Following the trace of harvesting seed losses – a model to predict the soil seed bank and oilseed rape volunteers

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Introduction

Seed loss during harvesting of oilseed rape (*Brassica napus*, OSR) is more than just an economic loss because seeds can fall dormant, survive non-germinated for many years in the soil seed bank, and emerge in following crops (Gulden et al., 2003; Gruber et al., 2010). These volunteer plants are unwanted because they increase crop densities, affect the harvesting process and finally can lead to admixtures of different genotypes in the harvested crops. Seed admixture is particularly unwanted if the volunteer variety has seed ingredients different from the crop currently grown, or if it is genetically modified. Many studies from the last 15 years have collected data about OSR seed bank dynamics, and how the seed bank can be reduced by tillage or by growing low-dormancy genotypes. These approaches exist more or less in isolation from each other, and they are difficult to interpret and apply by practicing farmers in a consistent way. The aim of the study was to develop a practical model based on existing data which would allow a consistent calculation of the number of OSR volunteers emerging on a farmer's field. The model could be used 1. to better understand processes of OSR volunteer dynamics in a crop sequence, and 2. to predict the expected number of volunteers on a particular field using a minimum of input data.

Materials and methods

Data were collected from several pre-existing studies, many of them from the Hohenheim working group for oilseed rape from previous years, and integrated into a simple linear and deterministic model on a spreadsheet. The data base includes the movement of plastic pellets under different tillage systems (Mohler et al., 2006, pers. comm.; Gruber et al., 2010), seed mortality (Banhardt et al., 2011), values for seed dormancy (Weber et al., 2010), harvesting losses (Gruber et al., 2007a), and fitness of oilseed rape volunteers (Gruber et al, 2007b).

Table 1. Input data as required for a model to determine the soil seed bank of oilseed rape

Input data	Range of input
Data for the time between OSR harvest and sowing of the 1st following crop	
Harvesting loss seeds m^{-2}	Unlimited (average: 4000)
Dormancy level %	Possible range: 0-100
1st post-harvest tillage	After > 28 days, or < 28 days
Primary tillage	Deep inversion/non-inversion, shallow non-inversion, no till
Data for the time during following crops	
Crop species	Winter cereals, spring cereals, pulses, maize, oilseed rape
Flowering volunteers	Yes/no
1st post-harvest tillage	After > 28 days, or < 28 days
Primary tillage	Deep inversion/non-inversion, shallow non-inversion, no till

One single, simply-structured table requires minimum data entry: harvesting seed loss, mode of tillage, crop sequence, occurrence of flowering volunteers, and dormancy level of the volunteer source variety (Table 1). The model includes modules for different crops (spring and winter cereals, maize, pulses and oilseed rape) that follow an initial oilseed rape crop, and which can be chosen freely for up to 5 years after harvesting the initial oilseed rape. The mode of soil tillage can be selected from P (deep inversion by mouldboard plough, 20 cm), CP (deep non-inversion by chisel plough, 18 cm), RTT: rototiller (shallow non-inversion, 8 cm), or NT (no till). If first post-harvest tillage (S: superficial/stubble tillage) is made earlier than four weeks after harvesting, the model calculates that dormancy induction will be higher than for delayed post-harvest tillage. The model furthermore considers, by fixed values, seed bank decline due to natural release of seeds from dormancy or seed mortality, natural seedling mortality by biotic impacts and herbicides, and seed bank replenishment by volunteers. The model output is the number of seeds falling dormant and surviving until the next crop in the soil seed bank, which depends on time and mode of tillage, seed mortality, and the dormancy level of the variety. As OSR seeds do not emerge from soil horizons below 10 cm (Gruber et al., 2010), only the quantity of seeds in a soil depth of 0-10 cm is shown, though seeds in all horizons are considered in the model background calculation. Tillage operations move seeds from the deep soil to the topsoil, or do not move them vertically at all, depending on their depth and the mode of inversion or non-inversion. Volunteers' emergence, flowering, seed set and replenishment of the soil seed bank are calculated as typical effects of the competitive situation for volunteers growing in winter wheat, spring barley, maize or oilseed rape (Gruber et al., 2007b, and unpublished). The user has access to all data and formulas which are provided in the background, to adapt the model if necessary, and to understand the underlying processes. Data from the simulation were calibrated with data from a long-term field experiment (Gruber et al., 2010), as a mean over five years for all treatments. Crop rotation for the calibration following the initial OSR was: winter wheat, maize, oat, triticale, maize. The initial seed input accounted for 20,000 seeds m^{-2} of the high-dormancy variety Smart (90 % dormancy). For the current study, the topsoil seed bank was also calculated for a low-dormancy variety Express (10 % dormancy), and compared with the high-dormancy variety Smart (90 % dormancy) seed bank, under all tillage treatments.

Results

The results from the model calculations correspond with data used for testing from a field experiment, with a coefficient of determination of 0.88 under the given input data (Fig. 1).

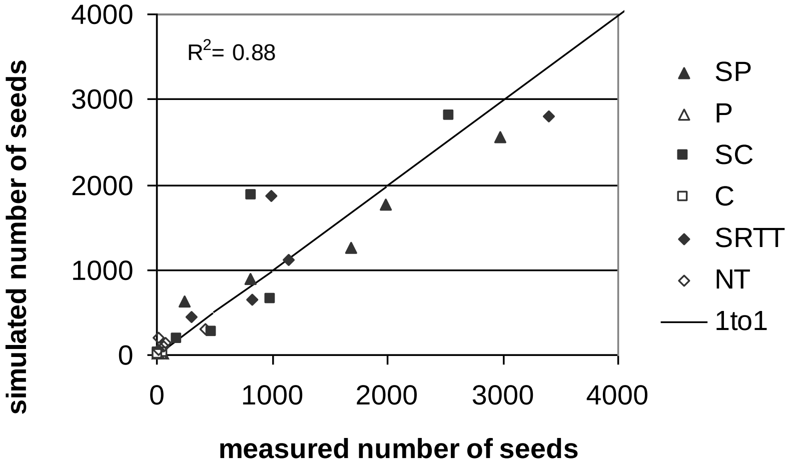

Fig. 1. Calibration of the model: comparison of simulated and measured seeds in the soil seed bank (total of all depths, 5-year crop rotation). S: immediate superficial tillage, combined with primary tillage P: mouldboard plough, CP: chisel plough, RTT: rototiller, NT: no till. Initial seed rain: 20,000 seeds m^{-2}, cultivar Smart, 90% dormancy.

Overall, the soil seed bank (soil depth 0-10 cm) in spring after initial harvesting of oilseed rape (in the first crop following winter cereals) was lowest if the first tillage operation was performed more than 4 weeks after the seed rain (P, CP; Fig. 2). The highest number of rapeseeds in the topsoil occurred if first tillage was performed immediately after the seed rain, and under non-inversion tillage (SCP, SRTT). The total seed number in SP appeared similar to that in SCP and SRTT in the first year after oilseed rape, but most of the SP seeds were located in 10-20 cm soil depth in this first year due to soil inversion (data not shown).

If a comparison was modelled for low-dormancy (10% dormancy) and high-dormancy varieties (90% dormancy), and for a high (20,000) and a medium seed rain at harvesting (4,000 seeds m^{-2}.), the low dormancy variety at high seed rain resulted in a similar seed bank size as the high dormancy at low seed rain.

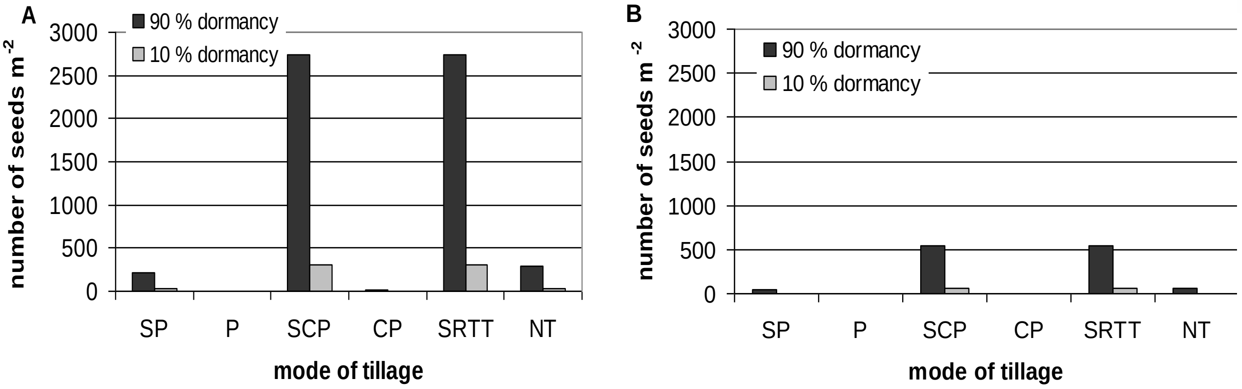

Fig. 2. Soil seed bank from modelling high- and low-dormancy OSR varieties from a seed rain of 20,000 (A) or 4,000 (B) seeds m^{-2}). S: immediate superficial tillage, combined with primary tillage P: mouldboard plough, CP: chisel plough, RTT: rototiller , NT: no till.

Discussion

The calibration yielded sufficient results for the seed bank simulation of the high-dormancy variety Smart over a practice-related crop rotation. Therefore, the structure of the model is suitable for realistically characterizing the situation for a soil seed bank under a five year crop rotation after harvesting OSR. The modelling procedure showed, however, that current literature and data alone are not sufficient to explain seed losses by predation, disease, or environmental factors, and that the mechanism of seed mortality is not yet understood in seed bank dynamics. Additional studies are necessary at this point to fill the information gap and to better understand the processes involved in seed or seedling mortality.

The volume of seed loss at harvesting was a crucial factor in determining the size of the soil seed bank, but this factor cannot be sufficiently controlled by farming practices today, as a survey of over more than 20 farmers' fields showed (Weber et al., 2009). It has become apparent over the last decade that time and mode of soil tillage after OSR harvesting are crucial in establishing or avoiding a large OSR soil seed bank; leaving the soil untouched after harvesting for some weeks minimises the soil seed bank (Gruber et al., 2005). However, growers do not have always the choice of time and depth of tillage operations; they are in fact dependent on climatic and current weather conditions, on the availability of equipment, on soil properties, and crop sequence. Finally, because harvesting seed loss cannot be easily influenced by farming practices, and because soil tillage can be – deliberately or unconsciously – performed in the wrong way for many reasons, the genotype seems to be a more reliable way to minimise the soil seed bank. Here, low-dormancy genotypes can be used as biological containment systems to avoid gene escape via the soil seed bank, from genetically modified oilseed rape or from any conventional oilseed rape with specific traits as well.

The number of seeds in 0-10 cm soil depth with potential to emerge turned out to be generally low in the first year directly after ploughing (soil inversion). In short crop rotations, or if gene escape by volunteers must be avoided, only shallow non-inversion tillage seems appropriate for the next years after ploughing, to keep the soil seed bank in deeper soil. Generally, the model can be applied to assess the potential of gene escape, especially in very short crop rotations with oilseed rape, and to predict the number of volunteers in a crop based on different crop rotations.

Outlook

The model calculations helped to clarify the underlying interactions of the factors in agro-ecosystems which affect seed bank dynamics and the life-cycle of oilseed rape. The model can be used as a support tool for extension services, for teaching students, or directly by growers themselves. Once the specific risk of OSR volunteers has been calculated for a certain area, optimized management practices can be adopted, such as changes in the crop sequence or changes in time and mode of tillage. Even more important, however, is the gain of insight from the model on how an OSR seed bank is established after the seed rain, and thus how to avoid a large soil seed bank. The model could well be combined with a similar, pre-existing model which calculates GM admixtures depending on the number of OSR volunteers in an OSR crop.

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