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Prediction of weed emergence in the field

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Summary

A simple descriptive model is presented for the extent and timing of emergence of *Polygonum persicaria*, *Chenopodium album* and *Spergula arvensis* after soil cultivation. Inputs in the model are the date of soil cultivation, the degree of dormancy of the seeds in the seed bank at the date of soil cultivation, and the soil temperature in the week after cultivation. The model was evaluated with help of experimental data on seedling emergence following five different dates of soil cultivation in spring. The number of seedlings emerging in the seedling flush and the onset of seedling emergence could be described fairly accurately.

Introduction

Many researchers have studied the seasonal distribution of weed seedling emergence under field conditions (Roberts, 1964; Roberts & Feast, 1970; Stoller & Wax, 1973; Roberts & Potter, 1980; Ogg & Dawson, 1984). Major factors affecting the seasonal pattern of field emergence were the dormancy cycle of the species, the timing of soil cultivation, the temperature in the field, and the distribution of rainfall.

Prediction of weed emergence patterns in relation to cultivation measures and weather conditions is important for weed management, since the number of seedlings that emerge and the distribution of emergence times affect the degree of interference with subsequent crop growth (Roberts & Potter, 1980; Kropff & Van Laar, 1993). In this paper, a model is presented, describing field emergence as a function of seed dormancy, soil cultivation date and soil temperature. As yet, the effect of rainfall is not incorporated in the model.

The model was evaluated with data from a field experiment in which seeds of the arable weed species *Polygonum persicaria* L., *Chenopodium album* L. and *Spergula arvensis* L. were buried in sterilised soil, and emergence patterns were recorded following a single soil cultivation at different times in spring. Simultaneously to the field observations on seedling emergence, soil temperature was measured and changes in dormancy of the buried seeds determined.

Materials and Methods

Experiment

Seeds of *P. polygonum*, *C. album* and *S. arvensis* were collected in summer 1993 in arable fields in the vicinity of Wageningen. They were dried in open trays at room temperature for one month. Subsequently they were cleaned and stored at 2°C.

In November 1993 18 circular field plots were created by sinking 18 open-ended PVC cylinders, which were 20 cm deep and had a diameter of 30 cm, into the soil, so that approximately 0.5 cm projected above the surface. The experiment was laid out in three blocks, each consisting of a row of 6 plots. The plots were situated in an experimental arable field, with a sandy loam soil. The soil inside the cylinders was removed, bulked, thoroughly mixed and divided into 18 equal portions. These soil portions were irradiated with X-ray radiation to an amount of 1 MRad, to ensure that seeds present in the soil were killed.

In December 1993, 18 equal seed samples of each of the three weed species were weighed out. In a concrete mixer these were mixed through the 18 portions of sterilized soil, after which the soil was put back into the cylinders in the field. The starting situation for the experiment created in this way thus consisted in 18 plots divided in 3 blocks with qualitatively and quantitatively exactly the same seedbank. The approximate seed density per cm depth in the soil profile down to 20 cm was 7100 seeds $m^{-2}cm^{-1}$ for *P. persicaria*, 10600 seeds $m^{-2}cm^{-1}$ for *C. album* and 5000 seeds $m^{-2}cm^{-1}$ for *S. arvensis*.

Emergence of seedlings in the plots was observed from December 1993 until July 1994. Observations were made at about three days' intervals. After being counted, seedlings were cut off to prohibit double counting.

No crop was grown in the field where the plots were situated. The field was regularly sprayed with glyphosate to prevent growth of weeds and contamination of the plots with seeds from outside. During herbicide application the plots were covered with plastic lids.

In each block five plots were cultivated at five different dates in spring, and one plot remained uncultivated. The dates of soil cultivation were 8 March, 21 March, 12 April, 21 April and 3 May 1994. These dates span the period when the soil is cultivated for the planting of summer-grown crops in the Netherlands. In each block cultivation dates were attributed randomly to the plots. Soil cultivation consisted in a thorough mixing of the soil. At the date of soil cultivation the soil in the cylinders concerned was dug out with a trowel to a depth of 15 cm, and stirred thoroughly in a shallow plastic tray, in order to expose the seeds buried in the soil to daylight and to redistribute them randomly. Subsequently, the soil was put back in the cylinder. The layer from 15 to 20 cm functioned as a buffer zone to avoid mixing with the soil from the arable field containing the natural seedbank.

From 8 March onwards, soil temperature in the experimental field was measured in one hour intervals at a depth of 1 cm in two separate, undisturbed plots that were also surrounded by PVC cylinders dug into the soil.

Parallel to the field observations on the emergence of the three weed species, seasonal changes in dormancy of seeds buried in the field were assessed. For this purpose, in December 1993 envelopes made of fine mesh nylon gauze were filled with sterilized soil containing 100 seeds. For each species 30 envelopes were filled. The envelopes were buried in the field, close to the experimental plots, at a depth of approximately 8 cm below the soil surface. At dates as close as possible to the dates of soil cultivation, 6 envelopes of each species were exhumed according to a random scheme in order to test germination. The exhumation dates were 9 March, 22 March, 12 April, 21 April and 1 May. The soil containing the seeds was put into 50 mm petri dishes with one layer of filter paper, moistened with 10 mM KNO_3. The soil layer in the petri dish had a depth of approximately 3 mm. It was irradiated with red light from both above and below for 20 minutes. Subsequently the petri dishes were placed in incubators at temperatures of 5°C, 7.5°C, 10°C, 15°C, 20°C and 25°C in darkness. Observations in green safe light were continued until no additional germination occurred.

Model

The extent and timing of weed emergence in the field after soil cultivation is determined by the degree of dormancy of the seeds in the soil at the moment of cultivation, the germination of seeds and pre-emergence growth of seedlings. By cultivating the soil at different dates, seeds were stimulated to germinate at different stages of their dormancy cycle, but also at different weather conditions, which causes differences in the germination and emergence process.

The extent of field emergence following soil cultivation can be estimated by

$$N_e = d\, f_g\, N_b \qquad (1)$$

where N_e is the number of seedlings emerging as a result of soil cultivation (seedlings m^{-2}), f_g is the fraction of seeds in the soil germinating as a result of soil cultivation (seedlings $seeds^{-1}$), N_b is the number of seeds buried per cm in the cultivated soil layer (seeds $m^{-2}cm^{-1}$), and d is the critical burial depth (cm), above which all seeds that germinate produce seedlings that reach the soil surface, and below which no emergence occurs.

The temperature-sum approach (Garcia-Huidobro, Monteith & Squire, 1982a, 1982b) was used to describe the timing of emergence following soil cultivation. The temperature sum is calculated by accumulating daily average temperature above a base temperature, starting at the day of soil cultivation. The accumulation of temperature S_t (°Cday) at day t is given by

$$S_t = T_t - T_b \quad \text{if } T_t > T_b, \qquad (2a)$$
$$S_t = 0 \quad \text{if } T_t < T_b, \qquad (2b)$$

where T_t is the average temperature (°C) at day t, and T_b is the base temperature (°C). A fraction x of the final number of seedlings is attained when the temperature sum ΣS_t (°Cday), starting from the day of soil cultivation, reaches a thermal time θ_x (°Cday).

Results and discussion

In Fig. 1 weekly average soil temperature at a depth of 1 cm in undisturbed soil in the period from 8 March until 1 July are shown. In this period, the average soil temperature increased gradually from about 5°C to about 20°C.

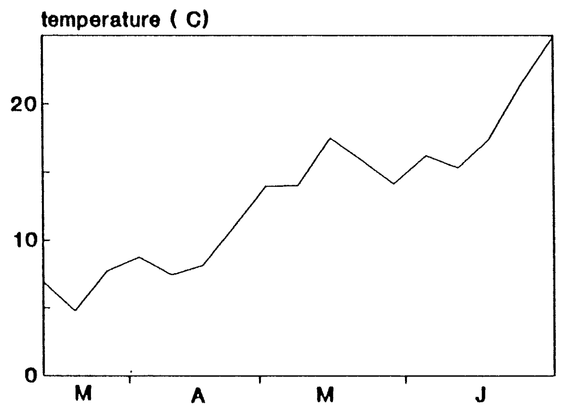

Fig 1. Weekly average soil temperature (°C) at a depth of 1 cm in the period from 8 March until 1 July.

As an example of the changes in dormancy of the buried seeds, Fig. 2 shows germination percentages of the seed portions that were exhumed shortly before or shortly after soil cultivation, when tested at a temperature of 7.5°C. In *P. persicaria* and *C. album* dormancy gradually decreased (germinability increased) in the period from 9 March to 1 May. Dormancy in *S. arvensis* stayed at approximately the same level during March and April, while some relief in dormancy occurred between 21 April and 1 May.

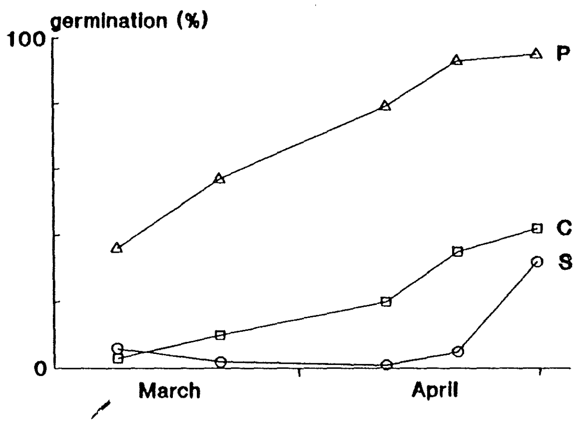

Fig 2. The germination percentage in the germination test at 7.5°C as a function of exhumation date. P: *P. persicaria*, C: *C. album*, S: *S. arvensis*.

In the experiment, N_e is the emergence between the day of soil cultivation and the end of the observations on 30 June. Fraction f_g was estimated from the germination results of the seed portions that were exhumed simultaneously to soil cultivation. It was equalled to the fraction of seeds that would have germinated in the test if the exhumed seeds had been tested at the average field temperature T at a depth of 1 cm in the week after soil cultivation. It was assumed that soil cultivation led to irradiation of all seeds buried in the upper 15 cm. The best estimation was made if maximal emergence depth d was equalled to 1.7 cm in *P. persicaria*, 1.5 cm in *C. album*, and 2.0 cm in *S. arvensis*. In Table 1 numbers of emerged seedlings, estimated according to eq. (1), are compared to the numbers observed.

Apart from a large overestimation of *P. persicaria* emergence after soil cultivation at 12 April, field emergence was estimated reasonably well. Germination in the uncultivated plots cannot be estimated in this way, since the date of soil cultivation is input in the model. The later in spring the soil was cultivated, the higher the numbers of seedlings emerging. This resulted from both an increase in temperature and a decrease in the degree of dormancy of the seeds in the seed bank.

In the estimation of T_b and θ_x, values of T_b were varied, and for all five emergence curves it was calculated how many °Cdays (θ_x) passed between soil cultivation and the attainment of an emergence percentage x. The base temperature T_b at which values of θ_x were constant between emergence curves, and the accompanying value of θ_x were used as estimates in the model. In this way, the onset of emergence after soil cultivation could be described reasonably well (Table 2). Onset of emergence was defined as the date when 5% of the seedlings in the seedling flush have emerged. Estimates for T_b and $\theta_{0.05}$ were 5.2°C and 78.1°Cday for *P. persicaria*, 0.0°C and 101.5°Cday for *C. album*, and 2.0°C and 87.3°Cday for *S. arvensis*. Description of later stages in the emergence process, like the median of the distribution of emergence times, was poor. This may be due to periods of reduced soil moisture, occurring in late spring, which temporarily cease the emergence process (Roberts, 1984; Finch-Savage & Phelps, 1993).

Table 1. The observed and described seedling density caused by soil cultivation at five different dates (seedlings m^{-2}) (x1000). For the observed seedling densities standard errors are given (± s.e.).

	P. persicaria		*C. album*		*S. arvensis*	
cultivation date	obs.	pred.	obs.	pred.	obs.	pred.
8 March	4.0±0.2	3.2	1.1±0.1	0.5	0.2±0.03	0.5
21 March	4.2±0.1	5.8	0.5±0.1	1.3	0.3±0.07	0.2
12 April	5.7±0.4	10.0	2.2±0.4	3.3	0.4±0.06	0.1
21 April	12.1±0.7	11.2	10.5±0.6	8.8	1.2±0.02	0.6
3 May	13.5±0.9	10.5	10.3±0.9	11.1	2.1±0.14	2.3

Table 2. The observed and described onset of emergence after five different dates of soil cultivation. The described onset of emergence is expressed as the deviation from the observed date in number of days.

	P. persicaria		*C. album*		*S. arvensis*	
cultivation date	obs.	pred.	obs.	pred.	obs.	pred.
8 March	11 April	+3	21 March	+3	25 March	+3
21 March	21 April	-2	31 March	+2	5 April	-1
12 April	28 April	0	26 April	-3	28 April	-4
21 April	2 May	-1	29 April	0	28 April	+1
3 May	11 May	+1	11 May	-1	9 May	+1

Conclusions

Knowing the size of the seed bank, the degree of dormancy of the buried seed population at the time of soil cultivation and the average temperature in the field in the week following cultivation, the number of seedlings in the emergence flush in spring could be described reasonably well by a simple descriptive model. The average field temperature in the week after cultivation may be forecasted with sufficient accuracy. This implies that an estimation of the degree of dormancy at the day of soil cultivation would enable a prediction of the extent of the seedling flush that follows cultivation. Simulation models describing the seasonal patterns in seed dormancy of buried weed seeds as a function of soil temperature (Bouwmeester & Karssen, 1992; Vleeshouwers & Bouwmeester, 1993) may fulfil this need.

The onset of emergence after soil cultivation can be predicted by accumulating temperature from the date of soil cultivation until the thermal time for the first germination is reached. However, the further time course of the spring emergence flush is described poorly. This may indicate that inclusion of the effect of soil moisture is needed to quantify the emergence pattern.

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