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Effects of crop rotation and field management methods on weed density and species composition in the southeastern part of Latvia

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Abstract. **Integrated weed management (IWM) is a complex approach to weed control that is based on use of several different methods complementing each other, instead of relying on one single method, like chemical weed control. Weed control methods that can be used as parts of IWM strategy include mechanical weed control, application of herbicides, low tillage, changes in the rate and application time of fertilizers, use of undersown crops and crop rotation. Weed surveys were carried out in 2013 and 2014 in the southeastern part of Latvia. The aim of this study was to assess the effect of crop rotation and other field management practices on weed density and weed species composition using the data collected in the surveys. Survey was carried out in the arable fields of conventional farms within four different size categories. One of the significant factors that explained the variation of weed composition within a field was a proportion of cereals in crop rotation within a four year period. Further surveys are required to estimate the effects of climatic variables. Density-dependence can also be important for practical management decisions for particular weed species and should be investigated.**

Keywords: **Integrated weed management, crop rotation, weed survey.**

I INTRODUCTION

Integrated weed management (IWM) is a complex approach to weed control that is based on use of several different methods that complement each other, instead of relying on one single method like chemical weed control. Weed control methods that can be used as parts of IWM strategy include mechanical and chemical weed control, reduced tillage methods, changes in the rate and application time of fertilizers, use of undersown crops and crop rotation (reference). To choose the combination of methods for a successful IWM strategy in a particular situation, it is necessary to take into account climatic, edaphic, economic and even social factors in the region. It is also essential to know the composition of local weed flora.

Crop type in general and crop rotation has been shown as defining factors of weed species composition [1], [2], [3]. However, some of the IWM methods used in a number of countries may not be appropriate for conditions in Latvia. Crop rotation is practised in many farms in Latvia. Therefore it is important to find out how crop rotation in particular conditions affects overall weed density and weed composition, to be able to advise best practice for successful weed control as well as balanced weed flora in the fields [4].

The aim of this study was to assess the effect of crop rotation on weed density and weed species composition in the southeastern part of Latvia using the data collected during field surveys.

II MATERIALS AND METHODS

Weed survey was carried out in summer 2013 and 2014 in 72 fields from 12 conventional farms in the South-Eastern part of Latvia. Weed species and density of each species was determined according to the method developed by Rasiņš and Tauriņa [4]. The surveys were performed from the 3rd decade of June to the 2nd decade of July, when the majority of weeds were in the flowering stage and were easier to identify.

Canonical correspondence analysis (CCA) of the data was performed with species data from 72 fields (2014) and 58 fields (2013), the dataset from 2013 was smaller due to incomplete information on field management. Six constraining variables were chosen for the analysis. Crop group in the year of the survey and the preceding crop (crop group in the previous year), the crop groups were: Spring cereals, Winter

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cereals, Spring oilseed rape, Winter oilseed rape and other crops (maize, root crops and legumes) in the year of the survey (2013 or 2014). Proportion of cereals in crop rotation in the last four years (2014) or proportion of cereals in crop rotation in the last three years (2013) including the current year. Number of herbicide applications in the year of the survey.

TABLE I

GROSS AND NET EFFECTS (PROPORTION OF CONSTRAINED VARIANCE) OF FIELD MANAGEMENT FACTORS IN THE WEED DENSITY DATASETS COLLECTED IN 2014 AND PROPORTION OF VARIANCE EXPLAINED WHEN ALL 6 FACTORS WERE USED AS CONSTRAINING VARIABLES. NUMBER OF FIELDS IN THE ENTIRE DATASET WAS 72, IN THE SUBSET OF SPRING CEREALS – 31, WINTER CEREALS – 21. IN EACH CASE SIGNIFICANCE WAS TESTED WITH 999 PERMUTATION TESTS (*** - P < 0.001; ** - P < 0.01; * - P < 0.05).

	Entire dataset			Spring cereals			Winter cereals		
	All variables	Separate CCA	Partial CCA	All variables	Separate CCA	Partial CCA	All variables	Separate CCA	Partial CCA
Cereal proportion	***	0.03 **	0.024 **	**	0.066**	0.061**	**n.s.**	0.055	0.061
Crop 2014 (group)	***	0.12 **	0.10**	---			---		
Previous crop (group)	**n.s.**	0.06	0.05	---			---		
Herbicide applications	**n.s.**	0.02	0.02*	*	0.057*	0.055*	*	0.092*	0.083*
N fertilizer	**n.s.**	0.019	0.018*	**n.s.**	0.034	0.036	**n.s.**	0.066	0.054
Farm size	**n.s.**	0.015	0.015	**n.s.**	0.041	0.041	**	0.075	0.082*
Proportion of constrained variance	**0.254**			**0.198**			**0.294**		

Size of the farm (four values were assigned: (1) <100 ha; (2) 100-500 ha; (3) 500-1000 ha; (4) >1000 ha). Amount of nitrogen fertilizer applied as supplement to the pre-sowing fertilizer (four values were assigned: (1) 0 – 50 kg/ha; (2) 50-100 kg/ha; (3) 100-140 kg/ha; (4) >140 kg/ha). Separate and partial CCA analysis with individual factors were performed (in partial CCA other factors were included as co-variables), to estimate gross and net effect of the significant factors according to the method described by Lososova *et al.* [5] and Fried *et al.* [1]. In each case, significance of the overall model and individual variables was tested by 999 permutation tests. Additionally, two subsets were analysed within the data table containing weed density observations in 2014: Spring cereals (Spring wheat, Spring barley, oats: 31 fields) and Winter cereals (Winter wheat, Winter rye Winter triticale: 21 fields). Four constraining variables were used due to smaller number of observations. Species association with gradients of the factors that were significant in each crop subset were identified in partial CCA plots where each factor was used as a constraining variable and other factors as co-variables. Pearson correlation of each species' density and site loadings (weighted species scores) was tested. All tests were performed using R (The R Foundation for Statistical Computing Platform, 2014) and particularly the package vegan, version 2.2-1 [7].

III RESULTS AND DISCUSSION

In total, 119 weed species were detected during the survey in 2014. Average number of species per field was 19.8, ranging from 5 to 43 species. Average weed density in the field was 73.5 plants m^{-2} ranging from 8 to 160 plants m^{-2}. The most frequent species detected in 97% of the fields was *Viola arvensis* Murray. Other frequent species found in more than 50% of the fields were *Equisetum arvense* L., *Polygonum convolvulus* L., *Galeopsis* spp., *Elymus repens* L., *Galium aparine* L., *Lamium purpureum* L., *Veronica arvensis* L., *Chenopodium album* L., *Polygonum aviculare* L., *Tripleurospermum inodorum* (L.) Sch. Bip., *Fumaria officinalis* L. and *Euphorbia helioscopia* L. The weeds with highest average density were *Viola arvensis* (13.6 plants m^{-2}) and *E. repens* (8.8 plants m^{-2}). In the CCA analysis of 2014 weed density data with all nine field variables used as constraints (Fig. 1) proportion of constrained variance was 25.4% of the total variance (Table I), the overall model was significant ($P < 0.005$). Significant terms in 2014 were crop group ($P < 0.005$) and proportion of cereals in crop rotation ($P < 0.005$).

TABLE II

GROSS AND NET EFFECTS OF FIELD MANAGEMENT FACTORS IN THE WEED DENSITY DATASETS COLLECTED IN 2013 AND PROPORTION OF VARIANCE EXPLAINED WHEN ALL 6 FACTORS WERE USED AS CONSTRAINING VARIABLES. THE NUMBER OF FIELDS INCLUDED IN THE ANALYSIS WAS 58. IN EACH CASE SIGNIFICANCE WAS TESTED WITH 999 PERMUTATION TESTS (*** - P < 0.001; ** - P < 0.01; * - P < 0.05).

	All variables	Separate CCA	Partial CCA
Cereal proportion	**n.s.**	0.081	0.022
Crop 2013 (group)	***	0.085**	0.073**
Previous crop (group)	**n.s.**	0.080**	0.056
Herbicide applications	**n.s.**	0.025	0.019
N fertilizer	**	0.034**	0.029
Farm size	**	0.025	0.025*
Proportion of constrained variance	**0.248**		

The proportion of cereals in crop rotation was also significant in the subset of Spring cereals, and in both cereals subsets number of herbicide applications was significant (Table I). In CCA analysis with all field variables in the subset of Spring cereals the overall model was significant ($P < 0.005$), proportion of constrained variance was only 19.8% of the total variance. The model analysis with all field variables in the subset of Winter cereals was also significant ($P < 0.005$), proportion of constrained variance was 29.4% of the total variance. In total, 121 weed species were detected during the weed surveys in 2013. Average number of species per field was 15.5 ranging from 5 to 31 species. Average weed density in the field was 54.1 plants m^{-2}, ranging from 6 to 254 plants m^{-2}. The most frequent species were *Equisetum arvense*, *Viola arvensis*, *Elymus repens*, *Chenopodium album*, *Polygonum convolvulus*, *Polygonum aviculare*, *Euphorbia helioscopia* and *Veronica arvensis*. The weeds with highest average density across all 72 surveyed fields were *Elymus repens* (11.1 plants m^{-2}) and *Viola arvensis* (6.1 plants m^{-2}). In the CCA analysis of 2013 weed density data with all six field variables used as constraints (Fig. 2) proportion of constrained variance was 24.8% of the total variance (Table II), the overall model was significant ($P < 0.05$). Three factors were significant when tested with 999 permutations: farm size, crop group and nitrogen fertilizer dose (Table II). Increased use of herbicides and nitrogen fertilizer are reported to be main field management factors that determined dramatic decrease of both density and species number of weeds in Germany [9]. The effect of nitrogen fertilizer on weed species composition was not evident in 2014, but it requires further investigation in a larger dataset comprising data from other regions of Latvia.

Proportion of constrained variance did not exceed 25% in both years, it means that some important factors that influence weed density and species distribution have not been identified in this study. Potentially important are edaphic factors – moisture, soil properties, and field management factors such as crop density, sowing date, kind of herbicides applied.

Also, factors that were not accounted for in this analysis could have influenced weed density and species composition in a particular year, like weather conditions in the current year. Crop rotation data were only available since 2011, so proportion of cereals and other crops in crop rotation was not analysed equally for both years.

One of the significant factors in 2014 in the subset of Winter cereals and in 2013 was the size of the farm. This factor is associated with a complex of farming practice that is often difficult to interpret. Generally, larger farms tend to implement more intensive farming methods, but in our case the largest farms were mixed dairy and crop farms, where proportion of grassland in crop rotation was relatively high. This influences both farming practice and weed species composition associated with the farm size.

In both years a major factor explaining data variation was crop group (Tables I, II). This means that field management practices associated with certain crops – time of ploughing, doses of fertilizer, herbicide application and crop rotation – are important for the resulting weed species composition.

Species associated with significant factors in cereal subsets are shown in Table III. In Spring cereals species most strongly associated with low proportion of cereals in crop rotation were *Vicia cracca*, *Chenopodium album and Artemisia vulgaris*; species associated with high proportion of cereals were *Avena fatua and Viola arvensis*. Species most strongly associated with less herbicide applications in 2014 were *Apera spica-venti* and *Poa pratensis*; species associated with more applications were *Trifolium repens* and *Elymus repens*. In the subset of Winter cereals species most strongly associated with small farm size were *Geranium pusillum*, *Polygonum persicaria, Poa pratensis and Atriplex patula*; species associated with large farm size were *Vicia spp*., *Thlaspi arvense, Melandrium album*. Species associated with less herbicide applications were *Poa pratensis*, *M. recutita*, *Capsella bursa-pastoris*, *Convolvulus arvensis*, *A. spica-venti, A. fatua*, *E. crus-galli*, while species associated with more herbicide applications where *Erodium cicutarium*, *Equisetum arvense*, *Lolium perenne* (Table III)

TABLE III

SPECIES ASSOCIATED WITH GRADIENTS OF INDIVIDUAL FIELD FACTORS IN SPRING AND WINTER CEREAL SUBSETS OF DATA 2014. ASSOCIATION WAS DETECTED BY PERFORMING PARTIAL CCA ANALYSIS WITHIN THE SUBSET USING THE INDIVIDUAL FACTOR AS THE CONSTRAINING VARIABLE AND OTHER FIELD FACTORS AS CO-VARIABLES. PEARSON CORRELATION COEFFICIENTS OF THE SPECIES DENSITY VS SITE LOADINGS ARE SHOWN IN PARENTHESES.

Spring cereals		Winter cereals	
Cereal proportion	Herbicide applications	Farm size	Herbicide applications
Low	One	< 100 ha	None
Vicia cracca (0.34)	*Apera spica-venti (-0.66)*	*Geranium pusillum (0.53)*	*Poa pratensis (-0.41)*
Euphorbia helioscopia (0.25)	*Poa pratensis (-0.22)*	*Polygonum persicaria (0.62)*	*Capsela bursa-pastoris (-0.55)*
Chenopodium album (0.32)		*Poa pratensis (0.51)*	*Convolvulus arvensis (-0.38)*
Artemisia vulgaris (0.38)		*Atriplex patula (0.48)*	*Apera spica-venti (-0.59)*
		Lycopsis arvensis (0.52)	*Avena fatua (-0.52)*
		Avena fatua (0.42)	*Juncus bufonius (-0.42)*
		Rumex crispus (0.34)	*Cerastium arvense (-0.49)*
			Echinochloa crus-galli (-0.49)
			Veronica agrestis (-0.44)
Apera spica-venti (-0.31)	*Elymus repens (0.41)*	*Myosotis arvensis (-0.47)*	*Equisetum arvense (0.38)*
Viola arvensis (-0.42)	*Achillea millefolium (0.28)*	*Juncus bufonius (-0.49)*	*Veronica arvense (0.43)*
Erodium cicutarium (-0.26)	*Trifolium pratensis (0.43)*	*Melandrium album (-0.47)*	*Lolium perenne (0.33)*
Capsela bursa-pastoris (-0.26)		*Thlaspi arvense (-0.54)*	*Erodium cicutarium (0.35)*
Avena fatua (-0.42)		*Vicia spp. (-0.44)*	
High	Two	> 1000 ha	Three

Annual monocot weed species (*Apera spica-venti*, *Echinochloa crus-galli*, *Avena fatua*) were associated with fields with high proportion of cereals in rotation and less herbicide applications (Table III). All of these species are common in cereal crops. Although in Germany *E. crus-galli* is reported to be associated mainly with maize fields, its seedbank was larger in cereal monoculture in a long-term study in USA [8], [9]. This association can be explained with the use of herbicides that do not provide sufficient control of monocot species as well as favourable conditions for them in cereal monocultures. Monoculture promotes development of less diverse weed flora that is difficult to control, for example, long-term wheat monoculture is favourable for proliferation of a persistent weed *Avena fatua* [10].

Association of *Avena fatua* with smaller farms (Table III) may be due to use of non-certified seed material contaminated with *A. fatua* seeds. Annual *Poaceae* species were also associated with smaller number of herbicide applications. Insufficient control of these weed species can promote further infestation of the fields as well as adjacent fields. While more intensive use of herbicides may not always be the best option due to high costs and possible contamination of the environment, integrated weed management methods must be explored more intensively, especially appropriate crop rotation, sowing rates and use of certified seed material.

In 2014 *Elymus repens* was associated with more herbicide applications (Table III). This association may be due to low efficacy of the applied herbicides on this species. *E. repens* was one of the most frequent species across the surveyed fields in both years. Decrease of *E. repens* in cereals in Finland and Denmark with more intensive use of glyphosate-containing products [11]. In the surveyed fields in both 2013 and 2014 glyphosate containing products were used in less than 50% of the fields. Other options, such as mechanical control, could be used where possible. Association of some species with more herbicide applications is probably due to lack of effective herbicides or inappropriate application.

Species often recorded in oilseed rape fields (Fig. 1, 2) are *Sinapis arvensis*, *Erysimum cheiranthoides, Thlaspi arvense*. Fried *et al*. [1] reported that due to changing field management methods, especially use of herbicides, in the last few decades weed species composition in oilseed rape in France changed from species typical for Winter wheat to species that are specialists for oilseed rape. This process may not yet be advanced in Latvia, where growing oilseed rape became popular later, but still indicates that appropriate crop rotation is advisable to prevent these specialist species from spreading. Crop rotation and enhances weed control by increasing variation in environmental conditions, increasing competition and allelopathic effect among weeds and crops and, as a result, create more unstable conditions, unfavourable for proliferation of certain weed species. However, for more successful weed control, different complementing methods should be used alongside with crop rotation, like intercropping and a choice of competitive crop cultivars [10].

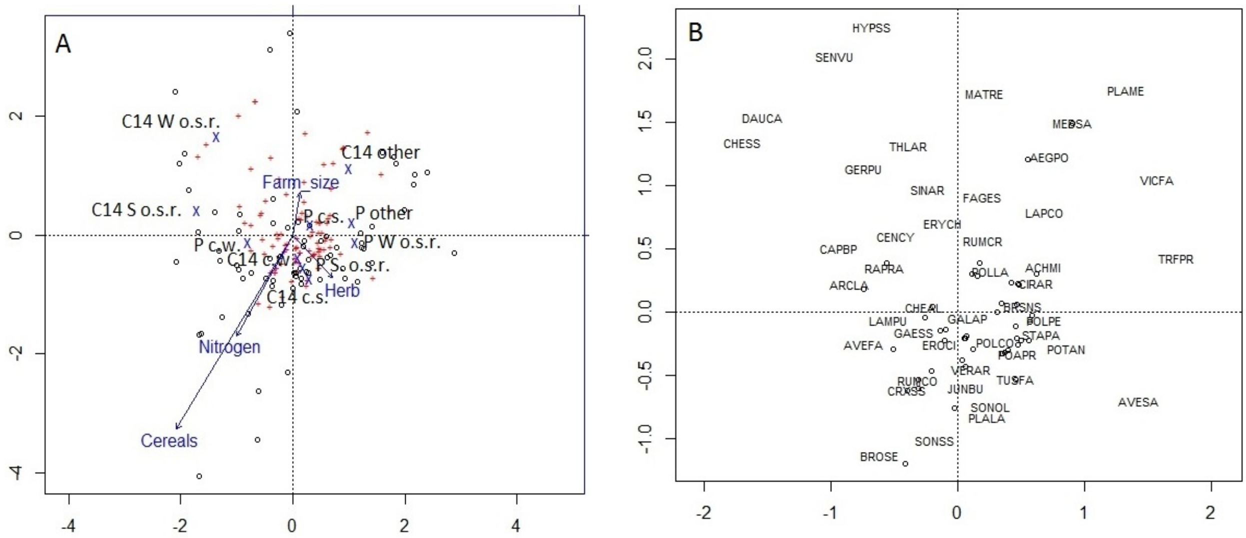

Fig. 1. CCA analysis (axes 1 and 2) of the entire data set from 2014 containing weed densities, with 6 field variables included as constraints (A constraining variables displayed; B species codes displayed). The constraining variables were: crop group in 2014 (C14) and preceding crop (P) where c.s. – Spring cereals; c.w. – Winter cereals; S o.s.r. – Spring oilseed rape; W o.s.r. – Winter oilseed rape; proportion of cereals (Cereals) in crop rotation in last four years; number of herbicide application times in 2014 (Herb); dose of supplementary N fertilizer applied in 2014 (Nitrogen); size of the farms (Farm_size). Significance was tested with 999 permutation tests (*P* < 0.05). Species codes are used according to the Bayer code system [14].

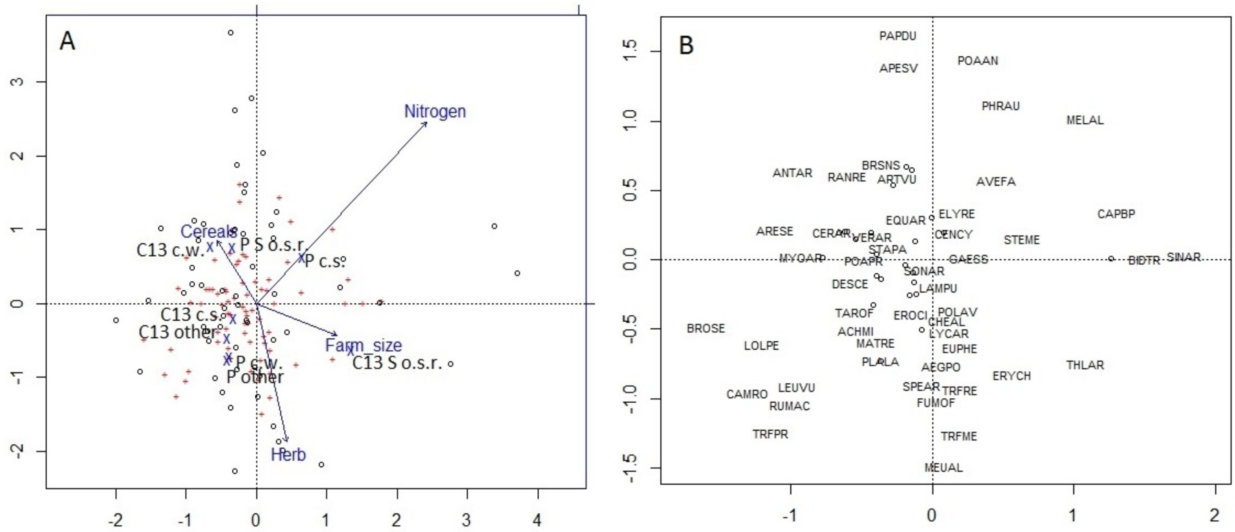

Figure 2. CCA analysis (axes 1 and 2) of the entire data set from 2013 containing weed densities, with 6 field variables included as constraints (A constraining variables displayed; B species codes displayed). The constraining variables were: crop group in 2014 (C13) and preceding crop (P) where c.s. – Spring cereals; c.w. – Winter cereals; S o.s.r. – Spring oilseed rape; W o.s.r. – Winter oilseed rape; proportion of cereals (Cereals) in crop rotation in last four years; number of herbicide application times in 2014 (Herb); dose of supplementary N fertilizer applied in 2014 (Nitrogen); size of the farms (Farm_size). Significance was tested with 999 permutation tests (*P* < 0.05). Species codes are used according to the Bayer code system [14]

The effect of crop rotation on weed control must be evaluated taking into account the number of crops included in rotation and rotation period [12], [13]. In the present survey there were 11 fields (15.3%) with cereal monoculture in the four-year-period, where only Winter and Spring cereals were grown. This could explain the significance of cereal proportion in crop rotation in the analysis. However, the dataset of explaining variables was very heterogeneous and for some factors there may not have been sufficient number of replications. This is caused by the survey method that was chosen, surveying weed populations in the same fields every year and not in the fields with the same crop. Analysis of the survey data from a larger territory and in a longer time period may reveal effects of pH, soil properties, temperature and other environmental and field management factors. Further surveys of the weed populations is also required to determine the significance of density-dependence in particular weed species because it can influence the success of weed control methods and therefore, is important for practical management decisions [12].

IV CONCLUSIONS

Crop type was the most influential factor explaining variance in weed composition within weed survey data collected in 2014 and 2013 in the southeastern part of Latvia. In 2014 the proportion of cereals in crop rotation during last four years was one of the statistically significant factors that explained the variation of weed community composition. Herbicide application intensity was an important factor influencing weed flora in 2014 in both Spring and Winter cereals. Further research is needed to identify other important factors that determine weed species composition in this region.

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