nt on weed community in cereal crop rotation

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ABSTRACT

The efficacy of different frequently used selective herbicides and their impact on weed community were assessed in the field experiment with cereal crop rotation in 2013-2016. All herbicide treatments provided effective weed control, but community composition changed after 4 years. The density of many weed species increased on the untreated plots. Annual grasses *Apera spica-venti* and *Alopecurus myosuroides* had temporal increase at plots treated with 2,4-D, florasulam and aminopyralid, but decline at plots treated with pyroxsulam and/or chlorsulfuron. Significant treatment effect was confirmed only for Shannon´s index (*H´*), where the highest *H´* was found in untreated controls (1.83) and the smallest in plots treated with 2,4-D + florasulam + aminopyralid (1.61). The pyroxsulam + florasulam + aminopyralid showed the greatest efficacy on a broad spectrum of weeds while maintaining reasonable species diversity.

Keywords: chemical weed management; herbicide efficacy; field trial; weed diversity

[illegible] part of agroecosystems. Individual weed species differ in their ecological function and competitive ability towards the crop (Marshall et al. 2003). Besides their negative effect on crop yield and quality (Hance and Holly 1990), many weed species have an important ecological function in maintaining farmland biodiversity (Storkey and Westbury 2007). Weed species diversity has declined in agricultural landscape during recent decades mainly due to agricultural intensification (Murphy and Lemerle 2006, Storkey 2011) accompanied by simplification of crop rotations (Meyer 2013, Stoate et al. 2001) and excessive herbicide and fertiliser use (Salonen et al. 2012, Storkey et al. 2010). A new approach to biodiversity-friendly weed management requires finding a balance between sufficient crop production and maintaining satisfactory species diversity (Marshall et al. 2003). This goal is an effective control of highly competitive problem species while sustaining beneficial species at economically acceptable levels (Storkey and Westbury 2007). Studies by Ulber et al. (2010) and Jones and Smith (2007) indicate that treatment by selective herbicides can provide considerable weed control with retention of beneficial species and species diversity.

The aim of this experiment is to evaluate the efficacy of different frequently used selective herbicides and their impact on weed species diversity. Herein, we focused on weed management in winter cereal rotation because the majority of current temperate conventional cropping systems are characterised by monocultures or simple rotations with a limited number of crops. Our goal is to determine the effect of a low cost strategy using cheaper herbicides which have been in use for a long time and have a narrower efficacy spectrum than the modern products that contain 3 active ingredients and hence a broader efficacy spectrum. High weed control efficiency in cereal crops has been attributed to acetolactate synthase (ALS) inhibitors which target a broad spectrum of broadleaf and grass weeds (Hyvönen et al. 2003). We therefore tested selective herbicides with active ingredients in this group. Our s with sub-optimal effect leads to a shift in hard-to-control weed species and negatively affects some parameters of species diversity.

MATERIAL AND METHODS

Experimental site. The field experiment was established in 2009 in the experimental area of the Crop Research Institute in Praha – Ruzyně. The site characteristics are listed in Table 1. The trial area was split into 20 randomised plots with 5 different herbicide treatments in 4 replications. Herbicide treatments differed in the herbicide target - only dicots and dicots + annual grasses; and in intensity of weed control - narrower spectrum and broader spectrum (Table 2). The area of each plot was 100m^2 and the 10 by 10m plots were separated from field boundaries and from each other by 2m on all sides in order to eliminate interaction between plots. Herbicides were applied post emergency in spring from the tillering crop stage to the beginning of stem elongation (BBCH 21-31) by the Agrio-Napa 12 sprayer. A sequence of winter wheat (2014-2016) and winter barley (2013) was grown in the experimental field. Barley was sown on 11 September 2012, wheat on 9 October 2013, 3 October 2014 and 12 October 2015. Uniform cropping practice was carried out in the entire study area: mouldboard ploughing, 0.20-0.25m deep, seedbed preparation with power harrow and mineral fertilisation before sowing with 45 kg N/ha, 20 kg P/ha, 37 kg K/ha; and sowing at 350 seeds/m^2. Fungicides were used before heading in case of infection pressure.

Assessment. Weed species composition and weed density were assessed from 2013 to 2016. Weed data was recorded in spring at the 4 to 6-leaf crop stage before herbicide application and 4 weeks after herbicide application. Individual plants in each plot were counted in five 0.25 m^2 random sampling squares (0.5m by 0.5m) and densities of these five squares were averaged and converted to 1m^2 samples. The weed species composition at trial

…e following species prevailed in April 2013: *Papaver* spp. L., *Veronica* spp. L., *Galium aparine* L., *Apera spica-venti* (L.) P.Beauv., *Stellaria media* (L.) Vill. and *Fumaria officinalis* L. A total of 35 different species were identified over the experimental period. Weed cover (%) and herbicide efficacy (%) were estimated 4 weeks after herbicide application. Headlands and plot edges were excluded from sampling. Weed species were identified at the species level whenever possible and some species, such as *Vicia* spp. L., were identified at genus level. Botanical nomenclature followed Kubát et al. (2002).

Efficacy evaluation of herbicides was performed in EPPO (European and Mediterranean Plant Protection Organisation) standard PP1/152(4) and PP1/93(3) (Bulletin OEPP/EPPO 2012). We used the subjective estimation method which compares % weed cover at treated plots with untreated control and evaluates weed damage due to herbicide application. Efficacy of the studied herbicides was recorded in range 0-100 % (0% = no weed control; 100% = full weed control with no weed survival). For weed species on which a lower efficacy than 90% was observed, the population density was also recorded.

Special attention was paid to weed species considered beneficial for biodiversity and those providing resources for invertebrates and seed-eating birds (Marshall et al. 2003, Storkey 2006). These are marked * in the text.

Statistical analysis. Weed community species diversity was calculated for each plot repetition by Simpson´s dominance ($D = \sum_i p_i^2$), Shannon´s diversity ($H' = -\sum_i p_i \ln (p_i)$) and evenness ($E = H/\ln S$) indices; where p_i is the proportion of individuals of ith species in the total number of individuals (S) in the sample quadrate (Pielou 1966). The effects of treatment and year on diversity indices, weed density and herbicide treatment efficacy were tested by ANOVA, and Tukey´s HSD multiple comparison test at $\alpha = 0.05$ determined homogenous groups. Analysis was conducted in STATISTICA 13.3 software (TIBCO Software Inc., USA).

) 5 software (ter Braak and Ġmilauer, 2012) provided data exploration. Data logarithmic transformation preceded analyses and the optimal Redundancy Analysis (RDA) ordination method was used because of the gradient length on the first canonical axis in compositional turnover in Detrended Correspondence Analysis (DCA). Year and treatment explanatory variables were compiled, and the gross effects were tested using separate RDAs with single explanatory variables. Net effects were then tested using partial RDAs with a single explanatory variable and the other variable as covariate. Both effects of explanatory variables on weed species composition were tested by Monte-Carlo permutation tests for 999 permutations at P=0.05 significance level; as in Lososová et al. (2004). Finally, the ratio of particular canonical eigenvalues to the sum of all eigenvalues measured the proportion of explained variation.

RESULTS AND DISCUSSION

Species diversity and weed community composition. Three diversity indices were used to describe different diversity aspects. All indices were influenced by year, and diversity was significantly higher in 2015 and 2016 than at trial commencement (Table 3). Significant herbicide treatment effect was confirmed only by Shannon´s index (*H´*) where the highest *H´* was found in untreated control and the smallest at plots treated with 2,4-D + florasulam + aminopyralid. Other herbicide treatments showed the same effect (Table 3) and did not significantly differ compared to untreated control. Although the treatment effect was insignificant for Simpson´s dominance (*D*) and evenness (*E*) indices, treatment with 2,4-D + florasulam + aminopyralid had the highest *D* and the smallest *E.*

Decrease in species diversity due to herbicide treatment is supported by other studies. Edesi et al. (2012) showed decreasing Shannon´s index tendency from herbicide use in a fivend organic farming. Jones and Smith (2007) also confirmed the highest species richness at untreated plots and the smallest at herbicide treated plots in a short-term trial, and also higher species richness in single-component herbicide application than in sequential application of multiple herbicides. In contrast, we found no species diversity difference between the application of products with one active ingredient and those with three active ingredients. Pawlonka and Rymuza (2014) confirmed significant species richness decrease after 6-years chlorsulfuron application; and Zengin (2000) reported that the abundance of many weed species in spring wheat decreased after 3 or 4 years repeated 2,4-D applications. On the contrary, Derksen et al. (1995) and Ulber et al. (2010) recorded no significant effect of herbicide treatment on species richness.

Both explanatory variables (time and treatment) together explained 27.3% of total variation in weed species data. Partial RDA detected that species data variation explained by net effect of time was 20.4 % and by herbicide treatment it was 6.9 %. This is partly supported by Streit et al. (2003) who confirmed the significant effect of herbicide application on weed communities. In contrast to our findings, de Mol et al. (2015) recorded that year-factor made only a small contribution to weed species composition variation and de Mol et al. (2012) did not find a correlation between weed species composition and herbicide treatments. While long-term herbicide application affects both the composition of above ground weed communities and the soil seed bank (Bàrberi et al. 1997), a dominant short-term effect of herbicide application on above-ground weed species richness and abundance is confirmed in study of Hald (1999).

Ordination diagrams of partial RDA (Figure 1) show shifts in weed species composition under different herbicide treatment regimes. As expected, the abundance of many weed species increased in untreated control. These comprised common species such as *Veronica hederifolia* L., *Veronica persica* Poir., *Sinapis arvensis* L., *Viola arvensis* Murray and n species including *Lathyrus tuberosus* L., *Lycopsis arvensis* (L.) M.Bieb., *Consolida regalis* Gray and *Consolida orientalis* (Gr. et Godr.) Schrödinger. Plots treated with 2,4-D + chlorsulfuron caused the biggest time shifts in weed species (Figure 1B) and the pyroxsulam + florasulam + aminopyralid showed smaller time shifts than other treatments (Figure 1C). In addition, the *Apera spica-venti* and *Alopecurus myosuroides* Huds. annual grasses showed time increase at plots treated with 2,4-D and florasulam and decrease at plots treated with the pyroxsulam and chlorsulfuron. *V. persica* and *V. hederifolia* abundance increased at all plots, while *Galium aparine* and *Papaver* spp. abundance decreased. Some species with high biodiversity value, such as *Sinapis arvensis* L.*, *Lamium amplexicaule* L.*, and *Fallopia convolvulus* (L.) Á.Löve* increased at plots treated with the pyroxsulam + florasulam + aminopyralid and 2,4-D, but the density of other beneficial species, including *Centaurea cyanus**, *Polygonum aviculare* L.*, and *Stellaria media** decreased at all herbicide treated plots.

Weed density and treatment efficacy. We established significant impact of herbicide treatment on weed density before herbicide application (Figure 2), where the highest average weed density was at untreated control plots (168 plants/m^2) and the smallest at plots treated with the pyroxsulam + florasulam + aminopyralid and 2,4-D (124 and 127/m^2, respectively); and treatment with 2,4-D + florasulam and the 2,4-D + chlorsulfuron provided the same effect.

The Tukey HSD test proved significant differences in herbicide efficacy (Table 5). The pyroxsulam + florasulam + aminopyralid showed the highest efficacy on dicot and grass weeds (96% and 98%, respectively) and the 2,4-D + chlorsulfuron showed the least efficacy (95.4% and 89%). Lower efficacy of all herbicide treatments (90-95%) were recorded for the following species: *Consolida regalis, C. orientalis, Galium aparine, Papaver* spp*., *Fumaria officinalis* L.* and *Fallopia convolvulus**. The *Alopecurus myosuroides* density on herbicide from untreated control plots; with the average number of plants ranging from 0.7 to 1.6/m^2. Keller et al. (2015) also found an increase in this weedôs frequency after three decades of field experiment and ascribed this to a high proportion of winter cereals in the crop rotation.

The *Veronica* spp. density on untreated plots was comparable with herbicide treated plots, except in plots treated with the pyroxsulam + florasulam + aminopyralid and 2,4-D where *Veronica* spp. density was significantly lower. *Apera spica-venti* was best controlled by the pyroxsulam + florasulam + aminopyralid and we recorded the highest abundance of this weed after other tested herbicide treatments (Table 6). Pawlonka and Rymuza (2014) recorded an increasing density of this species after chlorsulfuron applications.

Conclusion: The treatment with all tested herbicides provided effective weed control. Modern products containing 3 active ingredients had slightly better efficacy than older products containing 1-2 active ingredients which also caused bigger weed species time shifts. Huricane (pyroxsulam + florasulam + aminopyralid) proved the best tested product in winter cereal rotation for efficacy on a broad spectrum of weeds while maintaining reasonable species diversity. Huricane treatment enabled survival of some species with high biodiversity value, such as *Sinapis arvensis**, *Lamium amplexicaule** and *Fallopia convolvulus**; other beneficial species, including *Centaurea cyanus**, *Polygonum aviculare** and *Stellaria media**, were suppressed at all herbicide treated plots. Mustang Forte (2,4-D + florasulam + aminopyralid) is another modern herbicide with a broader spectrum (only dicot) and high efficacy, but it left poorest weed community with low species diversity. Treatment only 2,4-D effectively suppressed some dicotyledonous weeds without significant decrease in diversity; thus this product can be recommended for fields with a low density of grass weeds.

Acknowledgments

culture of the Czech Republic, institutional support MZE-RO0418. We thank Dr Raymond J. Marshall for language review.

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			annual temperature	Average annual precipitation total	FAO Classification	pH (KCl)	Organic carbon/ clay content
		m	°C	mm			%
14°30´E	50°08´N	345	7.9	472	Haplic Luvisols, on loess	6.3	2.4 31.3

…tive ingredients used in the trial. Classification Group by Herbicide Resistance Action Committee (HRAC).

herbicide	dose	formulation	active ingredient	content of a.i.	HRAC group	target weeds
Esteron	0.8 L/ha	EC	2,4 - D	600 g/l	O	dicot, narrower spectrum
Esteron Glean 75 PX	0.8 L/ha 15 g/ha	EC WG	2,4 - D chlorsulfuron	600 g/l 750g/l	O B	annual grasses + dicot, narrower spectrum
Mustang Forte	1 L/ha	SE	aminopyralid 2,4 - D florasulam	10g/l 180g/l 5g/l	O O B	dicot broader spectrum
Huricane	200 g/ha	WG	aminopyralid florasulam pyroxsulam	50g/l 25g/l 50g/l	O B B	annual grasses + dicot, broader spectrum
Untreated control						

…essed in April 2013. Average number of plants/ m^2 ± standard errors (SE), proportion of individual species in the dataset (%).

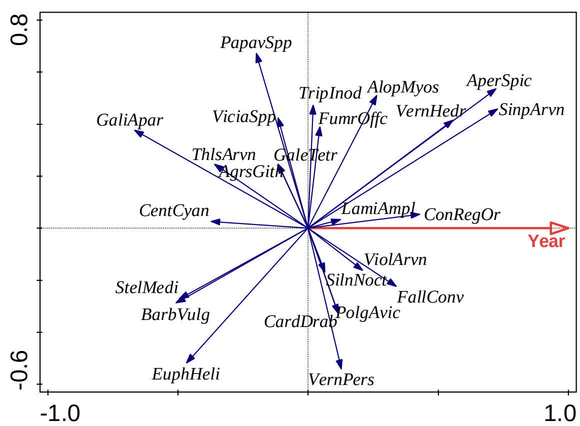
Weed species	**number of plants**		**%**	
	Avg.	SE	Avg.	SE
Papaver spp. L.	52.6	22.9	30.9	17
Veronica spp. L.	20.1	15.5	15.1	9.7
Galium aparine L.	16.1	11.8	11.9	9.1
Apera spica-venti (L.) P.Beauv.	15.3	10.3	10.5	
Stellaria media (L.) Vill.	5.7	5.1	6.1	5.8
Fumaria officinalis L.	4.5	4.1	4.1	3.3
Viola arvensis Murray	3.5	2.1	2.9	2.5
Thlaspi arvense L.	3.3	2.5	2.7	1.9
Consolida spp. (DC) Gray	3.2	3	4	3.8
Lamium spp. L.	2.4	2.1	1.9	1.5
Euphorbia helioscopia L.	1.8	1.1	1.3	0.8
Centaurea cyanus L.	1	0.9	1.2	1
Tripleurospermum inodorum (L.) Schultz-Bip.	1	0.8	1.2	0.9
Silene noctiflora L.	1	0.9	1	1
Polygonum aviculare L.	<1		<1	
Erodium cicutarium (L.) L`Hér.	<1		<1	
Sonchus arvensis L.	<1		<1	
Agrostemma githago L.	<1		<1	
Alopecurus myosuroides Huds.	<1		<1	

(Avg.) ± standard errors (SE) in monitored years and treatments. The averages marked by the same letter in individual columns did not significantly differ at Ŭ= 0.05 (Tukey HSD test).

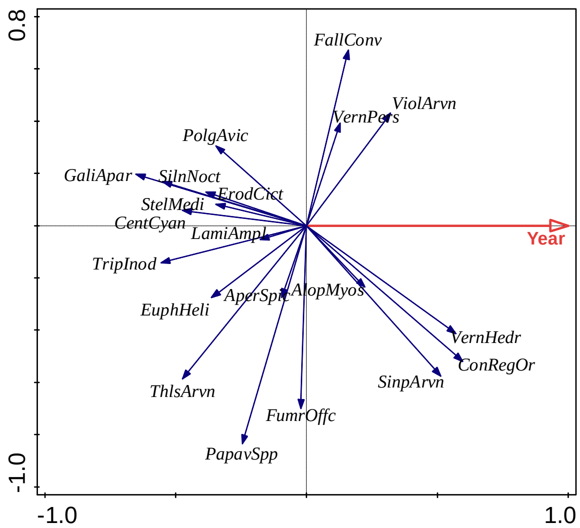
year	**Shannon´s index**		**Shannon evenness**		**Simpson index**	
	Avg.	SE	Avg.	SE	Avg.	SE
2013	1.62[a]	0.06	0,67[ab]	0.03	0.31[b]	0.03
2014	1.55[a]	0.04	0,62[a]	0.02	0.34[b]	0.02
2015	1.90[b]	0.05	0,75[c]	0.02	0.21[a]	0.01
2016	1.88[b]	0.03	0,73[bc]	0.01	0.22[a]	0.01
treatment						
2,4-D	1.75[ab]	0.04	0.7[a]	0.02	0.26[a]	0.02
2,4-D + chlorsulfuron	1.71[ab]	0.05	0.7[a]	0.02	0.27[a]	0.02
aminopyralid +2,4- D + florasulam	1.61[a]	0.07	0.65[a]	0.02	0.3[a]	0.03
aminopyralid + florasulam + pyroxsulam	1.79[ab]	0.07	0.71[a]	0.03	0.26[a]	0.03
untreated control	1.83[b]	0.08	0.7[a]	0.02	0.25[a]	0.03

...rtial Redundancy Analysis (RDA) of weed species composition in different treatments. A) 2,4-D, B) 2,4-D + chlorsulfuron, C) aminopyralid + 2,4-D + florasulam, D) aminopyralid + florasulam + pyroxsulam, E) untreated control; year as explanatory variable and repetition as covariate.

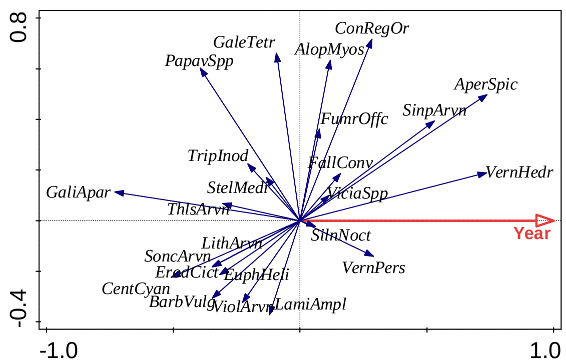
A



B



C



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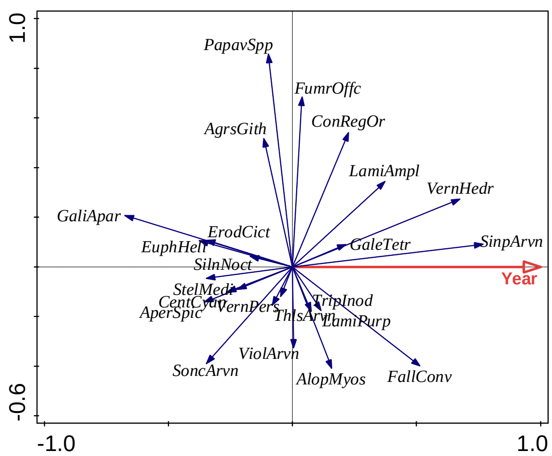

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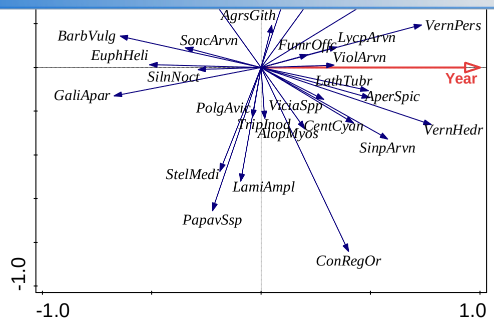
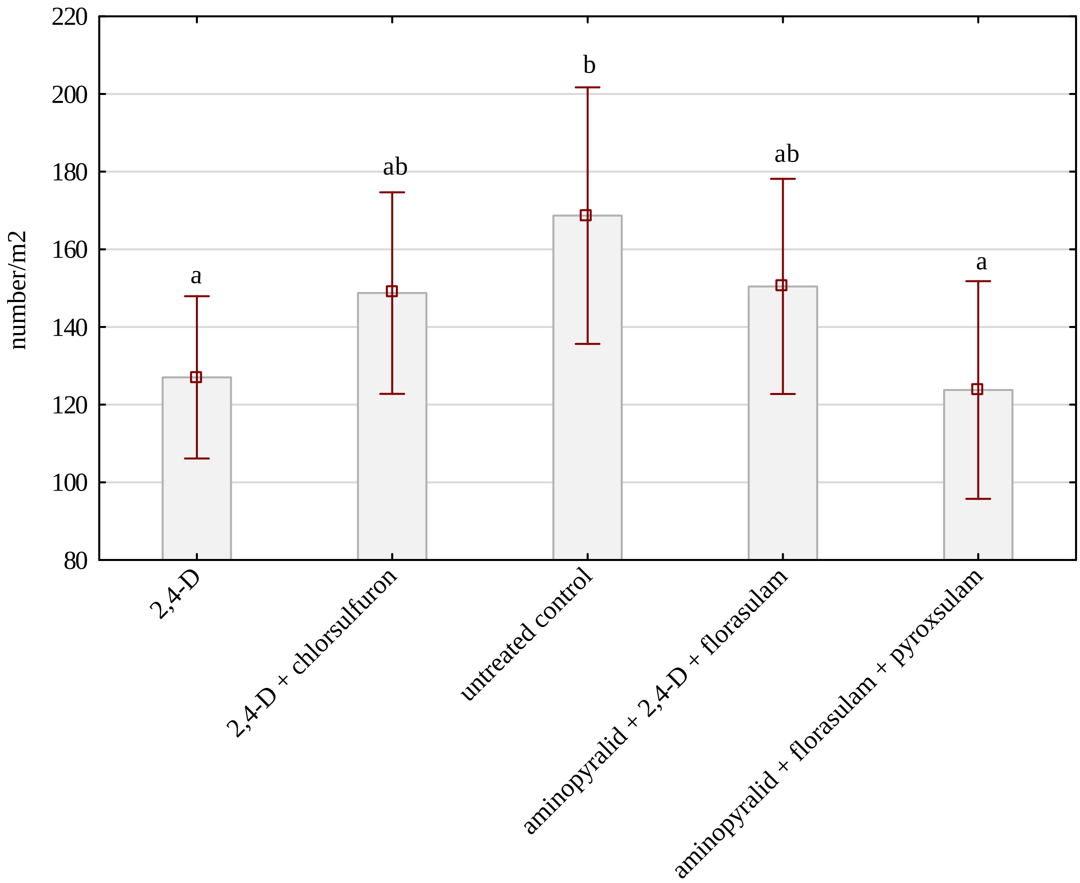


Abbreviations for Figure 1: AgrsGith (*Agrostemma githago*), AlopMyos (*Alopecurus myosuroides*), AperSpic (*Apera spica-venti*), BarbVulg (*Barbarea vulgaris*), CardDrab (*Cardaria draba*), CentCyan (*Centaurea cyanus*), ConRegOr (*Consolida regia* and *C. orientalis*), ErodCict (*Erodium cicutarium*), EuphHeli (Euphorbia helioscopia), FallConv (*Fallopia convolvulus*), FumOffc (*Fumaria officinalis*), GaleTetr (*Galeopsis tetrahit*), GaliApar (*Galium aparine*), LamiAmpl (*Lamium amplexicaule*), LamiPurp (*Lamium purpureum*), LathTuber (*Lathyrus tuberosus*), LithArvn (*Lithospermum arvense*), LycpArvn (*Lycopsis arvensis*), PapavSpp (*Papaver* spp.), PolgAvic (*Polygonum aviculare*), SilnNoct (*Silene noctiflorum*), SinpArvn (*Sinapis arvensis*), SoncArvn (*Sonchus arvensis*), StelMedi (*Stellaria media*), ThlsArvn (*Thlaspi arvense*), TripInod (*Tripleurospermum inodorum*), VernHedr (*Veronica hederifolia*), VernPers (*Veronica persica*), ViciaSpp (*Vicia* spp.), ViolArvn (*Viola arvensis*)

... weed density for 2013-2016. Different letters indicate significant differences at α = 0.05 by Tukey HSD test, vertical columns show 0.95 confidence interval.



cacy on weeds in % ± standard error (SE) for 2013-2016. The averages marked by the same letter in individual columns did not significantly differ at Ŭ= 0.05 (Tukey HSD test).

herbicide	**dicot**		**grasses**	
	Avg.	SE	Avg.	SE
2,4-D	95.8[ab]	0.26	0[a]	-
2,4-D + chlorsulfuron	95.4[a]	0.19	89[b]	2.6
aminopyralid + 2,4-D + florasulam	95.6[a]	0.23	95[c]	0.33
aminopyralid + florasulam + pyroxsulam	96.5[b]	0.16	97.8[c]	0.17

tandard error after treatment of selected weed species
lue (Marshall et al. 2003, Storkey 2006)

Weed species/ treatment	**2,4-D**	**2,4-D + chlorsulfuron**	**aminopyralid + 2,4-D + florasulam**	**aminopyralid + florasulam + pyroxsulam**	**untreated control**
Veronica spp.	$4.5^{b} \pm 0.3$	$4.3^{b} \pm 0.3$	$4.7^{b} \pm 0.4$	$2.3^{a} \pm 0.2$	$3.9^{b} \pm 0.4$
*Viola arvensis**	$1.3^{c} \pm 0.2$	$1.7^{c} \pm 0.3$	$0.3^{a} \pm 0.7$	$0.5^{ab} \pm 0.1$	$1.1^{bc} \pm 0.2$
*Stellaria media**	$0.3^{ab} \pm 0.09$	$0.1^{a} \pm 0.05$	$0.1^{a} \pm 0.04$	$0.5^{b} \pm 0.1$	$1.2^{c} \pm 0.1$
Apera spica venti	$8.8^{cd} \pm 0.7$	$7^{bc} \pm 0.5$	$6.4^{b} \pm 0.5$	$2.7^{a} \pm 0.3$	$9.6^{d} \pm 0.7$