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Effect of reduced tillage practices on yield, total protein content and weed infestation of winter barley

Wpływ uproszczonych metod uprawy roli na plon ziarna, zawartość białka ogólnego i zachwaszczenie jęczmienia ozimego

Abstract. A multi-year field experiment aimed to evaluate grain yield, yield structure elements, total protein content, and weed infestation indices of winter barley cultivated in a conventional tillage system (CT) and two no-tillage variants: (i) reduced without glyphosate (RT) and (ii) reduced with glyphosate (RT + G). Common peas served as the previous crop in each study year on all plots. Shallow ploughing and pre-sowing ploughing were applied in the CT system after previous crop harvest. In turn, cultivating instead of shallow ploughing and a cultivation unit (a cultivator + a string roller) instead of pre-sowing ploughing were used on RT plots. Finally, shallow ploughing was replaced by glyphosate treatment, whereas pre-sowing ploughing – by a cultivation unit in the RT + G system. A higher grain yield was determined on CT plots than RT and RT+G plots, i.e., by 18% and 23.3%, respectively. The grain yield was also observed to differ significantly between study years. Spike number and 1000 grain weight were differentiated by tillage practices, whereas plant number after emergence by study years. There were no differences in the protein content of winter barley grain as affected by the variants of tillage practices and study years. In contrast, the weeds produced a higher air-dry weight on RT plots than on CT and RT + G plots. Weed bio-diversity determined at the tillering stage was greater on RT than CT plots, whereas that assessed at the milk maturity stage on CT than RT + G plots. The weed diversity index was determined by study year in both terms of assessment.

Keywords: grain yield, weed flora species, number of weeds, air-dry weight of weeds, Shannon-Wiener's diversity index

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INTRODUCTION

Soil cultivation aims to provide crops with best conditions for producing high grain yield. Such conditions can be achieved in the conventional tillage system by means of a moldboard plow and also in the no-till system and in the direct sowing system. However, tillage cannot be focused only on boosting grain yields but also on protecting the soil from fertility loss [Rühlemann and Schmidtke 2015, King and Blesh 2017]. Conventional tillage coupled with insufficient natural fertilization and removal of post-harvest residues from the filed increase losses of organic carbon and nutrients from the soil and adversely affect the soil environment [Zhang et al. 2015, Maillard et al. 2016, Dębska et al. 2020]. According to Woźniak and Rachoń [2022], the quality of soil as well as its fertility improvement are strongly affected by crop rotation, post-harvest residues left on the soil surface, and soil tillage system [Roldán et al. 2005, Pranagal and Woźniak 2021]. Practices recommended in order to preserve soil fertility include those involving its enrichment with post-harvest residues (straw, leaves, and stems) and no-tillage cultivation [Blair et al. 2006, Głąb and Kulig 2008, Farooq et al. 2011, Brennan et al. 2014, Ruisi et al. 2014]. Nevertheless, views on the conventional ploughing and no-till systems are inexplicit, whereas results achieved in these systems depend on soil and climate conditions and on the level of agroengineering implemented [Zikeli et al. 2013, Jaskulska et al. 2018]. No-tillage system performed with a cultivator or chisel proves better in semi-arid regions, as it affects the preservation of post-harvest residues on the soil surface, retains soil moisture, but also improves soil bioactivity [Deike et al. 2008, Farooq et al. 2011]. As reported by De Vita et al. [2007], a strong correlation can be noticed between barley grain yield, tillage practice, and the sum of precipitation in the growing season. The no-tillage system performs better on the areas with low sums of precipitation, whereas the conventional tillage system – on those with moderately high sums of precipitation [Ruisi et al. 2014]. According to Josa et al. [2010], this is due to the fact that tillage performed with a plow leads to excessive soil loosening and aeration, as well as increased evaporation of water from this soil, compared to the cultivation performed with other tools acting on soil surface. Excessive loosening of the soil contributes to the rapid mineralization of organic matter and, as a result, to the loss of humus in the soil [Micucci and Taboada 2006].

Soil tillage systems determine the condition and structure of weed infestation on arable fields [Gruber and Claupein 2009, Tracy and Davis 2009, Swanton et al. 2015, Woźniak and Rachoń 2022]. In addition, they influence the species composition of weeds and their distribution in the crop stand. As Woźniak [2020] reports, cereals grown in the no-tillage system are quantitatively dominated by weeds of the upper and middle levels, which mature before the cereals are harvested and are dispersed by the wind. As Hernández Plaza et al. [2015] claim, the tillage system also affects weed seed distribution in the soil. The no-till system promotes species with fine seeds of high fertility, capable of fast germination from soil surface. In turn, crop stands in the conventional tillage system are predominated by large-seeded weed species able to germinate from deeper soil layers. Consequently, the no-till system promotes the growth of grassy weeds and those dispersed by wind, i.e., by anemochory [Feledyn-Szewczyk et al. 2020, MacLaren et al. 2020]. This has also been confirmed in a study by Melander et al. [2008], in which the greatest density of *Apera spica-venti* occurred on plots where winter wheat was sown after itself in the no-till system. At the same time, the results of this study indicate that the abundance of this species was affected to a greater extent by crop rotation than by tillage system. Also in the study conducted by Woźniak and Soroka [2022] was the weed community in the winter wheat monoculture formed mainly by grassy weeds, including especially *Apera spica-venti* and *Avena fatua*. According to MacLaren et al. [2020], weeds enter into reactions with and are regulated by the agroecosystem.

Based on the cited literature, research hypotheses were formulated which assumed that: (i) higher grain yield of winter barley can be achieved in the conventional than reduced tillage system, and (ii) diversified tillage practices cause various effects on the formation of weed community in winter barley stands. The aim of the present study was, therefore, to assess the grain yield of winter barley in different variants of tillage practices and their impact on the condition and structure of weed infestation of the crop stand.

MATERIALS AND METHODS

Experiment localization and scheme

A field experiment performed in 2007 evaluated various modifications of soil tillage. The experiment was established at the Experimental Farm Uhrusk, belonging to the University of Life Sciences in Lublin and located in the central-eastern Poland (51°18'N, 23°36'E). The results presented in the manuscript were collected in the years 2020–2022 during an experiment established in completely randomized blocks (25 m × 6 m) design in three replications. The study addressed winter barley of 'Zenek' cultivar that was grown in the conventional tillage system (CT) and two reduced tillage variants: (i) without glyphosate (RT) and (ii) with glyphosate (RT + G). The previous crop used on all plots in each study year was common peas. Shallow ploughing (up to 10–12 cm) and pre-sowing ploughing (up to 20 cm) were performed after previous crop harvest on CT plots in the first week of September. In turn, cultivating instead of shallow ploughing and a cultivation unit (a cultivator + a string roller) instead of pre-sowing ploughing were used on RT plots. In the RT + G system, glyphosate (4 dm^3 ha^{-1}) was applied instead of shallow ploughing and a cultivation unit (a cultivator + a string roller) instead of pre-sowing ploughing. Winter barley was sown on all plots at a sowing density of 280 seeds per m^2 in the third week of September. Fertilization prior to sowing included: 20 kg N ha^{-1}, 30 kg P ha^{-1}, and 85 kg K ha^{-1}. In the spring, nitrogen fertilizers were applied in two terms: (1) at the tillering stage – 60 kg N ha^{-1} (23–24 in the BBCH scale) [Meier 2018]; and (2) at the shooting stage – 30 kg N ha^{-1} (33–34 BBCH).

Winter barley crop was protected against weeds by harrowing at the tillering stage and against fungal diseases by the use of fungicides containing: (a) flusilazole and carbendazim (1 dm^3 ha^{-1}) at the tillering stage, and (b) propiconazole and fenpropidin (1 dm^3 ha^{-1}) at the shooting stage.

Soil and weather conditions

The experiment was established on Rendzic Phaeozem [FAO 2015], with the following mineral fraction distribution: sand – 52%, silt – 25%, and clay – 23%, and with a slightly alkaline pH value (pH_{KCl} = 7.1). Total nitrogen, available phosphorus (P), potassium (K), magnesium (Mg), and organic C contents in the 0.25 m soil layer were 0.80–0.88 g kg^{-1}, 110–120 mg kg^{-1}, 190–210 mg kg^{-1}, 68–70 mg kg^{-1}, and 11.2–12.6 g kg^{-1}, respectively. This soil was classified as a very good rye complex.

At the study site, the growing season begins at the turn of March and April (i.e., spans for 210–220 days), and the average daily air temperature recorded in this period exceeds +5°C. The annual sum of precipitation ranged from 515 (in 2021) to 585 mm (in 2022). In the spring and summer months (April–September), the sum of precipitation ranged from 346 mm (2020) to 433 mm (2022), whereas in the autumn and winter months (October–March), from 146 mm (2022) to 175 mm (2020) – Tab. 1. The highest air temperatures were recorded in June, July, and August, whereas the lowest ones in December, January, and February (Tab. 2).

Table 1. Monthly sums of precipitation (mm)

Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Total
2020	24.5	22.0	29.8	34.6	56.8	64.8	73.2	65.2	51.7	34.0	34.1	30.6	521.3
2021	35.0	65.5	5.5	39.5	76.5	37.0	33.5	96.0	74.5	13.5	16.0	22.5	515.0
2022	42.0	27.0	1.0	59.0	50.0	70.0	92.0	40.0	122.0	29.0	30.0	23.0	585.0
1995–2019	32.0	31.7	37.7	44.0	72.3	73.2	89.8	74.7	56.6	48.6	36.6	25.6	622.9

Table 2. Average monthly air temperature (°C)

Years	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Average
2020	1.2	2.8	4.3	8.2	11.2	18.9	18.9	19.8	15.1	10.7	5.2	1.3	9.8
2021	0.0	–3.4	–0.5	12.8	15.9	18.9	19.3	20.8	15.5	10.0	3.1	0.1	9.4
2022	–0.5	1.0	3.0	7.0	12.5	19.0	20.0	19.5	14.0	10.5	5.5	1.0	9.4
1995–2019	0.2	0.1	2.3	9.3	13.2	18.9	19.4	20.0	14.9	10.4	4.6	0.8	9.5

Production traits and statistical analysis

The experiment aimed to determined the following production traits: (1) winter barley grain yield and its components, i.e.: plant number after emergence per m^2 (13–14 BBCH), spike number per 1 m^2 before harvest, grain weight per spike, 1000 grain weight; (2) total protein content of the grain; (3) weed number per 1 m^2 in two terms: (i) at the tillering stage (23–24 BBCH) and (ii) at the milk maturity stage (73–74 BBCH) of barley; (4) air-dry weight of weeds at the 73–74 BBCH stage; (5) Shannon-Wiener diversity index (*H'*); and (6) weed flora species composition at stages 23–24 BBCH and 73–74 BBCH.

Grain was harvested with a plot harvester, at 13% moisture content. Plant number after emergence and spike number per m^2 were counted per the area of 1 m^2 of each plot. Grain weight per spike was determined based on 30 spikes randomly collected from each plot, whereas the 1000 grain weight was established by counting 2 × 500 grains and weighing them. Protein content of the grain was determined with the Near Infrared Reflectance Spectroscopy (NIRS) method.

The weed species composition, weed density, and air-dry weight of weeds were evaluated twice on the 1 m^2 area randomly selected from each plot. The assessment of the air-dry weight of weeds consisted in collecting weeds from the specified areas, removing their root system, and keeping their aerial parts in a well-ventilated room until a constant weight had been reached.

The Shannon-Wiener's diversity index (H') was computed using the following formula: $H' = -\Sigma\ (\frac{ni}{N})\ \log\ (\frac{ni}{N})$ where: ni – is number of individuals of each species and N – is total number of individuals of all species.

The analysis of variance (ANOVA) was used to process experimental results, whereas the Tukey's HSD test (at $P < 0.05$) was applied to determine the significance of differences between mean values for tillage practices (TP), study years (Y), and their interactions (TP × Y).

RESULTS

Grain yields and its components, and protein content of the grain

Both tillage practices and study years were observed to differentiate winter barley grain yield. The grain yields were higher in the CT system than in RT and RT+G systems, by 18% and 23.3%, respectively, and also in 2021 compared to the other study years (by 12.9–23.9%) – Tab. 3). Barley plant number per m^2 after the emergence stage (13–14 BBCH) was affected only by the study year, being higher in 2021 than in the other study years. In turn, the number of spikes per m^2 was higher on CT plots than on RT (by 13.4%) and RT+G (by 40.1%) plots. A significantly higher number of spikes per 1 m^2 was additionally determined on RT than RT + G plots. Barley grain weight per spike was similar in all variants of tillage practices and study years, whereas the 1000 grain weight depended only on the tillage practice variant and was higher on CT than on RT and RT + G plots. The evaluation of variance components indicates that grain yield was similarly affected by tillage practices and study years. In contrast, the spike number per 1 m^2 and 1000 grain weight were found to be determined only by tillage practices, whereas plant number after emergence – only by study years (Tab. 4).

The protein content of winter barley grain was similar in all variants of tillage practices and study years (Tab. 5).

Weed infestation indices

A significantly higher weed number per m^2 was determined on RT than on CT and RT + G plots at the two analyzed stages of winter barley development, i.e. tillering stage (23–24 BBCH) and milk maturity stage (73–74 BBCH) – Tab. 6. A similar observation was made for the air-dry weight of weeds (Tab. 7), which was higher by 40.1% and 28.6% on RT plots than on CT and RT + G plots, respectively. Also study years differentiated the values of this parameter because weeds produced the greatest air-dry weight in 2020, a smaller one in 2022, and the smallest in 2021.

Tillage practices were also observed to influence weed biodiversity (Tab. 8). The Shannon-Wiener's index (H') computed at the winter barley tillering stage (23–24 BBCH) was significantly higher in the RT than CT system. Weed biodiversity was also affected by study years, i.e., a higher value of the H' index was noted in 2020 than in 2021 and 2022, as well as by TP × Y interactions, i.e., significantly greater weed biodiversity

Table 3. Grain yield of winter barley and its components

Years (Y)	Tillage practices (TP)			Mean
	CT	RT	RT + G	
grain yield (t ha^{-1})				
2020	6.51	5.89	4.29	5.56
2021	6.69	5.31	6.84	6.28
2022	5.89	4.96	4.36	5.07
Mean	6.36	5.39	5.16	–
$HSD_{0.05}$ for TP = 0.39; Y = 0.39; TP × Y = ns				
plant number per 1 m^2 (13–14 BBCH)				
2020	242	244	234	240
2021	255	264	271	263
2022	247	240	238	242
Mean	248	249	248	–
$HSD_{0.05}$ for TP = ns; Y = 16; TP × Y = ns				
spike number per 1 m^2				
2020	501	497	373	457
2021	559	460	358	459
2022	491	411	378	426
Mean	517	456	369	–
$HSD_{0.05}$ for TP = 51; Y = ns; TP × Y = ns				
grain weight per spike (g)				
2020	1.31	1.19	1.15	1.22
2021	1.20	1.16	1.23	1.19
2022	1.20	1.21	1.16	1.19
Mean	1.24	1.19	1.18	-
$HSD_{0.05}$ for TP = ns; Y = ns; TP × Y = ns				
1000 grain weight (g)				
2020	49.3	47.0	45.2	47.2
2021	48.3	48.1	44.8	47.1
2022	49.0	47.2	43.8	46.7
Mean	48.9	47.5	44.6	–
$HSD_{0.05}$ for TP = 0.7; Y = ns; TS × Y = ns				

CT – conventional tillage; RT – reduced tillage; RT + G – reduced tillage + glyphosate; ns – not significant

Table 4. Effect of tillage practices (TP) and study year (Y) on the yield and its components

Specification	Value	TP	Y	TP × Y
Grain yield	*F*	35.4	32.1	10.3
	p	**	**	ns
Plant number per 1 m^2 (23–24 BBCH)	*F*	0.04	8.9	1.1
	p	Ns	*	ns
Spike number per 1 m^2	*F*	8.7	12.7	5.4
	p	*	ns	ns
Grain weight per spike (g)	*F*	1.7	0.4	1.7
	p	Ns	ns	ns
1000 grain weight (g)	*F*	122.1	1.3	3.9
	p	**	ns	ns

* $p < 0.05$; ** $p < 0.01$; ns – not significant

Table 5. Protein content of winter barley grain in $g \cdot kg^{-1}$

Years (Y)	Tillage practices (TP)			Mean
	CT	RT	RT + G	
2020	105.0	105.0	104.0	104.7
2021	110.0	106.0	104.0	106.7
2022	108.0	108.0	107.0	107.7
Mean	107.7	106.3	105.0	–
$HSD_{0.05}$ for TP = ns; Y = ns; TP × Y = ns				

CT – conventional tillage, RT – reduced tillage, RT + G – reduced tillage + glyphosate, ns – not significant

Table 6. Number of weeds per 1 m^2 in winter barley crop

Years (Y)	Tillage practices (TP)			Mean
	CT	RT	RT + G	
23–24 BBCH				
2020	9.8	26.6	16.4	17.6
2021	15.7	29.0	18.5	21.1
2022	9.2	23.0	19.0	17.1
Mean	11.6	26.2	17.9	–
$HSD_{0.05}$ for TP = 5.6; Y = ns; TP × Y = ns				
73–74 BBCH				
2020	25.1	39.8	36.8	33.9
2021	27.5	32.6	28.4	29.5
2022	21.3	40.1	24.2	28.5
Mean	24.6	37.5	29.8	–
$HSD_{0.05}$ for TP = 7.3; Y = ns; TP × Y = ns				

CT – conventional tillage, RT – reduced tillage, RT + G – reduced tillage + glyphosate, ns – not significant

Table 7. Air-dry weight of weeds in g m^{-2} of winter barley crop (73–74 BBCH)

	Tillage practices (TP)			Mean
	CT	RT	RT + G	
2020	50.0	74.5	54.3	59.6
2021	44.0	58.5	48.4	50.3
2022	47.4	65.1	51.2	54.6
Mean	47.1	66.0	51.3	–
$HSD_{0.05}$ for TP = 3.7; Y = 3.7; TP × Y = 5.8				

CT – conventional tillage; RT – reduced tillage; RT + G – reduced tillage + glyphosate, ns – not significant

Table 8. The Shannon-Wiener's diversity index (*H'*)

Years (Y)	Tillage practices (TP)			Mean
	CT	RT	RT+G	
23–24 BBCH				
2020	0.65	0.73	0.63	0.67
2021	0.60	0.62	0.65	0.62
2022	0.56	0.63	0.66	0.62
Mean	0.60	0.66	0.64	–
$HSD_{0.05}$ for TP = 0.04; Y = 0.04; TP × Y = 0.07				
73–74 BBCH				
2020	0.77	0.70	0.75	0.74
2021	0.72	0.71	0.69	0.71
2022	0.66	0.69	0.58	0.64
Mean	0.72	0.70	0.67	-
$HSD_{0.05}$ for TP = 0.04; Y = 0.04; TP × Y = ns				

CT – conventional tillage, RT – reduced tillage, RT + G – reduced tillage + glyphosate, ns – not significant

occurred in 2020 than in 2022 on CT plots, and also in 2020 compared to 2021 and 2022 on RT plots. When winter barley was assessed at the milk maturity stage (73–74 BBCH), greater weed biodiversity was noted in the CT than RT+G system, in 2020 than in 2022, and also in 2021 compared to 2022.

The species composition of weed flora in winter barley stands was influenced by both tillage practices and study years (Table 9). In 2020, at the tillering stage of barley (23–24 BBCH), the weed community observed on all plots consisted of 5–6 short-term species, with *Anthemis arvensis*, *Papaver rhoeas*, and *Galium aparine* prevailing in the CT system; and *Apera spica-venti*, *G. aparine*, *Avena fatua*, and *P. rhoeas* predominating in the RT and RT + G systems. In 2021, the weed community was formed by 4–5 species, with *Veronica persica*, *G. aparine* and *A. spica-venti* prevailing in the CT system; and *A. spica-venti*, *V. persica*, and *A. arvensis* in the RT and RT+G systems. Also 4–5 species formed the weed community in 2020, with *A. spica-venti*, *A. fatua*, and *P. rhoeas* predominating on both CT, RT, and RT + G plots.

Table 9. Species composition of weeds at the tillering stage of winter barley (23–24 BBCH)

Species composition	Tillage practices		
	CT	RT	RT + G
2020 year			
Anthemis arvensis L.	3.5	3.0	–
Apera spica-venti (L.) P. Beauv.	1.2	8.9	6.6
Avena fatua L.	–	4.3	3.0
Consolida regalis Gray	0.8	–	–
Galium aparine L.	1.8	4.8	3.2
Lamium purpureum L.	–	2.8	0.8
Papaver rhoeas L.	2.5	2.8	2.8
2021 year			
Anthemis arvensis L.	3.4	5.0	4.5
Apera spica-venti (L.) P. Beauv.	3.8	12.0	5.2
Consolida regalis Gray	–	3.4	0.8
Galium aparine L.	4.0	–	4.0
Lamium purpureum L.	–	1.8	–
Veronica persica Poir.	4.5	6.8	4.0
2022 year			
Apera spica-venti (L.) P. Beauv.	4.2	8.9	6.8
Avena fatua L.	2.0	5.8	4.3
Galium aparine L.	–	2.0	2.2
Papaver rhoeas L.	1.5	4.5	3.5
Veronica persica Poir.	1.5	1.8	2.2

CT – conventional tillage, RT – reduced tillage, RT + G – reduced tillage + glyphosate

When evaluated at the milk maturity stage of winter barley (73–74 BBCH), the weed community formed in 2020 included 7 species, with *A. spica-venti*, *P. rhoeas*, and *Fallopia convolvulus* predominating in the CT system; *P. rhoeas*, *A. spica-venti*, and *A. fatua* in the RT system as well as *A. fatua*, *A. spica-venti*, and *Consolida regalis* in the RT + G system (Tab. 10). Weeds identified on CT, RT, and RT + G plots in 2021 belonged to 5–7 species, with the most abundant ones including: *P. rhoeas* and *A. spica-venti* on CT plots; *A. spica-venti*, *F. convolvulus*, and *Sonchus asper* on RT plots; as well as *A. spica-venti*, *G. aparine*, and *A. fatua* on RT + G plots. In 2022, the weed community was formed by 4 to 6 species, including mainly: *A. spica-venti*, *G. aparine*, and *P. rhoeas* on CT plots; *A. spica-venti*, *G. aparine*, and *A. fatua* on RT plots; as well as *A. spica-venti*, *A. fatua*, *P. rhoeas*, and *G. aparine* on RT + G plots.

Table 10. Species composition of weeds at the milk maturity stage of winter barley (73–74 BBCH)

Species composition	Tillage practices		
	CT	RT	RT + G
2020 year			
Anthemis arvensis L.	3.2	4.8	4.0
Apera spica-venti (L.) P. Beauv	6.8	12.2	10.0
Avena fatua L.	1.2	5.8	10.5
Consolida regalis Gray	–	1.2	6.3
Fallopia convolvulus (L.) A. Löve	3.4	–	2.2
Galium aparine L.	4.3	1.8	2.2
Papaver rhoeas L.	5.4	12.8	–
Polygonum lapathifolium L.	0.8	–	1.6
Sinapis arvensis L.	–	1.2	–
2021 year			
Apera spica-venti (L.) P. Beauv	7.8	12.0	6.8
Avena fatua L.	2.2	4.2	6.2
Fallopia convolvulus (L.) A. Löve	2.8	6.6	–
Galeopsis tetrahit L.	0.2	1.8	–
Galium aparine L.	2.8	3.2	6.6
Papaver rhoeas L.	8.9	–	4.5
Sonchus asper (L.) Hill.	2.8	4.8	4.3
2022 year			
Apera spica-venti (L.) P. Beauv	6.2	16.9	8.9
Avena fatua L.	3.0	5.8	4.2
Fallopia convolvulus (L.) A. Löve	1.5	4.9	–
Galium aparine L.	5.4	6.5	4.4
Papaver rhoeas L.	5.2	3.2	6.7
Polygonum lapathifolium L.	–	2.8	–

CT – conventional tillage, RT – reduced tillage, RT + G – reduced tillage + glyphosate

DISCUSSION

Crop productivity is a resultant of the synergistic effect of habitat factors and agricultural practices, including crop rotation, fertilization, soil tillage, and plant protection. The agricultural practice has proved that the choice of the soil tillage method depends on the quality and usability of soil and hydrothermal conditions. High grain yields may be promoted by conventional tillage (CT) performed using a moldboard plow with multiple cultivating measures or extremely reduced no-tillage (NT) [De Vita et al. 2007, Deike et al. 2008]. Previous studies have shown that in semi-arid areas and on dry and airy soils incapable of water storage, definitely better production effects are obtained in a ploughless tillage system, e.g. no-tillage (NT) or reduced tillage (RT), and in an area with moderate rainfall and soils of average moisture – in the conventional tillage system (CT) [De Vita et al. 2007, Głąb and Kulig 2008, Farooq et al. 2011, Ruisi et al. 2014]. In the present research conducted on moderately moist soils and annual precipitation totals of nearly 600 mm, significantly higher yields of winter barley grain were obtained in conventional tillage (CT) than in both variants of reduced tillage (RT and RT + G). In this experiment, barley grain yield depended to a similar extent on the tillage practices (TP) and the study years (Y).

The soil tillage method affects also the composition of weed community in the crop stand [Hernández Plaza et al. 2015, MacLaren et al. 2020]. As claimed by many authors [Gruber and Claupein 2009, Tørresen and Skuteruda 2002, Feledyn-Szewczyk et al. 2020], the NT system increases the reservoir of diaspores in the topsoil, which ultimately leads to the infestation of successive crops by weeds. Nevertheless, the glyphosate used in this system effectively eliminates weeds present on the stubble, which affects the weed infestation of the successive crop. In the conventional plough system, weed seeds are moved into deeper soil layers, only a small part of which germinates and potentially infests crops [Riemens et al. 2007, Santín-Montanyá et al. 2016]. Woźniak and Soroka [2022] showed that small seeds of weeds belonging to the upper layer of the stand (*A. spica-venti*) mature before cereal crop harvest and can be dispersed by wind over long distances. In the ploughless cultivation system, they can represent a serious source of weed infestation. Tillage practices also affect weed biodiversity [Naeem et al. 2021]. This has been proved in a study by Woźniak and Rachoń [2022], in which greater biodiversity was found for the weed community in the reduced tillage system (RT) than in the conventional (CT) and no-till (NT) systems. In the present study, the biodiversity of weeds was evaluated in two terms: at the tillering stage and before harvest of winter barley. In the first term, greater weed biodiversity was observed on RT plots, whereas before barley harvest – on CT plots. Woźniak and Soroka [2015] demonstrated the biodiversity of weed communities in cereal stands to be affected by plant succession in the crop rotation. The weed community was characterized by greater biodiversity in the crop rotation with root and legume plants, than in the cereal monoculture.

CONCLUSIONS

The grain yield of winter barley was similarly affected by tillage practices and study years. Higher grain yields were achieved in the conventional tillage system (CT) than in the reduced tillage (RT) and reduced tillage with glyphosate (RT + G). Significant differences in the grain yield were also found between study years. In addition, tillage practices differentiated spike number and 1000 grain weight, whereas study years caused differences in plant number after emergence. In contrast, the protein content of winter barley grain was similar in all variants of tillage practices and study years. A higher number and air-dry weight of weeds were determined on plots with reduced tillage (RT) than on those with conventional tillage (CT) and reduced tillage with glyphosate (RT + G). At the tillering stage of winter barley, greater weed biodiversity was noted in the RT than CT system, whereas at the milk maturity stage – in the CT system compared to the RT + G system. In both terms of infestation assessment, weed biodiversity was also affected by study years.

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