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Regional distribution of genetically modified organisms (GMOs)—Up-scaling the dispersal and persistence potential of herbicide resistant oilseed rape (*Brassisca napus*)

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ABSTRACT

Most genetically modified (GM) crop plants are designed to be grown on large areas. However, empirical investigations for risk assessment are limited in their temporal and spatial extent. In the case of GM crop plants it is difficult to test the relevance of anticipated risks on the same spatial scale as the intended use. Processes which are difficult to assess experimentally include combinatory effects, interactions between different integration levels, persistence, long distance dispersal and occurrence of rare events. To a limited extent, it is possible to combine results of investigations on small spatial scales in a way that large-scale and long-term implications on the regional scale can be analysed by using modelling and extrapolation approaches. It is thus possible to indicate some of the involved risks which are not accessible otherwise.

In this paper we present the results of an extrapolation methodology comprising several scales from the field size up to the landscape level. This methodology aimed at analysing the implications of a large-scale release of genetically modified oilseed rape (GM OSR). The approach consisted of an extrapolation scheme beginning with a landscape analysis which generated representative scenarios considering climate and OSR cultivation characteristics. For the spatial extent of several fields this information was applied in an individual-based model representing ontogeny, dispersal and persistence of cultivated, volunteers and feral oilseed rape. In a final step, simulation results were extrapolated to the region of Northern Germany.

Here we focus on the model results which were extrapolated to the regional level by applying a set of ecological indicators which allowed to assess potential implications on this level. These indicators included the number and distribution of flowering GM plants and the dynamics of GM OSR seeds in the soil seedbank. Specific results related to the long-term dynamics in the seedbank and volunteer development. Model results emphasise the long-term consequences of GM OSR cultivation and the explicit necessity to regard high variability in potential GMO admixture. This has to be considered when developing landscape management schemes for co-existence.

The extrapolation approach presented here, integrates different traits to assess effects of GMOs on large spatial scales with respect to persistence and dispersal. The developed methodology is equally applicable for other crops, regions and different agricultural conditions.

1. Introduction

Genetically modified organisms (GMOs) are designed to replace conventional crops to a large extent. In some countries, e.g., the USA, Canada, Argentina and Brazil, GM crops like maize, soybeans, cotton and oilseed rape are already commonly used (James, 2007). In contrast, the cultivation of GM crops in Europe is still very limited with currently a larger number of GMO in the regulation process.

The replacement of conventional crops with GM varieties implies a large-scale cultivation with potential environmental effects on the same spatial scale. In contrast, the assumptions made

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in the environmental risk assessment (ERA), primarily base on small-scale investigations (in laboratories, greenhouses and on single fields). These spatial and temporal limitations considerably restrict the observed range of ecological interactions and organisation levels (Andow and Hilbeck, 2004; Snow et al., 2005; Henri, 2006). Thus ecological processes like long-term effects, e.g., on food webs, long distance dispersal of seed and pollen and persistence of wild populations may not be addressed adequately due to the spatial and temporal limitations of the risk assessment. Hybridisation and out-crossing as well as potential combinatory effects in plants with multiple transgenes and the resulting ecological implications cannot be captured to full extent by laboratory methods and experiments restricted to a few hundred meters in space and a few plant generations in time. This applies to rare events as well. These may not be observed in laboratories, but may be of crucial importance since through the potential of self-organised reproduction, even extremely unlikely combinations may occur when large-scale cultivation takes place with billions of plants producing pollen and seeds. Thus, with respect to the ecological risk assessment of GMO, we have to state a gap in knowledge and respective methodologies referring to higher organisational levels.

Therefore it is essential, not only to assess risks related to small-scale experimental releases of GMO, but also to develop and apply appropriate methodologies which allow extrapolation and up-scaling of small-scale processes to anticipate effects on larger scales and also take into account the structural regional characteristics of the receiving environment including land use practices. For this purpose, a combination of different modelling tools is well suited, as these allow not only to represent processes on different spatial scales but also to represent interactions and feedback processes between these scales. As large-scale dynamics may be described as the result of interacting entities and local processes under a given set of external constraints (O'Neill et al., 1986; Wu, 1999) modelling can help to analyse underlying causalities in order to identify driving forces, which in a further step may be applied in scenarios representing different application situations (Breckling et al., 2005; Reuter et al., 2005, 2008).

Scaling methodologies referring to properties and processes from local sites to landscapes and vice versa are currently discussed in landscape ecology and in ecology in general (Schneider, 2001; Miller et al., 2004; Urban, 2005) and in the context of predictions and risk assessment (Peters et al., 2004). Management problems cannot be adequately addressed by directly extrapolating locally measured variables to larger areas and longer periods as processes and patterns measured at small scales do not necessarily have the same role or qualitative implications at larger scales (Schneider, 2001; Reuter et al., 2005). As up-scaling we denote a method to transform local processes, properties and information in an aggregated form to higher scales while partially decreasing resolution. In this context individual-based models constitute a good starting point (Urban, 2005) as they allow to integrate complex interactions and knowledge on several integration levels.

For the assessment of environmental effects of GMO a consistent extrapolation methodology and appropriate applications have not been published. First approaches focus on large-scale dispersal models for pollen (Shaw et al., 2006) and for the frequency of hybridisation events (Wilkinson et al., 2003) as well as for specific aspects on an intermediate scale (Garnier et al., 2006). Yet, the implications of large-scale cultivation is a key issue which must be explicitly addressed when analysing risks of GMO.

Any extrapolation methodology also implies the identification and application of relevant ecological and economical indicators that can be used in the scaling process to estimate effects beyond the farm-scale level. These indicators may be used to evaluate and describe states and the potential environmental impact on the respective organisational levels and establish a relation between these levels (Dale and Beyeler, 2001; Kurtz et al., 2001). In an up-scaling process the application of indicators allows to focus on those parameters with a high predictive value as well as a good accessibility. In the context of GMOs it is essential to consider the bio-geographic variability of the region for which a crop is intended for cultivation. This includes landscape structure, climatic conditions, and the composition of the local species pools which potentially may be directly affected by the cultivated crop or by hybridisation partners. Additionally the agricultural practice and cultural habits should be considered as far as they refer to management schemes.

In the context of GMOs, oilseed rape (OSR, *Brassica napus*) is regarded as a crop with a potential to cause environmental and economical problems because volunteers (plants that grow unintendedly on the cultivated land in subsequent crop rotations) frequently occur and ferals (plants that grow outside cultivation, e.g., on marginal land) allow persistence of genotypes in the wild. In addition, OSR is known for its hybridisation potential with several wild and weedy species (Crawley and Brown, 1995; OECD, 1997; Pessel et al., 2001; Chevre et al., 2004; Legere, 2005). OSR pollen is dispersed over several kilometres which leads to long distance out-crossing probabilities (e.g., Timmons et al., 1995; Ramsay et al., 2003; Rieger et al., 2002; Devaux et al., 2007). Seeds have the potential to survive in the soil seedbank with persistence times beyond 10 years promoting long-term emergence of volunteers (Lutman et al., 2005; Begg et al., 2006; Jørgensen et al., 2007; D'Hertefeldt et al., 2008) or ferals (Pivard et al., 2008). Oilseed rape is frequently cultivated in Central Europe with Germany accounting for 11.5% of the worldwide production in 2005 (FAO, 2005). Cultivation in Germany mainly occurs in the North-East, with the federal states of Schleswig-Holstein and Mecklenburg-Western Pomerania having the high densities of OSR fields. However, both regions are also examples for different cultivation conditions. In Mecklenburg-Western Pomerania as well as in Brandenburg cultivation takes place on large fields. This is a result of land reforms in the former German Democratic Republic after World War II, whereas in Schleswig-Holstein the agricultural landscape is highly structured with a decisively smaller average field size (Table 1). Because of the spectrum of relevant causal traits, oilseed rape is an important example to investigate relationships between different spatial scales and implications arising from a large-scale cultivation with conclusions also relevant for other genetically modified crops.

The aim of this paper is to present a methodology to assess the potential ecological impact and to anticipate landscape effects of genetically modified oilseed rape before approval for cultivation. The approach might be used as part of an ecological risk assessment of GMOs applying relevant indicators with the focus on effects of the regional level relating, e.g., to the soil seedbank and the spatial distribution of GM admixture.

2. Up-scaling oil seed rape dispersal and persistence

The persistence and the distribution of oilseed rape on the landscape level results from processes on different spatial scales. On the level of single plants, physiological processes determine, e.g., life span, germination, flowering and fruit maturation. On the level of the population, dispersal of pollen and seeds are important. On the regional level, e.g., the distribution, size and shape of fields, the distribution and persistence of feral OSR populations and populations of related species as potential hybridisation partners are decisive factors. Climatic constraints and influences of crop management and cultivation technology set the general conditions on each of the included levels.