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RESEARCH ARTICLE

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Effect of tillage system on the structure of weed infestation of winter wheat

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Abstract

The study aimed to evaluate the structure of weed infestation of winter wheat grown in different weeding systems: conventional tillage (CT), reduced tillage (RT), and herbicide treatment (HT). In CT system, shallow ploughing and pre-sow ploughing were conducted after the harvest of the previous crop. In RT system, shallow ploughing was replaced by cultivator tillage, whereas pre-sow ploughing by a tillage set. In HT system, shallow ploughing was replaced by spraying with glyphosate and pre-sow ploughing by cultivator tillage. At the tillering stage (22-23 in BBCH scale), species composition and number of weeds/m^2 were determined with the botanical-gravimetric method, whereas at the stage of waxy maturity of wheat (82-83 BBCH) analyses were conducted for species composition as well as density, air-dry weight, and weed distribution in crop levels. The Shannon-Wiener's diversity index (*H'*) and degrees of phytosociological constancy (*S*) of weeds were determined as well. The study showed that more weeds occurred in RT and HT systems than in the CT system and they produced higher biomass in RT than in CT and HT systems. The tillage system affected weed distribution in crop levels. In CT system, the highest weed density was identified in the ground and lower levels, whereas in RT and HT systems in the ground and middle levels. Values of the species diversity index (*H'*) indicate a similar diversity of weed species composition between weeding systems and more diverse between study years.

Additional keywords: species richness; air-dry weight of weeds; weed distribution in crop levels; degrees of phytosociological constancy.

Abbreviations used: CT (conventional tillage); DM (dry matter); GS (growth stage); *H'* (Shannon-Wiener index); HSD (honestly significant difference); HT (herbicide treatment); RT (reduced tillage); TS (tillage system).

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Introduction

The tillage system and improvement of agrotechnical measures have a significant effect upon the condition and extent of crops infestation with weeds (Gruber *et al.*, 2012; Nichols *et al.*, 2015; Woźniak & Soroka, 2017). According to Tørresen & Skuterud (2002) and to Gruber & Claupein (2009), the no-till system increases reserves of diaspores in the topsoil, which leads to crop infestation with weeds (Cardina *et al.*, 2002; Chauhan *et al.*, 2006; Mohler *et al.*, 2006; Małecka-Jankowiak *et al.*, 2015). As reported by Hoffman *et al.* (1998), Bàrberi *et al.* (2001) and Woźniak (2007), from 60 to 90% of the seed bank may be deposited in the topsoil. During mechanical cultivation, weed seeds with a short resting period are transferred from the topsoil into deeper soil layers, from where only few are capable of sprouting. It results in a depletion of the seed bank in the soil and, thus, in lesser crop infestation with weeds (Riemens *et al.*, 2007; Gruber & Claupein, 2009). In turn, seeds with a long resting period may germinate even after decades of resting in the soil (Basset & Crompton, 1975). The weeding system affects also the biodiversity of weeds. Usually, the replacement of mechanical treatments by chemical ones facilitates weed diversity decrease and compensation of herbicide-tolerant species (Wesołowski *et al.*, 2008). As shown by Woźniak & Soroka (2015a), the highest number of weed species in pea crops occurred in the reduced tillage system with the use of a tillage unit consisting of a cultivator and a roller, whereas the lowest number in the system of direct sowing. Herbicides used in the conservation and stubble systems eliminate perennial species and effectively reduce infestation with short-lived species (Gruber & Claupein, 2009). Streit *et al.* (2002) showed that for no-tillage technologies without herbicides, the weed density was lower than that in conventional or minimum tillage. In technologies with herbicides, Ishaya *et al.* (2008) found converse results.

The detrimental effect of weeds depends on their ability to compete with the crop. This ability depends likewise in their growth rate at early stages, their canopy, the density of the crop and also, on the number and biomass of weeds. Significant is also height of the weeds in relation to the cereal crops (Woźniak & Soroka, 2015b). Generally, weeds of the upper level spread anemochorically, these of the middle level either fall down before harvest or are harvested with the crop, whereas weeds of the bottom and ground levels ripen in the stubble field and increase the seed bank in the soil. Naturally, upper and middle level also does increase the seed bank in the soil by gravity or air-transport (Woźniak & Soroka, 2017).

The study aimed to evaluate the structure of weed infestation – number of species, mass of weeds, species composition and species distribution in levels of winter wheat crop sown in conventional, reduced, and herbicide tillage systems.

Material and methods

Study site and habitat conditions

A field experiment was established in 2007 at the Uhrusk Experimental Station (51°18'11"N, 23°36'43"E), whereas data presented herein were collected in 2014-2016. The soil on which the experiment was conducted was Rendzic Phaeozem, according to the classification of IUSS Working Group WRB (2015). The soil is characterized by alkaline pH (pH_{KCL}=7.2), high contents of phosphorus (133 mg P/kg DM) and potassium (310 mg K/kg DM), but low content of magnesium (37 mg Mg/kg DM). Contents of total nitrogen, nitrate nitrogen ($N\text{-}NO_3$), ammonia nitrogen ($N\text{-}NH_4$), and organic C in the soil reach: 0.97 g N/kg DM, 30.8 mg/kg DM, 1.21 mg/kg DM, and 6.38 g/kg DM, respectively.

At study area, the average annual sum of precipitation since wheat sowing till harvest, *i.e.* since September till August, reaches 580 mm, whereas the highest monthly precipitation occurs in May (65 mm), June (73 mm), and July (80 mm). The average air temperature in the vegetative season of wheat (since March to August) is 12.6 °C, whereas the highest average monthly air temperatures occur in June (16.7 °C), July (18.4 °C), and August (17.6 °C). In winter months, the average monthly air temperatures reach -1.8 °C in December, -4.0 °C in January, and -2.8 °C in February, while sums of precipitation reach: 30 mm, 23 mm, and 26 mm, respectively.

Experimental design

In this experiment, winter wheat (*Triticum aestivum* L.) of 'Ozon' cultivar was sown in the following tillage systems (1) conventional (CT), (2) reduced (RT), and (3) herbicide (HT). The experiment was established with the method of completely randomized blocks (8 × 75 m) in three replications. In the CT system, shallow ploughing (at a depth of 10-12 cm) was applied after the harvest (in August) and pre-sow ploughing (20-25 cm) in the middle of September. In the RT system, shallow ploughing was replaced by cultivating measures (10-15 cm), while pre-sow ploughing by a tillage set (10-12 cm). In the HT system, shallow ploughing was replaced by spraying with glyphosate (Roundup 360 SL in a dose of 4 L/ha), whereas pre-sow ploughing by cultivating measures. At all plots, pea was sown as the previous crop before winter wheat.

Sowing, fertilization and crop protection

Winter wheat was sown at the end of September in the amount of 450 seeds/m^2. Before pre-sow ploughing, nitrogen, phosphorus, and potassium fertilizers were applied in the following doses: 20 kg N/ha, 30 kg P/ha, and 85 kg K/ha. In the springtime, after vegetation resumed, wheat crops were fertilized with nitrogen in three terms: (1) 70 kg/ha at the tillering stage (22-23 in BBCH scale) (BBCH Working Group, 2001); (2) 40 kg/ha at the shooting stage (32-33 BBCH); and (3) 20 kg/ha at the beginning of ear formation (52-53 BBCH). The total amount of fertilizers reached 150 kg N/ha. In each study year, wheat was harvested between the 1st and 5th of August using a Wintersteiger plot harvester.

Wheat crops were protected against fungal diseases using fungicides: 1.0 L/ha of Alert 375 SC (a.i. flusilazole + carbendazim) at the shooting stage (31-32 BBCH) and 1.0 L/ha of Tilt Turbo 575 EC (a.c. propiconazol + fenpropidin at the ear formation stage) (43-44 BBCH). Weed control included spraying with 1.5 L/ha of Chwastox Trio (MCPA + mecoprop + dicamba) at the tillering stage (23-24 BBCH), *i.e.* after the first term of weed infestation assessment.

Yield parameters and statistical analysis

Weed infestation was evaluated with the botanical-gravimetric method in two terms: (1) at the tillering stage (22-23 BBCH) and (2) at the waxy maturity stage of wheat (82-83 BBCH). Determinations conducted in term (1) included the number and species composition of weeds/m^2, whereas these conducted in term (2) included the number, air-dry weight produced by weeds and species composition of weeds. These determinations were conducted twice at each plot using a frame of 0.5 × 1.0 m. The air-dry weight was determined by placing the weeds on openwork shelves in a well ventilated and dry room until complete drying. The weeds collected at the waxy maturity stage of wheat (82-83 BBCH) were divided according to their height relative to wheat: (1) weeds of the upper level – higher than wheat; (2) weeds of the middle level – reaching the full height of wheat; (3) weeds of the low level – reaching half the full height of wheat; and 4) weeds of the ground level, reaching approx. 10 cm in height.

The Shannon-Wiener's diversity index (*H'*) was calculated from the formula:

$$H' = -\sum\left(\frac{ni}{N}\right)\log\left(\frac{ni}{N}\right),$$

where *ni* = number of individuals of each species and *N* = total number of individuals of all species. Also degrees of phytosociological constancy (S) of a species were evaluated in the study, using the following scale: V (80-100% occurrence), IV (60-80%), III (40-60%), II (20-40%), and I (<20%) (Woźniak & Soroka, 2015b).

Results were evaluated with the analysis of variance (ANOVA), whereas the significance of differences between mean values (years, tillage systems and interaction: years × tillage systems) was evaluated with Tukey's HSD test, $p<0.05$.

Results

Weed density was 50% higher during waxy maturity stage of wheat (82-83 BBCH) than during tillering stage (22-23 BBCH) (Table 1). Also higher number of weeds, by 18.2-23.3%, was found in the RT and HT than in the CT systems at waxy maturity stage of wheat. Differences in the number of weeds occurred also between study years. The highest number of weeds was reported in 2014, whereas lower by 50% number of weeds was found in 2015 and by 35% in 2016. In turn, the air-dry weight of weeds determined at the waxy maturity stage of wheat (82-83 BBCH) was higher by 32.1% in the RT than in the CT system and by 25.3% than in the HT system (Table 2).

The species composition of weeds was affected by both tillage system and year of study (Table 3). At the tillering stage of wheat (22-23 BBCH), from 6 to 12 species were identified in CT plots, the most abundant of which were *Consolida regalis, Veronica persica*, *Galium aparine*, and *Lamium amplexicaule*. From 8 to 14 species were identified in RT plots, with the prevailing ones including *Stellaria media*, *G. aparine*, *V. persica*, and *Viola arvensis*. Finally, the number of weeds species identified in HT plots ranged from 7 and 13, and the most abundant ones included *C. regalis*, *Apera spica-venti*, *Capsella bursa-pastoris*, and *V. persica*.

At the stage of waxy maturity of wheat (82-85 BBCH), from 9 to 19 species occurred in plots cultivated in the CT system and the prevailing ones included *C. regalis*, *Papaver rhoeas*, *S. media*, *V. arvensis*, and *G. aparine*. In RT plots, the number of weed species ranged from 10 to 21 and the prevailing ones were: *V. arvensis*, *G. aparine*, *L. amplexicaule, S. media*, and *C. regalis*. In turn, in HT plots weeds were represented by 9 to 16 species with the most abundant ones including *V. arvensis*, *C. regalis*, *L. amplexicaule*, *G. aparine*, and *P. rhoeas* (Table 4).

Diversity of weed communities in wheat crop was evaluated using the Shannon-Wiener's diversity index (*H'*) (Woźniak & Soroka, 2017). Its values indicate a similar diversity of weed species composition between weeding systems and more diverse between the years of research (Table 5).

In the CT system, the following species represented the highest degree (V degree) of phytosociological constancy: *C. regalis, P. rhoeas, S. media, G. aparine, L. amplexicaule*, and *V. persica*. In the RT system these

Table 1. Number of weeds/m^2 in winter wheat crop.

Specification	Years (Y)			Mean
	2014	2015	2016	
Growth stage (GS)				
22-23 BBCH	41.0	20.2	27.2	29.5
82-83 BBCH	83.0	41.8	53.4	59.4
Tillage system (TS)[a]				
CT	52.3	26.0	35.3	37.8
RT	68.9	36.1	43.1	49.3
HT	64.9	31.1	42.5	46.2
Mean	62.0	31.0	40.3	-

$HSD_{0.05}$ for GS = 6.2; TS = 7.1; Y = 7.1; GS × Y = 10.3; TS × Y = 12.1

[a] CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment. HSD, honestly significant difference.

Table 2. Air-dry weight of weeds in g/m^2 in winter wheat crop (82-83 in BBCH scale).

Specification[a]	Years (Y)			Mean
	2014	2015	2016	
CT	21.0	17.3	18.0	18.8
RT	32.1	22.6	28.4	27.7
HT	20.8	15.3	26.1	20.7
Mean	24.7	18.4	24.2	-

$HSD_{0.05}$ for TS = 6.9; Y: ns, TS × Y: ns

[a] CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment.

Table 3. Species composition and density (plants/m^2) of weeds in winter wheat crop at the tillering stage (22-23 in BBCH scale).

Species composition	CT[A]			RT			HT		
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Consolida regalis	8.0^{a}	3.0^{c}	1.3^{d}	1.8^{d}	1.3^{d}	1.7^{d}	6.5^{b}	4.1^{c}	5.4^{b}
Capsella bursa-pastoris	4.0^{a}	-	-	3.3^{a}	0.3^{c}	0.4^{c}	4.4^{a}	2.3^{b}	1.6^{b}
Veronica persica	3.9^{b}	5.5^{b}	8.3^{a}	4.2^{b}	2.9^{c}	4.0^{b}	2.0^{c}	7.0^{a}	2.4^{c}
Galium aparine	3.7^{c}	3.5^{c}	8.8^{a}	6.6^{b}	4.5^{c}	8.6^{a}	9.1^{a}	-	5.8^{b}
Stellaria media	3.6^{c}	0.6^{d}	0.8^{d}	9.8^{a}	6.0^{b}	-	2.9^{c}	-	-
Polygonum aviculare	3.6^{a}	-	0.8^{b}	-	-	3.0^{a}	-	-	-
Lamium amplexicaule	2.8^{c}	4.4^{b}	5.6^{a}	0.8^{d}	1.9^{c}	2.2^{c}	1.2^{d}	3.0^{c}	5.8^{a}
Thlaspi arvense	2.5^{a}	-	-	1.8^{a}	-	-	1.5^{a}	-	-
Chenopodium album	1.6^{b}	-	-	-	-	-	4.4^{a}	-	-
Geranium pusillum	0.6^{a}	-	0.8^{a}	-	-	-	-	-	0.8^{a}
Papaver rhoeas	0.2^{c}	0.2^{c}	0.8^{b}	1.2^{b}	-	-	4.6^{a}	3.7^{a}	3.6^{a}
Apera spica-venti	0.2^{c}	-	-	3.5^{a}	-	-	1.8^{b}	-	-
Viola arvensis	-	-	-	4.0^{b}	0.7^{d}	0.8^{d}	5.9^{a}	-	2.9^{c}
Vicia villosa	-	-	-	-	-	-	-	3.6	-
Veronica hederifolia	-	-	-	1.3^{a}	1.6^{a}	1.7^{a}	-	-	-
Sonchus oleraceus	-	-	-	-	-	-	-	-	0.8
Polygonum lapathifolium	-	-	-	-	-	-	0.5	-	-
Lamium purpureum	-	-	-	0.4^{b}	-	-	-	0.6^{b}	1.6^{a}
Fumaria officinalis	-	-	-	1.8^{a}	-	-	2.4^{a}	-	-
Fallopia convolvulus	-	-	-	0.5^{a}	-	0.8^{a}	-	-	0.4^{a}
Number of weeds/m^2	34.7^{b}	17.2^{d}	27.2^{c}	41.0^{a}	19.2^{d}	23.2^{c}	47.2^{a}	24.3^{c}	31.1^{b}
Number of species	12^{a}	6^{b}	8^{b}	14^{a}	8^{b}	9^{b}	13^{a}	7^{b}	11^{a}

[A] CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment. [a,b,c,d] mean values in rows denoted with the same letters do not differ significantly, $p<0.05$.

were *C. regalis, G. aparine, L. amplexicaule, C. bursa-pastoris, V. arvensis, V. persica*, and *Veronica hederifolia*, whereas in the HT system the species of the V degree constancy included *C. regalis, P. rhoeas, G. aparine, L. amplexicaule, V. persica*, and *C. bursa-pastoris* (Table 6).

Evaluation of weed infestation structure and weed distribution in levels of winter wheat crop demonstrated that 60% of weed species occurred in the ground and lower levels in the CT system, 63% of weeds occurred in the ground and middle levels in the RT system, whereas in the HT system as much as 72% of weeds were found in the ground and middle levels (Table 7). Most of the weeds appeared in the second half of the vegetative season and underwent complete development cycle on the stubble field.

Discussion

Results achieved by Gruber *et al.* (2012) as well as by Woźniak & Soroka (2017) proved that no-till system increases weed infestation of crops, but also results often indicate a higher number and biomass of weeds in the conventional than in the no-till method (Tuesca *et al.*, 2001; Nichols *et al.*, 2015). As reported by Lundkvist (2009) and Brandsaeter *et al.* (2011), the number and weed biomass, and their species diversity are determined by the method and term of cultivating measures. According to Mohler *et al.* (2006) and Pekrun & Claupein (2006), the no-till system increases the number of weeds maturing on the stubble field that fall down, germinate, and increase infestation (Mohler, 1993; Cardina *et al.*, 2002; Chauhan *et al.*, 2006; Sosnoskie *et al.*, 2006). In the present study, lower weed density with weeds was observed in CT than in RT and HT systems. In the study conducted by Mas & Verdu (2003) the structure of weed infestation were affected to a greater extent by study years than tillage systems. According to Pekrun & Claupein (2006), the no-till method enhances the presence of weeds maturing in the stubble field. This was also confirmed in this study wherein as much as 44% of weed species occurred in the ground level in the HT system, whereas

Table 4. Species composition and density (plants/m^2) in winter wheat crop at the stage of waxy maturity (82-83 in BBCH scale).

Species composition	CT^{A}			RT			HT		
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Consolida regalis	15.1^{a}	2.9^{e}	7.7^{d}	3.9^{e}	13.2^{b}	13.2^{b}	7.5^{d}	12.8^{b}	10.9^{c}
Papaver rhoeas	8.5^{a}	1.6^{d}	4.2^{c}	0.6^{d}	8.1^{a}	7.4^{a}	2.3^{d}	5.9^{b}	7.2^{a}
Stellaria media	7.3^{a}	1.6^{c}	2.2^{c}	7.0^{a}	5.6^{b}	0.8^{d}	0.8^{d}	0.4^{d}	0.4^{d}
Viola arvensis	5.9^{d}	2.9^{e}	2.2^{e}	21.6^{a}	2.1^{e}	7.1^{c}	21.0^{a}	1.3^{f}	9.2^{b}
Galium aparine	5.6^{d}	6.2^{d}	8.8^{c}	11.6^{b}	10.7^{b}	14.6^{a}	8.0^{c}	8.4^{c}	11.3^{b}
Galeopsis tetrahit	5.0^{a}	-	-	1.0^{b}	-	-	0.8^{b}	-	-
Polygonum aviculare	5.0^{a}	-	-	2.4^{b}	-	-	-	-	-
Lamium purpureum	4.4^{c}	-	2.5^{d}	7.9^{a}	-	3.4^{d}	6.0^{b}	-	3.0^{d}
Fallopia convolvulus	4.0	-	-	-	-	-	-	-	-
Apera spica-venti	1.8^{a}	-	-	1.2^{a}	-	-	0.4^{b}	-	-
Capsella bursa-pastoris	1.6^{d}	9.4^{a}	2.1^{c}	3.0^{b}	1.2^{d}	2.0^{c}	3.8^{b}	2.4^{c}	3.4^{b}
Melandrium album	1.4^{b}	-	-	0.2^{c}	-	-	3.0^{a}	-	-
Lamium amplexicaule	1.1^{e}	2.3^{d}	2.7^{c}	10.8^{a}	1.8^{d}	1.2^{e}	10.9^{a}	3.2^{c}	4.2^{b}
Veronica persica	1.1^{c}	0.8^{c}	1.9^{b}	1.0^{c}	2.9^{a}	3.6^{a}	2.4^{b}	0.7^{c}	0.9^{c}
Chenopodium album	1.0^{a}	-	-	1.2^{a}	-	-	-	-	-
Fumaria officinalis	0.4^{a}	-	-	0.4^{a}	-	-	-	-	-
Sonchus oleraceus	0.2^{a}	-	-	0.4^{a}	-	-	-	-	-
Thlaspi arvense	0.2^{c}	-	-	9.6^{a}	-	-	5.8^{b}	-	-
Vicia villosa	0.2^{b}	-	-	0.8^{b}	-	-	3.5^{a}	-	-
Avena fatua	-	7.0^{b}	9.1^{a}	-	4.0^{c}	5.2^{b}	-	2.8^{d}	3.4^{c}
Veronica hederifolia	-	-	-	5.6^{a}	3.3^{b}	4.4^{b}	5.5^{a}	-	-
Geranium pusillum	-	-	-	3.3	-	-	-	-	-
Polygonum lapathifolium	-	-	-	3.2^{a}	-	-	0.9^{b}	-	-
Number of weeds/m^2	69.8^{c}	34.7^{f}	43.4^{e}	96.7^{a}	52.9^{d}	62.9^{c}	82.6^{b}	37.9^{f}	53.9^{d}
Number of species	19^{a}	9^{b}	10^{b}	21^{a}	10^{b}	11^{b}	16^{a}	9^{b}	10^{b}

^{A} CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment. ^{a,b,c,d,e,f} mean values in rows denoted with the same letters do not differ significantly, $p<0.05$.

Table 5. The Shannon-Wiener's diversity index (*H'*).

Years (Y)	Tillage systems (TS) ^{a}			Mean
	CT	RT	HT	
22-23 in BBCH scale				
2014	0.96	1.00	1.02	0.99
2015	0.66	0.78	0.78	0.74
2016	0.70	0.80	0.93	0.81
Mean	0.77	0.86	0.91	-
$HSD_{0.05}$ for TS = 0.07; Y = 0.07; TS × Y = 0.12				
82-83 in BBCH scale				
2014	1.08	1.09	1.03	1.07
2015	0.85	0.89	0.78	0.84
2016	0.92	0.92	0.88	0.91
Mean	0.95	0.97	0.90	-
$HSD_{0.05}$ for TS: ns, Y = 0.09; TS × Y: ns				

^{a} CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment.

the number of weeds at this level in the RT system reached 36%. In turn, when investigating crops of spring cereals, Woźniak & Soroka (2017) demonstrated the highest number of weeds in the middle level of the crop, whereas the highest mass of weeds in the upper and middle levels.

Tillage system affects also diversity of weed species. This study showed presence only the short-lived of weeds. Out of these, 7-8 represented the V or IV degree of phytosociological constancy, which means that they occurred in each study year and at all plots. Also the value of Shannon-Wiener diversity index indicate a similar diversity of weed species composition between weeding systems and more diverse between the years of research. In contrast, in the study conducted by Woźniak & Soroka (2015a) the highest number of weed species occurred on RT plots, and the lowest one on HT plots. This indicates that replacing mechanical treatments by chemical ones decreased the species diversity of weeds.

Table 6. Degree (from I to V) of phytosociological constancy (S) of weeds in winter wheat crop (average of the years 2014-2016).

Species composition	Tillage systems[a]		
	CT	RT	HT
Consolida regalis	V	V	V
Papaver rhoeas	V	IV	V
Stellaria media	V	IV	III
Galium aparine	V	V	V
Lamium amplexicaule	V	V	V
Veronica persica	V	V	V
Capsella bursa-pastoris	IV	V	V
Viola arvensis	III	V	IV
Polygonum aviculare	III	II	-
Lamium purpureum	III	II	IV
Apera spica-venti	II	II	II
Chenopodium album	II	I	I
Thlaspi arvense	II	II	II
Avena fatua	II	II	II
Geranium pusillum	II	I	I
Galeopsis tetrahit	I	I	I
Fallopia convolvulus	I	II	I
Melandrium album	I	I	I
Fumaria officinalis	I	II	I
Sonchus oleraceus	I	I	I
Vicia villosa	I	I	II
Veronica hederifolia	-	V	I
Polygonum lapathifolium	-	I	III

[a] CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment.

Such conditions facilitate compensation of herbicide-tolerant species and even development of biotypes resistant to these agents.

As conclusions, the more weeds occurred in winter wheat crop in the RT and HT systems than in the CT system, although they produced higher biomass in the RT than in CT and HT systems. The tillage system affected weed distribution in crop levels. In CT system, the highest number of weeds was identified in the ground and lower levels, whereas in RT and HT systems in the ground and middle levels. Values of the species diversity index (*H'*) indicate a similar diversity of weed species composition between weeding systems and more diverse between the years of research.

Table 7. Contribution percentage of weed species in particular levels of winter wheat crop (average of the years 2014-2016).

Crop level	Tillage systems[a]		
	CT	RT	HT
Upper level	14	14	17
Middle level	26	27	28
Lower level	30	23	11
Ground level	30	36	44
$HSD_{0.05}$	4	5	5

[a] CT, conventional tillage; RT, reduced tillage; HT, herbicide treatment.

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