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ORIGINAL PAPER

YIELD AND QUALITY OF DURUM WHEAT GRAIN IN DIFFERENT TILLAGE SYSTEMS

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Abstract

The objective of this study was to analyze the effect of different tillage systems on the yield, quality and mineral composition of grain of durum wheat. Three tillage systems were compared in the experiment: 1) conventional (CT), 2) reduced (RT) and 3) herbicide (HT). In the CT system, shallow ploughing and harrowing were performed after the harvest of the previous crop and late autumn ploughing was carried out before winter. In the RT system, double cultivation was performed instead of ploughing, whereas in the HT system the cultivation treatments were replaced by a herbicide containing a.s. glyphosate. In the springtime, a tillage set consisting of a cultivator, string roller and harrow was applied on all plots. Yields of wheat were higher in the years with high precipitation (years 2013-2014) than in the year with low precipitation (2015), as well as in the HT system than in the CT and RT systems. The content of total protein and wet gluten, as well as grain volume weight and grain uniformity were affected more by the study years than by the tillage systems. High sums of precipitation facilitated the accumulation of phytate-P and copper (Cu) in the grain, whereas the precipitation deficit increased the content of potassium (K) and magnesium (Mg) in grain. The CT system contributed to the accumulation of phytate-P and iron, the RT system favoured the accumulation of calcium and manganese, whereas the HT system stimulated the accumulation of phosphorus, potassium, magnesium and copper in durum wheat grain.

Keywords: *Triticum durum*, soil tillage, grain yield, grain quality.

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INTRODUCTION

Non-traditional solutions in crop cultivation are being search for in the pursuit of plant production optimization (Morris et al. 2010, Lahmar 2010). However, as demonstrated by Gruber et al. (2012), not all solutions prove to be adequate because their effectiveness depends on farm-specific conditions. According to López-Bellido et al. (1996) and to De Vita et al. (2007), in areas with low sums of precipitation higher yields of cereals are reported in the no-tillage than in the conventional tillage system. This implication is confirmed by Lahamr (2010), who repported that in arid years crops of cereals were higher by 10-15% in the no-tillage than in the conventional tillage system. In turn, as demonstrated by Woźniak et al. (2014) and by Zikeli et al. (2013), higher yields of durum wheat were determined in the conventional than in the reduced tillage system in years with high precipitation. The tillage system also affects the quality and chemical composition of grain (Kraska 2011, Woźniak, Makarski 2013, Rachoń et al. 2015). Woźniak et al. (2014) obtained grain of better quality, i.e. with a higher content of protein and gluten and with higher grain volume weight, in the conventional than in the reduced tillage. In a study by Woźniak and Makarski (2013), grain from the conventional tillage was characterized by a higher content of potassium, magnesium and manganese, whereas that from the reduced tillage contained higher levels of zinc and copper. As reported by Gomez-Becerra et al. (2010), the quality and chemical composition of grain are significantly determined by habitat conditions.

This study was aimed at evaluating the effect of conventional, reduced and no-tillage systems on the yield, quality and chemical composition of durum wheat grain.

MATERIAL AND METHODS

A controlled field experiment was conducted in 2013-2015, at the Experimental Station Uhrusk (51°18′10″ N, 23°36′44″ E), owned by the University of Life Sciences in Lublin. It was aimed at evaluating the yielding and quality of grain of durum wheat (*Triticum durum* Desf.) of the cultivar Duromax (European Union 2012), sown in three tillage systems: 1) conventional (CT), 2) reduced (RT), and 3) herbicide (HT). The experiment was established in three replications in a system of randomized blocks, 6 m x 75 m in size, which were divided in 3 sub-blocks. In the CT system, shallow ploughing (at a depth of 10-12 cm) and harrowing were performed after the harvest of the previous crop and late autumn ploughing was carried out before winter (25-30 cm). In the RT system, double cultivation was performed instead of ploughing (10-15 cm), whereas in the HT system the cultivation treatments were replaced by a herbicide containing a.s. glyphosate (Roundup 360 SL) and applied in a dose of 4 L ha^{-1}. In the springtime, a tillage set consisting of a cultivator, string roller and harrow was applied on all plots (10-12 cm). The soil under experimental plots was Rendzic Phaeozem (IUSS Working Group WRB 2015). The content of clay and silt fractions as well as the concentrations of available forms of nutrients in the soil are presented in Table 1.

Table 1

Physicochemical properties of soil (0-35 cm)

Characteristic	Value
Organic C (g kg^{-1} d.m.)	6.40
Total N (g kg^{-1} d.m.)	1.00
N-NO_3 (mg kg^{-1} d.m.)	31.0
N-NH_4 (mg kg^{-1} d.m.)	1.19
P (mg kg^{-1} d.m.)	130
K (mg kg^{-1} d.m.)	318
Mg (mg kg^{-1} d.m.)	71.0
pH_{KCl}	7.20
Clay fraction (%)	24.3
Silt fraction (%)	13.2

Each year, durum wheat was sown in the first ten days of April, in an amount of 500 seeds m^{-2}. Fertilization with phosphorus (35 kg ha^{-1} P) and potassium (84 kg ha^{-1} K) was applied in the spring before sowing. Fertilization with nitrogen (120 kg ha^{-1} N) was performed on four dates: before sowing 50 kg ha^{-1}, at the stage of wheat tillering 30 kg ha^{-1} (23/24 in Zadoks scale) (Zadoks et al. 1974), at the shooting stage 20 kg ha^{-1} (33/34 stage) and at the stage of ear formation 20 kg ha^{-1} (53/54 stage). Crops were protected against fungal diseases with the following fungicides: flusilazole + carbendazim (Alert 375 SC) 1.0 L ha^{-1} (32/33 stage) and propiconazol + fenpropidin (Tilt Plus 400 EC) 1.0 L ha^{-1} (53/54 stage). In turn, herbicide containing mecoprop + MCPA + dicamba (Chwastox Trio 540 SL) - 1.5 L ha^{-1} (23/24 stage) was applied for weed control.

The following parameters were determined regarding 1) the crop yield: grain yield (t ha^{-1}), number of plants after emergence m^{-2} (12/13 on the Zadoks scale), number of spikes m^{-2}, 1000 grain weight (g); 2) regarding the grain quality: content of total protein (%), content of wet gluten (%), grain volume weight (kg hL^{-1}), grain uniformity (%), content of carotenoids; and 3) mineral composition of grain: content of total phosphorus (P), phytate phosphorus (phytate-P), potassium (K), magnesium (Mg), calcium (Ca), zinc (Zn), manganese (Mn), iron (Fe), and copper (Cu). Wheat was harvested with a Wintersteiger plot harvester, at the stage of full grain maturity. The number of plants after sprouting and the number of spikes were determined twice on each plot from an area of m^{-2}. The 1000 grain weight was determined by counting and weighing 2 × 500 grains. The content of total protein and wet gluten was assayed with the near infrared reflectance spectroscopy (NIRS) method using an Inframatic 9200 apparatus. Bulk grain volume weight was determined using a densimeter with the volume of 1 L, whereas grain uniformity was evaluated on a trieur with the mesh size of 2.5 mm x 25 mm. Total carotenoids were determined with the spectrophotometric method at a wavelength of λ = 450 nm, against pure petroleum benzine (PN-EN 12136: 2000). The content of minerals in wheat grain was determined after wet-mineralization of the samples at 600°C. The resultant ash was dissolved in 5 mL 6M HCL, and then replenished with redistilled water to 50 mL. Measurements were carried out with the Atomic Absorption Spectrometry method (AAS) excited in an acetylene-air flame in a Unicam 939 apparatus (Woźniak and Makarski 2013). Determinations were conducted in 3 replications for each plot.

The course of weather conditions at the Experimental Station Uhrusk is presented in Table 2. In the period from sowing to harvest of durum wheat

Table 2

Weather conditions at the Uhrusk Experimental Station

Years	Months						Total or mean
	March	April	May	June	July	August	
Precipitation (mm)							
2013	48	55	114	143	82	14	456
2014	30	44	152	88	36	85	435
2015	39	34	62	16	45	7	203
1963-2010	29	41	64	73	80	65	352
Air temperature (°C)							
2013	-2.7	8.1	15.7	18.3	19.2	19.3	13.0
2014	6.1	9.3	13.9	15.8	20.8	18.8	14.1
2015	4.7	7.7	13.1	17.1	21.7	22.2	14.4
1963-2010	1.2	7.8	13.6	16.7	18.4	17.6	12.6

(from March to August), the distribution and sums of precipitation were significantly diversified. The highest sums of precipitation and the lowest average air temperatures were noted in the plant growth season of 2013, whereas the lowest precipitation but the highest air temperatures were recorded in 2015. Generally, the precipitation and thermal conditions observed in the study years differed significantly from the conditions occurring in the longitudinal period of 1963-2010.

The results were developed statistically using the analysis of variance (ANOVA), whereas the least significant difference (*LSD*) was evaluated with the *F*-test for $P < 0.05$.

RESULTS

Grain yield and its components

Higher yields of wheat grain were observed in the years with high precipitation (2013 and 2014), whereas significantly lower ones (by over 15%) in the year with low precipitation (2015), cf. Table 3. Also higher wheat yields were determined in the HT than in the CT and RT systems (respectively by 15% and 23%). The evaluation of the analysis of variance components indicates that grain yield was determined more by a tillage system than by the year of study (Table 4). The years and tillage systems did not differentiate

Table 3

Grain yield of durum wheat and its components

Years (Y)	Tillage system (TS)			Mean
	CT*	RT**	HT***	
Grain yield (t ha^{-1})				
2013	2.66	2.43	3.13	2.74
2014	2.68	2.45	3.15	2.76
2015	2.25	2.06	2.65	2.32
Mean	2.53	2.31	2.98	-
$LSD_{0.05}$ for Y = 0.14; TS = 0.14; Y x TS = ns				
Number of plants per m^2 (12/13 in Zadoks scale)				
2013	365	316	360	347
2014	388	316	393	366
than HT2015	340	409	346	365
Mean	364	347	366	-
$LSD_{0.05}$ for Y = ns; TS = ns; Y x TS = ns				
Spike number m^{-2} (90/91 in Zadoks scale)				
2013	446	386	444	425
2014	473	388	479	447
2015	484	446	446	458
Mean	467	406	456	-
$LSD_{0.05}$ for Y = ns; TS = 48; Y x TS = ns				
1000 grain weight (g)				
2013	41.0	40.9	44.3	42.1
2014	44.0	42.2	43.0	43.3
2015	40.8	39.0	40.1	40.0
Mean	41.9	40.9	42.5	-
$LSD_{0.05}$ for Y = 1.5; TS = 1.5; Y x TS = ns				

* CT – conventional tillage; ** RT – reduced tillage; *** HT – herbicide tillage; ns – not significant, $P < 0.05$.

Table 4

Analysis of variance of grain yield and its components, $P < 0.05$

Effects	DF***	Grain yield	Number of plants	Spike number	1000 grain weight
		F-value			
Y*	2	41.1	2.9	3.2	39.4
TS**	2	76.9	2.4	10.5	49.8
Y x TS	4	0.2	0.7	1.5	0.07

* Y – years, ** TS – tillage system, *** DF – degrees of freedom.

the number of plants after emergence m^{-2}, but affected the number of spikes m^{-2}, which was higher in the CT and HT systems than in the RT system (respectively by 13% and 11%). In turn, 1000 grain weight was higher in 2013 and 2014 than in 2015 as well as in the HT compared to the RT system. The components of variance analysis indicate that the 1000 grain weight was more affected by the tillage systems than by study years.

Grain quality

The highest content of total protein was found in the grain harvested in 2015 (with the lowest precipitation), whereas a significantly lower one occurred in the grain from 2013 (with the highest precipitation), cf. Table 5. Similar observations were made for the wet gluten content, which was the highest in 2015 and the lowest in 2013. The wet gluten content of grain was also influenced by the tillage systems, i.e. it was significantly higher value in the grain harvested from the CT than from RT plots. Likewise, grain volume weight and grain uniformity were influenced only by the year of study. A significantly lower volume weight and poorer uniformity were found for the grain harvested in 2015 compared to the grain from 2013 and 2014. Components of the analysis of variance demonstrate that grain quality was determined to a greater extent by the course of weather conditions in the study years than by the tillage systems (Table 6). The content of carotenoids in durum wheat grain depended on both years of the study and tillage systems. The highest content of these compounds was assayed in the grain harvested in the warmest and driest year, i.e. 2015, whereas significantly concentrations occurred in the year with heavy precipitation, i.e. 2013. In addition, significantly higher levels of carotenoids were determined in grain from the RT and HT than from the CT plots.

Mineral composition

The content of phosphorus (P) was significantly higher in the grain harvested in 2015 than in the one harvested in 2013, as well as in the grain from the HT than from the RT plots (Table 7). Most of phosphorus occurred in the phytate form. Wheat grain was characterized by the highest content of

Table 5

Quality parameters of durum wheat grain

Years (Y)	Tillage system (TS)			Mean
	CT*	RT	HT	
Total protein (%)				
2013	13.8	13.4	13.5	13.5
2014	14.5	14.1	14.2	14.3
2015	15.2	14.7	14.8	14.9
Mean	14.5	14.0	14.2	-
$LSD_{0.05}$ for Y = 0.8; TS = ns; Y x TS = ns				
Wet gluten (%)				
2013	29.5	27.4	28.1	28.4
2014	30.8	28.7	29.4	29.6
2015	31.6	29.4	30.1	30.3
Mean	30.6	28.5	29.2	-
$LSD_{0.05}$ for Y = 1.6; TS = 1.6; Y x TS = ns				
Grain volume weight (kg hL^{-1})				
2013	83.7	82.3	83.4	83.1
2014	87.6	86.0	87.3	86.9
2015	76.8	75.5	76.5	76.3
Mean	82.7	81.3	82.4	-
$LSD_{0.05}$ for Y = 2.2; TS = ns; Y x TS = ns				
Grain uniformity (%)				
2013	79.3	85.9	82.4	82.5
2014	76.8	83.2	79.8	79.9
2015	72.8	78.8	75.6	75.7
Mean	76.3	82.6	79.3	-
$LSD_{0.05}$ for Y = 3.6; TS = ns; Y x TS = ns				
Carotenoids (mg kg^{-1})				
2013	1.49	1.56	1.79	1.61
2014	1.61	1.74	1.71	1.69
2015	1.59	2.01	1.73	1.78
Mean	1.56	1.77	1.74	-
$LSD_{0.05}$ for Y = 0.10; TS = 0.10; Y x TS = 0.38				

* Key as in Table 3.

phytate-P in 2013, and the the lowest one in 2015. Also, more phytate-P was found in the grain harvested from the CT than from HT plots. The content of potassium was significantly higher in the grain collected 2015 than in 2013 and 2013, as well as in the grain from the HT plots compared to the CT and

Table 6

Analysis of variance for grain quality parameters, $P < 0.05$

Effects	DF	Total protein	Wet gluten	Grain volume weight	Grain uniformity	Carotenoids
		F-value				
Y*	2	14.2	14.9	80.7	8.9	4.0
TS	2	1.8	11.0	1.6	7.6	6.3
Y x TS	4	1.2	0.1	0.1	0.2	3.1

* Key as in Table 4.

RT plots. Also, the magnesium (Mg) content was higher in the grain harvested in 2015 than in the grain from 2013 and 2014, as well as in the grain from the HT and CT systems compared to RT. The content of calcium (Ca) in grain was similar in 2014 and 2015 and significantly lower in 2013. In turn, wheat grown in the CT and HT system contained less calcium than the grain cultivated in the RT system.

The content of microelements: manganese (Mn) and iron (Fe) was determined only by the tillage system, the content of copper (Cu) depended on the study years and tillage systems, whereas that of zinc (Zn) was independent of the experimental factors (Table 8). The content of manganese was significantly higher in the grain from the RT than from the HT system, the content of iron in the grain was higher from CT and HT systems compared to the RT system, whereas the content of copper in the grain was higher from HT than from RT plots. In addition, the lowest content of copper was found in the grain harvested in 2015.

DISCUSSION

Grain of durum wheat is a valuable and essential component of human diet (Cubadda et al. 2009, Ficco et al. 2009, Kumar et al. 2010). However, its quality and nutritive value are determined by the variability of weather factors and the extent of agrotechnical measures applied (Gomez-Becerra et al. 2010, Zaccone et al. 2010, Zina et al. 2010). In our study, we demonstrated that the content of total protein and wet gluten in the grain, grain volume weight, grain uniformity and content of total carotenoids were affected more by the course of the weather than by the tillage systems applied. Similar effects were achieved in a previous study by Woźniak et al. (2014), which additionally demonstrated various responses of durum wheat cultivars to hydro-thermal conditions and tillage. Also, De Vita et al. (2007) demonstrated a correlation between the quality of durum wheat grain and the course of

Table 7

Content of macroelements and phytate-P in durum wheat grain

Years (Y)	Tillage system (TS)			Mean
	CT*	RT	HT	
Phosphorus (g P kg^{-1} dm)				
2013	2.00	1.96	2.04	2.00
2014	2.10	2.01	2.00	2.04
2015	2.00	2.01	2.14	2.05
Mean	2.03	1.99	2.06	-
$LSD_{0.05}$ for Y = 0.04; TS = 0.04; Y x TS = 0.13				
Phytate-P (g kg^{-1} dm)				
2013	1.24	1.04	1.02	1.10
2014	0.97	1.05	1.02	1.02
2015	1.07	1.00	0.81	0.96
Mean	1.09	1.03	0.95	-
$LSD_{0.05}$ for Y = 0.08, TS = 0.08, Y x TS = 0.19				
Potassium (g K kg^{-1} dm)				
2013	4.50	4.73	4.79	4.67
2014	4.63	4.62	4.79	4.68
2015	4.79	4.75	4.90	4.82
Mean	4.64	4.70	4.83	-
$LSD_{0.05}$ for Y = 0.10; TS = 0.10; Y x TS = ns				
Magnesium (g Mg kg^{-1} dm)				
2013	0.91	0.79	1.07	0.92
2014	0.94	0.81	1.05	0.93
2015	1.14	1.01	0.97	1.04
Mean	1.00	0.87	1.03	-
$LSD_{0.05}$ for Y = 0.09, TS = 0.09, Y x TS = ns				
Calcium (g Ca kg^{-1} dm)				
2013	0.39	0.41	0.36	0.39
2014	0.40	0.57	0.45	0.47
2015	0.54	0.51	0.39	0.48
Mean	0.44	0.50	0.40	-
$LSD_{0.05}$ for Y = 0.04, TS = 0.04, CS x TS = 0.09				

* Key as in Table 3.

weather conditions. It has been found that if the sum of precipitation from sowing till harvest is below 300 mm, then the grain of wheat cultivated in the HT system is characterized by a better quality (i.e. a higher content of protein, volume weight and 1000 grain weight) compared to the grain from

Table 8

Content of microelements in durum wheat grain

Years (Y)	Tillage system (TS)			Mean
	CT*	RT	HT	
Zinc (mg Zn kg^{-1} dm)				
2013	22.1	21.7	23.6	22.5
2014	22.8	22.5	24.2	23.2
2015	24.2	21.7	21.5	22.5
Mean	23.0	22.0	23.1	-
$LSD_{0.05}$ for Y = ns; TS = ns; Y x TS = ns				
Manganese (mg Mn kg^{-1} dm)				
2013	19.4	19.9	18.6	19.3
2014	19.3	20.3	17.8	19.1
2015	18.4	20.2	20.1	19.6
Mean	19.0	20.1	18.8	-
$LSD_{0.05}$ for Y = ns; TS = 1.15; Y x TS = ns				
Iron (mg Fe kg^{-1} dm)				
2013	23.6	18.1	18.9	20.2
2014	22.8	18.1	20.3	20.4
2015	18.0	18.7	23.6	20.1
Mean	21.5	18.3	20.9	-
$LSD_{0.05}$ for Y = ns; TS = 2.04; Y x TS = 4.12				
Copper (mg Cu kg^{-1} dm)				
2013	3.44	3.33	2.75	3.17
2014	3.34	3.39	4.20	3.64
2015	2.50	2.30	3.65	2.82
Mean	3.09	3.01	3.53	-
$LSD_{0.05}$ for Y = 0.48; TS = 0.48; Y x TS = 1.14				

* Key as in Table 3.

the CT system. In turn, in an area with higher precipitation, a better grain quality was achieved in the CT than in the HT system. This finding was also confirmed in a study by Woźniak et al. (2014) conducted in a moderately humid area of south-eastern Poland, where grain characterized by the highest content of protein and gluten and by the highest volume weight was obtained in the CT system compared to the RT and HT systems. In addition, it was demonstrated that grain quality parameters were determined to a greater extent by a tillage system than by the previous crops of durum wheat. Also, in a study by López-Bellido et al. (2001) conducted in southern Spain, better quality grain was obtained in the CT than in the HT system, especially when precipitation in May reached 80 mm and the air temperature was at 26-27°C. In our experiment, the tillage system affected only the content of wet gluten in grain, which was higher in the grain from the CT than from the RT system, and the content of carotenoids, which was higher in the grain from the RT and HT than from the CT plots. The tillage system and weather conditions also influence the content of mineral components in the grain. Investigations by Kraska (2011) demonstrated that the content of potassium, manganese and sulfur in spring wheat was higher in the grain from plots cultivated in the ploughing system compared to the conservative tillage system. In turn, the conservative tillage induced an increase in the content of phosphorus and copper in grain compared to the ploughing system. In our study, the CT system facilitated the accumulation of phytate-P and iron in grain, the RT system favoured the accumulation of calcium and manganese, whereas the HT system stimulated the accumulation of phosphorus, potassium, magnesium and copper in grain. High sums of precipitation in the stages of durum wheat growth and development (season 2013 and 2014) facilitated the accumulation of phytate-P and copper in grain of durum wheat, whereas precipitation shortages in 2015 contributed to high concentrations of potassium and magnesium in grain. According to Cubadda et al. (2009), grain of durum wheat is a valuable source of some minerals, especially selenium, copper, magnesium and zinc, which was also demonstrated in our study. Zaccone et al. (2010) emphasize the importance of grain origin, which may be characterized by higher concentrations of nickel, lead and zinc. In turn, Woźniak and Makarski (2013) demonstrated that wheat grain harvested from a crop rotation system contained more phosphorus, calcium, iron and zinc than grain from a monoculture. While evaluating the chemical composition of grain, worthy of attention are phytates as they are the main form of phosphorus accumulating in plant tissues (Kumar et al. 2010). They are synthesized during grain maturation and in this period constitute from 60 to 90% of total phosphorus (Loewus 2002). In our experiment, phytate-P represented 47-55% of the total phosphorus in grain. As reported by Sandberg (2002), phytate-P forms complex bonds with iron and zinc, which may induce deficiencies of these elements in the human diet.

Climatic and soil conditions as well as cropping systems determine yields of durum wheat. As reported by López-Bellido et al. (2001), it may be stated that generally grain yield volume is negatively correlated with its quality. In our study, higher yields of wheat grain were obtained in the years with high precipitation and in the HT system compared to the CT and RT systems. It is worth noticing is that in 2015, a year characterized by the lowest rainfalls (203 mm), wheat grain yield in the HT system was higher by 15.1% than in the CT system and by 22.3% than in the RT system. This supports the findings reported by De Vita et al. (2007) and López-Bellido et al. (1996). In our study, the lowest grain yield was achieved in the RT system, compared to HT and CT system, which was due to a lower spike number m^2 and a lower 1000 grain weight.

CONCLUSIONS

In summary, over 15% higher yields of durum wheat were determined in the years with high precipitation (2013-2014) than in the year 2015 with a low sum of precipitations, as well as in the HT compared to the CT and RT systems. The quality of grain (content of total protein and wet gluten, grain volume weight and grain uniformity) was affected more by the study years than the tillage systems. More protein and gluten was found in the grain harvested in 2015 (with the lowest precipitation) than in the grain from 2013 (with the highest precipitation), whereas higher grain volume weight and grain uniformity were determined in the grain from 2013 than from 2015. High sums of precipitation facilitated the accumulation of phytate-P and copper in grain, whereas precipitation shortages contributed to a greater accumulation of potassium and magnesium in grain. The CT system enhanced the accumulation of phytate-P and iron, the RT system favoured the accumulation of calcium and manganese, whereas the HT system stimulated the accumulation of phosphorus, potassium, magnesium and copper in grain of durum wheat.

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