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ORIGINAL RESEARCH

Weed community in crop rotation and in a 33–35-year winter wheat monoculture

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Abstract

The formation of weed communities in agricultural crops is determined by habitat conditions, soil fertility, and agricultural practice deployed. A multi-year experiment evaluated the species composition, the number and air-dry weight of weeds in winter wheat, the horizontal (layered) distribution of weeds in the canopy as well as values of Shannon–Wiener's diversity index and Sørensen's similarity coefficient in a weed community. Winter wheat was sown in a crop rotation: potato – winter wheat – peas – winter durum wheat and in a 33–35-year monoculture. Weed infestation indices were evaluated at the tillering stage and the milk maturity stage of winter wheat. At both developmental stages of winter wheat, an almost 3-fold higher number of weeds was recorded in the monoculture than in the crop rotation. Also, the air-dry weight of weeds was higher in the monoculture than in the crop rotation at both developmental stages compared. Weeds of the upper and middle levels accounted for 82–92.3% of the weed community in the crop rotation and for 98.5–100% in the monoculture. A higher value of the Shannon–Wiener's biodiversity index was computed for the weed community from the crop rotation than from the monoculture. In turn, the Sørensen's similarity coefficient of the weed community reached 70–76% at the tillering stage and 68–78% at the milk maturity stage of winter wheat.

Keywords

weed flora; number of weeds; air-dry weight; Shannon–Wiener's diversity index; Sørensen's similarity coefficient; level distribution of weeds

1. Introduction

The development of a community of segetal weeds is determined by habitat conditions, abundance of nutrients in soils, and agricultural measures (Albrecht & Pilgram, 1997; Andreasen et al., 2018; Bond & Grundy, 2001; Swanton et al., 2015). Different weed communities are formed on dry and nutrient-poor soils than on fertile and moist ones and also in crop rotation than in monoculture (Woźniak & Soroka, 2022). As proposed by MacLaren et al. (2020), various cropping systems and agricultural measures increase the diversity of the weed community and reduce their competitiveness against crops. In the experiment conducted in the crop rotation system by Woźniak and Soroka (2015) on nutrient-dense soil, the weed community was formed by species belonging mainly to the syntaxonomic classes *Stellarietea mediae*, *Molinio-Arrhenatheretea*, and *Agropyretea intermedio-repentis*.

The importance of weeds to agrosystems varies but they are usually competitive to crops, which in most instances leads to crop yield reduction (Jeschke, 2014; Marshall et al., 2003). According to Mahajan and Timsina (2011), nutrient-rich soil allows weeds to produce greater biomass, which makes them stronger competitors against crops. As reported by Oerke (2006), in uncontrolled conditions, weeds may cause even a 34% decline in the global yields of all crops. Weeds do not pose a large threat to crops in a multiple-species crop rotation but may be difficult to eradicate (even using herbicides) in the monoculture (Bourgeois et al., 2019; Weisberger et al., 2019). According to Mortensen et al. (2012), various cultivation systems and weed control methods deployed in crop rotation diminish weed competitiveness against crops. In turn, crop cultivation in the monoculture promotes the compensation of sparingly-controllable multiple weed species (Chauhan et al., 2012; Woźniak, 2023). In the study conducted by Woźniak and Soroka (2022), these were mainly *Apera spica-venti* and *Avena fatua,* i.e., weeds higher than wheat. As reported by Storkey (2006) and Gaba et al. (2017), these weeds are highly competitive to cereals.

The main sources of cultivable field infestation by weeds are their seeds deposited in the soil (Feledyn-Szewczyk et al., 2020; Franke et al., 2009). Their number depends on plant fertility, dispersal method, and agricultural practice, including plant succession in a crop rotation and tillage system (Andreasen & Stryhn, 2008; Legere et al., 2011). As reported by Storkey and Westbury (2007) and Smith et al. (2020), these weeds appear on fields due to natural processes of seed dispersal and dormancy, whereas the abundance of nutrients and limited biotic resistance of agrosystems promote their colonization by multiple weed species, including ruderal ones. Bagavathiannan and Norsworthy (2012) report that the falling of seeds onto soil is crucial to the field infestation; hence, it is necessary to eradicate weeds before they produce seeds. Seeds of many weed species ripe before crop harvest and are dispersed by wind. This holds true especially for the weeds heavily populating cereal monocultures or crops grown in the no-till systems (Feledyn-Szewczyk et al., 2020; Woźniak & Soroka, 2022). As reported by Hernández Plaza et al. (2015), the no-till system promotes weed species with fine seeds with high fertility, capable to germinate from the soil surface. Consequently, the no-till system promotes the quantitative preponderance of grassy weeds over dicotyledonous species. In turn, crops grown in the conventional tillage are most heavily infested by large-seeded weed species able to germinate from deeper soil layers. As a consequence, weed communities observed in the conventional tillage system are characterized by greater biological diversity than those in the no-till system, which leads to their lesser competitiveness against cultivated crops (Bitarafan & Andreasen, 2020; Zimdahl, 2004).

Based on a literature overview and agricultural practice, a hypothesis was formulated assuming that the cultivation of winter wheat in a 33–35-year monoculture may lead to the preponderance of a few weed species, best adapted to habitat conditions and agricultural practice. The predominance of these weeds may be counteracted by crop rotation including various groups of plants. Therefore, this study aimed to evaluate qualitative and quantitative changes in weed flora found in the crop rotation and in the 33–35-year winter wheat monoculture.

2. Material and methods

2.1. Experiment localization and scheme

A strict field experiment was established in 1988 at the Uhrusk Experimental Farm (51°18′N, 23°36′E) belonging to the University of Life Sciences in Lublin (south-eastern Poland). The results presented in the manuscript were collected in the years 2021–2023, i.e., in the 33rd–35th year of the experiment. The experimental scheme involved winter wheat cultivation in crop rotation and monoculture. The plant sequence in the crop rotation was as follows: potato (*Solanum tuberosum*) – winter wheat (*Triticum aestivum*) – common peas (*Pisum sativum*) – winter durum wheat (*Triticum durum*). Winter wheat and the other crops were sown on 25 × 6 m plots, in 3 replications, in the randomized block system.

Winter wheat of 'Bilanz' cultivar was grown in the conventional tillage system. The agricultural measures applied in the crop rotation system after the harvest of the previous crop, i.e., potatoes, included harrowing and a cultivation unit consisting of a cultivator and a string roller. In the monoculture, shallow ploughing (at a depth of 10 cm) was performed after wheat harvest and pre-sowing ploughing (at a depth of 18 cm) with harrowing in the 3rd week of September. Winter wheat was sown in the first week of October, at the sowing density of 380 seeds per m^2. Before sowing, the soil was fertilized with 150 kg N ha^{-1}, 30 kg P ha^{-1}, and 85 kg K ha^{-1}. The phosphorus and potassium fertilizers were applied prior to wheat sowing, whereas the nitrogen

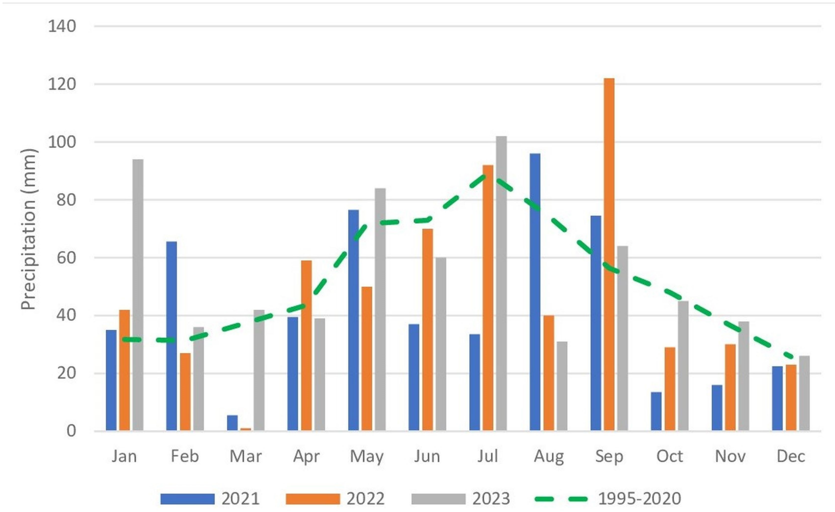

Figure 1 Monthly sums of precipitation (mm).

ones were administered prior to sowing – 20 kg N ha^{-1}, and in the springtime: at the tillering stage – 70 kg N ha^{-1}, at the shooting stage – 40 kg N ha^{-1}, and at the ear formation stage – 20 kg N ha^{-1}. Weed control entailed harrowing stands in the springtime at the wheat tillering stage and 7 days later.

2.2. Soil and weather conditions

The Uhrusk Experimental Farm is located in the eastern part of Lubelskie Province, in the macroregion of Polesie Wołyńskie and the mesoregion of Pagóry Chełmskie (Kondracki, 2009). This area is characterized by great diversity in terms of soil cover and hydrological conditions (Dobrzański & Borowiec, 1961). The experiment was established on a field located at 170 m a.s.l. The soil at the farm is classified as Rendzic Phaeozem (IUSS Working Group WRB, 2015), with the following mineral composition: 52% of sand, 25% of dust, and 23% of loam, and has slightly alkaline pH (pH$_{KCl}$ = 7.1). It has high contents of available forms of phosphorus (194 mg P kg $^{-1}$) and potassium (202 mg K kg^{-1}) and an average content of magnesium (70 mg mg kg^{-1}). The total nitrogen content of the soil is 0.80 g N kg^{-1} and that of organic carbon is 12.4 g C kg^{-1}.

The growing season (period with the average daily air temperature over +5 °C) spans 210–215 days and begins at the end of March. The annual sum of atmospheric precipitation recorded over the study years ranged from 515 mm to 661 mm, with the majority of precipitation observed in the spring and summer months, i.e., from April to September, ranging from 357 mm to 433 mm, respectively (Figure 1). The highest air temperatures were recorded in the summer months: June, July, and August, whereas the lowest ones – in the winter months, i.e., December, January, and February (Figure 2).

2.3. Production traits and statistical analysis

The experiment aimed to assess: (1) the number and air-dry weight of weeds at the tillering (22–23 in the BBCH scale) and milk maturity (73–75 BBCH) stages of winter wheat (Meier, 2018); (2) species composition of weeds at the wheat tillering and milk maturity stages; (3) horizontal (layered) distribution of weeds in the wheat canopy at the milk maturity stage; (4) Shannon–Wiener's biodiversity index (H') at the wheat tillering and milk maturity stages; and (5) Sørensen's similarity coefficient (S) of weed communities in the crop rotation and monoculture at the wheat tillering and milk maturity stages.

The number of weeds, weed species composition, and air-dry weight of weeds were evaluated on a 1 m^2 area randomly selected from each plot. In turn, the assessment

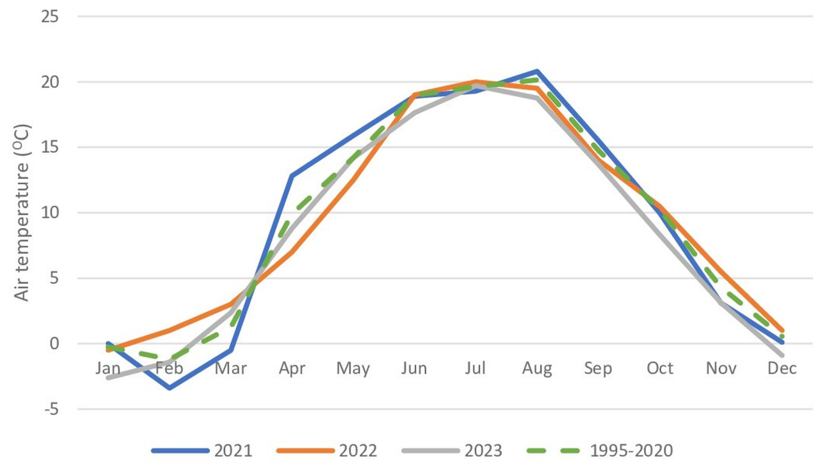

Figure 2 Average monthly air temperature (°C).

of the air-dry weight of weeds consisted in collecting weeds from the specified areas, placing their aerial parts on open-work shelves in a well-ventilated and dry room till they reached constant weight.

The assessment of the horizontal (layered) distribution of weeds in the wheat canopy was carried out according to the following criteria: (1) the upper level – populated by weeds higher than wheat; (2) the middle level – including weeds reaching the full height of wheat; (3) the lower level – constituted by weeds reaching half the wheat height; and (4) the ground level – populated by creeping weeds reaching a few centimeters in height.

The Shannon–Wiener's biodiversity index of weeds in the crop rotation and monoculture was computed according to the following formula: $H' = -\Sigma(\frac{ni}{N})\log(\frac{ni}{N})$, where: ni – number of individuals of each species and N – total number of individuals of all species. In turn, the Sørensen's similarity coefficient of weed communities in the crop rotation and monoculture was computed according to the following formula: $S = \frac{2C}{A+B}$, where: A – number of species in sample A; B – number of species in sample B; C – number of species common for both samples.

Results obtained were subjected to the analysis of variance (ANOVA), whereas the significance of differences between mean values for crop succession (cropping system) and study years and their interactions was determined with the Tukey's HSD test, $P < 0.05$.

3. Results

3.1. Number and air-dry weight of weeds

At the tillering stage of winter wheat, the weed density per m^2 was almost 3-fold greater in the monoculture than in the crop rotation (Table 1). A higher number of weeds was also determined in 2023, compared to the other study years. Likewise, the air-dry weight of weeds was higher in the monoculture than in the crop rotation, as well as in 2023 than in the other study years. At the milk maturity stage of winter wheat, the number of weeds was comparable in the monoculture and crop rotation, whereas their air-dry weight was over 2-fold higher in the monoculture than in the crop rotation (Table 2). Also, more weeds were recorded on the plots in 2021 than in the other study years, whereas the highest weed weight was determined in 2021 and 2023.

The variance analysis components allow concluding that, at the winter wheat tillering stage, the number and air-dry weight of weeds were affected to a greater extent by the cropping system than by the study years (Table 3). In turn, at the milk maturity stage of winter wheat, the number of weeds depended only on the study years, whereas their air-dry weight was mainly affected by the cropping system.

Table 1 Number and air-dry weight of weeds per m^2 in the tillering stage of winter wheat.

Cropping system (CS)	Years (Y)			Mean
	2021	2022	2023	
Number of weeds per m^2				
Crop rotation	19.6	13.6	24.4	19.2
Monoculture	53.8	50.4	65.3	56.5
Mean	36.7	32.0	44.8	–
$HSD_{0.05}$ for CS = 5.1, Y = 7.6, CS × Y = ns				
Air-dry weight in g m^{-2}				
Crop rotation	14.9	9.5	19.5	14.7
Monoculture	40.9	35.3	52.2	42.8
Mean	27.9	22.4	35.9	–
$HSD_{0.05}$ for CS = 3.8, Y = 5.7, CS × Y = ns				

ns – not significant.

Table 2 Number and air-dry weight of weeds per m^2 in the milk maturity stage of winter wheat.

Cropping system (CS)	Years (Y)			Mean
	2021	2022	2023	
Number of weeds per m^2				
Crop rotation	63.2	50.7	60.2	58.0
Monoculture	71.5	56.5	69.8	65.9
Mean	67.4	53.6	65.0	–
$HSD_{0.05}$ for CS = ns, Y = 13.7, CS × Y = ns				
Air-dry weight in g m^{-2}				
Crop rotation	39.8	31.9	37.9	36.6
Monoculture	86.5	68.4	84.5	79.8
Mean	63.2	50.2	61.2	–
$HSD_{0.05}$ for CS = 7.8, Y = 11.7, CS × Y = ns				

ns – not significant.

Table 3 Variance analysis for the number and air-dry weight of weeds.

Specification	Value	CS[a]	Y[b]	CS ×Y
Number of weeds per m^2 (tillering stage of wheat)	*F*	255.6	10.33	0.69
	p	**	**	ns
Air-dry weight in g m^{-2} (tillering stage of wheat)	*F*	256.1	19.76	1.68
	p	**	**	ns
Number of weeds per m^2 (milk maturity stage of wheat)	*F*	3.49	4.05	0.07
	p	ns	*	ns
Air-dry weight in g m^{-2} (milk maturity stage of wheat)	*F*	144.3	5.07	0.89
	p	**	*	ns

[a]CS – cropping system, [b]Y – year, * $p < 0.05$, ** $p < 0.01$.

3.2. Species composition of weeds

At the tillering stage of winter wheat, the plots were infested by 9 to 11 weed species in both the crop rotation and monoculture systems (Table 4). In 2021, the most abundant weeds identified on the crop rotation plots included *Consolida regalis*, *Capsella bursa-pastoris*, *Papaver rhoeas*, and *Veronica persica*; in 2022, the most abundant were *Stellaria media, Apera spica-venti, C. regalis*, and *C. bursa-pastoris*, whereas in 2023

Table 4 Species composition of weeds at the tillering stage of winter wheat development in crop rotation.

Species composition	Years		
	2021	2022	2023
Consolida regalis Gray	5.8	2.0	4.5
Capsella bursa-pastoris (L.) Medik	2.8	1.6	2.5
Papaver rhoeas L.	2.5	–	2.2
Veronica persica Poir.	2.0	0.5	–
Galium aparine L.	1.8	1.2	1.5
Fumaria officinalis L.	1.2	–	-
Galeopsis tetrahit L.	1.2	–	4.2
Stellaria media (L.) Vill.	0.8	3.2	3.2
Viola arvensis Murr.	0.8	0.5	–
Apera spica-venti (L.) P. Beauv.	0.5	2.4	2.0
Matricaria perforata Mérat	0.2	1.2	1.6
Centaurea cyanus L.	–	1.0	–
Lamium purpureum L.	–	–	2.2
Veronica hederifolia L.	–	–	0.5
Number of weeds per m^2	19.6	13.6	24.4
Number of species	11	9	10

Table 5 Species composition of weeds at the tillering stage of winter wheat development in monoculture.

Species composition	Years		
	2021	2022	2023
Apera spica-venti (L.) P. Beauv.	17.5	11.0	18.5
Consolida regalis Gray	12.8	7.2	8.8
Matricaria perforata Mérat	5.0	4.1	2.8
Papaver rhoeas L.	4.2	2.5	8.5
Veronica persica Poir.	4.0	6.9	3.5
Galium aparine L.	3.8	10.0	1.8
Avena fatua L.	3.8	3.5	3.2
Lamium purpureum L.	1.5	1.9	11.5
Fallopia convolvulus (L.) A. Löve	1.2	–	3.2
Galeopsis tetrahit L.	–	–	1.5
Stellaria media (L.) Vill.	–	1.8	2.0
Viola arvensis Murr.	–	1.5	–
Number of weeds per m^2	53.8	50.4	65.3
Number of species	9	10	11

they included *C. regalis*, *Galeopsis tetrahit*, *S. media*, and *C. bursa-pastoris*. The prevailing weed species identified in the monoculture plots included *A. spica-venti, C. regalis, Matricaria perforata*, and *P. rhoeas* in 2021, *A. spica-venti, Galium aparine, C. regalis*, and *V. persica* in 2022, and *A. spica-venti, Lamium purpureum, C. regalis*, and *P. rhoeas* in 2023 (Table 5).

At the milk maturity stage of wheat, its plots were infested by 12 to 14 weed species (Table 6). In 2021, the most abundant weed species turned out to be *Avena fatua, A. spica-venti, L. purpureum*, and *G. aparine*; in 2022, these were *A. fatua, A. spica-venti, V. persica*, and *P. rhoeas*, whereas the prevailing weed species noted in 2023 included *A. spica-venti, A. fatua, Fallopia convolvulus*, and *P. rhoeas*. In the wheat monoculture, the plots were populated by 8 to 11 weed species (Table 7). In 2021, the most abundant of these turned out to be *A. spica-venti, A. fatua, Centaurea cyanus*, and

Table 6 Species composition of weeds at the milk maturity stage of winter wheat development in crop rotation.

Species composition	Years		
	2021	2022	2023
Avena fatua L.	22.5	18.0	10.5
Apera spica-venti (L.) P. Beauv.	6.8	6.5	19.2
Galium aparine L.	4.2	2.0	3.0
Lamium purpureum L.	4.0	–	2.8
Veronica persica Poir.	4.0	5.2	–
Galeopsis tetrahit L.	3.5	–	2.2
Fallopia convolvulus (L.) A. Löve	3.4	3.3	7.5
Consolida regalis Gray	2.8	–	2.5
Matricaria perforata Mérat	2.5	1.8	3.2
Viola arvensis Murr.	2.5	2.5	–
Polygonum lapathifolium L.	2.2	–	1.2
Sonchus oleraceus L.	2.2	–	1.8
Papaver rhoeas L.	1.8	5.2	4.5
Centaurea cyanus L.	0.8	1.2	–
Myosotis arvensis (L.) Hill Veg.	–	1.2	–
Cirsium arvense (L.) Scop.	–	1.8	–
Elymus repens (L.) Gould	–	1.8	–
Veronica hederifolia L.	–	0.2	–
Lamium amplexicaule L.	–	–	1.8
Number of weeds per m^2	63.2	50.7	60.2
Number of species	14	13	12

Cirsium arvense; in 2022, these were *A. spica-venti, A. fatua, C. regalis*, and *G. aparine*, whereas the most abundant species identified in 2023 included *A. spica-venti, A. fatua, C. arvensis*, and *C. cyanus*.

3.3. Horizontal distribution of weeds in winter wheat canopy

At the milk maturity stage of winter wheat, the weeds of the upper and middle levels represented from 82% to 92.3% of the weed community in the crop rotation and from 98.5% to 100 of the weed community in the monoculture (Table 8).

3.4. Weed infestation indices

At the tillering stage of winter wheat, a higher value of the Shannon–Wiener's diversity index was computed for the weed community in the crop rotation compared to that in the monoculture (Table 9). Also, greater diversity was recorded for the weed community in 2023 than for those from the other study years. Likewise, at the milk maturity stage of winter wheat, a higher value of the Shannon–Wiener's diversity index was determined for the weed community from the crop rotation than from the monoculture and also for the weed community from 2021 than from 2022. The variance analysis components indicate that the Shannon–Wiener's diversity index of weeds was affected to a greater extent by the cropping system than by the study years at both developmental stages of wheat compared (Table 10).

The Sørensen's coefficient of weed community similarity reached 70–76% at the tillering stage and 68–78% at the milk maturity stage of winter wheat (Table 11).

4. Discussion

The weed infestation of agroecosystems is the resultant of agronomic conditions, agrotechnical measures applied and biological characteristics of weeds, including seed production and methods of their dispersal (Davis et al., 2005; Feledyn-Szewczyk et al.,

Table 7 Species composition of weeds at the milk maturity stage of winter wheat development in monoculture.

Species composition	Years		
	2021	2022	2023
Apera spica-venti (L.) P. Beauv.	28.4	27.0	29.8
Avena fatua L.	21.0	17.7	22.8
Centaurea cyanus L.	6.5	1.8	2.8
Cirsium arvense (L.) Scop.	6.2	0.8	3.5
Consolida regalis Gray	4.2	2.5	2.2
Fallopia convolvulus (L.) A. Löve	2.8	–	–
Galium aparine L.	1.2	2.0	1.2
Papaver rhoeas L.	1.2	1.8	1.8
Galeopsis tetrahit L.	–	–	2.5
Polygonum lapathifolium L.	–	–	2.2
Sonchus oleraceus L.	–	–	0.2
Matricaria perforata Mérat	–	1.8	0.8
Veronica persica Poir.	–	0.8	–
Number of weeds per m^2	71.5	56.2	69.8
Number of species	8	9	11

Table 8 Percentage contribution of weeds in particular levels at the milk stage of winter wheat.

Crop level	Years (Y)		
	2021	2022	2023
Crop rotation			
Upper level	56.6	62.1	65.1
Middle level	26.5	19.9	27.2
Lower level	16.9	15.2	4.7
Ground level	–	2.8	3.0
Monoculture			
Upper level	70.8	85.9	79.4
Middle level	29.2	12.6	20.6
Lower level	–	1.5	–
Ground level	–	–	–

Table 9 Shannon–Wiener's (H') diversity index computed for weeds of winter wheat.

Cropping system (CS)	Years (Y)			Mean
	2021	2022	2023	
Tillering stage of wheat				
Crop rotation	0.91	0.89	0.95	0.92
Monoculture	0.73	0.78	0.90	0.80
Mean	0.82	0.84	0.93	–
$HSD_{0.05}$ for CS = 0.05, Y = 0.08, CS × Y = ns				
Milk maturity stage of wheat				
Crop rotation	0.97	0.91	0.92	0.93
Monoculture	0.69	0.62	0.69	0.67
Mean	0.83	0.77	0.81	–
$HSD_{0.05}$ for CS = 0.04, Y = 0.05, CS × Y = ns				

ns – not significant.

Table 10 Variance analysis for Shannon–Wiener's (H') diversity index for weeds.

Specification	Value	CS[a]	Y[b]	CS × Y
Tillering stage of wheat	*F*	23.01	7.77	2.39
	p	**	**	ns
Milk maturity stage of wheat	*F*	197.6	4.05	1.08
	p	**	*	ns

[a] CS – cropping system, [b] Y – year, * $p < 0.05$, ** $p < 0.01$.

Table 11 Sørensen coefficient of similarity of weed communities in crop rotation and monoculture of winter wheat.

Development stage	Years			Value	
	2021	2022	2023	*F*	*p*
Tillering stage of wheat	0.70 a	0.74 ab	0.76 b	8.11	*
Milk maturity stage of wheat	0.68 a	0.73 b	0.78 c	12.2	*

a – mean values in rows denoted with the same letter do not differ significantly, * $p < 0.05$.

2020; Hernández Plaza et al., 2015). Minimized tillage and cereal monocultures are the underlying causes of fields being predominated by several weed species that are difficult to control (Garnier & Navas, 2012; Neve et al., 2009). Also in the present study, a few weed species of the upper and middle levels of the wheat canopy accounted for 98.5% to 100% of the weed community in the monoculture. Storkey (2006) and Gaba et al. (2017) have shown that weeds higher than cereals are more competitive to them. As reported by Marshall et al. (2003), weeds exhibiting a high growth rate have a huge competitive potential against cereals. In turn, Fried et al. (2009) and Perronne et al. (2015) have demonstrated that the agronomic conditions promoting crop performance promote also weeds having the same phenology and nutritional demands. In turn, a study conducted by Finn et al. (2013) has shown that the diversity of crop species and forms in the crop rotation may minimize weed competitiveness against them. Also, Clements et al. (1994) have proved that crop rotation reduces weed abundance and promotes their diversity by modifying the conditions of tillage, fertilization, and plant protection accordingly to the target crop. Also in the present study, the crop rotation was observed to cause a 2–3-fold reduction in the number and air-dry weight of weeds, compared to the monoculture. The number of weed species identified in the monoculture was lower than of those found in the crop rotation; however, the monoculture was characterized by a greater prevalence of grassy weeds (*A. spica-venti* and *A. fatua*) over the other weed species. Weed abundance in the monoculture can only be reduced by means of herbicides; however, as evidenced by Mohler (2001), the frequent use of herbicides may modify the composition of a weed community towards species resistant to the herbicide's active substance. According to Hicks et al. (2018), weeds may develop resistance to herbicides within a short time span. As reported by Heap (2024), 273 weed species identified across the globe have been found resistant to herbicides, and 21 out of 31 known mechanisms of their action have been confirmed.

The diversity of weed species and the variety of cropping systems applied diminish the competitiveness of weeds against crops (MacLaren et al., 2020). Also in the present study, the Shannon–Wiener's diversity index was significantly higher in the wheat canopy from the crop rotation than from the monoculture. In turn, the similarity of the weed communities assessed in the crop rotation and monoculture based on the Sørensen's coefficient ranged from 70% to 76% at the tillering stage and from 68% to 78% at the milk maturity stage of winter wheat. The remaining part of the weed community included little abundant species or those appearing sporadically. These included *Fumaria officinalis, Centaurea cyanus, Lamium purpureum*, and *Viola arvensis* at the tillering stage and *Cirsium arvense, Elymus repens, Galeopsis tetrahit*, and *Polygonum lapathifolium* at the milk maturity stage. Many of these species are specific to the weed community found in root plants, which served as the previous crop for wheat in the present study. As reported by Woźniak (2023), the alternating cultivation of spring and winter crops effectively modifies the species composition of weeds and reduces their abundance in the canopy as well as counteracts the compensation of troublesome species.

5. Conclusions

At the tillering and milk maturity stages of winter wheat, an almost 3-fold higher number of weeds was recorded in the monoculture than in the crop rotation. Also, the air-dry weight of weeds was higher in the monoculture than in the crop rotation at both developmental stages compared. At the milk maturity stage of winter wheat, the weeds of the upper and middle levels accounted for 82–92.3% of the weed community in the crop rotation and for 98.5–100% in the monoculture. A higher value of the Shannon–Wiener's biodiversity index was computed for the weed community from the crop rotation than from the monoculture. In turn, the Sørensen's coefficient of similarity computed for weed communities reached 70–76% at the tillering stage and 68–78% at the milk maturity stage.

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