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FACTORS INFLUENCING WEED SPECIES DIVERSITY IN SOUTHEASTERN PART OF LATVIA: ANALYSIS OF A TWO-YEAR WEED SURVEY DATA

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Changes in field management and plant protection methods in the last few decades have affected arable weed flora in many European countries often causing the loss of biodiversity. While weed control is necessary to protect crop yields and prevent spread of invasive weed species, complete eradication of weeds is both impractical and unnecessary. Many weed species interact both among themselves and with other organisms and can be beneficial for the agro-ecosystem. In this study we investigated the effect of field management, herbicide application and crop rotation on weed density and species diversity using data collected during weed surveys in 2013 and 2014 in the southeastern part of Latvia. Weed species diversity positively correlated with weed density. Analysis of the weed density and species number showed that the amount of nitrogen fertilizer, crop sown in the current season and soil pH affected weed species diversity and density in the surveyed fields. Results indicate that species richness is negatively influenced by the degree of intensity of field management.

Key words: weed diversity, weed survey, nitrogen.

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INTRODUCTION

Weed species diversity has become a concern in last decades because loss of biodiversity is documented in European countries with intensive agriculture. Loss of weed biodiversity and decline of particular species is associated with increased intensity of agriculture and use of herbicides, as well as reduced diversity of different crops that the weeds are associated with. Abandonment of arable land also causes reduction of rare weed species on larger scale (in Europe), with higher numbers of rare weed species observed in countries with higher wheat yields (Storkey et al. 2012)

Weed species interactions can be beneficial to crops, reducing weed competition. Increased weed diversity without substantial increase of weed density can be also beneficial to other organisms such as arthropods and soil microorganisms (Clements et al. 1994). As integrated weed management (IWM) is the recommended alternative to purely chemical weed control, it is important to understand how different agricultural land management practices influence weed diversity. De Mol et al. (2011) reported that, according to the analysis based on the competition-related properties of different weeds, more diverse weed vegetation is not associated with higher risk of yield loss to the crop (oilseed rape). More general value of arable weed species is their importance for bird and non-vertebrate species of the arable lands, where loss of diversity has been also documented (Meyer et al 2013).

Although weed density and species composition depend to a great extent on climatic and edaphic conditions, crops and associated management practices are also important (Lososova et al 2004; Pysek et al. 2005, Fried et al. 2008). Meyer and his coworkers (2013) in the extensive analysis of changes in weed flora in Central Germany pointed out the negative influence of the increasing nitrogen fertilizer doses, increased use of herbicides, effective seed cleaning methods and simplification of crop rotation on weed diversity. Hawes et al. (2010) investigated weed diversity in the Eastern part of Scotland and reported that highest diversity on the regional scale was associated with integrated farming system as compared to conventional and organic systems, because of larger diversity of crops and cropping practices in the integrated farms. However, species richness was highest in organic farms on the small scale. Although decrease of weed diversity is connected with increasing herbicide use, other field management practices are also important because they select species with certain traits. Importantly, seed traits influence the ability to adapt to management practices, especially tillage methods (Colbach et al. 2014).

The aim of this study was to compare impact of different agricultural practices on weed species density and diversity using the results of weed monitoring that was carried out in the southeastern part of Latvia in 2013 and 2014.

MATERIAL AND METHODS

Weed monitoring

Weed monitoring was carried out in summer 2013 and 2014 in 72 fields from 12 farms in the southeastern part of Latvia. Weed species and density of each species was determined according to method developed by A. Rasiņš and M. Tauriņa (1982). The study was performed in the period from the 3rd decade of June to the 2nd decade of July, when the majority of weeds are in the flowering stage and are easier to identify. Information about each field was recorded in both years, as well as previous history of field management, where possible.

Data analysis

The variables that characterized fields were crop group (spring cereals, winter cereals, spring oilseed rape, winter oilseed rape, other crops) in the year of the survey (2013 or 2014), proportion of cereals in crop rotation during four-year period (for 2014) or three-year period (for 2013), herbicide application in the year of the survey, ploughing (yes/no) in the year of the survey, size of the farm [sizes were grouped in four categories: F1 (<100 ha); F2 (100 – 500 ha); F3 (500 – 1000 ha); F4 (>1000 ha)], soil pH and the amount of nitrogen fertilizer applied as supplement to the pre-sowing fertilizer [four values were assigned: N1 (0 – 50 kg ha^{-1}); N2 (50 – 100 kg ha^{-1}); N3 (100 – 140 kg ha^{-1}) N4 (>140 kg ha^{-1})], NPK (dose of pre-sowing fertilizer, kg ha^{-1}) and use of glyphosate-containing herbicides in the current year (yes/no). Incomplete records were deleted from the analysis, therefore there were 72 complete records from 2014 and 58 complete records from 2013.

Poisson regression (generalized linear model with family Poisson) was used separately for datasets of 2014 and 2013 and for the entire dataset. The dependent variables were total species richness, common species richness (common species were defined as species detected in more than 25% of the surveyed fields) and rare species richness (rare species were defined as species detected in 10%

or less of the surveyed fields), an approach similar to one used by Gabriel et al. (2006). Initially model contained all nine explanatory variables, then variables with non-significant coefficients were removed from the model. Variable "Year" was added when data from both surveys were analyzed together. Overdispersion of the models was estimated by dividing residual deviance by residual degrees of freedom. Relation between total species richness and weed density was analyzed for 2014 and 2013 datasets using Poisson regression model.

Generalized linear model with family Quasi-Poisson was used analysis for the entire dataset with dependent variable weed density (plants m^{-2}) and the same field variables as described above (dispersion parameter = 9.5).

Diagnostic plots were used to assess linearity, normality and homogeneity of variance of model residuals and detect influential points (points with leverage 1 were removed from the analysis). Data on rare species count was zero-inflated, therefore zero-inflated Poisson model was used with reduced number of variables included in the analysis.

To define the field data parameters that influence weed communities in the surveyed fields in both years, a constrained analysis (RDA) was performed using data of both years. Data for species density and species richness was transformed as proportion of the maximum value of each variable. Parameters that described weed vegetation were total species density, common species richness and rare species richness. Field variables included the same variables that were used in generalized linear models, then additional analysis was performed with significant variables only. Significance of the overall analysis and individual field variables was assessed with permutation tests (999 permutations in each case). All tests were performed using R program, version 3.03 (The R Foundation for Statistical Computing Platform, 2014), "vegan" package was used for RDA (Oksanen et al. 2015) and "pscl" package was used for zero-inflated Poisson models (Zeileis et al. 2008).

RESULTS AND DISCUSSION

The total number of weed species detected in the surveys was 121 in 2013 and 119 and 2014. Average number of species per field was 15.5 species (from 5 to 31) in 2013 and 19.8 species (from 5 to 43) in 2014. Average weed densities were 54.1 plants m^{-2} (from 6 to 254) in 2013 and 73.5 plants m^{-2} (from 8 to 160) in 2014. Both average weed density and average species number are comparable with the result of weed survey in conventional farms conducted in Finland (Salonen et al. 2011), although weed density is lower than reported in that study (average 160 plants m^{-2}). Ten most frequent species in 2013 were *Equisetum arvense*, *Viola arvensis*, *Elymus repens*, *Chenopodium album*, *Polygonum convolvulus*, *Polygonum aviculare*, *Euphorbia helioscopia*, *Veronica arvensis*, *Galeopsis* spp. and *Cirsium arvense*, recorded in 49 – 89% of the fields. Ten most frequent species in 2014 were. *V. arvensis*, *E. arvense*, *P. convolvulus*, *Galeopsis* spp., *E. repens*, *Galium aparine*, *Lamium purpureum*, *Veronica arvensis*, *Ch. album* and *P. aviculare*, recorded in 61 – 97% of the fields.

Crops cultivated in the 72 surveyed fields in 2013 were: winter wheat (22 fields), spring wheat (15 fields), spring oilseed rape (10 fields), spring barley (9 fields), maize (4 fields), oats (3 fields), beans, triticale, winter oilseed rape (2 fields each), buckwheat, potato and rye with wheat (one field each). Crops cultivated in 2014 were: spring wheat (24 fields), winter wheat (18 fields), maize (7 fields), spring barley (6 fields), winter oilseed rape (6 fields), spring oilseed rape (3 fields), grassland or fallow (2 fields), potato, beans, oats, triticale, rye and beet (one field each). Larger proportion of spring wheat in 2014 is due to severe weather conditions in winter 2014 that damaged winter wheat sown in 2013.

Significant coefficients in the quasi-Poisson regression model of weed density against field variables were found for year ($p < 0.0001$), nitrogen fertilizer groups 3 and 4 ($p = 0.0006$ and $p = 0.002$, respectively) and crop group (negative coefficients for spring and winter cereals and other crops except oilseed rape, $p < 0.01$ in all cases). The reduced model where only variables with significant coefficients were retained, was not statistically different from the full model. Tables 1 and 2 show model coefficients for generalized linear models of total species richness (Table 1) and common species richness (Table 2) against field management variables and crop groups. In each year separately and in the complete dataset nitrogen fertilizer had significant negative coefficient. Weed density and total species richness were significantly related in both years (Fig. 1), so it is consistent that higher doses of nitrogen fertilizer had similar effect on both these values. Increased nitrogen input can favor certain weed species, e.g. *Galium aparine* and *Stellaria media,* but generally use of nitrogen fertilizer increases crop competitiveness and thus reduces weed density and species richness (Pysek et al. 2005, Meyer et al. 2013). In this case it can be an indicator of a generally more intensive farming practice because the variable used in this analysis was not nitrogen content in the soil but the amount of the fertilizer used on the field. While no significant effect of pH was shown for total and common species richness, it was significant in the model with relatively rare species richness (Table 3) and in the RDA analysis (Fig. 2). Hawes et al. (2010) reported that soil properties, including pH, are important for weed species composition and that larger weed seed banks were associated with the lower pH.

Year was a significant factor in models where data from both years were used (Tables 1, 2). This indicates that other factors, such as rainfall and temperature, can be important and should be included in the analysis, as well as that a long-term survey of weed vegetation is required. Weed diversity has been shown to depend on several climatic and edaphic factors (Lososova et al. 2004), while the importance of field management factors may depend on the time-span of the analysis and weed survey methods (Fried et al. 2008). The gradients of climatic conditions (latitude, altitude) are not pronounced in our case because the study was confined to one region.

Results of the GLM regressions are similar to the results of the constrained analysis (RDA), where four variables were significant and explained 33% of the variation in weed density, common and rare species richness: year, nitrogen fertilizer, pH and crop group. Species richness was negatively associated with higher nitrogen fertilizer rate, high pH and cereals (Fig. 2).

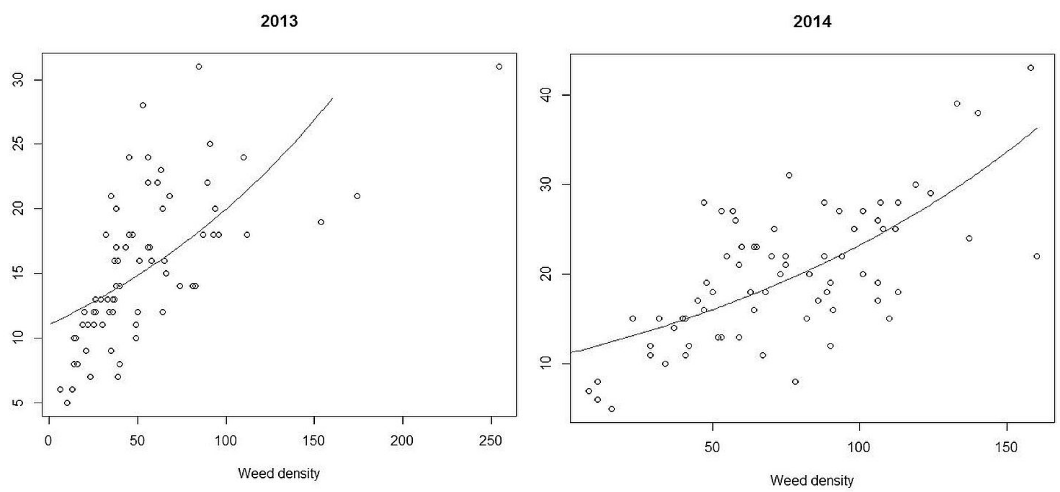

Fig. 1. Generalized linear models (Poisson) of the total species richness against species density in 2014 and 2013. Model coefficients were 2.41 ($p < 0.0001$) in 2014 and 2.40 ($p < 0.0001$) in 2013. Residual deviance / residual d.f. ratio was used to estimate model overdispersion (1.62 in 2014 and 1.35 in 2013).

Table 1. Generalized linear models (Poisson) of the total species richness against field management characteristics and crop group in the surveyed fields in 2014 and 2013 and in both years. Full model with 9 field variables and a reduced model, with only variables that had significant coefficients in the full model, are shown. Significant model coefficients are shown with *p* value in parentheses, values of the coefficients are given as difference from the intercept. Residual deviance / residual *d.f.* ratio was used to estimate model overdispersion

Factors	2014	2014	2013	2013	Both years	Both years
Intercept	3.97	3.34	3.27	3.34	–491.5	–493.8
Year	---	---	---	---	0.24 (<0.0001)	0.24 (<0.001)
Farm size (F1 as reference group)				---		---
F2	–0.22 (0.029)	–0.19 (0.017)	n.s.		n.s.	
F3	–0.30 (0.014)	–0.17 (0.048)	n.s		–0.19 (0.039)	
F4	n.s.	n.s.	n.s.		n.s.	
N fertilizer (N1 as reference group)						
N2	n.s.	n.s.	n.s.	–0.27 (0.001)	–0.12 (0.06)	–0.15 (0.007)
N3	n.s.	n.s.	–0.29 (0.041)	–0.53 (<0.001)	–0.37 (<0.0001)	–0.37 (<0.0001)
N4	–0.29 (0.006)	–0.33 (0.0003)	n.s.	–0.32 (0.012)	–0.30 (0.0001)	–0.36 (<0.0001)
Herbicide applications	n.s.	---	n.s.	---	n.s.	---
Ploughed (Y/N)	n.s.	---	n.s.	---	n.s.	---
Proportion of cereals in crop rotation	n.s.	---	–0.48 (0.014)	n.s.	n.s.	---
pH	–0.13 (0.020)	n.s.	n.s.	---	n.s.	---
Glyphosate (Y/N)	n.s.	---	n.s.	---	n.s.	---
NPK	n.s.	---	n.s.	---	n.s.	---
Crop groups (spring oilseed rape as reference group):		---				
Winter oilseed rape	n.s.		---	---	n.s.	n.s.
Spring cereals	n.s.		–0.35 (0.002)	–0.36 (0.0002)	–0.25 (0.001)	–0.28 (<0.0001)
Winter cereals	n.s.		n.s.	n.s.	n.s.	n.s.
Other	n.s.		n.s.	n.s.	n.s.	n.s.
Residual deviance/ res. *d.f.*	2.9	2.48	0.97	1.08	1.71	1.65

Table 2. Generalized linear models (Poisson) of the common species richness (common species were defined as species found in >25% of the fields in the year of survey) against field management characteristics and crop group in the surveyed fields in 2014 and 2013 and in both years. Full model with 9 field variables and a reduced model, with only variables that had significant coefficients in the full model, are shown. Significant model coefficients are shown with *p* value in parentheses, values of the coefficients are given as difference from the intercept. Residual deviance / residual *d.f.* ratio was used to estimate model overdispersion

Factors	2014	2014	2013	2013	Both years	Both years
Intercept	3.46	2.81	2.53	2.93	-7.35.5	-748.6
Year	---	---	---	---	0.36 (<0.0001)	0.37 (<0.0001)
Farm size (F1 as reference group)		---		---		---
F2	n.s		n.s		n.s	
F3	n.s		n.s		n.s	
F4	n.s		n.s		n.s	
N fertilizer (N1 as reference group)						
N2	n.s	n.s	n.s	–0.22 (0.027)	n.s	n.s
N3	n.s	n.s	–0.32 (0.062)	–0.54 (<0.0001)	–0.30 (0.0006)	–0.31 (<0.0001)
N4	–0.26 (0.03)	–0.31 (0.0015)	n.s	n.s.	–0.23 (0.017)	–0.30 (0.0003)
Herbicide applica-tions	n.s	---	n.s	---	n.s	---
Ploughed (Y/N)	n.s	---	n.s	---	n.s	---
Proportion of cereals in crop rotation	n.s	---	n.s	---	n.s	---
pH	n.s	---	n.s	---	n.s	---
Glyphosate (Y/N)	n.s	---	n.s	---	n.s	---
NPK	n.s	---	n.s	---	n.s	---
Crop groups (spring oilseed rape as refer-ence group):		---				
Winter oilseed rape	n.s		---	---	n.s	–0.24 (0.06)
Spring cereals	n.s		-–0.48 (0.0002)	–0.48 (<0.0001)	–0.31 (0.0006)	–0.29 (0.0005)
Winter cereals	n.s		n.s	–0.24 (0.03)	–0.18 (0.038)	–0.19 (0.025)
Other	n.s		n.s	n.s	n.s	–0.23 (0.026)
Residual deviance/ res. *d.f.*	1.55	1.50	0.86	0.86	1.37	1.31

GLM models with both total species and common species richness had significant negative coefficients for nitrogen fertilizer groups with highest doses (groups N3 and N4). This result is in agreement with the report from the study in Scotland, where inorganic nitrogen input was negatively associated with both weed abundance and species richness (Hawes et al. 2010).

Contrary to what could be expected, number of herbicide applications in the vegetation season and use of glyphosate were not significant in the regressions with total or common species richness (Tables 1 and 2), although there was a significant negative coefficient for glyphosate use in the model for rare species richness in 2014 (Table 3). This can be explained by low herbicide use intensity in the surveyed region, where glyphosate was used in less than 50% of the fields and herbicide were usually applied only once or twice in the vegetation season. Farm size is a variable that can indicate the general importance of farming practice but it is not always easy to interpret. While larger farms usually tend to adopt more intensive field management methods, in this survey largest farms were of mixed type (crop and dairy) that can be associated with less intensive management and more diverse crop rotation. In contrary, farms that belonged to F2 and F3 groups were mostly crop producers, the proportion of cereals in crop rotation that can indicate high intensity of field management was highest in F3 group.

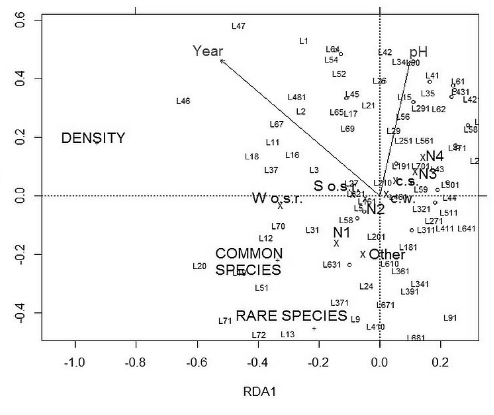

Fig. 2. Influence of field variables and crop groups on weed density, common and rare species richness in 2013 and 2014. Constrained analysis (RDA) with five constraining variables: Year (2013 or 2014), N_group (N1 0-50, N2 50-100, N3 100-140, N4 >140 kg ha–1 pure nitrogen per hectar), pH and crop group (c.s. – spring cereals, c.w. – winter cereals, S o.s.r. – spring oilseed rape, W o.s.r. – winter oilseed rape, Other – other crops, including maize, grassland, root crops and legumes). The proportion of constrained variation was 33%, the overall analysis and each of the factors were significant ($p < 0.05$), significance tested with permutation tests.

Current results do not predict long-term changes in species richness of the arable weed communities depending on farming practices, because the surveys were conducted only for two years. Changes in management like reduced herbicide application, reduced fertilization may not have immediate effect on weed flora and also depend on the crop type (annual or perennial) (Meiss et al. 2011). This can be partly due to slower rate of changes in seed bank composition (Hawes et al. 2010; Sans et al. 2011). However, our current results can be used to further analyze the results of weed surveys in order to identify what management methods are most useful for both preventive weed control and maintaining diverse weed vegetation.

Redwitz et al. (2011) conducted multivariate analysis of weed density and diversity in maize in Germany. Although no single factor defining weed density and diversity was identified, crop rotation *vs* monoculture was important with higher weed density and reduced diversity in maize monoculture. In our study, higher weed density was associated with higher species richness. Probably more intensive agricultural practices can also result in better weed control, but at the same time reduce weed species range to common arable species and species that are more difficult to control (e.g. *Viola arvensis*). In contrast, non-intensive management, such as in organic farming, allows species that are not typical weeds to enter arable communities, which increases biodiversity and is beneficial for the food chain (Sans et al. 2011).

Table 3. Zero-inflated Poisson regression models of the rare species richness (rare species were defined as species found in <10% of the fields in the year of survey) against field management characteristics and crop group in the surveyed fields in 2014 and 2013 and in both years. Significant model coefficients are shown with *p* value in parentheses, values of the coefficients are given as difference from the intercept

Factors	2014	2014	2013	2013	Both years
Intercept	0.61	1.35	3.82	4.62	4.58
Farm size groups	n.s	---	---	---	---
Proportion of cereals in crop rotation	---	---	–0.82 (0.055)	–0.98 (0.014)	–1.06 (0.009)
N fertilizer (N1 as reference group)		---		n.s.	
N2	n.s		n.s.		n.s.
N3	n.s		n.s.		n.s.
N4	n.s		–1.44 (0.049)		–1.05 (0.005)
Herbicide applications	n.s	---	---	---	--
pH	n.s	---	–0.41 (0.039)	–0.52 (0.0001))	–0.55 (0.002)
Glyphosate (Y/N)	–0.95 (0.034)	–1.35 (0.001)	n.s.	---	n.s.
NPK	---	---	---	---	n.s.
Crop groups:	n.s.	n.s.	---	---	---

In the present study no factors that explain diversity of rare weed species were clearly identified, therefore it is important to analyze weed survey data on a larger scale, where differences between farming practices may be more apparent, especially, comparing regions with different soil fertility and proportion of monoculture. In this study "rare" species were species relatively less represented in these farms, rather than species that are genuinely rare on the scale of the country or on a wider scale. From the species included in the Europe-wide list of rare and threatened species (Storkey et al. 2012), *Centaurea cyanus* and *Bromus secalinus* were recorded in our surveys. *C. cyanus* was recorded in 22% of the fields in 2013 and in 40% of the fields in 2014, *B. secalinus* was not recorded in 2013 but was recorded in 3% of the fields in 2014.

CONCLUSIONS

Analysis of the data obtained from weed surveys in 2013 and 2014 in the southeastern part of Latvia indicates that amount of nitrogen fertilizer applied, crop sown in the current season and soil pH were factors that influenced species diversity and density in this area. Larger input of nitrogen fertilizer is negatively related to species richness and weed density. As difference between years was apparent, further surveys are required to investigate the effect of rainfall and temperature. Soil properties also need to be included in future analysis. Weed diversity was positively related to weed density, so deeper understanding of the way field management and other factors influence arable species is needed to maintain the diversity of weed flora, at the same time achieving adequate weed control.

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