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When herbicides don't really matter: Weed species composition of oil pumpkin (*Cucurbita pepo* L.) fields in Hungary

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ABSTRACT

Oil pumpkin is a major emerging alternative crop with several unresolved weed management questions in central-eastern Europe, one of the focal regions of oil pumpkin production worldwide. This study aims to assess the importance of three groups of factors: environment, non-chemical management (all management excluding herbicides), and chemical weed management, in determining the weed species composition of oil pumpkin crops in Hungary. We surveyed the weed flora of 180 oil pumpkin fields across the country, along with 32 background variables. Applying a minimal adequate model consisting of 18 terms with significant net effects, 30.8% of the total variation in weed species data could be explained. Most variation in species composition was determined by environmental factors, with climatic conditions (precipitation and temperature) being most influential. The net effects of seven non-chemical management variables (preceding crop, N and P fertilisers, seeding rate, crop cover, cultivating tillage, and manual weed control), and two herbicides (S-metolachlor and linuron) were also significant. Variation partitioning demonstrated the dominance of environmental factors, and it also showed that non-chemical management practices accounted for five times more variance than herbicides. Within non-chemical management, the relative impact of cultural variables was nearly five times larger than that of mechanical weed management. Among the abundant weeds, *Chenopodium polyspermum* and *Ambrosia artemisiifolia* were positively associated with precipitation, *Datura stramonium* and *Hibiscus trionum* correlated with higher temperature, and *Chenopodium album* favoured larger potassium content of the soil. High seeding rate and crop cover suppressed *Amaranthus retroflexus*, cultivating tillage reduced *Ambrosia artemisiifolia* and *Setaria pumila*, while conspicuous tall weeds like *Abutilon theophrasti* and *Chenopodium album* were most vulnerable to manual weed control. Although the short stature of pumpkin with its poor weed-suppressive ability could unfavourably influence the results of some cultural practices, our findings suggest that the weed vegetation of oil pumpkin fields can be efficiently managed also with environmentally benign methods.

1. Introduction

Edible oils are produced from various *Cucurbita pepo* L. cultivars throughout the World. One of these plants is “Styrian oil pumpkin” or *Cucurbita pepo* L. subsp. pepo var. *styriaca* Greb., which is grown in numerous varieties/hybrids in many countries of south-eastern part of Europe (mainly in Austria, Hungary, Slovenia and Serbia) and its special oil is increasingly used in food and pharmaceutical industry (Fruhwirth and Hermetter, 2008; Lelley et al., 2009). Oil pumpkin is eligible under the EU agricultural ‘greening programme’ as an option for crop diversification, and it is considered as an excellent preceding crop very beneficial for soil structure. Furthermore and most importantly, the cultivation of oil pumpkin has proven to be highly profitable (Madai and Lapis, 2016; Niedermayr et al., 2016). In Hungary, its annual growing area is approximately 20 000–25 000 ha, with average seed yields ranging between 0.4 and 1.2 ton ha^{-1} depending on weather conditions (Madai and Lapis, 2016).

Weed control is the most critical element of management practice in Cucurbits production worldwide. At the beginning of their vegetation period pumpkins have only a weak competitive

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ability against weeds. Consequently, early weed infestations can result in high yield losses. Developed pumpkin vegetation will provide some shading and weed suppression, but in turn, its vining habit makes cultivation difficult later in the season. Moreover, there are only a limited number of registered herbicides applicable, which also come with potential crop injury risks, high costs, and insufficient efficacy (Brown and Masiunas, 2002; Kammler et al., 2008; Marr et al., 2004; Walters and Young, 2010). In addition to herbicide sensitivity issues, the main target markets (health and wellness industries) also suggest that the weed management of oil pumpkin crops should rely on non-chemical practices as much as possible (Farkas, 2015).

Our earlier studies showed that due to their large gradient length, environmental factors were the most important drivers in determining the weed species composition in Hungarian summer arable weed vegetation (Pinke et al., 2012) and also in soybean fields (Pinke et al., 2016). Hungarian oil pumpkin production is generally concentrating in three different regions in the western, south-eastern and northern part of the country. Because of the contrasting soil and weather conditions, environmental variables are expected again to play the largest role in determining weed species composition of these fields. Nevertheless, in our recent study in soybean crops, where chemical weed management are regarded as an indispensable element of the production, herbicides turned to be more important than cultural practices (Pinke et al., 2016). Oil pumpkin crops after all, where herbicides are generally considered only as supplemental tools along the much more important cultural practices and mechanical weed control (Farkas, 2015), offer a good opportunity for studying the assumed relevance of non-chemical weed management. The main goal of this study was to assess whether non-chemical weed management can be really more important predictor than herbicides in the weed species composition of pumpkin crops? Measuring and ranking the role of different variables might provide new information about the assembly rules of weed communities and could be used to optimise weed control strategies.

2. Materials and methods

2.1. Data collection

First, we searched for oil pumpkin-growing farmers who permitted access to their fields and were willing to be interviewed about management factors. This operation yielded 180 arable fields throughout Hungary (Fig. 1). According to our sampling strategy, each main oil pumpkin-growing districts in the western, south-eastern and northern part of the country are represented equally with 60 fields. Weed data were recorded in the years 2015 and 2016 at the seasonal peak of summer annual weed vegetation, between the end of July and beginning of September each year. Weed vegetation was sampled in the fields in four randomly selected 50 m^2 plots. One plot was located on the field edge (inside the outermost seed drill line), whereas the remaining three plots were located inside the fields at different distances (between 10 and 200 m) from the edge. Percentage ground cover of plant species in the plots was estimated visually, which method is widely used in arable weed surveys (Kolárová and Hamouz, 2016). In total, 720 plots were sampled (4 plots in 180 fields).

Management information was received directly from the farmers. In order to avoid rare levels of categorical variables, the preceding crop species occurring less than ten times were considered to be ‘miscellaneous’. A soil sample of 1000 cm^3 from the top 10 cm layer was collected from each field. Soil analyses were carried out in two laboratories belonging to Synlab Ungarn GmbH and BETA Research Institute accredited by NAT (Hungarian Accreditation System for Testing). Climatic conditions were represented by mean annual temperature values taken from the WorldClim database, and mean annual precipitation values taken from the Hungarian Meteorological Service.

Altogether 32 predictor variables (12 *environmental*: 2 site, 2 climate, 8 soil; 16 *non-chemical management*: 11 cultural, 5 mechanical management; and 4 *chemical weed control factors*) were included in the analysis (Table 1). Management variables were

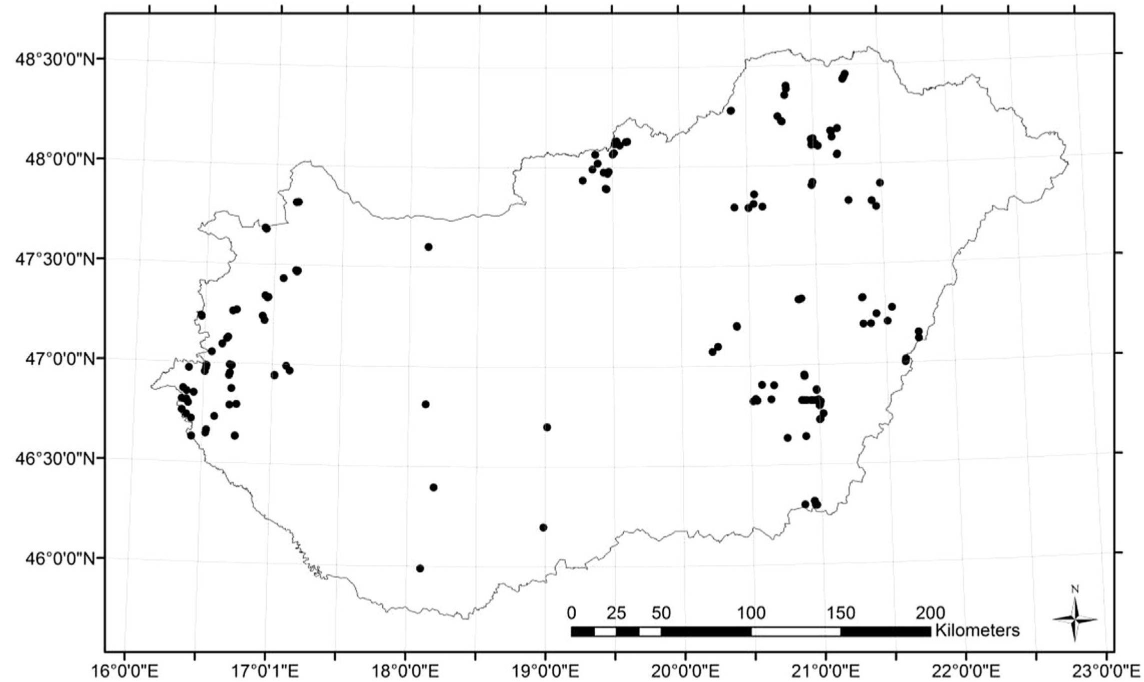

Fig. 1. The distribution of the 180 surveyed oil pumpkin fields across Hungary (a single point may represent multiple fields).

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Table 1
Units and ranges of continuous variables and values of categorical variables.

Variable (unit)	Range/Values
ENVIRONMENTAL	
Site	
Plot location	Edge, core
Altitude (m)[a]	81–292
Climate	
Mean annual precipitation (mm)	465–761
Mean annual temperature (°C)	9.06–11.29
Soil	
Soil pH (KCl)	3.75–7.8
Soil texture (KA)[b]	25–60
Soil properties (m m%$^{-1}$)	
Humus	0.92–7.65
$CaCO_3$	0.1–17.6
Soil properties (mg kg^{-1})	
P_2O_5	20–2530
K_2O	73.7–1547
Na[b]	12.2–284
Mg	54.6–1710
NON-CHEMICAL MANAGEMENT[c]	
Cultural	
Crop cover (%)	5–100
Plant density (plants ha^{-1})[b]	12 000–26000
Seeding rate (kg ha^{-1})	3–8
Field size (ha)[b]	0.14–135
Cultivar type[b]	Vining, semi-vining, bush
Date of sowing[b]	15 April–28 May
Preceding crop	Cereal, maize, oil pumpkin, miscellaneous
Organic manure (t ha^{-1})[b]	0–100
Amount of fertiliser (kg ha^{-1})	
N	0–123
P_2O_5	0–100
K_2O[a]	0–180
Mechanical	
Primary tillage depth (cm)[b]	15–70
Tillage system[b]	No-tillage, ploughing
Secondary tillage (times)[b]	0–5
Cultivating tillage (times)	0–5
Manual weed control (times)	0–7
CHEMICAL WEED CONTROL	
Herbicides (g a.i. ha^{-1})	
Linuron	0–1220
S-metolachlor	0–2400
Clomazone[b]	0–144
Glyphosate[b]	0–2880

[a] Variables not included into the analysis due to multicollinearity.
[b] Variables dropped during the backward selection process.
[c] All management excluding herbicides.

grouped following the classification of Blackshaw et al. (2007) and Cloutier et al. (2007); accordingly, cultural and mechanical weed management variables together were considered as the elements of 'non-chemical management', and we considered chemical weed control as a different group following the logic of the key questions of this study.

2.2. Statistical analysis

The statistical analysis followed the same lines as the analysis described in Pinke et al. (2012, 2011); so we only present here a brief summary thereof. The intercorrelations between the environmental, management and herbicide variables (potential model terms) were assessed prior to the analysis by calculating variance inflation factors. Altitude and K fertiliser had to be dropped during this process, while the rest of the variables showed only slight intercorrelations, which should not bias the analysis (the highest GVIF score adjusted by degree of freedom was 1.89). Cover values of the weed species were averaged across all the three plots from each field core to perform the average community composition of the inner part of the individual fields. Data from field edges were regarded separately. Cover values were subjected to Hellinger transformation (Borcard et al., 2011), and were examined in a redundancy analysis (RDA) together with the management and environmental data. Only the species with >10 occurrences were included in the analyses. The number of explanatory variables was decreased by stepwise backward selection using a $P < 0.01$ threshold for type I error, which led to a minimal adequate model containing 18 terms (out of 30). As a next step of the multivariate analysis, we estimated the gross and net effects of each explanatory variable of the reduced model, as carried out by Lososová et al. (2004). In most of the partial RDAs there was only one constrained axis, except for preceding crop, where three constrained axes were tested. Based on the results, a common rank of 'importance' was settled among all explanatory variables according to the R^2_{adj}-values of the net effects of the pRDA models. To show the responses of the weed species to the significant factors, for each pRDA model we identified those 10 species that represented the highest explained variation in the constrained axis/axes ("strongly associated" species). Variation partitioning based on partial RDA (Borcard et al., 2011) was applied to establish the relative effects of the different groups of explanatory variables on species composition. The entire statistical analysis was conducted in the R Environment (R Development Core Team, version 3.2.2) using the Vegan add-on package (vegan 2.3–1).

3. Results

Altogether 168 weed species were found. *Chenopodium album* L., *Convolvulus arvensis* L., *Echinochloa crus-galli* (L.) P. Beauv, *Ambrosia artemisiifolia* L., *Hibiscus trionum* L. and *Setaria pumila* (Poir.) Schult. were the most abundant weeds (Fig. 2).

The full RDA model (comprising 30 explanatory variables) explained 35.39% of the variance, while, the reduced model (comprising 18 explanatory variables) still explained 30.79% of the total variation in species data. According to the pRDA, all of the 18 remaining variables have significant net effects with climatic conditions (precipitation and temperature) being the most influential (Table 2). In addition, the effects of seven further environmental parameters (plot location; Mg, K, Ca, P, and humus content of the soil, as well as soil pH), seven non-chemical management variables (preceding crop, N and P fertilisers, seeding rate, crop cover, cultivating tillage and manual weed control), and two herbicides (S-metolachlor and linuron) were significant (Table 2).

The responses of the 10 most associated weed species (the ones with the highest pRDA fit) for each predictor variable are showed in the supplementary information (Table S1), for all predictors having just one constrained axis. In Tables 3 and 4, we featured the most abundant four species from these 'most associated' species. In the case of the preceding crop, only the first two constrained axes were significant (Fig. 3). Fields with the two hoed previous crops (maize and oil pumpkin) separated from those with cereals along the first axis, while the second axis distinguished fields with the preceding crop maize from those with oil pumpkin. However, the weed species associated do not fully follow this separation, as most of them are concentrated in the centre of the ordination diagram (Fig. 3).

In the reduced RDA ordination (Fig. 4), the first axis can be most related to the explanatory variables precipitation and temperature, as well as soil humus and K content, while the second axis is correlated with soil Mg content, cultivating tillage, S-metolachlor, as well as P and N fertilisers. Samples from the cooler, more humid regions, which were also typically characterised with soils poor in potassium and the presence of *A. artemisiifolia*, *Chenopodium polyspermum* L. and *S. pumila*, generally exhibit positive values on the first RDA axis. In contrast, sites in the warmer and drier regions

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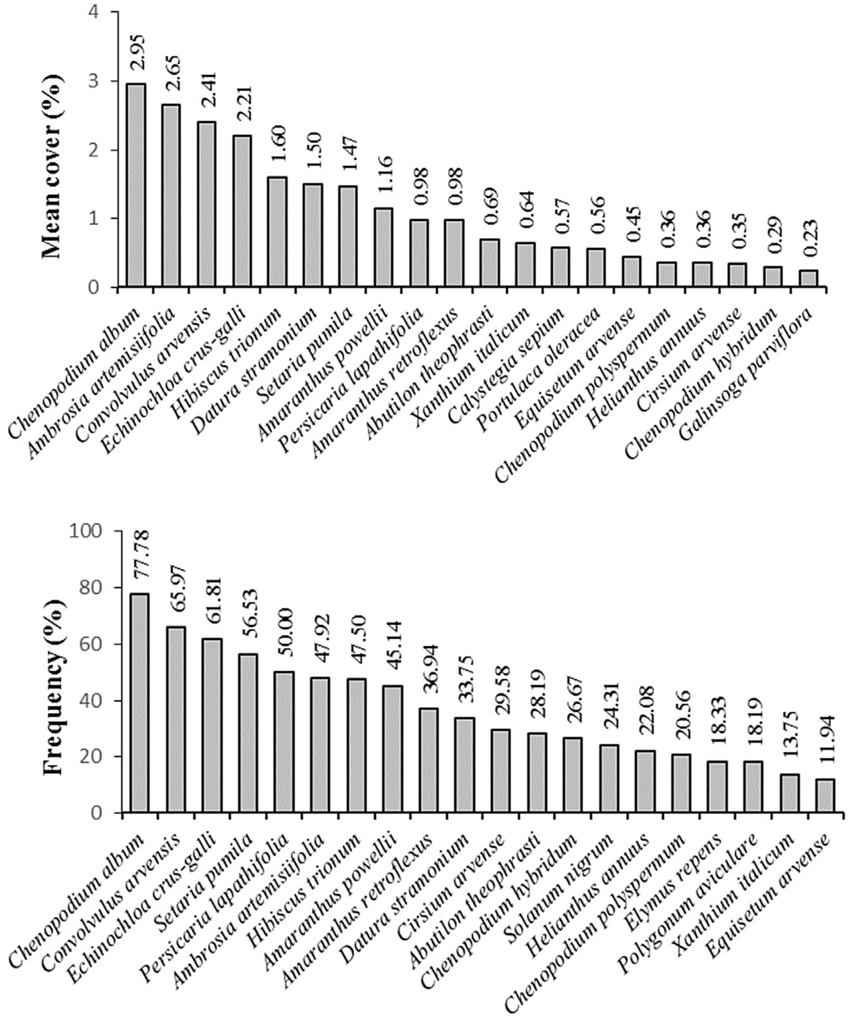

Fig. 2. The mean cover values (% of the surface covered) and the frequency of occurrence (% of the fields surveyed) of the twenty most dominant/frequent weed species.

Table 2
Gross and net effects of the explanatory variables on the weed species composition identified using (p)RDA analyses with single explanatory variables.

Factors	d.f.	Gross effect		Net effect			
		Explained variation (%)	R^2_{adj}	Explained variation (%)	R^2_{adj}	*F*	*P*-value
Precipitation	1	9.660	0.0938	3.364	0.0333	14.629	***
Temperature	1	8.064	0.0778	1.805	0.0167	7.8499	***
Soil Mg content	1	3.191	0.0289	1.595	0.0145	6.9356	***
Preceding crop	3	2.217	0.0129	1.863	0.0124	2.7004	***
Fertiliser N	1	1.523	0.0121	1.027	0.0085	4.4645	***
Soil K content	1	6.713	0.0642	0.864	0.0067	3.7595	***
Fertiliser P	1	0.928	0.0062	0.863	0.0067	3.7547	***
S-metolachlor	1	1.926	0.0162	0.845	0.0065	3.6771	***
Cultivating tillage	1	1.377	0.0107	0.755	0.0056	3.2843	***
Soil pH	1	5.923	0.0563	0.733	0.0054	3.1901	***
Manual weed control	1	0.820	0.0051	0.693	0.0049	3.0122	***
Soil humus content	1	4.343	0.0404	0.677	0.0048	2.9446	***
Soil Ca content	1	2.894	0.0259	0.655	0.0045	2.8505	***
Seeding rate	1	1.932	0.0163	0.624	0.0042	2.7135	***
Plot location	1	0.950	0.0064	0.578	0.0037	2.5143	***
Linuron	1	1.261	0.9521	0.578	0.0037	2.5131	**
Crop cover	1	1.351	0.0104	0.566	0.0036	2.4602	**
Soil P content	1	0.981	0.0067	0.560	0.0035	2.4334	**

$^{**}P < 0.01$ and $^{***}P < 0.001$.

with more K-rich soils and the frequent presence of *Datura stramonium* L. and *H. trionum* were characterised with low axis 1 values.

The variation partitioning of the RDA model revealed that

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Table 3
Names, fit and score values of species giving the highest fit along the first constrained axis in the partial-RDA models of the significant environmental variables specified in Table 2. (Excerpt from Table S1).

	Ax 1 score	Fit		Ax 1 score	Fit		Ax 1 score	Fit
Precipitation (+ high, − low)			Soil Mg (− high, + low)			Soil humus (− high, + low)		
Chenopodium polyspermum	0.242	0.223	*Hibiscus trionum*	0.307	0.094	*Abutilon theophrasti*	−0.131	0.031
Convolvulus arvensis	−0.276	0.071	*Echinochloa crus-galli*	0.159	0.029	*Chenopodium hybridum*	−0.063	0.016
Hibiscus trionum	−0.260	0.068	*Datura stramonium*	−0.146	0.019	*Polygonum aviculare*	0.054	0.013
Ambrosia artemisiifolia	0.247	0.049	*Chenopodium hybridum*	−0.068	0.018	*Convolvulus arvensis*	0.107	0.010
Temperature (− high, + low)			Soil K (+high, − low)			Soil P (− high, + low)		
Solanum nigrum	−0.096	0.056	*Datura stramonium*	0.179	0.029	*Datura stramonium*	0.167	0.025
Setaria pumila	0.180	0.052	*Amaranthus retroflexus*	0.109	0.021	*Chenopodium hybridum*	−0.073	0.021
Datura stramonium	−0.197	0.035	*Chenopodium album*	0.125	0.017	*Galinsoga parviflora*	−0.030	0.010
Hibiscus trionum	−0.186	0.034	*Cirsium arvense*	−0.054	0.016	*Stachys annua*	0.022	0.010
Soil pH (+high, − low)			Soil Ca (− high, + low)			Plot location (+inside, − edge)		
Sonchus arvensis	0.028	0.053	*Abutilon theophrasti*	0.111	0.023	*Polygonum aviculare*	−0.144	0.098
Setaria pumila	−0.126	0.025	*Hibiscus trionum*	0.123	0.015	*Helianthus annuus*	0.103	0.029
Datura stramonium	0.134	0.016	*Chenopodium hybridum*	−0.056	0.012	*Artemisia vulgaris*	−0.018	0.021
Convolvulus arvensis	−0.129	0.015	*Convolvulus arvensis*	−0.114	0.012	*Elymus repens*	−0.055	0.017

Table 4
Names, fit and score values of species giving the highest fit along the first constrained axis in the partial-RDA models of the significant non-chemical management and chemical weed control variables specified in Table 2. (Excerpt from Table S1).

	Ax 1 score	Fit		Ax 1 score	Fit
Crop cover (+high, − low)			Cultivating tillage (− high, + low)		
Amaranthus powellii	0.091	0.013	*Ambrosia artemisiifolia*	0.163	0.021
Datura stramonium	0.120	0.013	*Setaria pumila*	0.109	0.019
Amaranthus retroflexus	−0.086	0.013	*Galinsoga parviflora*	−0.039	0.018
Portulaca oleracea	−0.063	0.012	*Echinochloa crus-galli*	−0.107	0.013
Seeding rate (+high, − low)			Manual weed control (− high, + low)		
Chenopodium album	0.164	0.030	*Abutilon theophrasti*	0.150	0.041
Amaranthus retroflexus	−0.127	0.028	*Portulaca oleracea*	−0.080	0.021
Plantago major	−0.023	0.019	*Heliotropium europaeum*	−0.031	0.021
Persicaria lapathifolia	0.086	0.014	*Chenopodium album*	0.131	0.019
Fertiliser P (+high, − low)			Linuron (− high, + low)		
Chenopodium album	0.212	0.049	*Chenopodium album*	0.137	0.020
Chenopodium polyspermum	0.080	0.024	*Solanum nigrum*	0.041	0.010
Ambrosia artemisiifolia	−0.149	0.018	*Amaranthus retroflexus*	0.074	0.009
Amaranthus retroflexus	0.088	0.013	*Echinochloa crus-galli*	0.091	0.009
Fertiliser N (+high, − low)			S-metolachlor (+high, − low)		
Ambrosia artemisiifolia	0.274	0.061	*Amaranthus retroflexus*	−0.187	0.061
Chenopodium album	−0.188	0.039	*Setaria pumila*	−0.155	0.038
Xanthium strumarium	0.026	0.015	*Solanum nigrum*	−0.054	0.018
Chenopodium polyspermum	−0.060	0.014	*Echinochloa crus-galli*	−0.119	0.016

environmental variables altogether accounted for 3.6 times the variance of non-chemical management variables, 17.8 times that of herbicides and non-chemical management practices stand for five times more variance than herbicides (Fig. 5 A). The relative impact of cultural variables are nearly five times larger than that of mechanical treatments; the relevance of chemical weed control is only slightly larger than that of mechanical treatments; and cultural variables altogether stand for 3.8 times more variance than the chemical weed control variables (Fig. 5 B).

4. Discussion

4.1. Environmental variables

Our study revealed that among the 18 most important variables eight were recruited from weather and soil conditions (Table 2), and environment accounted for far the greatest variance in the weed species composition of the oil pumpkin fields (Fig. 3). This is in accordance with the findings of other Hungarian (Pinke et al., 2016, 2013, 2012) and similar European studies (de Mol et al., 2015; Lososová et al., 2004), where climatic and edaphic factors were more important than land use. Anyway, it should be noted that large gradients can positively influence the importance of environmental factors. As oil pumpkin can be successfully grown in a relatively wide range of climatic conditions and soil properties (Eberdorfer, 2016), the contrasting abiotic environments in our study area could be resulted in the increased relevance of their effects.

In terms of climate, the northern and western oil pumpkin-growing regions were cooler and more humid, than the warmer and drier south-eastern region, and this phenomenon could be detected in the experienced distribution pattern of the most characteristic thermophile species (e.g. *H. trionum*, *D. stramonium*) and of those that are better adapted to the cooler and wetter conditions (e.g. *C. polyspermum*, *S. pumila*). It should be noted that the explained variance of climatic variables is generally strongly related to altitude (Cimalová and Lososová, 2009; Nowak et al., 2015), which was also the case in the present study, as the south-eastern oil pumpkin-growing regions were plain but the two others were hilly landscapes. Although, due to strong multicollinearity we had to omit altitude before the analyses, it is likely to have strengthened indirectly the impact of climatic factors.

We found that several soil properties, including Mg, K, Ca, P, and humus content, as well as soil pH were also relevant drivers in shaping the weed vegetation. This is in accordance with our earlier findings which revealed similar correlations in poppy, sunflower,

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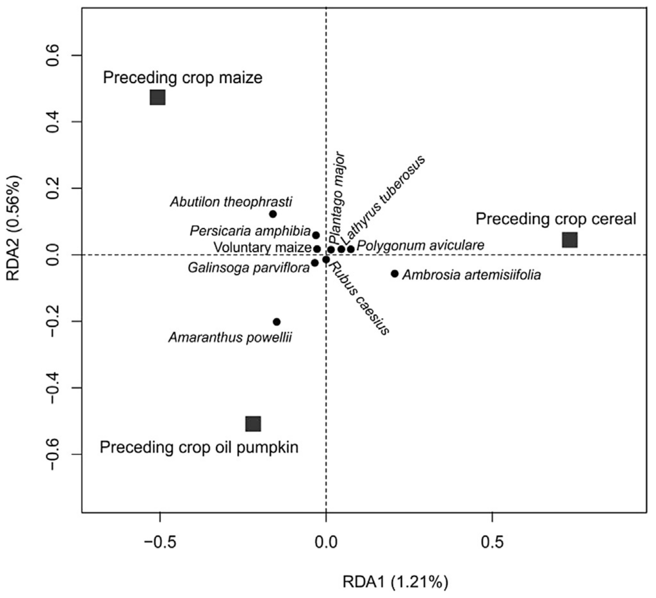

Fig. 3. Ordination diagram of the partial RDA model containing the explanatory variable preceding crop. The 10 species with the highest weight on the first two RDA axes are presented. Note that only the first two axes are significant at 5% level.

and soybean fields (Pinke et al., 2016, 2013, 2011). Other investigations also showed that these elements significantly influenced the occurrence of some arable weeds (Andreasen and Skovgaard, 2009; Ahmad et al., 2016; Mavunganidze et al., 2016; Vidotto et al., 2016). In our study, regarding the most abundant species, *C. album* was associated with high potassium, *E. crus-galli* with low magnesium, while *C. arvensis* with high calcium and low humus content (Table 3). In our present study, the non-significant impact of soil texture, which is generally regarded important in the above cited investigations, could be explained by its actual shorter gradient. Namely, very loose sandy and too heavy clay soils are not suitable for the cropping of oil pumpkin (Farkas, 2015), consequently this types of soils were fairly underrepresented in the course of our survey.

Our finding that plot location as a site variable was among the relevant explanatory predictors also concurs with our earlier study in soybean (Pinke et al., 2016), however in soybean it was the first, and now in pumpkin it is only the 15th most important factor. In field edges, among others, the light conditions are generally more favourable than in the inner parts of the fields dominated by the crop, which can influence weed distributions (Seifert et al., 2014). Nonetheless, due to the smaller stature of pumpkin and ordinary lower plant densities, there are probably not so sharp differences between the light conditions in the edges and cores of these fields, as it is in the higher and usually denser soybean crops, where the competition for light is much stronger. In other crops, the decreasing effects of intensive crop management towards the field periphery can be also resulted in divergent weed species composition between the edges and cores (Pinke et al., 2012). However, in oil pumpkin fields, the lower chemical inputs could mitigate this phenomenon.

4.2. Non-chemical management variables

4.2.1. Cultural practices

Preceding crop was found to be the most important explanatory predictor among cultural variables, which concurs with the earlier findings in Hungarian poppy and sunflower (Pinke et al., 2013, 2011), in German oilseed rape and maize (de Mol et al., 2015; Hanzlik and Gerowitt, 2011), as well as in French arable fields (Fried et al., 2008). According to the present study, the most characteristic species associated with the preceding crop maize was *Abutilon theophrasti* Medik., while *A. artemisiifolia* tended to be most typical after the previously cropped cereals, and *Amaranthus powellii* S. Watson followed generally oil pumpkin in greater abundances (Fig. 3). Formerly, it was more common, that Hungarian farmers grew oil pumpkin in monoculture for some years, but the increasing weed infestations led to unmanageable problems (Farkas, 2015). Other hoed crops (e.g. maize or sunflower) are neither suitable as a previous crop, but winter cereals regarded to be the best option because of their different weed flora. Blackshaw et al. (2007) also highlighted that rotating crops with different life cycles can disrupt the development of weed-crop associations, thus the proper selection of the preceding crop could be one of the most efficient tools of cultural weed management. Consequently, according to our expectations, much more troublesome weed species should have been accompanying with oil pumpkin and maize, and much fewer of them with cereals. At the same time, there was not such a clear separation between the most strongly associated weed species related to previous crops (Fig. 3). This might be explained by the common practice of performing stubble ploughing with a long delay after the cereal fields had been harvested, and thus the developing summer annual weed vegetation can replenish weed seedbanks with species, which are also characteristic for hoed weed communities, such as *A. artemisiifolia* (Pinke et al., 2013).

Nitrogen and phosphorous fertilisers were also relevant for the weed species composition in oil pumpkin fields. Their application can result in a more homogenous crop canopy, leading to the suppression of even some nitrophilic weeds, as it was experienced in the Hungarian soybean crops as well (Pinke et al., 2016). Although higher nitrogen doses could result in denser crop stands, still according to experiments in US (Reiners and Riggs, 1997) and Austria (Eberdorfer, 2016) this does not enhance pumpkin yield, and comes with many disadvantageous physiological impacts on the crop (Farkas, 2015). Another argument for a cautious fertiliser application is that, according to Blackshaw et al. (2007), this can increase the competitive ability of weeds more than that of the crop. Our analyses also suggested that some troublesome weeds, such as *C. album*, *C. polyspermum* and *Amaranthus retroflexus* L. were likely to be favoured by higher P, while *Xanthium strumarium* L. and *A. artemisiifolia* by higher N amounts (Table 4). This suggests that although fertilisers can be used to increase the competitive abilities of the crop, but for species with cultures with a shorter stature, like pumpkin can be easier overwhelmed by larger, faster-growing weeds as a result of the increased competition for light triggered by the higher N and P inputs.

Seeding rate and crop cover were also significant in our study, both of which certainly suppressed *A. retroflexus* in the higher domain of their value ranges (Table 4). The manipulation of seeding rate or planting density is an essential tool for improving crop competition and thereby decreasing weed abundances in many crops worldwide (Mhlanga et al., 2016; Sardana et al., 2017). Crop cover can be regarded as an indirect cultural variable, which definitely depends on many direct cultural practices, like seeding rate, plant density, cultivar type and fertilisers. The management of these parameters targets the development of a dense crop canopy as early as possible, which can be able to overcome the emerging weed populations (Blackshaw et al., 2007). Nevertheless, our analyses indicated that certain weeds, including *C. album*, *Persicaria lapathifolia* (L.) Delarbre, *A. powellii*, and *D. stramonium* could still occur in great abundance in case of a dense crop cover and/or high seeding rates (Table 4). This might underline again that these large-sized and rapidly growing weeds can easily overgrow the much

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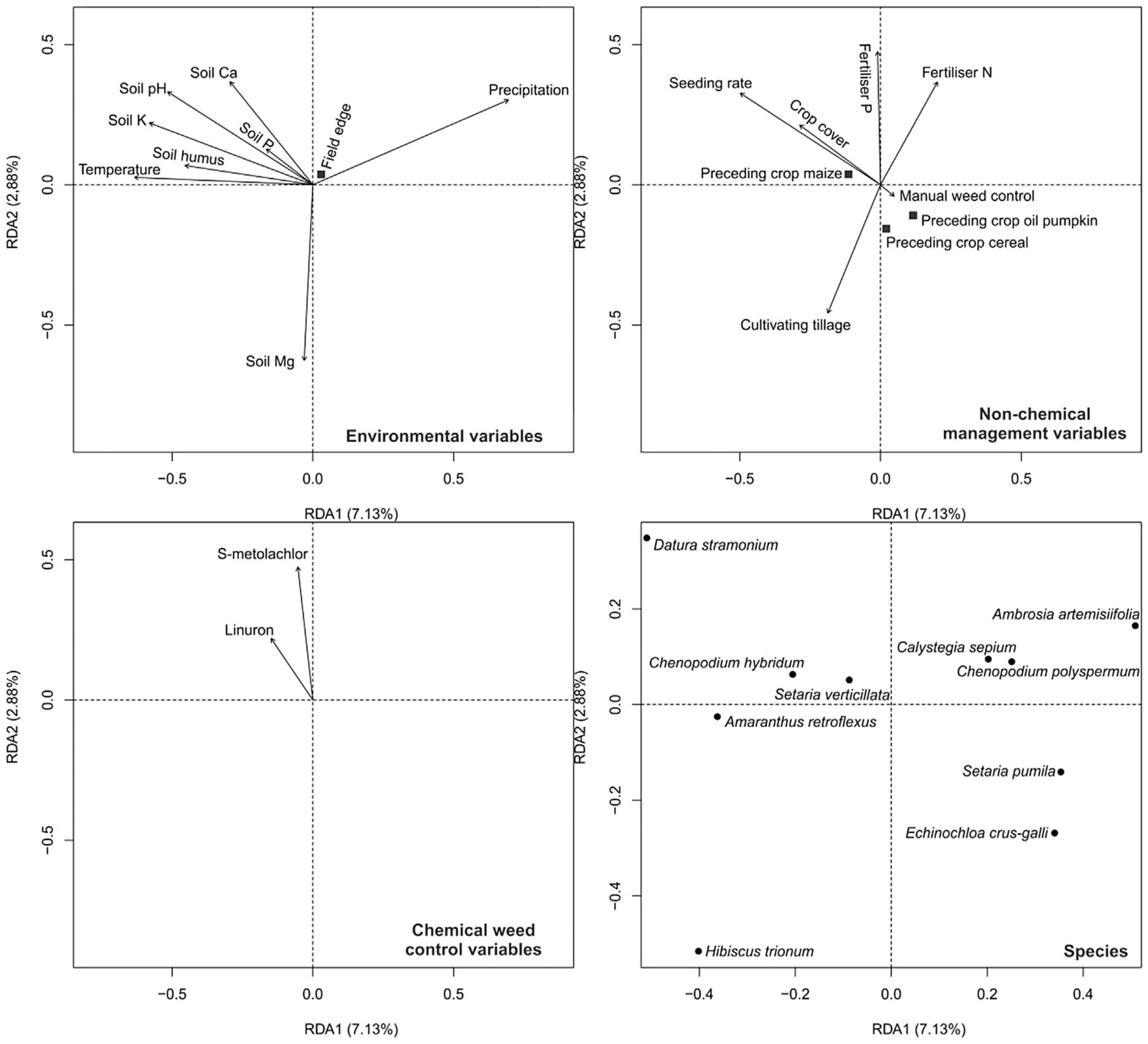

Fig. 4. Ordination diagrams of the reduced RDA model containing the 18 significant explanatory variables and the species. Only the species with the highest weight on the first two RDA axes are presented.

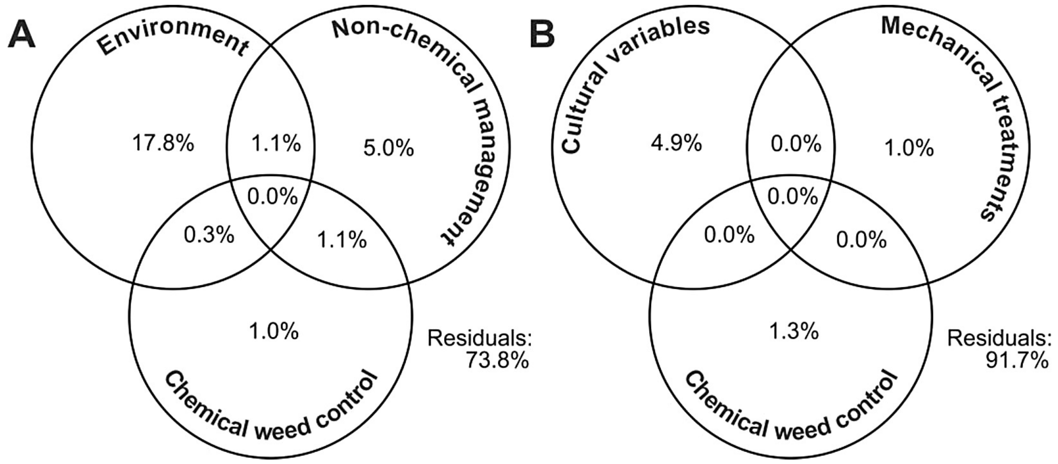

Fig. 5. Percentage contributions of groups of significant explanatory variables to the variation in weed species composition, identified by variation partitioning. A: environmental vs. non-chemical management vs. chemical weed control variables; B: cultural vs. mechanical vs. chemical components of weed management (environment variables are among the residuals here).

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shorter pumpkin vegetation, and can create an upper vegetation layer even above the dense pumpkin canopies.

4.2.2. Mechanical weed management

According to Cloutier et al. (2007) mechanical weed management consists of three main techniques: the use of tillage, cutting weeds and pulling weeds. Our study has shown that from among the different tillage types cultivating tillage significantly influenced the weed species composition of oil pumpkin fields. This type of tillage could apparently reduce the abundance of some pernicious weeds, such as *A. artemisiifolia* and *S. pumila* (Table 4). However, in addition to its weeding action, as Cloutier et al. (2007) pointed out, any cultivator passage might also stimulate weed seed germination and emergence. This can be reflected by the encouraging impact of cultivating tillage on the populations of *Galinsoga parviflora* Cav. and *E. crus-galli* in our study (Table 4). Nevertheless, the weed control efficacy of cultivating tillage and its other positive agronomical contributions are highly acknowledged in Hungarian oil pumpkin production (Farkas, 2015). It is usually repeated two or more times until the pumpkin-vines start running. The subsequently developing weed vegetation does generally not cause remarkably yield losses, and it can have even some beneficial effects, as it can provide some shelter from wind beat and heliosis for the ripening pumpkin fruits. Nonetheless, in case of high infestations of troublesome weeds, farmers can intervene with hand weeding one or several times during the late-season. Manual weed control, which involved mainly hand hoeing, pulling, and (seldom) cutting the weeds, also turned out to have significant effects in our study. Our analyses suggest that the more eye-catching, tall weeds, like *A. theophrasti* and *C. album* were most vulnerable to this operation, while shorter species, such as *Portulaca oleracea* L. and *Heliotropium europaeum* L. were either less targeted or could have more frequently avoided the attention of the field workers (Table 4). Even though, several farmers were reluctant to employ manual weed control due to the unreliability of the recruited labourers, our study suggests that it can be an efficient complement of the inter-row cultivating tillage. This is in accordance with the recommendation of Pannacci et al. (2017), namely for achieving good weed control efficacy, inter-row cultivation should be combined with some intra-row interventions.

4.3. Herbicides

Owing to its soft and succulent texture, pumpkin is not tolerant of most of the herbicides, and there are only pre-emergent chemical weed-killers that are authorised for this crop. In our study two of the four active ingredients in use were found to be significant: S-metolachlor and linuron. Among the troublesome weed species, *C. album* appeared to be sensitive only to linuron, while *A. retroflexus*, *Solanum nigrum* L. and *E. crus-galli* were susceptible to both herbicides (Table 4). Linuron is also efficiently used in other vegetables, like carrot (Bell et al., 2000) and bean (Soltani et al., 2011), while S-metolachlor is also applied in pepper (Mohseni-Moghadam and Doohan, 2015) and radish (Odero et al., 2016), but reportedly did not provide adequate control of many weeds, including *C. album*. It is more generally regarded in US that herbicides are necessary to achieve adequate weed control in pumpkin production (Brown and Masiunas, 2002; Kammler et al., 2008; Walters and Young, 2010), but our research revealed that Hungarian oil pumpkin-growers are more divided relating to this issue. Definitely, we could relatively clearly distinguish two groups among farmers. Namely, one part of them more strongly insisted on using herbicides, while the rest rather relayed on operating with more frequent cultivating tillage.

5. Conclusions

In agreement with our preliminary expectations, we found that the predictors with the strongest impact on oil pumpkin weed vegetation were the environmental variables with the longest gradients in the sample. We also managed to detect a highly significant influence of non-chemical management factors on the weed flora, even if our study was not based on controlled field experiments, but a broad-scale field survey. Although, our analysis documented some influence of the herbicide treatments, variation partitioning showed an almost equal relevance of chemical and mechanical weed management and a much larger relative impact of non-chemical than chemical practices on the weed vegetation. The responses of the most abundant weed species to the studied variables can be used to improve weed management strategies. Even if the short height of pumpkin connected to its weak weed-suppressive ability might be disadvantageous for the outcome of some cultural practices, our study suggests that oil pumpkin can be successfully grown also in more “eco-friendly” ways.

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Appendix A. Supplementary data

Supplementary data related to this chapter can be found at http://dx.doi.org/10.1016/j.cropro.2017.06.018.

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