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The importance of climate, site and management on weed vegetation in oilseed rape in Germany

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ABSTRACT

Data on the occurrence of weed species in 1463 German oilseed rape (OSR) fields were used to multivariately investigate the interactions of management practices and ecological processes with weed species composition. Partial canonical correspondence analysis (pCCA) served to quantify the relative contribution of 25 characteristics of climate, site and crop to weed species composition. According to pCCA the considerable differences in weed species composition of OSR fields were mainly associated with the crop preceding OSR, the tillage intensity and soil quality. Longitude and precipitation were the most important environmental parameters. Factors driving the occurrence of weed species differed for the categories 'common', 'frequent' and 'rare' weed species. Common weed species showed the strongest response to factors acting at the field scale such as crop sowing date or soil quality, while only frequent species were affected by local environment, and the occurrence of rare weeds more than the other groups depended on large-scale geographical position variables as well as cropping intensity. Cluster analyses of thematically grouped explanatory variables resulted in the identification of four farming systems with different soil properties and management, two farming systems differing in the occurrence of OSR cropping, and five ecoregions, each with characteristic and statistically verified OSR weed communities.

1. Introduction

Rotational cropping selects, via diverse crop species, seeding rates and seeding times, for weeds with high competitive ability as manifested by traits such as rapid germination and early growth or greater height (Murphy and Lemerle, 2006). In contrast, short rotations with repetitive agronomic practices, as produced by high proportions of winter crops, induce crop mimicry by weed species (Fried et al., 2009). This means that for example broadleaved weeds grow in broadleaved crops and increasing proportions of winter annual crops promote weeds that germinate in autumn (Chancellor and Froud-Williams, 1986). Further examples of management filters include reduced tillage systems which may increase wind dispersed species and perennials or biennials sensitive to soil disturbance (Derksen et al., 1993; Zanin et al., 1997). Moreover, early crop sowing may promote early germinating weed species. Soil amendments may select for species that tolerate high nutrient levels (Andreasen and Skovgaard, 2009) and mechanised harvesting may favour early maturing and small seeded species that successfully escape seed removal at harvest (Murphy and Lemerle, 2006).

Leeson et al. (1999, 2000) recommended using on-farm research approaches to investigate interactions of management practices and ecological processes. This means including a larger number of fields from different farms within a region instead of analysing single management factors in field trials. However, this requires classifying farm management systems according to social, economic and land use variables (Aitchison, 1986), chemical input level and cropping history (Leeson et al., 1999) which then can be assessed regarding their effect on weed vegetation.

The current crop has been found to explain most of the variation in species composition between fields in France (Fried et al., 2008), Argentina (Poggio et al., 2004), Denmark (Andreasen and Skovgaard, 2009) and Sweden (Hallgren et al., 1999). In a number of other studies, large-scale climatic and edaphic factors (Ries, 1992; Andersson and Milberg, 1998; Šilc et al., 2009), altitude (Lososová et al., 2004; Pysek et al., 2005) and temperature (Qiang, 2005) have been found to explain weed species composition better than did crop-specific factors.

In order to exclude variation due to crop and sowing season our investigation was limited to one crop and focussed on the effect of various other management factors on weed species composition, including tillage intensity, crop variety, crop density, herbicide application and kind of fertilization. We chose oilseed rape (OSR) for our study because this crop has become one of the most important in Germany, with steady increases in cropping area and intensity during the last decade (Gurrath, 2009). The intensification of OSR cropping is supposed to have changed the weed vegetation in this crop by favouring cruciferous weeds (Wahmhoff, 2000) and

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problematic weeds in general due to weaknesses of the herbicide programmes in this crop (Lutman et al., 2009).

Our objectives were to:

(i) determine and rank the relative importance of environmental and management factors influencing the assembly of weed communities in OSR,
(ii) investigate whether the occurrence of common, frequent and rare weed species depends on the same factors, and
(iii) find out if different characteristic OSR weed communities can be distinguished in various classes of farming systems.

2. Materials and methods

An extensive monitoring of weeds in winter oilseed rape was conducted throughout Germany involving 478 fields in 2005, 491 in 2006, and 493 in 2007 (1463 in total). The sampling intensity was related to the regional occurrence of oilseed rape cropping in order to detect changes in the composition of weed species especially in areas of high OSR cropping intensity. The fields were in conventional agricultural use but the weed survey was conducted in parts of the rape fields which were unsprayed with herbicides (minimum area of 100 m^2) providing a quantitative overview of general weed intensity and the frequency of each species. Between mid October and the end of November, weed frequencies and densities were determined at the four to six leaf stage of rape by trained persons. A quadrat 0.32×0.32 m (i.e. 0.1 m^2) was placed randomly ten times in each field and all plants within the frame were identified and counted. Species densities of the ten sample points per field were pooled for the analysis. Each field was monitored once in the survey. Several genera were not identified to species level due to difficulties in separating the seedlings: *Bromus* spp., *Lolium* spp., *Vicia* spp., *Matricaria* spp., *Chenopodium* spp., *Lamium* spp., *Veronica* spp., *Geranium* spp., *Sysimbrium* spp., *Polygonum* spp., *Euphorbia* spp., *Anchusa* spp., *Sonchus* spp., *Rumex* spp., *Atriplex* spp., *Galinsoga* spp., *Amaranthus* spp., *Galeopsis* spp. and *Erodium* spp.

2.1. Data preparation

Those 72 weed species that occurred in at least ten fields were used for statistical analysis.

All 25 explanatory variables available for investigation are listed in Table 1. Data on management practices included the date of OSR sowing, crop density (OSR plants/m^2), OSR variety, continuity of OSR cropping (years since first cropping of OSR at the investigation site), tillage system (inversion tillage by mouldboard plough or non-inversion tillage by chisel plough), number of rape herbicides used in previous OSR at the site, the kind of fertilisation (none, organic, mineral or both), proportions of OSR, winter cereals, spring-sown crops and fallow land in the crop rotation, the field use history (field trial site or farmer's field) and the previous crop (grass ley, clover, fallow, pea, potato, maize, oats, spring barley, spring wheat, winter oilseed rape, winter barley, winter rye, winter triticale, and winter wheat). Soil conditions were characterised in terms of soil pH, soil texture and the arable soil quality index *(German "Ackerzahl", official German rating index of soil quality for arable production, in points out of 100).* Field size, as well as the distance from the sampling area to the field edge, served as characteristics of the local environment. The geographical position of each investigation site was defined by its latitude, longitude and altitude and climatic conditions were described by average rainfall and temperature during the growing season.

Variance inflation factors (Greenacre, 1984) were calculated to identify linear dependencies among the explanatory variables. Generally, a variable with a variance inflation factor higher than ten is regarded as redundant and should be excluded from analysis (Gross, 2003). None of the factors exceeded a value of ten. Two samples had to be excluded from analysis because they did not contain any weeds, four samples due to being sampled in the wrong season and seven due to single extreme values in the management data (crop density, field size, continuity of OSR cropping) which were likely to distort any ordination by creating unduly long environmental gradients. After removing another 698 incomplete rows from the environmental data matrix, 752 samples remained for analyses. As there was distinctive temporal fluctuation in the data, the variables "year" and "days after sowing" were used as covariables in CCA.

2.2. Statistical analyses

In order to get an overview of the data structure and the importance of the chosen explanatory variables the whole data set was submitted to canonical correspondence analysis (Ter Braak, 1987). To elucidate pseudosignificances of single factors resulting from interactions with other explanatory variables a series of stepwise analyses was performed. This was done by adding the explanatory variables to the model one by one in order of how strongly they explain residual variation in species composition (Hallgren et al., 1999). The canonical coefficients from intra-set correlation were used to assess the correlation of single variables with the canonical axes in the ordination. Spatial independence of residuals in the final CCA model was verified using a permutation test as performed by the R function mso{vegan} (Wagner, 2004).

Next, partial canonical correspondence analyses were carried out quantifying the gross and net effect of each explanatory variable. The gross effect was obtained from separate CCAs, each constrained by a single explanatory variable, while net effects describe the effects of particular variables after partialling out the effects shared with the other explanatory variables. The latter were calculated by use of partial CCAs applying one explanatory variable as a constraint and all remaining variables as covariables. Significances were tested by permutation tests ($n = 1000$) for the first canonical axis, while the ratio of particular canonical eigenvalues to the sum of all eigenvalues provided a rough measure of the proportion of explained variation (Borcard et al., 1992) in order to rank the explanatory variables by their impact on weed species composition. As recommended by Økland (1999), only the part of the variation explained by the explanatory variables (constrained inertia) was partitioned. Gross and net effects were specified for the complete species set and for three different subsets of species referred to as "common species" (the ten most frequent species of the survey), "frequent species" (frequencies between 30% and 7.5% of sampled sites, $n = 18$) and "rare species" (species that occurred in less than 7.5% of investigated fields, but with a minimum of ten sites, $n = 44$). These subsets of species were selected in order to test the hypothesis that there are different driving factors for generalist weeds and rarer species.

Those variables that were found to have a significant effect on species composition in CCAs were grouped thematically into "soil variables", "management variables" and "ecoregion variables" (see Table 3) for three separate cluster analyses. Dissimilarity matrices as the basis for clustering were calculated using the general dissimilarity coefficient of Gower (1971) because of its ability to handle data sets with mixed types of variables (numeric, ordinal and nominal). The partitioning around medoids algorithm (PAM) of Kaufman and Rousseeuw (1990) was applied as the clustering method since the medoids are a robust estimate of the cluster centres even in the presence of noise. Average silhouette width was used as a measure of the strength of clustering patterns (van der Laan et al., 2003). For each of the three thematic groups the optimum number of clusters was defined as the solution maximizing the mean average silhouette width over all clusters.