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ORIGINAL PAPER

Response of winter durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren) to reduced tillage: a multi-year field study[1]

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Abstract

In field experiments, the grain yield, grain quality and weed infestation of winter durum wheat were evaluated in conventional tillage (CT), reduced tillage (RT) and no-tillage (NT) systems. The C/N ratio in the soil was also assessed on all plots. In the CT system, shallow ploughing and pre-sowing ploughing were performed after harvest; in RT – the shallow ploughing and pre-sowing ploughing were replaced by cultivating; and in NT – glyphosate spraying was performed on the stubble field. The grain yield of winter durum wheat was higher in CT than in RT and NT systems. Also, more spikes per m^2 were found on the CT than on the RT and NT plots. Furthermore, the grain weight per spike and the 1000 grain weight were higher in the crops from the CT than from the RT and NT systems. Higher contents of total protein, wet gluten and starch were determined in wheat grains harvested from the CT plots than from the RT and NT plots. Also, the crop from the CT system had higher values of grain density and grain uniformity compared to the crop from the RT and NT systems. The tillage systems differentiated the number of weeds per m^2. On the RT and NT plots, the number of weeds and their air-dry weight were higher compared to the CT plots. The RT and NT plots were dominated by weeds of the upper level (they accounted for 51.3-54.2% of the weed number), whereas the CT plots were most densely infested by the weeds of the upper (31.9%) and the middle (35.5% of the weed number) levels. The most favorable C/N ratio occurred on the NT plots, and the least beneficial one on the CT ones.

Keywords: tillage system, grain yield, grain quality, weed infestation, C/N ratio

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INTRODUCTION

The purpose of tillage is to prepare the soil for sowing seeds and provide plants with favorable conditions for their growth and yielding. Depending on soil characteristics and weather conditions, this can be achieved in an inversion tillage or non-inversion tillage, e.g., reduced tillage, strip-till or direct drilling (Morris et al. 2010). According to Siddique et al. (2012), and Soane et al. (2012), the no-till system in combination with mulch proved best in the case of soils poor in organic matter, dry and prone to erosion. This applies to semi-desert areas, where water retention in the soil poses a fundamental problem in plant cultivation. As reported by many authors (Javůrek et al. 2008, Kertész et al. 2011), the no-till system also increases environmental biodiversity and protects the soil from eutrophication. This system, when coupled with mulch, benefits both biological and chemical soil processes. It also improves water and nutrient availability for plants. Additionally, it increases the organic C content, fixes soil structure and improves its water absorption capability (Li et al. 2014, Pranagal, Woźniak 2021). In contrast, conventional tillage increases soil aeration, which contributes to the rapid mineralization of organic matter, a decrease in organic C content and nutrient leaching (Micucci, Taboady 2006).

Soil cultivation affects the formation of weed communities in crops (Tracy, Davis 2009, Swanton et al. 2015). 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. In the conventional tillage system, crops are most heavily infested by the weeds of the lower and middle levels maturing on the stubble field and shedding their seeds at the place of occurrence. 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 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 (Feledyn--Szewczyk et al. 2020). The grain yield decrease recorded in the no-till system may be due to greater weed infestation of the crop (Davis et al. 2005, Peigné 2007) and to an increase in plant infestation by take-all disease compared to the conventional tillage system (Woźniak 2023).

The soil tillage system also affects the milling and baking parameters of the grain. Woźniak and Makarski (2012) showed that wheat grain harvested from no-till plots contained more ash than that harvested from the plots managed in the conventional tillage system, but it was characterized by lesser density and uniformity. According to Debaeke et al. (1996), the quality of wheat grain is affected by soil tillage only to a little extent as it mainly depends on soil fertilization with nitrogen.

Based on the cited literature, research hypotheses were formulated assuming that the yield and quality parameters of winter durum wheat grain would reach higher values in the conventional tillage (CT) system than in the reduced (RT) and no-till (NT) systems. This may be due to a higher number and air-dry weight of weeds on the RT and NT than on the CT plots. Also, the C/N ratio in the soil is expected to be more beneficial in the RT and NT than in the CT system.

Therefore, the present study aimed to evaluate grain yield, grain quality parameters and weed infestation of winter durum wheat, and to determine the C/N ratio in the soil cultivated in the conventional, reduced and no-till systems.

MATERIALS AND METHODS

Study site and experiment design

A field experiment was established in 2007 at the Uhrusk Experimental Farm belonging to the University of Life Sciences in Lublin (south-eastern Poland). Although the experiment was established in 2007, the present analysis focuses on the results collected from 2020 to 2023. The experiment was established with the method of completely randomized blocks (25 m × 6 m) in three replications. The subject of the study was winter durum wheat (*Triticum turgidum* L. subsp. *durum* (Desf.) van Slageren, Sambadur cultivar) grown in three tillage systems: conventional (CT), reduced (RT) and no-tillage (NT). Common pea was used as the previous crop of winter durum wheat in a 4-field crop rotation. In the CT system, shallow ploughing (to a depth of 10 cm) and pre-sowing ploughing (to a depth of 18-20 cm) were performed after harvest; in the RT system – these treatments were replaced by cultivation; whereas in the NT system – the stubble field was treated with the herbicide, i.e., Roundup 360 Plus at a dose of 4 L ha $^{-1}$ (a.s. glyphosate 360 g L^{-1}).

Before winter durum wheat sowing, the soil was fertilized with 20 kg N ha^{-1}, 35 kg P ha^{-1}, and 90 kg K ha^{-1}. The main dose of nitrogen in the form of ammonium nitrate (N total 34%) was used three times in the springtime: 70 kg N ha^{-1} at the tillering stage, 40 kg N ha^{-1} at the shooting stage, and 20 kg N ha^{-1} at the beginning of ear formation stage. The sowing density of wheat was 380 seeds per m^2, and sowing was carried out in the last week of September. The wheat harvest was carried out in the first week of August.

Weeds were eradicated on the plots only mechanically by double harrowing performed in the springtime during the wheat propagation phase. Alert 375 S.C. (flusilazole + carbendazim) and Tilt Turbo 575 EC (propiconazole + fenpropidin) were used to protect plants against fungal diseases.

Soil and weather conditions

According to the IUSS Working Group WRB (2022), the soil the experiment was established on is classified as a Rendzic Phaeozem. It contains 52% sand and 48% clay and dust, has a slightly alkaline pH, a high content of available forms of phosphorus and potassium and an average content magnesium (Table 1).

Table 1

Physicochemical properties of soil (from control plots, 0-35 cm)

Traits	Value
Clay (<0.002 mm)	22%
Dust (0.002-0.05 mm)	26%
Sand (0.05-2.0 mm)	52%
Total N (g kg^{-1})	0.90
P (mg kg^{-1})	131
K (mg kg^{-1})	169
Mg (mg kg^{-1})	89
pH_{KCL}	7.2

Over the experimental period, the annual sum of precipitation ranged from 515 to 661 mm, with 288 mm to 358 mm of precipitation recorded in the spring and summer months (March-August) and with 197 mm to 303 mm recorded in the autumn and winter months (September-February) – Figure 1. The average air temperature in the spring and summer months is 15.3°C, while in the autumn and winter months it is 1.6°C (Figure 2). The growing season with the average daily air temperature exceeding +5°C spans 210-215 days and begins at the turn of March and April.

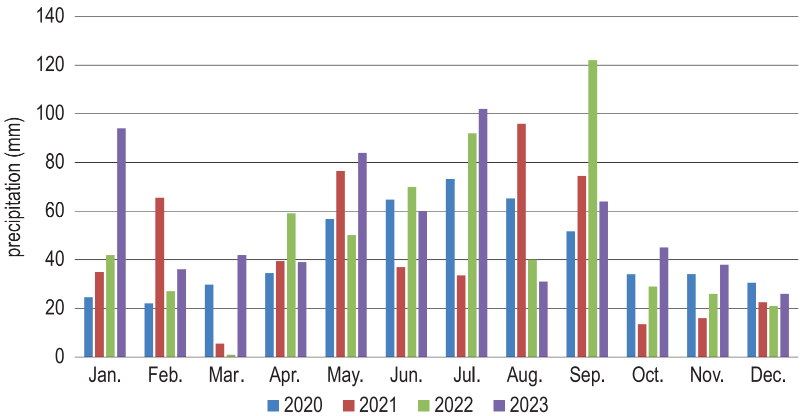

Fig. 1. Monthly sums of precipitation at the Uhrusk Experimental Station

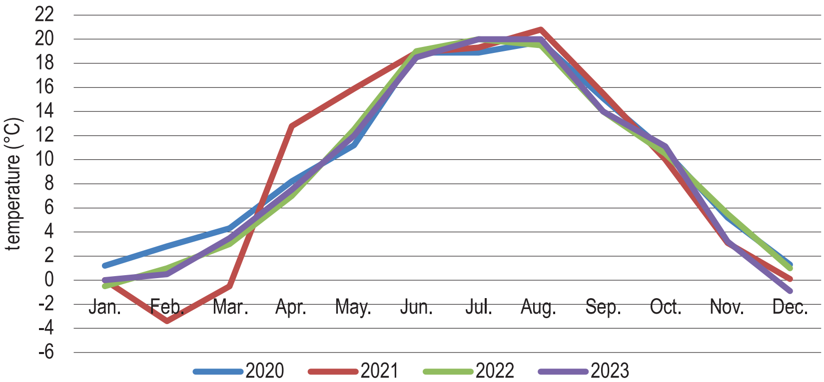

Fig. 2. Average air temperatures at the Uhrusk Experimental Station

Production traits and statistical analysis

The experiment aimed to assess: (1) the yield of winter durum wheat grain and its components, (2) the grain quality parameters, (3) the weed structure in the canopy, and (4) the C/N ratio in the soil. The wheat grain was harvested with a Wintersteiger field combine; the grain yield was determined at 13% moisture content of the grain; the number of plants after emergence (in the phase of 2-3 leaves) and the number of spikes were calculated over an area of one m^2; the grain weight per spike was determined on the basis of 40 randomly collected spikes, whereas the 1000 grain weight was assessed by counting and weighing 2×500 grains.

Total protein content, wet gluten content, Zeleny's sedimentation index, and starch content of the grain were determined by means of the Near Infrared Reflectance Spectroscopy (NIRS) using an OmegAnalyzer Grain device (Bruins Instruments). Grain density was measured using a 1-L cereal densitometer, whereas grain uniformity was determined using a sorter with a mesh size of 2.5 mm × 25 mm.

Canopy infestation by weeds was assessed at the waxy maturity stage of winter durum wheat. This evaluation consisted in determining: the number of weeds from an area of one m^2, species composition of weeds, air-dry weight of weeds, and horizontal (level) distribution of weeds in the canopy. Weeds collected from the surface area of one m^2 had their root system removed and then were placed in an airy room on openwork racks until their constant weight was obtained. The assessment of the horizontal (level) 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 – composed of weeds reaching half the wheat height; and 4) the ground level – populated by creeping weeds reaching a few centimeters in height.

After winter durum wheat was harvested, the total N content of the soil was determined with the Kjeldahl method and organic C content – with the Tuirin method. The C/N ratio in the soil was determined as well.

Statistical analysis

The results were developed statistically using the analysis of variance (ANOVA), whereas the significance of differences between mean values for the tillage systems (TS) was evaluated with the Tukey's HSD test, $P<0.05$. For all characteristics, the coefficients of variation (CV%) were calculated according to the formula: $CV = \frac{std}{x} 100\%$, where *std* is the standard deviation, and x – the arithmetic mean.

RESULTS

Grain yield and its components

Tillage systems significantly differentiated the grain yield of winter durum wheat (Table 2), which was higher on the CT plots than on the RT

Table 2

Grain yield of winter durum wheat and its components (mean from 2020-2023)

Specification	Tillage system (TS)			Value	
	CT	RT	NT	*F*	*p*
Grain yield in (t ha^{-1})	6.77^{a}	4.91^{b}	4.95^{b}	52.04	**
Plant number after emergence (per m^{2})	332.0^{a}	312.7^{ab}	299.3^{b}	13.90	*
Spike number (per m^{2})	495.1^{a}	400.0^{b}	403.7^{b}	29.13	*
Grain weight per spike (g)	1.58^{a}	1.18^{b}	1.23^{b}	177.3	**
1000 grain weight (g)	46.7^{a}	41.5^{b}	41.1^{b}	32.35	**

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences, * $p<0.05$, ** $p<0.01$

and NT plots by 37.9% and 36.8%, respectively. The tillage systems also influenced the number of plants after emergence (at the stage of 2-3 leaves). A 10.9% higher plant density was determined on CT than NT plots. Also, more spikes per m^{2} were found on the CT than on the RT and NT plots (23.8% and 22.6%, respectively). Similarly, the grain weight per spike and the 1000 grain weight were higher on CT than RT and NT plots.

The tillage systems influenced the variability of grain yield and its components (Table 3). Higher yield variability (CV%) was found in the RT and NT systems than in the CT one. Also, greater variation in plant density after emergence and spike number per m^{2}, as well as grain weight per spike and 1000 grain weight were determined in the RT and NT systems compared to the CT system.

Table 3

Coefficients of variation (CV%) computed for the yield of winter durum wheat and its components (mean from 2020-2023)

Traits	Tillage system		
	CT	RT	NT
Grain yield	6.4^{b}	15.3^{a}	12.9^{a}
Plant number after emergence (per m^2)	8.8^{b}	13.9^{a}	13.8^{a}
Spike number (per m^2)	6.8^{b}	14.0^{a}	13.2^{a}
Grain weight per spike	5.9^{c}	11.2^{b}	17.6^{a}
1000 grain weight	10.6^{b}	14.0^{a}	16.5^{a}

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences

Grain quality parameters

Significantly higher contents of total protein, wet gluten and starch were determined in wheat grain harvested from the CT plots compared to that from the RT and NT plots (Table 4).

Table 4

Quality parameters of winter durum wheat grain (mean from 2020-2023)

Specification	Tillage system (TS)			Value	
	CT	RT	NT	*F*	*p*
Total protein content (%)	16.1^{a}	13.2^{b}	13.2^{b}	10.47	*
Wet gluten content (%)	33.1^{a}	28.7^{b}	29.3^{b}	12.96	*
Zeleny's sedimentation index mL	49.6^{a}	50.8^{a}	50.2^{a}	1.93	ns
Starch content (%)	59.3^{a}	50.6^{b}	50.9^{b}	10.69	*
Grain density (kg hL^{-1})	73.6^{a}	70.8^{b}	70.4^{b}	24.40	**
Grain uniformity (%)	89.3^{a}	79.3^{b}	75.0^{b}	38.39	**

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences, * $p<0.05$, ** $p<0.01$, ns – not significant

Similarly, grain density and grain uniformity were higher in the CT than in the RT and NT systems. The coefficients of variation (CV%) computed for the grain quality parameters, i.e., protein, gluten and starch contents as well as grain density and grain uniformity, were higher for the crops from the RT and NT than from the CT system (Table 5).

Weed infestation indices

The tillage systems significantly differentiated the number of weeds per m^2 (Table 6). The number of weeds was 76.3% and 61.7% higher on RT and NT

Table 5

Coefficients of variation (CV%) for grain quality of winter durum wheat crop (mean from 2020-2023)

Traits	Tillage system		
	CT	RT	NT
Total protein content	8.7^{b}	13.3^{a}	15.2^{a}
Wet gluten content	6.8^{c}	12.4^{b}	17.4^{a}
Zeleny's sedimentation index	12.0^{a}	14.1^{a}	15.7^{a}
Starch content	6.5^{b}	15.2^{a}	15.6^{a}
Grain density	8.3^{b}	19.7^{a}	18.1^{a}
Grain uniformity	6.1^{b}	17.7^{a}	18.3^{a}

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences

Table 6

Number and air-dry weight of weeds in winter durum wheat crop (mean from 2020-2023)

Specification	Tillage system (TS)			Value	
	CT	RT	NT	*F*	*p*
Number of weeds (per m^2)	38.9^{b}	68.6^{a}	62.9^{a}	69.07	**
Air-dry weight of weeds (g m^{-2})	31.6^{b}	55.6^{a}	60.0^{a}	18.78	*

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences, * p<0.05, ** p<0.01

plots, respectively, than on the CT plots. A similar observation was made for the air-dry weight of weeds, which was 75.9% and 89.9% higher in the RT and NT systems than in the CT system. The number of weeds per m^2 and the air-dry weight produced by them on RT and NT plots were characterized by greater variability compared to the respective parameters assessed on the CT plots (Table 7).

Table 7

Coefficients of variation (CV%) for the number and air-dry weight of weeds in winter durum wheat (mean from 2020-2023)

Traits	Tillage system		
	CT	RT	NT
Number of weeds (per m^2)	17.5^{b}	26.3^{a}	31.5^{a}
Air-dry weight of weeds (g m^{-2})	23.9^{b}	31.7^{a}	36.6^{a}

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences

The tillage systems also influenced the number and composition of weed species. Among them, the most abundant were segetal short-lived spring and winter weeds. Eleven weed species were identified on CT plots and the most numerous of them were: *Fallopia convolvulus, Stellaria media, Lamium purpureum*, and *Galium aparine* (Table 8). On RT plots, 13 weed species were found, including 3 perennial ones. Of the short-lived weeds, the most abundant were *Apera spica-venti* and *Avena fatua,* which accounted for 43.3% of the weed community. Wheat crops on these plots were also heavily infested by *Matricaria perforata, Papaver rhoeas*, and *Viola arvensis*. The perennial weeds identified included: *Sonchus arvensis, Elymus repens,* and *Cirsium arvense*. In turn, 10 short-lived and 1 perennial weed species were identified on the NT plots. Also in this farming system, grassy weeds (*A. spica-venti* and *A. fatua*) prevailed quantitatively, accounting for 44.8% of the total weed number. *G. aparine, P. rhoeas* and *Consolida regalis* were also abundant.

The tillage systems were also observed to affect the horizontal (level) distribution of weeds in the wheat canopy (Figure 3). In the RT and NT sys-

Table 8

Species composition of weeds in a canopy of winter durum wheat (mean from 2020-2023)

Species composition	Tillage systems		
	CT	RT	NT
Short-lived weeds			
Apera spica-venti (L.) P. Beauv.	–	20.5	23.4
Avena fatua L.	4.0	9.2	4.8
Capsella bursa-pastoris (L.) Medik.	0.8	0.5	–
Consolida regalis Gray	–	2.2	4.5
Fallopia convolvulus (L.) A. Löve	6.8	–	1.2
Galeopsis tetrahit L.	0.8	4.5	2.3
Galium aparine L.	4.8	4.0	5.5
Lamium amplexicaule L.	3.0	–	–
Lamium purpureum L.	5.2	–	–
Matricaria perforata Mérat	3.8	7.0	4.2
Papaver rhoeas L.	–	5.4	5.5
Polygonum lapathifolium L.	2.5	–	–
Stellaria media (L.) Vill.	6.4	2.2	3.2
Viola arvensis Murray	0.8	5.0	3.5
Perennial weeds			
Cirsium arvense (L.) Scop.	–	1.8	–
Elymus repens (L.) Gould	–	2.8	–
Sonchus arvensis L.	–	3.5	4.8
Number of weeds per m^2	38.9	68.6	62.9
Number of species	11	13	11

CT – conventional tillage, RT – reduced tillage, NT – no-tillage

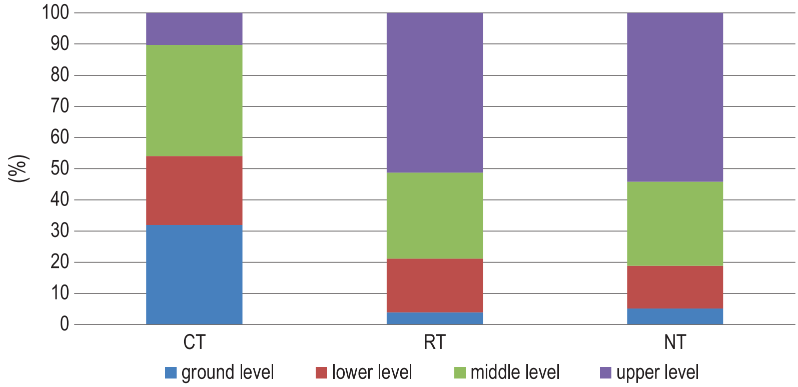

Fig. 3. Percentage contribution of weeds in particular levels of winter durum wheat (mean from 2020-2023)

tems, the most numerous were the weeds of the upper floor, which accounted for 51.3-54.2% of the total weed number. In turn, the weeds of the ground level (31.9%) and the middle level (35.5%) prevailed in the CT system.

C/N ratio in the soil

Tillage systems significantly differentiated the C/N ratio in the soil (Table 9). The highest C/N ratio was determined in the soil from the CT plots, lower in that from the RT plots, and the lowest in the soil from the NT system. Also, the coefficients of variation determined for soil C/N were higher in the CT than in the RT and NT systems.

Table 9

C/N ratio in the soil and coefficients of variation (CV%) mean from 2020-2023

Specification	Tillage system (TS)			Value	
	CT	RT	NT	*F*	*p*
C/N ratio	20.7[a]	18.3[b]	15.4[c]	353.35	**
CV%	17.5[a]	6.9[b]	7.1[b]	–	–

CT – conventional tillage, RT – reduced tillage, NT – no-tillage. Different letters indicate significant differences, ** $p<0.01$

DISCUSSION

Opinions on the impact of tillage systems on cereal grain yields are ambiguous and depend on the research agroecological conditions. As reported by Morris et al. (2010), the grain yield of crops is influenced by many interacting factors, the effects of which are sometimes difficult to predict. In general, however, a slightly lower grain yield is obtained in the no-till systems compared to the conventional cultivation. Also in our experiment, the grain yield of winter durum wheat was higher in the CT than in the RT and NT systems, with the difference exceeding 37%. According to López--Bellido et al. (1998), in areas with low rainfall and high air temperatures, durum wheat yields are higher under the no-tillage system, whereas De Vita et al. (2007) report that higher yields can be achieved with the conventional system in areas with greater total precipitation. These observations were also confirmed in our study, where annual precipitation averages 570 mm, with a significant predominance of rainfall during the plant growing season. Weather variability in this region, particularly shortages of rainfall in spring and during critical growth stages, can significantly affect wheat productivity. Such adverse conditions represent key limiting factors, directly influencing both the stability and predictability of yields, as well as grain quality. In the study by Woźniak and Rachoń (2020), the quality of durum wheat grain was affected to a greater extent by weather conditions than by tillage systems. The weather-related factors differentiated the grain volume, the protein and gluten contents of the grain, and the sedimentation index. On the other hand, wheat cultivation in the no-till system increased the ash content of the grain and deteriorated grain uniformity. Also in the present study, winter durum wheat grain from the conventional tillage (CT) system contained more protein, gluten and starch, and was denser and more uniform than that collected from both no-till systems (RT and NT).

Tillage systems had also a strong impact on crop canopy infestation by weeds (Tuesca et al. 2001, Lahmar 2010). In the present study, significantly more weeds were found on the RT than on the NT and CT plots. These weeds also produced a much higher biomass than those identified on plots cultivated in the conventional system. On the RT and NT plots, the main contributors to the weed community were the weeds of the upper level – *A. spica-venti* and *A. fatua*, whereas on the CT plots – mainly weeds of the ground and middle levels. According to Cardina et al. (2002), Chauhan et al. (2006), and Davis et al. (2005), the no-till system causes an increase in the proportion of weeds ripening on the stubble fields, which shed their seeds and thereby increase the seed bank in the soil. Short-lived weeds prevailed in the present research, while perennial species occurred only on the RT plots. It can be speculated that the absence of perennial weeds on CT plots is due to the mechanical cultivation of the soil, and on NT plots – to the glyphosate treatment used for weed control. According to Johal and Huber (2009), the absence or a small proportion of perennial weeds in the weed community is due to glyphosate commonly used after harvest, especially in the no-till system (NT).

Tillage systems affect many chemical characteristics of the soil. Roldán et al. (2005) and Wang et al. (2019) state that the no-till cultivation reduces N and organic C losses in the soil compared to conventional tillage, thereby narrowing the C/N ratio values and increasing nitrogen availability to plants. This was also confirmed in the conducted study, in which the C/N ratio was most preferable in the soil from the NT plots, compared to that from the RT and CT plots.

CONCLUSIONS

Winter durum wheat produced a higher grain yield in conventional tillage (CT) than in the reduced tillage (RT) and no-tillage (NT) systems. Also, more spikes per m^2 were found on the CT than on the RT and NT plots. Similarly, the grain weight per spike and the 1000 grain weight were higher on the CT plots compared to the RT and NT plots. Higher contents of total protein, wet gluten and starch were determined in wheat grains harvested from the CT plots than from the RT and NT plots. Also, grain density and grain uniformity reached higher values in CT than in RT and NT systems. The tillage systems significantly differentiated the number of weeds per m^2. Weed density per m^2 and their air-dry weight were higher on the RT and NT plots than on the CT plots. The RT and NT plots were dominated by weeds of the upper level, whereas the CT canopy was most heavily infested by weeds of the upper and middle levels. The most favorable C/N ratio occurred on the NT plots, and the least beneficial one on the CT plots.

Author contributions

The concept of the study and field research, data analyses and writing the manuscript: AW.

Conflicts of interest

The author has declared that no competing interests exist.

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