (Fig. 1) and incorporates each life stage as a separate sub-population: number of seeds in or on the ground, or still fastened to the plant; number of emerging seedlings; number and mass of plants in the vegetative and the reproductive growth stage. In the first version of the model, the population dynamics of each weed species is considered separately with no inter-specific competition other than between crop and weed. The time step of the model is 1 day. The vertical distribution of seeds in the soil is kept in 20 1-cm layers. Seed dormancy takes many forms (Baskin & Baskin 1998) but only primary dormancy is included directly in the model.

Soil tillage and seed germination

During tillage seeds will be shifted around among the 20 soil layers (the seeds on the soil surface follow those in the top 1-cm layer). Cousens & Moss (1990) formulated two models of the movement of seeds caused by harrowing and ploughing, respectively. We use their equations directly in our model considering the seed bank split into four 5-cm layers as they did. In the case of shallower treatments, we simply scale down the thickness of the layers and apply the same equations, e.g., for ploughing at 16 cm depth, the four layers would each be considered 4 cm thick. Mechanical weed control, which properly operated only disturb the top cm of the soil, is assumed not to shift seeds around, except mixing seeds from the soil surface into the top layer.

In undisturbed soil seeds will perish at a rate specific to the species. In the model we use the mortality rates determined by Chancellor (1986), which leads to an exponential decrease in seed numbers. For lack of knowledge we assumed mortality rates to apply equally to seeds at all soil depths. For seeds upon the soil surface we assumed a fixed mortality rate per day-degree common to all species. This mortality is thought primarily to be caused by non-specific predation by insects and birds.

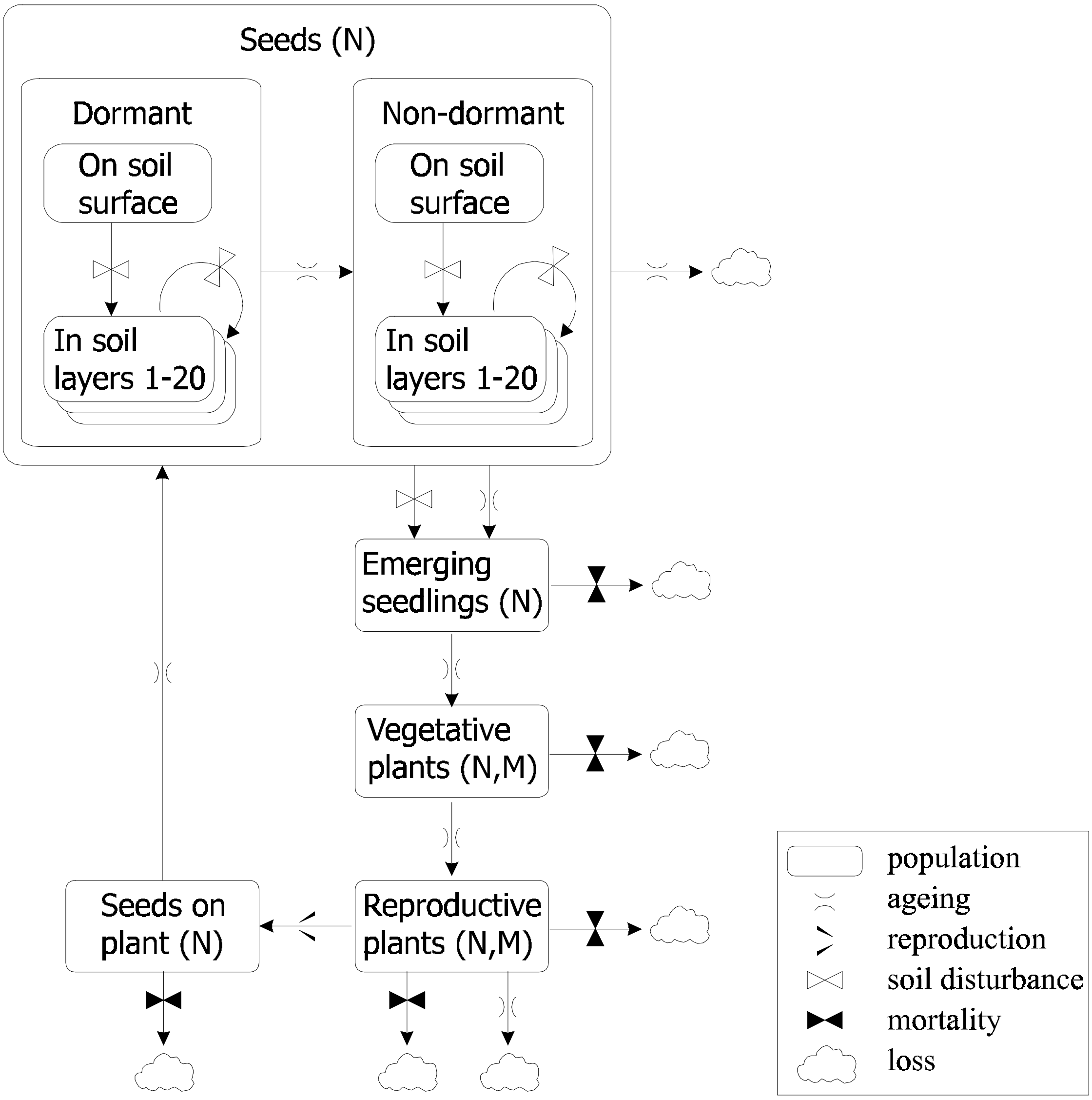

Figure 1. Weed life stages and processes included in the model. The population density of different life stages is kept in either *individuals per m^2* (N) or in *biomass dry-weight per m^2* (M).

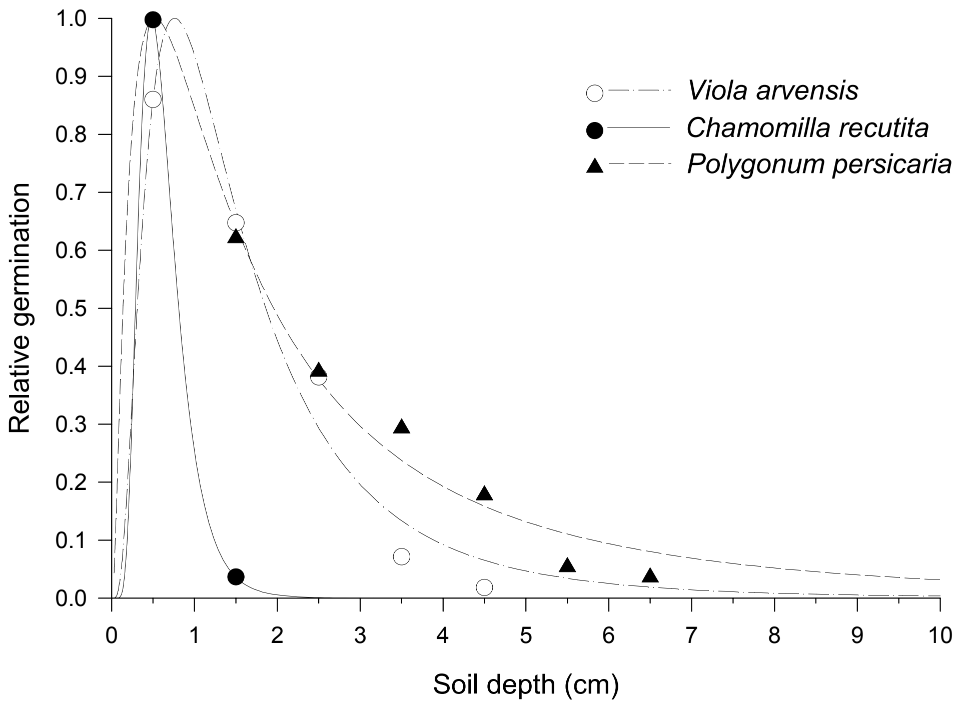

Figure 2. Seed emergence depending on soil depth summarised by log-normal curves (data after Chancellor 1964).

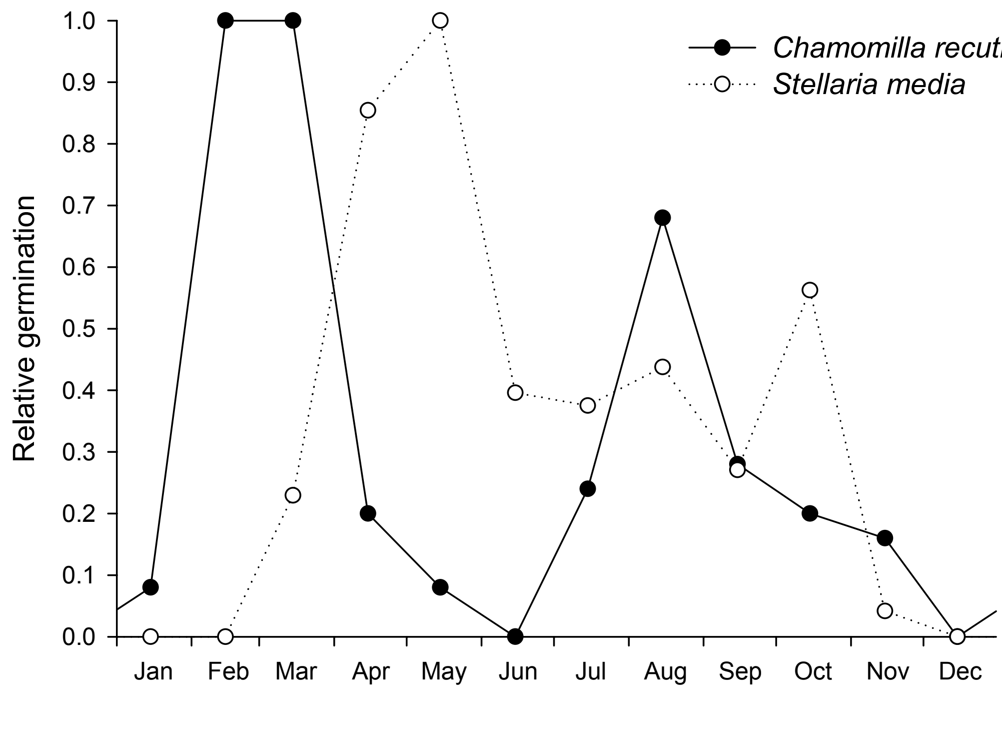

Figure 3. Phenology of seed germination (data after Chancellor 1986).

The germination rate of seeds depends on their vertical position in the soil, as described by Chancellor (1964). Based on his data we could summarise for each species the relative germination rate according to depth by a log-normal curve (Fig. 2). Furthermore, the propensity of seeds to germinate varies with the season. Sophisticated models of germination have been developed, incorporating the effects of soil temperature and humidity (Forcella 1998; Forcella et al. 2000) and dormancy (Vleeshouwers 1997; Benech-Arnold et al. 2000). However, we chose a simpler approach, because we are interested only in the typical course over the year of the weed life cycle and how it interacts with the typical timing of cultivation practices. Thus the phenology of germination was described, for each species, by a relative measure of germination for each calendar month, linearly interpolated to yield daily values (Fig. 3). These species-specific germination curves were determined by experts based on formal (Håkansson 1983; Chancellor 1986) and informal knowledge.

The number of seeds germinating from a certain soil layer on a specific date can now be obtained be multiplying the two relative rates (from Figs. 2 and 3) with the germination rate in undisturbed soil specific to the weed species. On dates when the soil is disturbed (to a certain depth by a certain cultivation practice), additional germination will occur. This is calculated multiplying the two relative rates with the maximum germination rate (determined experimentally under optimal conditions).

Weed growth and reproduction

The development through the life stages, emergence, vegetative and reproductive growth (Fig. 1), is modelled on a day-degree scale. For simplicity, competition is modelled for mass only, and numbers are translated into the projected final weed biomass, as plants leave the seedling stage and enter the vegetative stage.

The final biomass of the weed is calculated by multiplying the effect of intra-specific competition (Fig. 4) with the effect of the crop (Fig. 5), on the day the weeds shift from the emergence to the vegetative growth stage. The relation for intra-specific competition (Fig. 4) concerns the total number of seedlings emerging and not just those emerging on a single day. The effect of taking this into account is that those that emerge first are allotted a larger share of the final biomass than those that emerge later, which makes sense biologically.

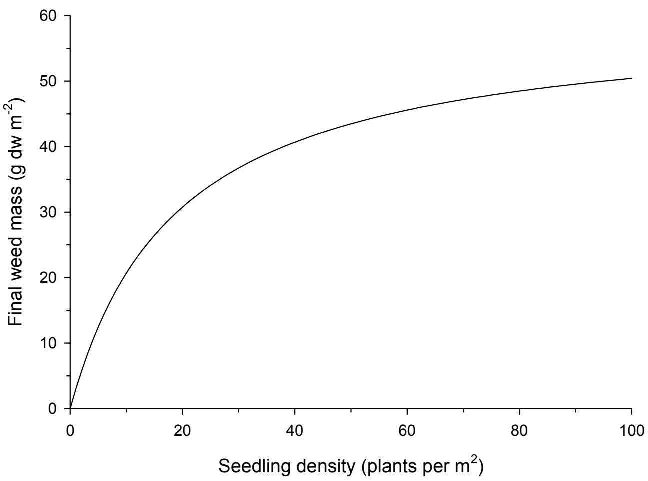

Figure 4. Example of how final, maximum weed biomass is calculated from seedling density.

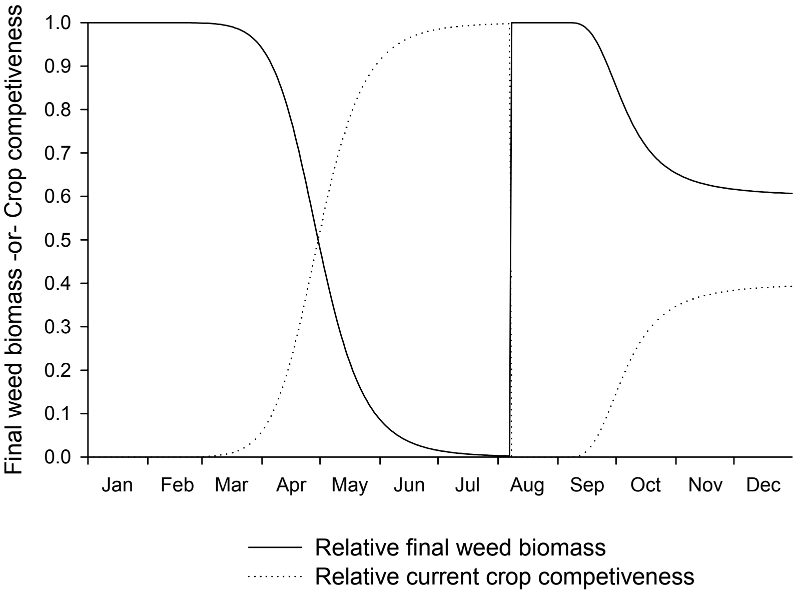

Figure 5. The phenology of crop competitiveness in a field with a spring-sown followed by an autumn-sown crop (dotted line), and the relative final biomass that the weed population would achieve if it emerged at a certain date (full line).

Seed production is assumed to happen at a fixed daily rate, specific to each species, which is proportional to the weed mass in the reproductive stage (Rasmussen 1993; Wilson et al. 1995).

Weed mortality caused by cultural practices

The effect of cultural practices depends on the mode of intervention (seeding, harrowing, ploughing, herbicide treatment, various mechanical weed control methods) and the life stage of the weed; seeds are unaffected (other than vertical movement: from plant to soil, from surface into soil, and between layers within soil), seedlings are the most sensitive, plants in the vegetative growth stage less sensitive, and reproductive plants the least sensitive. Effects are specified as the percentage mortality caused by each kind of cultural practice for each of the three susceptible life stages. In addition, the mortality caused by harvesting (removal) on seeds still on the plant can be specified.

Parameters for the model

Currently, model parameters are being estimated from literature data or, when information is lacking, from informal expert knowledge. Important literature sources include (Stevens 1932; Chancellor 1964; Holm et al. 1991; Moss 1985; Chancellor 1986; Legere & Deschenes 1989; Milberg 1990; Cousens & Moss 1990; Baskin & Baskin 1998; Bouwmeester 2001).

Evaluation of the model

At this early stage, the only evaluation carried out on the model is an expert panel assessing the results retrieved from the runs of the model under different scenarios. However, a great body of data from experiments over a long period of time with a record of crop rotation and cultivations, some with and without weed control, chemical as well as mechanical, will later be used to evaluate the model in a more objective manner.

Results

At the workshop, the model will be presented, and some examples of scenarios will be shown. The current version of model can be downloaded from www.agrsci.dk/plb/nho/fieldweeds.htm.

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