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YIELD AND QUALITY OF WINTER WHEAT, DEPENDING ON CROP ROTATION AND SOIL TILLAGE

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Abstract
Wheat (*Triticum*) grain is generally used for food due to its grain quality. The two-factorial trial was conducted in the Research and Study farm 'Pēterlauki', Latvia, with an aim of finding out the soil tillage and crop diversification in rotation effect on winter wheat grain yield and quality. Two soil tillage systems (traditional and reduced) and three crop rotation schemes with different winter wheat (*Triticum aestivum*) fore-crops (wheat, oilseed rape (*Brassica napus* ssp. *oleifera)*, faba bean (*Vicia faba*)) were used. The trial started in 2009. For this paper data from 2016/2017 and 2017/2018 growing seasons was used. Yields harvested in 2017 were significantly ($p<0.001$) higher than those in 2018 (on average 7.17 t ha^{-1} in 2017, 6.18 t ha^{-1} in 2018). The highest yield (8.06 t ha^{-1}) was gained in the variant where the fore-crop in 2017 had been faba bean. Crop rotation, including only repeated wheat sowings in both years, showed the lowest yield (on average 5.81 t ha^{-1}). Crop rotation with oilseed rape and wheat showed a significant wheat yield increase in the following two-year period in comparison to to repeated wheat sowings. A year as a factor had a significant ($p<0.05$) impact on crude protein content (%), Zeleny index, volume weight (g L^{-1}) and 1000 grain weight (g). Both, volume weight (g L^{-1}) and 1000 grain weight, were influenced ($p<0.05$) by the crop rotation and fore-crop. Zeleny index depended on all researched factors. Crude protein content was influenced by soil tillage method ($p<0.0016$) and fore-crop ($p=0.0052$). Hagberg falling number was not influenced by any of the investigated factors.
Key words: wheat, yield, grain quality, crop rotation, soil tillage.

Introduction

Wheat (*Triticum*) is an important crop globally due to its baking properties, which is dependent on such quality traits of grain as, for example, crude protein, Zeleny index and Hagberg falling number. Wheat grain yield and quality are strongly related to the growing conditions of crop that are possible to improve agronomically by carrying out an appropriate soil tillage and growing it in a well-planned crop rotation, which, in addition, helps to limit harmful organisms.

In the European Union (EU), a little more than a half of arable land is sown by cereals (wheat, barley (*Hordeum vulgare*), triticale *(×Triticosecale*), oats (*Avena sativa*), and rye (*Secale cereale*)). The highest proportion from all mentioned is taken by wheat – about 30% of the total harvested land. It may make one think that the crop diversificationin the EU is small. Crop diversification in rotations is constantly adapted to economic conditions and dependent on agricultural policy (Babulicová, 2016). Crop rotations with a high proportion of wheat are at risk of reducing yield level (Bonciarelli *et al.*, 2016). Wheat yield increases in cereal-based crop rotations if oilseeds (Sieling *et al.*, 2005) or pulses (Jensen, Peoples, & Hauggaard-Nielsen, 2010; Babulicová, 2016) are included as fore-crops in the rotation. Pulses (soybean (*Glycine max*), pea (*Pisum*), bean (*Vicia faba*), lupine (*Lupinus*), vetch (*Vicia*), lentil (*Lens*)) occupy a small part of the harvested land in the EU – 3.7% in 2017 (FAOSTAT data, 2019 March, available at: http://www.fao.org/faostat/en/#data/QC). It is reported that one of the main reasons why farmers do not want to grow pulses is unstable and more variable yield in comparison to non-legume crops in Europe (Cernay *et al.*, 2015).

Traditional soil tillage helps to limit harmful organisms like wheat leaf diseases (Bankina *et al.*, 2018) and weeds (Ausmane, Melngalvis, & Ruža, 2017), but is more time and energy consuming if compared to minimum soil tillage treatments (Strašil, Vach, & Smutný, 2015). In different studies, contradictory results are reported on advantages of soil tillage method (traditional or reduced) to ensure a higher yield and/or quality of wheat (e.g. Arvidsson, 2010; Cociu & Alionte, 2011; Amato *et al.*, 2013).

When crop diversification in rotation and different soil tillage is used, it is important to know whether they have an impact on grain quality. Important grain quality indicators for food are: crude protein (CP) content (%), Hagberg falling number (s) and Zeleny index. Cabinet of Ministers of the Republic of Latvia Regulations No. 461 (Cabinet of Ministers, 2014) prescribe grain quality requirements for food quality: the lowest value for CP content is 12.5%, for falling number – 220 s, and that for Zeleny index – 30. Significant indicators of yield are: 1000 grain weight (g) (TGW) and volume weight (g L^{-1}), which affect flour outcome in milling process (Liniņa & Ruža, 2015). Volume weight for food quality grain is set by grain purchasers and producers, e.g., stock company 'AS Dobeles Dzirnavnieks' purchases grains for food with the minimum volume weight of 750 g L^{-1}. Crop rotation and fore-crop impact on grain yield and quality indicators had also been studied in Slovakia, and the results showed the fore-crop (two fore-crops were compared - field pea and barley) effect on winter wheat grain and straw yield, TGW and volume weight (Babulicová, 2016).

The aim of this paper was to compare whether different soil tillage treatments and crop diversification in crop rotation have an impact on the winter wheat grain yield and grain quality.

Materials and Methods

Two-factor trial was conducted at the Research and Study farm 'Peterlauki' of Latvia University Life Sciences and Technologies (56° 30.658´ N and 23° 41.580´ E). This research was based on two-year data (2016/2017 and 2017/2018) from the trial started in 2009. The first factor was crop rotation, three variants in total: rotation (1) repeated winter wheat (*Triticum aestivum*) (hereinafter – wheat) sowings (W–W), rotation (2) oilseed rape (*Brassica napus* ssp. *oleifera)*–wheat–wheat (OR–W–W), rotation (3) faba bean–wheat–oilseed rape–spring barley (FB–W–OR–B) (hereinafter – barley). Rotation (2) (OR–W–W) had two plots each year (in 2017, wheat was grown in one plot with fore-crop OR, but in the 2[nd] plot OR was grown. In 2018, both plots were occupied by wheat: with fore-crop OR, and with fore-crop W, and the rotation (3) (FB–W–OR–B) had three variants (every year one of included crops was not grown). Winter wheat fore-crops in 2017 were: wheat (**W–**W, rotation (1)), oilseed rape (**OR**–W–W, rotation (2)) and faba bean (**FB–**W–OR–B, rotation (3)). In 2018, fore-crops were wheat (**W–**W, rotation (1), and OR–**W–**W rotation (2)), and oilseed rape (**OR**–W–W, rotation (2)). In rotation (3), wheat was not grown in 2018. The second factor was two soil tillage variants – conventional (CT) and reduced (RT). CT variant included mould-board ploughing at a depth of 22 – 24 cm, and RT – disc harrowing twice at a depth to 10 cm. Winter wheat variety 'Zentos' was used in 2017 and 'Skagen' in 2018. In 2017/2018, it was decided to change the used variety in described long-term experiment because 'Zentos' had lost its topicality among producers. Both varieties are characterised as suitable for bread baking. Soil type at the site was Cambic Calcisol (Bathyruptic, Episiltic, Protostagnic); soil texture was clay. Nitrogen rate was chosen according to the yield potential – 197 kg ha^{-1} in 2017, and 180 kg ha^{-1} in 2018. Yield was harvested at GS 89 (according BBCH) using direct combining, and recalculated to 100% purity and 14% moisture. Grain quality indicators were detected by express method using Infratec 1241 in 2017, and Infratec NOVA in 2018, the indicators measured were: CP content (%), Zeleny index, volume weight (g L^{1}). Standard methods were used for Hagberg falling number (s) (ISO 3093:2009) and TGW (g) (LVS EN ISO 520:2011) determination. Mathematical data processing was done by using rStudio Multi-way Anova analysis and correlation analysis.

Winter wheat vegetation started on April 14 in 2017 and on April 7 in 2018. Meteorological situation was favourable for high-yield formation in 2017, but unfavourable for plant growth and development in 2018. Autumn in 2016 started with a warm September and low precipitation, but continued with optimal conditions. A spring-summer season was good in 2017, the average temperatures in the vegetation period were close to those of long-term observations. The precipitation amount was lower if compared to long-term observations, except July, when the highest amount of precipitations was observed (Table 1). As air temperatures were mostly temperate, plants did not suffer from lack of moisture.

Next season (2017/2018) started with a high amount of precipitation in September, October and November; the sowing was delayed till the end of September, and the growing and development of plants was disturbed. In April 2018, air temperature

Table 1

Meteorological conditions at the trial site in 2016/2017 and 2017/2018 in comparison to long-term observations

Month	Temperature			Precipitation		
	2016/2017	2017/2018	Long-term observations	2016/2017	2017/2018	Long-term observations
Sowing year						
September	13.7	13.0	11.5	3.9	26.6	20.9
October	5.2	8.0	6.7	18.7	26.7	19.3
November	1.1	3.9	1.8	11.5	15.1	17.6
Harvesting year						
April	4.8	9.0	5.3	38.5	69.5	40.0
May	11.5	16.1	11.7	23.5	12.0	51.4
June	15.1	16.8	15.4	49.5	15.6	75.3
July	16.6	20.9	16.6	83.0	33.6	81.7
August	16.8	19.5	16.2	31.0	28.4	73.7

was higher than optimum for effective tillering. Subsequent air temperatures in this season were higher than long-term observations. Precipitation starting from May till harvesting in July was low (Table 1). Lack of moisture at important growth stages for yield formation was observed (during tillering, spike formation and grain filling): the vegetation period was also shorter. The above mentioned factors led to the reduction of yield and grain quality. Wheat yield was harvested on August 8 in 2017, and on July 24 in 2018.

Results and Discussion

The average winter wheat yield in two trial years differed significantly (p=0.0001) (Table 2). Lower yields were gained in 2018, when the meteorological conditions were unfavourable for high yield formation.

In 2017, when the average wheat yield was higher, a significant difference between soil tillage treatments was also found, and higher yield on average was gained in reduced soil tillage variant. Assessing the average two-year yield depending on soil tillage treatment, a significant difference was not found (Table 2). Similar results were found in Romania, where significant differences between different soil tillage variants (including CT and RT) were not established (Cociu & Alionte, 2011). An impact of different soil tillage variants (conventional tillage (CT), reduced tillage (RT), no-till (NT)) on wheat yield was also studied in Italy (Mediterranean climate), and the research resulted in wheat yield increase in NT variant in comparison to CT, when water stress was high, but a yield decrease was observed when the water stress was low (Amato *et al.*, 2013). In this trial, the interaction effect between year conditions and soil tillage variant was found (p=0.002).

The highest winter wheat grain yield was harvested in rotation (3) (FB-W-OR-B) in 2017, when wheat fore-crop had been faba bean – 8.06 t ha^{-1}. Wheat was fore-crop in rotation (1) – repeated wheat sowings, and rotation (2) (R-**W**-W). Wheat as a fore-crop caused wheat grain yield reduction on average per two trial years (6.01 t ha^{-1}), and also in every specific year, in comparison to oilseed rape and faba bean as fore-crops (Table 2). The same results on significant differences of wheat yield depending on crop rotation variants established from this trial in 2015 (Ruža *et al.*, 2016). R.L. Anderson found that wheat yield significantly increased when fore-crops were pulses or pulse-cereal mixture in comparison to fore-crop wheat (Anderson, 2008). M. Babulicová concluded that higher wheat yield was gained when fore-crop was field pea in comparison to barley (Babulicová, 2016).

A positive significant impact of oilseed rape as fore-crop was found also on the 2nd wheat yield in rotation (2) (R-W-**W**) (Table 3). Similar results were found also in Lithuania, in trials with oilseed rape as wheat fore-crop (personal communication with Dr. Z. Kriaučiuniene, 13 December 2018).

Winter wheat yield level between crop rotation variants, where fore-crop was also wheat, showed a positive impact of oilseed rape introduction in rotation and yield increasing effect of crop diversification in rotation. Wheat yield in rotation (2) after wheat (6.41 t ha^{-1}) showed yield increase by 22.6% in comparison

Table 2

Winter wheat grain yield depending on crop rotation scheme, fore-crop and soil tillage method

Factors	Year (p=0.0001)		Average
	2017	2018	
Crop rotation (p<0.001)			
W-W	6.38^{a}	5.23^{a}	5.81^{A}
W-W-OR	7.08^{b}	6.65^{b}	6.79^{B}
FB-W-OR-B	8.06^{c}	-	8.06^{C}
Fore-crop (p=0.039)			
wheat	6.38^{a}	5.82^{a}	6.01^{A}
oilseed rape	7.08^{b}	6.88^{b}	6.98^{B}
faba bean	8.06^{c}	-	8.06^{C}
Soil tillage (p=0.069)			
conventional	6.87^{a}	6.24^{a}	6.56^{A}
reduced	7.48^{b}	6.10^{a}	6.79^{A}
Average depending on trial year	7.17^{B}	6.18^{A}	×

W–W – wheat in repeated sowings; W–W–OR – wheat in rotation with oilseed rape; FB–W–OR–B – four different crop rotation, where wheat is sown after faba bean. Significantly different means are marked with different letters in superscript: $^{A, B, C}$ – significant difference for average yields of two trial years and means on factor graduations; $^{a, b, c}$ – significant difference in specific trial year.

Table 3

Winter wheat grain yield depending on fore-crop in rotation and soil tillage method in 2018

Soil tillage method	Fore-crop (in bold) in crop rotation			Average depending on soil tillage variant, p=0.444
	W-W	OR-**W**-W	**OR**-W-W	
Conventional	5.72	6.40	6.60	6.24
Reduced	4.74	6.42	7.16	6.10
Average depending on fore-crop, $LSD_{0.05}$=0.44	5.23	6.41	6.88	×

Table 4

Winter wheat grain crude protein content (%) depending on investigated factors

Factors	Year (p=0.0176)		Average
	2017	2018	
Crop rotation (p=0.1993)			
W-W	11.0^{a}	9.9^{a}	10.4^{A}
WW-OR	10.8^{a}	10.4^{a}	10.6^{A}
FB-W-OR-B	11.0^{a}	-	11.0^{A}
Fore-crop (p=0.0052)			
wheat	11.0^{a}	9.9^{a}	10.3^{A}
oilseed rape	10.8^{a}	10.9^{b}	10.8^{AB}
faba bean	11.0^{a}	-	11.0^{B}
Soil tillage (p=0.0037)			
conventional	10.6^{a}	10.0^{a}	10.3^{A}
reduced	11.3^{b}	10.4^{a}	10.9^{B}
Average depending on trial year	10.9^{B}	10.2^{A}	×

W–W – wheat in repeated sowings; W–W–OR – wheat in rotation with oilseed rape; FB–W–OR–B – four different crop rotation, where wheat is sown after faba bean. Significantly different means are marked with different letters in superscript: $^{A, B}$ – significant difference for average crude protein (%) of two trial years and means on factor graduations; $^{a, b}$ – significant difference in a specific trial year.

to wheat yield in repeated sowings (5.23 t ha^{-1}). The highest grain yield in 2018 was harvested if fore-crop was oilseed rape and reduced soil tillage was used.

Investigated CP content in grain was low (9.9 – 11.3%) and did not reach criterion set by the Cabinet Regulations (Cabinet of Ministers, 2014) for food quality – 12.5% (Table 4).

Protein content differed mathematically significantly depending on the year (p=0.0176), fore-crop (p=0.0052) and soil tillage variant (p=0.0037) (Table 4). The highest value was gained in the variant where reduced tillage was used in 2017 (11.3%). Regardless of the established mathematically significant average CP content difference between two soil tillage variants (Table 4), this difference was only 0.7% (10.9% in traditional tillage and 10.2% in reduced tillage variant), and it is not agronomically important. An opposite effect was found in three-year trial in Romania, where higher protein content was gained in traditional tillage variant (Cociu & Alionte, 2011). The higher average CP content was gained in 2017 (10.9%), but lower in 2018 (10.2%) A fore-crop impact (p=0.0052) on winter wheat grain CP content was found – an average higher value was determined if fore-crop was faba bean, and it significantly differed between wheat as fore-crop. In 2017, significant differences between fore-crops were not found, but in 2018 – oilseed rape as fore-crop had an impact on higher CP content in comparison to fore-crop wheat. A fore-crop impact on winter wheat grain CP content was not found in research conducted in the USA, if spring wheat fore-crop was field pea, which was compared to repeated wheat rotation (Carr, Martin, & Horsley, 2008).

Average values of CP quality, which were described as Zeleny index, differed significantly depending on all investigated factors (Table 5). Values of Zeleny index corresponded to food grain demands in 2017, but in 2018, they were dramatically low (on average 22.8, criterion is 30). High temperature in May affected negatively CP quality in 2018. O. Veisz, S. Bencza, & G. Vida (2007) stated that heat stress after flowering may affect a CP spatial structure. C. Blumenthal *et al.* (1995) had claimed that despite high CP content heat stress can decrease the glutenin-

Table 5

Zeleny index of winter wheat grain depending on researched factors

Factors	Year (p<0.001)		Average
	2017	2018	
Crop rotation (p=0.0249)			
W-W	33.5^{a}	20.4^{a}	26.9^{A}
WW-OR	30.3^{a}	24.0^{b}	26.1^{A}
FB-W-OR-B	31.9^{a}	-	31.9^{B}
Fore-crop (p=0.001)			
wheat	33.5^{a}	20.7^{a}	24.9^{A}
oilseed rape	30.3^{a}	27.0^{b}	28.7^{AB}
faba bean	31.9^{a}	-	31.9^{B}
Soil tillage (p=0.006)			
conventional	28.9^{a}	21.5^{a}	25.2^{A}
reduced	34.8^{b}	24.1^{b}	29.4^{B}
Average depending on trial year	31.9^{B}	22.8^{A}	×

W–W – wheat in repeated sowings; W–W–OR – wheat in rotation with oilseed rape; FB–W–OR–B – four different crop rotation, where wheat is sown after faba bean. Significantly different means are marked with different letters in superscript: $^{A, B}$ – significant difference for Zeleny index of two trial years and means on factor graduations; $^{a, b}$ – significant difference in a specific trial year.

Table 6

Volume weight (g L^{-1}) of winter wheat grain depending on investigated factors

Factors	Year (p<0.001)		Average
	2017	2018	
Crop rotation (p<0.001)			
W-W	814^{ab}	791^{a}	802^{A}
W-W-OR	809^{a}	802^{a}	804^{A}
FB-W-OR-B	818^{b}	-	818^{B}
Fore-crop (p=0.0002)			
wheat	814^{ab}	794^{a}	800^{A}
oilseed rape	809^{a}	807^{b}	808^{A}
faba bean	818^{b}	-	818^{B}
Soil tillage (p=0.8175)			
conventional	813^{a}	798^{a}	806^{A}
reduced	814^{a}	798^{a}	806^{A}
Average depending on trial year	813^{B}	798^{A}	×

W–W – wheat in repeated sowings; W–W–OR – wheat in rotation with oilseed rape; FB–W–OR–B – four different crop rotation, where wheat is sown after faba bean. Significantly different means are marked with different letters in superscript: $^{A, B}$ – significant difference for average volume weight of two trial years and means on factor graduations; $^{a, b}$ – significant difference in a specific trial year.

gliadin ratio, and the percentage of very large glutenin polymers can decrease protein quality. In our research, Zeleny index and protein content had strong positive correlation ($r=0.957 > r_{0.01}=0.372$; n=48).

Volume weight was significantly influenced by the year, crop rotation and fore-crop (Table 6). Volume weight of the harvested grain corresponded to criterion stated for food wheat by stock company ‘AS Dobeles Dzirnavnieks’ (>750 g L^{-1}).

Highest wheat volume weight was determined in crop rotation (3), where fore-crop was faba bean in 2017. In the same year, volume weight in repeated wheat sowings (rotation (1)) did not differ significantly from that in other two crop rotation variants, and the lowest value was gained in rotation (2) – after oilseed rape (Table 6). The situation was different in 2018, when higher average value of volume weight was determined, when wheat was grown after oilseed

Table 7

Winter wheat thousand grain weight (g) depending on investigated factors

Factors	Year (p<0.001)		Average
	2017	2018	
Crop rotation (p<0.001)			
W-W	44.6[a]	41.2[a]	42.9[A]
WW-OR	46.2[b]	42.2[a]	43.5[A]
FB-W-OR-B	47.6[b]	-	47.6[B]
Fore-crop (p<0.001)			
wheat	44.6[a]	41.4[a]	42.5[A]
oilseed rape	46.2[b]	42.7[b]	44.5[B]
faba bean	47.6[b]	-	47.6[C]
Soil tillage (p=0.4787)			
conventional	46.0[a]	41.9[a]	44.1[A]
reduced	46.3[a]	41.7[a]	43.9[A]
Average depending on trial year	46.2B	41.8A	×

W–W – wheat in repeated sowings; W–W–OR – wheat in rotation with oilseed rape; FB–W–OR–B – four different crop rotation, where wheat is sown after faba bean. Significantly different means are marked with different letters in superscript: [A, B, C] – significant difference for average TGW of two trial years and means on factor graduations; [a, b] – significant difference in a specific trial year.

rape. M. Babulicová (2016) found positive fore-crop effect on winter wheat volume weight if the fore-crop was field pea in comparison to variant where fore-crop was barley in Slovakia. P.M. Carr *et al.* reported that volume weight of spring wheat was influenced by interaction between crop rotation, tillage system and year (Carr, Martin, & Horsley, 2008). A tendency of such interaction was also found in our research (p=0.061).

Volume weight had a positive correlation with TGW ($r=0.807>r_{0.01}=0.372$; n=48); such a relationship has also been reported by Liniņa & Ruža (2015). TGW in the trial period was influenced by year, crop rotation and fore-crop (Table 7).

The lowest average TGW was found in repeated wheat sowings (W-W; rotation (1)), but higher average TGW when rotation was diversified (Table 7). Significant TGW differences were found depending on fore-crops – higher TGW gained after faba-bean and oilseed rape in 2017. M. Babulicová (2016) reported similarly that fore-crop field pea had a significant impact on TGW increase, if compared with variant where cereal (barley) fore-crop was used. Average TGW differed significantly between trial years, and it was higher by 4.4 g in 2017 in comparison to 2018 (on average 41.8 g). Other researchers in Latvia (Liniņa & Ruža, 2015; Skudra & Ruža, 2016) have concluded that meteorological situation in the vegetation period has the main influence on TGW. A.I. Cociu & E. Alionte (2011) also concluded that TGW of the same variant can differ significantly between years. Drought stress and heat stress may lead to lower TGW (Veisz, Bencza, & Vida, 2007). Soil tillage treatment did not show significant effect on average TGW (Table 7), and the same result was obtained in Romania (Cociu & Alionte, 2011). They found an interaction effect between year and used soil treatment on TGW.

The Hagberg falling number (on average in 2017 – 328 s, in 2018 – 338 s) was not significantly influenced by the investigated factors and was higher than grain food quality minimum requirements (220 s) according to the Cabinet Regulations No. 461.

Conclusions

Higher winter wheat grain yields were gained in rotations with crop diversification in them. Higher yields and quality indicators were determined in the year 2017 due to more favourable meteorological conditions. Crop rotation with different field crops also showed an improvement effect on grain quality indicators – Zeleny index, volume weight, 1000 grain weight. Fore-crop impact was investigated on crude protein content, Zeleny index, volume weight and 1000 grain weight. Small soil tillage influence was found on crude protein content and Zeleny index. Hagberg falling number was stable and not influenced by investigated factors.

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