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EFFECT OF TILLAGE SYSTEM AND PREVIOUS CROP ON GRAIN YIELD, GRAIN QUALITY AND WEED INFESTATION OF DURUM WHEAT

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ABSTRACT

The aim of this research was to evaluate the effect of tillage systems and previous crops on yield, grain quality and weed infestation of durum wheat (*Triticum durum* Desf.) cultivar 'Duroflavus'. The first experimental factor (main plots) was tillage system: 1) conventional tillage (CT) – shallow ploughing and harrowing after the harvest of previous crop; 2) reduced tillage (RT) – only a cultivator after the harvest of previous crop; and 3) herbicide tillage (HT) – only Roundup 360 SL herbicide after the harvest of previous crop. The secondary experimental factor was the previous crop of durum wheat: 1) oats (*Avena sativa* L.); 2) durum wheat (*Triticum durum* Desf.); and 3) pea (*Pisum sativum* L.). Higher grain yields of wheat were determined in the CT than in the RT and HT systems, both after pea and after oats or wheat. The analysis of variance components indicated that the grain yield was influenced to a greater extent by previous crops than by tillage systems. Grain of high quality (higher contents of protein and gluten, and higher density) originated from CT plots, compared to RT and HT plots. In terms of durum wheat grain quality, the best previous crop turned out to be pea. The CT system increased manganese (Mn) content of grain compared to RT and HT crops and copper (Cu) content compared to HT crop. Grain originating from RT crops contained more potassium and zinc than the grain from CT and HT crops, whereas grain harvested from HT was characterized by higher contents of phosphorus and calcium than the grain from CT and RT crops. On plots cultivated with the RT and HT systems, 3-fold higher weed infestation was observed than in the CT plot. Similar observations were made for weed biomass. The analysis of variance components demonstrated that weed infestation of durum wheat was affected to a greater extent by tillage systems than by previous crops.

Key words: *Triticum durum;* tillage system; previous crop; yield; grain quality; mineral composition; weed density; weed biomass.

INTRODUCTION

The high energy consumption of conventional tillage and its negative impact on the natural environment prompted the search for alternative solutions in tillage systems (Morris et al., 2010). Many studies have shown, however, that one perfect universal tillage system does not exist and that each system should be adjusted to conditions of an individual farm (Gruber et al., 2012). As reported by Morris et al. (2010), in conventional and no-tillage systems the yield of crop is influenced by many overlapping and hardly predictable factors. Yet, generally, the yield of crops from no-tillage system is slightly lower than that of crop from the conventional tillage. The most frequent reason behind yield decrease is increased weed infestation accompanying the no-tillage system (Davis et al., 2005; Peigné, 2007; Woźniak, 2012). Tørresen and Skuterud (2002) stated that the no-tillage system increases reserves of the seedbank in topsoil, and that these germinating seeds increase crop infestation with weeds (Cardina, 2002; Chauhan et al., 2006; Mohler et al., 2006). A solution to this problem are commonly applied herbicides, however their effectiveness depends on the co-action of many factors (Deike et al., 2008). In a study conducted by Gruber et al. (2012), the "no-till" system led to multiply higher weed infestation than tillage made with a mouldboard plough. Woźniak and Haliniarz (2012) demonstrated that weed infestation

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extent was additionally influenced by cereal species. In their study, higher weed density was observed in durum wheat than in common wheat and oats, especially under conditions of the no-tillage system.

The tillage system also affects the chemical composition and quality of wheat grain. Woźniak and Makarski (2012) demonstrated that the no-tillage system increased contents of total ash, zinc and copper, whereas the ploughing system – the contents of potassium, magnesium and manganese in wheat grain. As reported by Paris and Gavazzi (1972), the content of ash is affected by mineral fertilization, chemical protection of plants, and tillage system. Contents of mineral elements in grain were also demonstrated to depend on the type and composition of soil as well as on crop location (Cubadda et al., 1969). According to Morris et al., (2010), ash content of wheat grain is related to a greater extent to the environment than to genotype. As stated by Gomez-Becerra et al. (2010), the variability of mineral composition of wheat grain is also more influenced by the environment. In a study by Woźniak and Gontarz (2011), the quality of wheat grain was little affected by tillage system, but mainly by nitrogen fertilization. Debaeke et al. (1996) demonstrated that reduced tillage of wheat (low fertilization with nitrogen, no herbicides) had a negative impact on protein content and quality of grain.

The aim of this research was to evaluate the effect of tillage systems and previous crops on grain yield, grain quality and wheat infestation of durum wheat cultivar ‘Duroflavus’.

MATERIAL AND METHODS

A field experiment with tillage systems was conducted in the years 2007-2012 at the Experimental Station Uhrusk (51°18'12''N, 23°36'50''E), Poland. In the last years of the study, durum wheat (*Triticum durum* Desf.) of ‘Duroflavus’ cultivar was sown on plots. The experimental factors included tillage systems (main plots): 1) conventional (CT), 2) reduced (RT), and 3) herbicide (HT), as well as previous crops (subplots): 1) oats (*Avena sativa* L.), 2) durum wheat (*Triticum durum* Desf.), and 3) pea (*Pisum sativum* L.). The experiment was established in 3 replications in randomised sub-blocks 8 m x 25 m in size. The conventional tillage (CT) included shallow ploughing and harrowing after the harvest of previous crop and then pre-winter ploughing in the autumn. The reduced tillage (RT) involved only plot cultivation, whereas the herbicide tillage (HT) the use of Roundup 360 SL herbicide (a.s. glyphosate) – at a dose of 4 L ha^{-1}. In the spring, a cultivation set consisting of a cultivator, a string roller and a harrow, was used on all plots. The analyzed wheat cultivar is characterized by good fertility and grain quality, and is classified in the Common Catalogue of Varieties of Agricultural Plant Species (EU 2009).

Soil the experiment was established on is Rendzic Phaeozem (IUSS Working Group WRB, 2006) with a composition of light, poorly sandy clay, rich in available forms of phosphorus and potassium, with a slightly alkaline pH (Table 1).

Table 1. Physicochemical properties of soil (0-35 cm)

Traits	Value
Organic C (g kg^{-1} d.m.)	7.60
Inorganic N (g kg^{-1} d.m.)	1.03
Available P (g kg^{-1} d.m.)	0.21
Available K (g kg^{-1} d.m.)	0.24
Available Mg (g kg^{-1} d.m.)	0.04
PH_{KCl}	7.20
Clay fraction (%)	24.0
Dust fraction (%)	13.1

On the study area, the annual sum of atmospheric precipitation (data of the years 1963-2010) is 577.6 mm, including 351.3 mm in the period since sowing till harvest of cereals (since March till August). The mean annual air temperature reaches 7.5ºC, whereas since March till August it accounts for 13.8ºC. In the year 2011, the sum of precipitation since March till August reached 387.2 mm, and the mean air temperature reached 13.9ºC. In the year 2012 respective values accounted for 254.5 mm and 14.2ºC.

Durum wheat was sown in the first decade of April in the quantity of 450 seeds per m^2. Mineral fertilization was applied as follows: 120 kg N ha^{-1}, 34 kg P ha^{-1} and 83 kg K ha^{-1}. Phosphorus- and potassium-based fertilizers were applied before sowing, whereas nitrogen fertilizers – in the following terms and doses: 1) 50 kg ha^{-1} before sowing, 2) 30 kg ha^{-1} at stage 22/23 in Zadoks scale (Zadoks et al., 1974), 3) 20 kg ha^{-1} (32/33 in Zadoks scale), and 4) 20 kg ha^{-1} (61/62 in Zadoks scale). At the tillering stage (24/25 in Zadoks scale), Chwastox Trio 540 SL herbicide (a.s. mecoprop + MCPA + dicamba) was applied in a dose of 1.5 L ha^{-1}.

The following traits were evaluated: 1) grain yield and its components (number of spikes per m^2, grain weight per spike, 1000 grains weight), 2) grain quality and mineral composition (protein content, wet gluten content, grain vitreosity, grain density, and contents of P, K, Mg, Ca, Fe, Zn, Mn, and Cu), and 3) density and air-dry weight of weeds.

Grain yield was determined at each plot using a Wintersteiger plot harvester. The number of spikes per m^2 was assayed at each plot from an area of 2 x 0.5 m^2 marked by a 1.0 x 0.5 m frame fixed crosswise to rows. The weight of grain from spike was determined based on 40 spikes selected at random from each plot, whereas 1000 grains weight – by weighing 2 x 500 seeds.

Nitrogen content of wheat grain was determined with the Kjeldahl method and expressed per protein (N x 5.70), wet gluten was separated from dough prepared from flour with a 2% aqueous solution of sodium chloride, grain density was assayed using a cereal densitometer in a 1L measuring vessels, whereas grain vitreosity was determined with a farinotom device. Determinations of the content of mineral components in wheat grain were conducted after dry mineralization of the samples at a temperature of 600^{o}C. The resultant ash was dissolved in 5 mL of 6M HCl, and then filled up to the volume of 50 ml with redistilled water. Measurements were carried out with the method of Atomic Absorption Spectrometry with excitation in an acetylene-air flame in a UNICAM 939 apparatus.

Weed density (m^{-2}) and weed biomass (g m^{-2}) were evaluated at stage 75 of cereals growth in the Zadoks scale. Weed density was counted in two randomly selected 0.5 m^2 subplots (1.0 x 0.5 m) in each plot. All weeds were harvested from these areas and their air-dry weight was determined after keeping them in a dry room until they reached moisture content of 15%.

Results were statistically analysed with the analysis of variance (ANOVA), whereas the significance of mean values was evaluated with the Tukey's HSD test, $P<0.05$. Correlations between the investigated traits were evaluated with Pearson's correlation coefficients.

RESULTS

Grain yield and its components

The tillage systems were found to significantly differentiate the yield of wheat grain (Table 2). In the CT system wheat grain yield was higher – from 5.8 to 6.5% – than in the RT and HT systems. Grain yield was also differentiated by the previous crops. The highest yield of wheat was noted after pea, followed by oats and durum wheat. The difference in wheat grain yield between the worst and the best previous crop reached 14.4%. Assessment of variance components indicated that grain yield was affected to a greater extent by previous crops than by tillage systems (Table 3). The tillage systems were also observed to influence the number of spikes per m^2; in the HT system the spike number was significantly lower than in the CT system. Lower number of spikes per m^2 occurred also in the plot with durum wheat used as the previous crop, compared to the plots with oats and pea. The weight of grain per spike was differentiated only by previous crops. Significantly higher grain weight was noted on the plot after pea than on plots after oats and wheat. In contrast, the 1000 grains weight depended on both the tillage system and the previous crop. On CT plots, the 1.000 grains weight was significantly higher than on RT and HT plots. Higher 1000 grains weight was also noted after pea and oats than after wheat. Variance analysis components indicate that the 1000 grains weight was differentiated to a greater extent by the previous crops than by the tillage systems.

Table 2. Grain yield and biometric traits of durum wheat

Previous crop (PC)	Tillage systems (TS)			Mean
	^{z}CT	RT	HT	
Yield (t ha^{-1})				
Oats	5.91	5.23	5.37	5.51
Durum wheat	4.94	5.05	4.97	4.98
Pea	6.16	5.75	5.55	5.82
Mean	5.67	5.34	5.30	-
$HSD_{0.05}$ for TS = 0.24, PC = 0.24, TS x PC = ns				
Spike number (m^{-2})				
Oats	434	412	395	413
Durum wheat	397	390	381	389
Pea	433	410	408	417
Mean	421	404	394	-
$HSD_{0.05}$ for TS = 19.1, PC = 19.1, TS x PC = ns				
Grain weight per spike (g)				
Oats	1.37	1.28	1.36	1.34
Durum wheat	1.25	1.30	1.31	1.28
Pea	1.43	1.40	1.36	1.40
Mean	1.35	1.33	1.34	-
$HSD_{0.05}$ for TS = ns, PC = 0.08, TS x PC = ns				
1000 grains weight (g)				
Oats	50.5	49.0	49.8	49.7
Durum wheat	47.7	46.4	45.7	46.6
Pea	51.4	49.9	49.2	50.2
Mean	49.9	48.4	48.2	-
$HSD_{0.05}$ for TS = 1.12, PC = 1.12, TS x PC = ns				

^{z}CT = conventional tillage; RT = reduced tillage; HT = herbicide tillage; ns: not significant; P<0.05.

Table 3. Analysis of variance for grain yield and its components, P<0.05

Effects	DF	Yield	Spike number	Grain weight per spike	1000 grains weight
		F-Value	*F*-Value	*F*-Value	*F*-Value
*TS	2	8.49	5.99	0.21	7.78
PC	2	37.03	7.28	5.46	36.44
TS x PC	4	3.60	0.47	1.62	0.79

*TS = tillage systems; PC = previous crop.

Grain yield was significantly correlated with grain weight per spike, spike number per m^2 and 1000 grains weight (Table 4).

Table 4. Coefficients of Pearson correlation between grain yield and its components

Traits	Yield	Spike number m^{-2}	Grain weight per spike
Spike number m^{-2}	0.82		
Grain weight per spike	0.90	0.49	
1000 grains weight	0.86	0.85	0.67

Quality and mineral composition of grain

The content of protein in grain was significantly higher in the CT system than in the RT and HT systems (Table 5).

Table 5. Quality parameters of durum wheat grain

Previous crop (PC)	Tillage systems (TS)			Mean
	^{z}CT	RT	HT	
Total protein (%)				
Oats	14.7	12.7	13.7	13.7
Durum wheat	14.2	12.8	13.4	13.5
Pea	14.7	13.8	14.0	14.2
Mean	14.6	13.1	13.7	-
$HSD_{0.05}$ for TS = 0.27, PC = 0.27, TS x PC = 0.62				
Wet gluten (%)				
Oats	30.0	24.5	26.0	26.8
Durum wheat	29.0	24.0	26.1	26.4
Pea	32.7	29.3	28.7	30.2
Mean	30.6	25.9	26.9	-
$HSD_{0.05}$ for TS = 1.43, PC = 1.43, TS x PC = 3.31				
Grain vitreosity (%)				
Oats	82.0	85.0	72.7	79.9
Durum wheat	81.0	80.7	72.3	78.0
Pea	84.3	83.3	76.3	81.3
Mean	82.4	83.0	73.8	-
$HSD_{0.05}$ for TS = 1.92, PC = 1.92, TS x PC = ns				
Grain density (kg hL^{-1})				
Oats	77.2	76.2	75.6	76.3
Durum wheat	74.0	73.4	73.4	73.6
Pea	77.7	73.7	74.2	75.2
Mean	76.3	74.4	74.4	-
$HSD_{0.05}$ for TS = 1.39, PC = 1.39, TS x PC = ns				
Total ash (%)				
Oats	1.87	2.03	1.93	1.94
Durum wheat	1.89	2.03	1.93	1.95
Pea	1.82	1.96	1.90	1.89
Mean	1.82	2.01	1.93	-
$HSD_{0.05}$ for TS = 0.03, PC = 0.03, TS x PC = 0.07				

^{z}CT = conventional tillage; RT = reduced tillage; HT = herbicide tillage; ns: not significant; P<0.05.

Higher protein content was determined in grain harvested from HT plots, compared to the RT plots and in grain harvested from plots after pea than after oats and wheat. Variance analysis components show that protein content of grain was influenced to a greater extent by tillage systems than by previous crops (Table 6). Likewise, the content of wet gluten was higher in the grain collected from CT plots, compared to the RT and HT plots. Wheat cultivation after pea increased wet gluten content of the grain, compared to the remaining previous crops analysed in the study. Grain vitreosity was similar in the CT and RT crops and significantly higher than in the HT crops. Also on the plot after pea, the grain was characterized by greater vitreosity compared to the plot after wheat. Variance analysis components indicated that the tillage system had a greater influence on grain vitreosity than the previous crops did. The tillage system also affected grain density which was higher in the CT system than in the RT and HT systems. In addition, grain harvested from plots after wheat had higher density compared to that harvested from plots after oats and pea.

The total ash content was the highest in grain from the RT plots, lower in grain from the HT plots and the lowest in that from the CT plots. A higher content of ash was also found in the grain from plots after oats and wheat than in the grain from plots after pea. Analysis of variance components indicated that ash content of grain was differentiated to a greater extent by tillage systems than by previous crops.

Table 6. Analysis of variance for grain quality parameters, P<0.05

Effects	DF	Protein content	Gluten content	Grain vitreosity	Grain density	Ash content
		F-Value	*F*-Value	*F*-Value	*F*-Value	*F*-Value
*TS	2	99.39	37.70	94.18	7.88	67.98
PC	2	23.21	28.22	9.84	12.45	12.39
TS x PC	4	4.39	1.38	2.49	2.16	0.68

*TS = tillage systems; PC = previous crop.

Positive correlations occurred between protein content and gluten content of the grain, between grain vitreosity and density, whereas negative correlations were noted between these parameters and ash content of the grain (Table 7). The mineral composition of grain was influenced by the tillage system (Table 8).

Table 7. Coefficients of Pearson correlation between grain quality parameters

Traits	Total protein	Wet gluten	Grain vitreosity	Grain density
Wet gluten	0.87			
Grain vitreosity	0.84	0.80		
Grain density	0.92	0.96	0.93	
Total ash	-0.86	-0.85	-0.69	-0.83

The CT system significantly increased manganese (Mn) content of the grain, compared to the RT and HT systems, and copper (Cu) content compared to the HT system.

Table 8. Mineral composition of durum wheat grain in different tillage systems

Specification	Tillage systems			$HSD_{0.05}$
	^{z}CT	RT	HT	
P (g kg^{-1})	3.11	3.47	3.68	0.15
K (g kg^{-1})	3.45	4.82	3.83	0.17
Mg (g kg^{-1})	1.04	1.04	1.02	ns
Ca (g kg^{-1})	0.23	0.28	0.38	0.09
Fe (mg kg^{-1})	45.27	44.96	43.50	ns
Zn (mg kg^{-1})	19.49	32.97	24.00	4.21
Mn (mg kg^{-1})	19.90	18.51	18.11	1.01
Cu (mg kg^{-1})	6.47	5.99	5.50	0.90

^{z}CT = conventional tillage; RT = reduced tillage;
HT = herbicide tillage; ns: not significant; P<0.05.

The grain originating from the RT plots contained more potassium (K) and zinc (Zn) than that from the CT and HT plots, whereas the grain harvested from the HT plots contained more phosphorus (P) and calcium (Ca) compared to the grain from the CT and RT plots. Previous crops of durum wheat were also found to influence contents of mineral elements in the grain (Table 9). The grain harvested from the plot after oats contained more calcium (Ca) than the grain harvested after wheat and pea, and more zinc (Zn) than the grain harvested after wheat. In turn, the grain collected from the plots after pea was characterized by higher contents of phosphorus (P) and potassium (K) than the grain after oats and wheat, and by a higher content of copper (Cu) than the grain harvested after oats.

Table 9. Mineral composition of durum wheat grain depending on previous crop

Specification	Previous crop			$HSD_{0.05}$
	Oats	Durum wheat	Pea	
P (g kg^{-1})	3.34	3.36	3.70	0.13
K (g kg^{-1})	2.82	2.81	3.18	0.15
Mg (g kg^{-1})	1.14	1.07	1.17	ns
Ca (g kg^{-1})	0.37	0.28	0.21	0.07
Fe (mg kg^{-1})	36.43	39.96	39.43	ns
Zn (mg kg^{-1})	25.57	19.45	24.47	4.2
Mn (mg kg^{-1})	17.10	19.90	19.40	1.23
Cu (mg kg^{-1})	4.49	5.48	5.99	0.92

^{z}CT = conventional tillage; RT = reduced tillage; HT = herbicide tillage; ns: not significant; P<0.05.

Crop infestation with weeds

The plots cultivated with the RT and HT systems were characterized by 67.7 to 68.6% higher weed infestation than those cultivated with the CT system (Table 10). Higher weed density per m^2 was also determined on the plot where durum wheat was sown after itself than after oats and pea.

The analysis of variance components demonstrated that weed density was affected to a greater extent by the tillage systems (F=136.64) than by the previous crops (F=10.40) – Table 11. Analogous observations were made for weed biomass. A higher biomass – from 67 to 68.4% – was produced by weeds on the RT and HT plots than on the CT plots. The higher weed biomass was also determined on the plots after wheat than on these after pea and oats. The analysis of variance demonstrated that weed biomass was affected to a greater extent by the tillage system than by the previous crop.

Table 10. Number and air-dry weight of weeds

Previous crop (PC)	Tillage systems (TS)			Mean
	^{z}CT	RT	HT	
Number of weeds (m^{-2})				
Oats	17.2	51.9	57.1	42.1
Durum wheat	22.9	73.9	69.7	55.5
Pea	18.7	61.9	55.6	45.4
Mean	19.6	62.5	60.8	-
$HSD_{0.05}$ for TS=5.1, PC=5.1, TS x PC=11.3				
Air-dry weight of weeds (g m^{-2})				
Oats	19.5	75.1	80.5	58.4
Durum wheat	31.2	87.9	79.1	66.1
Pea	16.2	49.2	43.2	36.2
Mean	22.3	70.7	67.6	-
$HSD_{0.05}$ for TS=6.2, PC=6.2, TS x PC=13.1				

^{z}CT = conventional tillage; RT = reduced tillage; HT = herbicide tillage; ns: not significant; P<0.05.

Table 11. Analysis of variance for weed infestation parameters, P<0.05

Effects*	DF	Weed number	Weed biomass
		F-Value	*F*-Value
TS	2	136.64	189.73
PC	2	10.40	62.44
TS x PC	4	3.38	4.12

*TS = tillage systems; PC = previous crop.

DISCUSSION

As stated by Knight (2004), crop yields in the no-till system is only negligibly lower than in the conventional tillage. These observations were also confirmed elsewhere (e.g. López-Bellido et al., 1996; Gruber et al., 2012), and in our study which demonstrated that the yield of durum wheat sown in the RT and HT systems was lower by only a few per cents than in the CT system. According to López-Bellido et al. (1996), the yield of crops in the no-till system decreased along with an increasing sum of precipitation. Also De Vita et al. (2007) reported that in the southern regions of Italy with low rainfalls in the vegetative season, better yield is observed for durum wheat cultivated in the direct drilling system, compared to the conventional tillage. This was also corroborated in studies by Guy and Cox (2002) and by Hemmat and Eskandari (2004). According to Huang et al. (2008), this results from a higher capability of soil to accumulate water and from better effectiveness of its use in the no-till system than in the conventional tillage. Another factor influencing crop yields is the previous crop. It is common knowledge that wheat sown repeatedly after itself produces significantly lower yields than when being sown after leguminous, root and forage plants. This is due to plant infestation by take-all diseases and by increasing weed infestation (Struik and Bonciarelli, 1997). In our study, weed density and biomass were the highest on the plots where wheat was sown after itself, which could have contributed to the reduction in wheat spike number per m^2 and in grain weight per spike, and resultantly to a decreased grain yield.

According to De Vita et al. (2007), the quality of durum wheat grain depends on the tillage system and habitat conditions. The conventional tillage was observed to positively affect grain quality in the regions with higher sums of precipitation, whereas the no-tillage system – in the region with lower precipitation. As reported by De Vita et al. (2007), the no-tillage system had better effects than the conventional tillage in drier regions, owing to lower evaporation of water from soil, and thereby its higher availability for plants. In our experiment that was established in a moderately humid region, grain of the best quality originated from the CT plots especially with pea used as the previous crop. This was also extrapolated to the mineral composition of grain which in these conditions contained more phosphorus, potassium and calcium. López-Bellido et al. (2001) also obtained best-quality grain for breadmaking after leguminous plants.

Many literature references indicate that the no-till system leads to increased weed infestation (Gruber et al., 2012; Woźniak, 2012), and consequently to reduced crop yield (Davis et al., 2005; Peigné, 2007). According to Locke et al. (2002), grassy weeds are the main problem of the no-tillage system, whereas tillage reduced only to the use of a cultivator increases the contribution of annual weeds (Pekrun and Claupein, 2006; Gruber and Claupein, 2009). A research by Buhler et al. (1994) demonstrated that the no-tillage systems increased density and biomass of mainly perennial weeds. In our study, despite running the no-tillage cultivation for a few years, no increase was observed in the contribution of perennial or grassy weeds, except for *Avena fatua*. As a result, weeds emerging after wheat sprouting were successfully eliminated by the herbicide, whereas these appearing in the second half of the vegetative season were no competition to a dense crop of wheat, although as reported by Tørresen and Skuterud (2002), they were increasing reserves of weed seeds in the topsoil.

In summary it may be concluded that durum wheat cultivated in the CT system produced a higher yield than that from the RT and HT systems. Grain of better quality (higher contents of protein and gluten and higher density) also originated from the CT plots. The tillage systems were also observed to differentiate the mineral composition of wheat grain. In addition, higher yields of wheat were noted when wheat was sown after pea than after the remaining previous crops, whereas the harvested grain was characterized by higher contents of protein and gluten and more favourable mineral composition. Despite using the same weed control method in all plots, the density and biomass of weeds in the CT system was significantly lower than in the RT and HT systems.

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