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Effect of nitrogen fertilization on winter wheat yield and yield quality

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Abstract. Wheat (*Triticum aestivum* L.) is the most common cereal, which is grown in Latvia. Nowadays, farmers are trying to get high grain yields in line with food quality, at the same time trying to minimize production costs and to use environmentally friendly technologies. The objective of this experiment was to clarify the impact of nitrogen fertilization on winter wheat yield and yield quality under two soil tillage systems and after two forecrops. Trials were conducted at the Research and Study farm 'Peterlauki' of Latvia University of Agriculture (56° 30.658' N and 23° 41.580' E). Researched factors were (1) crop rotation (wheat/wheat and oilseed rape (*Brassica napus* ssp. *oleifera*)/wheat), (2) soil tillage (traditional soil tillage with mould-board ploughing at a depth of 22–24 cm and reduced soil tillage with disc harrowing at a depth below 10 cm), (3) nitrogen fertilizer rate (altogether eight rates: N0 or control, N60, N90, N120(90+30), N150(90+60), N180(90+60+30), N210(90+70+50), and N240(120+60+60)), and (4) conditions of the growing seasons 2014/2015, 2015/2016 and 2016/2017. The results indicate that winter wheat yield has been significantly affected by soil tillage, nitrogen fertilizer rate ($p < 0.001$) and forecrop ($p < 0.05$). Three-year research confirmed significant yield increase until the nitrogen fertilizer rate N180. Significantly higher average grain yield was obtained under traditional soil tillage. Nitrogen fertilizer affected significantly all tested yield quality indicators ($p < 0.001$). Increase of nitrogen fertilizer rate secured significant increase of winter wheat grain quality indices, except starch content, after both forecrops and in both soil tillage variants. Values of yield quality indicators increased significantly enhancing N-rate from N150 up to N210

Key words: nitrogen fertilization, grain quality, winter wheat, soil tillage.

INTRODUCTION

In recent years, wheat areas have increased in Latvia. Winter wheat is the most widely grown winter cereal in Latvia and farms are increasingly striving to use agrotechnical measures that reduce production costs. Nowadays, not only yield amount but also the quality of the produced grain is important, because the quality of the grains determines their direction of use. That is why farmers are trying to get high grain yields in line with food (accepted for bread baking) quality, while minimize production costs and using environmentally-friendly technologies.

One of the most important agro-technical measures is crop rotation. It is mentioned that the unfavourable preceding crops decrease significantly the yield of wheat and yield losses can be up to 10% (Sieling & Christen, 2015). In recent years, wheat growers have increasingly used short crop rotation. Wheat is mostly grown after oilseed rape or repeated several years after wheat, and this short crop rotation is combined with reduced soil tillage. Soil tillage is also an important agrotechnical measure. In literature, information about the effect of soil tillage impact on wheat yield and quality differs. Some authors (e.g. Seibutis et al., 2009) found that the wheat grain yield was not significantly affected by different soil tillage methods (conventional tillage – ploughing at 20–22 cm depth, presowing tillage – shallow seed bed prearation at 4–5 cm depth and reduced tillage – stubble cultivation at 10–12 cm depth were compared), but others (e.g. Šíp et al., 2013) indicated that soil tillage system effect on grain yield is significant (conventional tillage – ploughing to 22 cm depth and reduced soil tillage – surface stubble ploughing at 8–10 cm depth were compared). Moreover, soil tillage can affect nitrogen leaching (Stenberga et al., 1999).

Optimal nutrient provision is an important factor to get high yield with high grain quality. Nitrogen is one of the most important elements of plant nutrition, which often to a great extent determines not only wheat yield level, but especially grain baking quality. It is also one of the most mobile plant nutrients in the soil. Therefore, it is important to evaluate the use of high nitrogen fertilizer rates, because unsuitable nitrogen doses lead to increased nitrate leaching (Huang et al., 2018) which contributes to eutrophication of surface waters. In Latvia, nitrogen influence on wheat yields has been much studied, but with the development of agrotechnology and changing varieties (implementing high yielding ones), the effect of nitrogen fertilization is also changing. Therefore, it is important to look for cost-effective and environmentally friendly rates of N-fertilizers in different tillage systems with different forecrops for winter wheat. The objective of this experiment was to clarify the nitrogen fertilization impact on winter wheat yield and yield quality under two soil tillage systems and after two forecrops.

The research was funded by the 'State and European Union investment for encouragement in agriculture' theme 'Determination of maximal fertilizer norms for crops'.

MATERIALS AND METHODS

Field trials using equal methodology during all research years were conducted at the Research and Study farm 'Peterlauki' of Latvia University of Agriculture (56° 30.658' N and 23° 41.580' E). Trials were arranged using split plot design in four replications. The researched factors were: (1) crop rotation (wheat/wheat and oilseed rape (*Brassica napus* ssp. *oleifera)*/wheat), (2) soil tillage (traditional soil tillage with mould-board ploughing at a depth of 22–24 cm and reduced soil tillage with disc harrowing at a depth below 10 cm), (3) nitrogen fertilizer rate (altogether eight rates: N0 or control, N60, N90, N120(90+30), N150(90+60), N180(90+60+30), N210(90+70+50), and N240(120+60+60)), and (4) the conditions of the growing season (trial was repeated three years: 2014/2015, 2015/2016 and 2016/2017).

Trials were conducted in loam soil, *Endocalcaric Abruptic Luvisol* (Cutanic, Hypereutric, Ruptic, Siltic, Protostagnic, Epiprotovertic). Soil agrochemical characteristics were as follows: in 2014/2015 – pH KCL = 6.3 (potentiometrically in

1 *M* KCl suspension), organic matter content (oxidizing the soil with potassium dichromate ($K_2Cr_2O_7$)) 31 g kg^{-1}, P content (Egner– Riehm (DL) method) 30.08 mg kg^{-1} and K content (Egner – Riehm (DL) method) 131.14 mg kg^{-1} of the soil; in 2015/2016 – pH KCL = 6.9; organic matter content 24 g kg^{-1}, P content 107.69 mg kg^{-1} and K content 272.24 mg kg^{-1} of the soil; in 2016/2017 – pH KCL = 7.2; organic matter content 32 g kg^{-1}, P content 74.56 mg kg^{-1} and K content 171.81 mg kg^{-1} of the soil.

Before sowing fertilizer was applied: P 17.44–28.34 kg ha^{-1} and K 33.2–51.13 kg ha^{-1} depending on a year. Weeds were controlled by herbicides in all years, but wheat diseases were controlled by fungicide application once per season (growth stage (GS) 51 – beginning of heading (Lancashire et al., 1991)).

Cultivar 'Skagen' was sown at the rate of 450–500 germinable seeds m^{-2}. 'Skagen' is characterized by a good winterhardiness, which is combined with disease resistance and baking quality, notably high and stable falling number.

In spring, when the vegetation had renewed, nitrogen fertilizer (NH_4NO_3; N 34%) was applied for all variants, except the control variant N0. The whole rate of fertilizer was applied once for variants N60 and N90; rate was divided into two applications for variants N120 and N150, but into three applications – for variants N180 – N240. Second top-dressing was done at GS 29 (end of tillering) until 31 (early stem elongation) of winter wheat, but the third – at GS 47 (flag leaf sheet opening) until 51 (beginning of heading).

After harvesting the whole plots, yield was weighted, grain purity and moisture content detected, and yield data was recalculated to standard moisture (14%) and 100% purity. Wheat grain quality indices were analysed at the Grain and Seed Research laboratory of Latvia University of Agriculture using express method and standard methods. Crude protein (CP), gluten and starch content (%), volume weight (g L^{-1}) and Zeleny index were detected by Infratec^{TM} Grain Analyzer 1241 (FOSS); 1,000 grain weight was determined using standard method LVS EN ISO 520; the Hagberg falling number was measured by the Hagberg-Perten method according LVS EN ISO 3093.

Analysis of variance was used for data statistical processing. Bonferroni test was used for comparison of means; the differences were considered statistically significant when $p < 0.05$. Significantly different means were labelled with different letters (^{a,b,c,d,e,f,g,h} or $^{A, B}$) in superscript. Data processing was done using R-studio.

Meteorological conditions in all three trial years differed obviously from the long-term average data. Autumn of 2014 was long and cool, in 2015, it was relatively warm and dry, and similarly in 2016, it was warm and dry. All winters during the trial period were mild and favourable for good wheat overwintering. The vegetation renewed in mid-March in all years. In 2015, spring was moderately warm and wet; however, summer in June and August was dry, but July was characterized by high rainfall. In 2016, spring was warm with a little rainfall, but summer was very rainy. Spring of 2017 was warm with enough moisture; summer was rainy, especially with high rainfall in July, but in August the amount of precipitation decreased.

RESULTS AND DISCUSSION

Wheat yield. The results showed that the average wheat grain yield was very high in all three years of research (4.72 (N0) – 9.45 (N240) t ha^{-1}) (Table 1). All the researched factors showed significant effect on grain yield. The effect of the nitrogen fertilization on the wheat grain yield was the same in all years of study. Increase of nitrogen fertilization rate increased significantly the average grain yield in all years ($p < 0.001$) if compared to control. This result corresponds with the findings of other researchers (Rieger et al., 2008; Sieling & Christen, 2015). All N rates used, from the lowest (N60) to the highest (N240), have a significant effect on grain yield increase if compared to control. In our trial a significant average yield increase was observed until the nitrogen fertilizer rate N180, and further increase of N rate (i.e. till N210 and N240) did not give a significant increase of wheat yield (Table 1).

Table 1. Winter wheat yield depending on nitrogen fertilizer rate, forecrop, soil tillage and growing seasons, t ha^{-1}

Factors	N-rate, kg ha^{-1}								Average
	N0	N60	N90	N120	N150	N 180	N210	N240	
Forecrops ($p < 0.05$)									
Oilseed rape	4.77^{a}	6.83^{b}	7.64^{c}	8.46^{d}	8.82^{de}	9.30^{e}	9.46^{e}	9.46^{e}	8.09^{A}
Wheat	4.68^{a}	6.69^{b}	7.34^{c}	8.34^{d}	8.71^{de}	9.18^{ef}	9.38^{f}	9.43^{f}	7.99^{B}
Soil tillage ($p < 0.001$)									
Traditional	4.83^{a}	7.05^{b}	7.71^{b}	8.63^{c}	8.87^{cd}	9.36^{d}	8.63^{d}	9.50^{d}	8.18^{A}
Reduced	4.76^{a}	6.57^{b}	7.23^{b}	7.97^{c}	8.36^{cd}	8.72^{d}	8.80^{d}	8.88^{d}	7.71^{B}
Growing seasons ($p < 0.001$)									
2014/2015	4.20^{a}	6.40^{b}	7.42^{c}	9.00^{d}	9.09^{d}	9.85^{e}	10.22^{e}	10.23^{e}	8.30^{A}
2015/2016	5.33^{a}	7.10^{b}	7.56^{c}	8.15^{d}	8.80^{d}	9.12^{e}	9.30^{e}	9.36^{e}	8.09^{B}
2016/2017	4.63^{a}	6.78^{b}	7.49^{c}	8.05^{cd}	8.40^{de}	8.74^{e}	8.75^{e}	8.75^{e}	7.72^{C}
Average	4.72^{A}	6.76^{B}	7.49^{C}	8.40^{CD}	8.76^{D}	9.24^{E}	9.42^{E}	9.45^{E}	×

^{a,b,c,d,e,f,g} – yields labelled with different letters are significantly different in rows depending on N-rate; $^{A,\ B,\ C}$ – average yields labelled with different letters are significantly different depending on forecrop, soil tillage, growing season, and on average per trial period.

In the trial, soil tillage affected grain yield significantly ($p < 0.001$). Similar results were observed in another study, which demonstrated that the soil tillage had a significant effect on grain yield (Šíp et al., 2013). Our result does not conform to the findings in other studies concluding that the grain yield is not significantly affected by different soil tillage methods (Seibutis et al., 2009; Šíp, 2009), and over the long term, the yield of winter wheat under reduced soil tillage did not differ markedly from that provided by conventional soil tillage (Šíp, 2009). In our trial, the grain yield was significantly lower in variant, where the reduced soil tillage system (4.76–8.88 t ha^{-1}) was used if compared with the variant of traditional soil tillage (4.83–9.50 t ha^{-1}).

Data mathematical processing shows that the forecrop had a significant ($p < 0.05$) effect on the grain yield. The average grain yield was mostly higher in variant, where oilseed rape was the forecrop (Table 1). Similarly, Sieling et al. (2005) found that the wheat following oilseed rape provided a higher grain yield if compared with variant where wheat was grown after wheat. However, when wheat was grown in repeated sowings in three-year period, the third wheat crop reduced the yield by 20% if compared with the first crop. In our trial, average grain yield was 4.77–9.46 t ha^{-1} when wheat was grown after oilseed rape depending on nitrogen rate, but in repeated wheat sowings average grain yield was 4.68–9.43 t ha^{-1}. Winter wheat grain yields increased significantly until nitrogen rate N180 after both forecrops. Use of higher N-rates smoothed out yield differences depending of forecrop, e.g. in the variant where N240 was used, yields after oilseed rape and after wheat were almost equal: 9.46 and 9.43 t ha^{-1}, respectively.

Despite the fact that winter wheat grain yield was very high on average per all research years (7.72–8.30 t ha^{-1}, Table 1) it was significantly ($p > 0.001$) affected by conditions in the growing season. In growing season 2014 /2015, the highest grain yield was obtained, but it was the lowest in 2016/2017.

Crude protein (CP) content. Grain CP content is the most important indicator of wheat grain quality. CP content ranged from 8.7 to 13.7% on average per all trial years depending on nitrogen fertilizer rate (Table 2). Results show that the nitrogen fertilizer increased significantly ($p < 0.001$) the CP content in grain. It coincides with the results of another study demonstrating that protein was significantly influenced by nitrogen treatment (Weber et al., 2008). Average CP content per trial period in wheat grain increased in correlation with the nitrogen rate increase. The highest protein content was established when the highest fertilizer rates were used. CP content in grain increased significantly until nitrogen fertilizer rate N180 (Table 2), and the next significant increase was observed when N rate was increased until N240. The standards for food quality wheat grain CP content is from 12% (https://dzirnavnieks.lv/lv/graudu-piegadatajiem). In our trial, average CP content, which conforms to food quality lowest border, was obtained using nitrogen fertilizer rate N180 (12.8%). Similarly, Weber et al. (2008) concluded from research in Germany, that N-rate 180 kg N ha^{-1} is needed to obtained CP content suitable for bread baking.

Table 2. Winter wheat crude protein content depending on nitrogen fertilizer rate, forecrop, soil tillage and growing seasons, %

Factors	N-rate, kg ha^{-1}								Average
	N0	N60	N90	N120	N150	N180	N210	N240	
Forecrops ($p < 0.001$)									
Oilseed rape	9.0^{a}	9.1^{a}	10.0^{ab}	10.7^{b}	12.0^{c}	13.9^{cd}	13.4^{d}	13.7^{d}	11.4^{A}
Wheat	8.5^{a}	8.8^{ab}	9.5^{bc}	10.2^{c}	11.5^{d}	12.6^{e}	13.2^{ef}	13.8^{f}	11.0^{B}
Soil tillage ($p < 0.001$)									
Traditional	8.8^{a}	9.1^{a}	9.9^{ab}	10.5^{b}	11.8^{c}	12.9^{cd}	13.4^{d}	13.8^{d}	11.3^{A}
Reduced	7.8^{a}	8.3^{ab}	9.0^{b}	10.0^{c}	11.1^{d}	12.1^{e}	12.4^{ef}	13.1^{f}	10.5^{B}
Growing seasons ($p < 0.001$)									
2014/2015	8.0^{a}	8.2^{a}	8.4^{a}	8.8^{a}	10.8^{b}	11.4^{bc}	12.3^{bc}	12.7^{c}	10.0^{A}
2015/2016	9.8^{a}	9.8^{a}	10.6^{ab}	11.0^{b}	12.6^{c}	13.6^{d}	14.1^{de}	14.5^{e}	12.0^{B}
2016/2017	7.9^{a}	8.3^{a}	9.3^{b}	10.3^{c}	11.1^{d}	12.2^{e}	12.7^{ef}	13.2^{f}	10.6^{C}
Average	8.7^{A}	8.9^{A}	9.8^{B}	10.4^{B}	11.8^{C}	12.8^{D}	13.3^{DE}	13.7^{E}	×

^{a,b,c,d,e,f,g} – yields labelled with different letters are significantly different in rows depending on N-rate; $^{A,\,B,\,C}$ – average yields labelled with different letters are significantly different depending on forecrop, soil tillage, growing seasons, and on average per trial period.

In the trial, the forecrop affected the wheat CP content significantly ($p < 0.001$). This result does not conform to the findings of other research, where it was found that the choice of forecrops had no significant influence on the CP content of wheat grain (Jankowski et al., 2015). In our trial, oilseed rape was a better forecrop for higher winter wheat CP content formation if compared with repeated sowing wheat after wheat. Soil tillage also had a significant ($p < 0.001$) impact on the protein content. Under traditional tillage system (8.8–13.8%) the protein content of winter wheat was higher than under reduced soil tillage (7.8–13.2%) in all N-fertilizer variants (Table 2). Conditions of growing season affected significantly ($p < 0.001$) the grain protein content. On average, the highest protein content was observed in growing season 2015/2016 (12.0%). Lower protein content in the grains was observed during the growing season 2014/2015 (10.0%) and 2016/2017 (10.6%). Seasons 2014/2015 and 2016/2017 characterize with a lot of cloudy days, and the lack of sun can be one of reasons of lower grain CP content; in addition, the highest yield was obtained in 2014/2015; thus more N can be used for yield formation.

Gluten content. Nitrogen fertilization has a positive impact on gluten content of grain and the content of nitrogen substances is closely related to the gluten content in grain (Kozlovsky et al., 2009). Results of our trial show that the average gluten content in wheat grain was 14.73–28.74% depending on nitrogen rate ($p < 0.001$). Similarly to CP content, also gluten content in grain increased significantly until nitrogen fertilizer rate N180 and the next significant increase was secured by N240. The lowest border of food demand of gluten content was obtained when nitrogen fertilizer rate N180 was used. Forecrop also affected the gluten content in grain significantly ($p < 0.01$). Higher average gluten content was observed when wheat was grown after oilseed rape. This result is similar to the findings of other research showing that significantly lower wet gluten concentrations were obtained when winter wheat was grown in monoculture if compared with winter wheat growing after oil plants (Jankowski et al., 2015). Soil tillage affected the gluten content significantly ($p < 0.001$). Under traditional soil tillage system the gluten content was higher than under reduced soil tillage. Results show that the growing season also had a significant ($p < 0.001$) impact on gluten content, and explanation can be the same as for CP content (see above).

Table 3. Average winter wheat quality indicators depending on nitrogen fertilizer rate

Grain quality indicators	N-rate, kg ha^{-1}								Average
	N0	N60	N90	N120	N150	N180	N210	N240	
Gluten content (%)	14.73^{a}	14.91^{a}	16.89^{b}	18.78^{b}	22.79^{d}	25.90^{e}	27.47^{ef}	28.74^{f}	21.24
Zeleny index	17.58^{a}	18.52^{a}	22.85^{b}	27.90^{c}	37.14^{d}	45.11^{e}	50.57^{f}	54.61^{f}	34.19
Starch content (%)	70.66^{a}	70.89^{a}	70.39^{ab}	69.69^{b}	68.32^{c}	67.13^{d}	66.63^{de}	66.13^{e}	68.74
Volume weight (kg hl^{-1})	76.13^{a}	76.76^{ab}	77.91^{ac}	78.74^{ad}	79.55^{bcd}	80.24^{cd}	80.57^{cd}	80.33^{cd}	78.77
Falling number, s	314^{a}	334^{ab}	379^{bc}	361^{cd}	371^{c}	382^{d}	383^{d}	381^{d}	363
1,000 grain weight, g	44.84^{a}	46.24^{ab}	46.38^{ac}	46.34 ^{ad}	47.07^{bcd}	47.73^{bcd}	48.09^{bcd}	47.76^{bcd}	46.80

^{a,b,c,d,e,f,g} – yields labelled with different letters are significantly different in rows depending on N-rate.

Zeleny index. Zeleny index determines quantity and quality of gluten proteins (Kozlovsky et al., 2009). Results show that the nitrogen fertilizer increase has a significant ($p < 0.001$) impact on Zeleny index (Table 3). Similar results were obtained in other studies (Weber et al., 2008; Liniņa & Ruža, 2012). In our trial, significant increase of Zeleny index was observed until nitrogen fertilizer rate N210. Zeleny index was affected significantly ($p < 0.001$) by the forecrop. Higher results were observed when wheat was grown after oilseed rape if compared to wheat growing after wheat. In addition, soil tillage had a significant ($p < 0.001$) effect on Zeleny index. Under traditional soil tillage system Zeleny index was higher than under reduced soil tillage. Growing season affected the Zeleny index significantly ($p < 0.001$). More favourable conditions for higher Zeleny index formation were in 2015/2016 when also the highest average CP content in grain accumulated.

Starch content. Starch content was affected significantly ($p < 0.001$) by the use of nitrogen fertilizer, but this indicator decreased with increased nitrogen fertilizer rate. Average starch content was 66.13–70.89% depending on N-rate. Our study confirmed the negative relationship between protein and starch content in grain once more: protein content decreased if starch content increased. In our trial, forecrop ($p < 0.001$), soil tillage ($p < 0.001$) and conditions of growing season ($p < 0.001$) had a significant impact on starch content. All obtained starch results depending on mentioned factors were opposite to CP content. Criterion for starch content is not set for winter wheat if it is used for bread baking.

Volume weight. It is an indicator of flour outcome at milling enterprise (Kozlovsky et al., 2009). Higher volume weight indicated better grain maturation and richness with nutrients; more flour can be obtained from such grain during processing as well (Liniņa & Ruža, 2015). Our results showed a significant effect of nitrogen fertilizer on volume weight, which agrees with results of other research (Skudra & Ruža, 2016). Average per trial period volume weight was between 76.13–80.57 kg hl^{-1} depending on nitrogen fertilizer rate. Increase of nitrogen fertilizer rate also increased volume weight, and a significant ($p < 0.001$) increase was observed until fertilizer rate N150; applying higher nitrogen fertilizer rates volume weight did not increase significantly. Volume weight demand for food grain is 75.0 kg hl^{-1} and above. Our results showed volume weights that were in line with food quality demands even in the control (76.13 kg hl^{-1}). Result showed that the forecrop had no significant ($p = 0.062$) impact on volume weight. This result does not agree with other findings stating that the volume weight was significantly affected by different forecrops, and winter wheat grown in monoculture was characterized by significantly lower volume weight (Jankowski et al., 2015). Our results showed significant ($p < 0.001$) impact of soil tillage on volume weight. Under reduced soil tillage volume weight was higher than in variant with traditional soil tillage. Other authors stated that the conditions of growing season had a significant effect on volume weight (Skudra & Ruža, 2016). Our findings agree with it: the highest wheat grain volume weight was produced in 2016/2017, but the lowest – in 2015/2016.

Falling number. It indicates the rate of alpha-amylase activity in grain. Falling number increases up to its maximum value at full maturity during maturation. It is mentioned in literature that the falling number value is mostly influenced by genetic and environmental factors, especially weather conditions at maturation stage (Grausruber et al., 2000). In our trial, falling number values ranged between 314–383 s on average per all years. It is mentioned by Perten already in 1964 that bread volume is diminished and a dry crumb results when the falling number is greater than 350 s. Increase of nitrogen fertilizer rate had a significant ($p < 0.001$) impact on falling number increase until nitrogen fertilizer rate N180. This result does not agree with other studies, where significant effect of nitrogen fertilizer application on falling number values was not found (Erekul, 2012; Liniņa & Ruža, 2012). Criterion for falling number in Latvia is 280 s; a slightly higher result was obtained even in control variant with N0 (314 s) in our trial (Table 3). When growing wheat after oilseed rape, we observed a tendency that the falling number was slightly higher than in variant where wheat after wheat was grown.

This coincides with the observations of Jankowski et al. (2015), who found that the wheat grown after winter rapeseed characterizes by higher falling number if compared with winter wheat grown in monoculture. Results show that the soil tillage system had no significant ($p > 0.05$) impact on value of falling number. Growing season affected significantly ($p < 0.001$) the falling number in our trial. This agrees with conclusion of Gooding et al. (2003) that the falling number is a grain quality indicator whose value is affected by climate conditions during the grain filling period, and the precipitation during maturation has a greater impact on falling number than fertilization. Despite the fact that falling number in all trial years exceeded demands for bread baking, it was the highest in 2015/2016.

1,000 grain weight (TGW) characterizes the size of seed and is used as one of the parameters for assessing the quality of grain. Grains with higher TGW have better milling quality and ensure better emergence (Protić et al., 2013). At the same time, TGW is also a yield component. Results showed that the nitrogen fertilizer rate affected the TGW significantly ($p < 0.001$). Effect of N-rate on TGW is shown also by Linina & Ruza (2015). The average TGW depending on nitrogen fertilizer rates was 44.84–48.09 g, total increase of 3.24 g was observed; although more expressed TGW increase was observed until nitrogen fertilizer rate N150. Opposite results were obtained by Protic et al. (2007) and Linina & Ruza (2015). Linina & Ruza (2015) found that increase of nitrogen fertilizer rates causes significant decrease of TGW, and the highest TGW was obtained when the nitrogen fertilizer rates N60 and N90 were used. Data mathematical processing showed a significant ($p < 0.001$) effect of forecrop on the TGW. Average TGW decreased when wheat was grown after wheat if compared with growing wheat after oilseed rape. This result agrees with another study stating that the wheat as preceding crop mainly decreased the TGW (Sieling & Christen, 2015). Seibutis et al. (2009) found that soil tillage had no significant impact on TGW, but the slightly higher TGW was found in the wheat monocrop if compared with other forecrops. Our results showed that the soil tillage had a significant ($p < 0.001$) impact on TGW. When comparing the soil tillage systems, it was observed that the higher average TGW was ensured in reduced soil tillage variant (48.88 g) than in traditional soil tillage (46.94 g) variant. Similarly to the results of Skudra & Ruža (2016), the growing season also had a significant ($p < 0.001$) impact on TGW. TGW significantly varied over the years, and the highest average TGW was observed in the growing season 2016/2017 (48.63 g), but the smallest grain was observed in 2015/2016 (44.79 g).

CONCLUSIONS

Winter wheat yield has been significantly affected by nitrogen fertilizer rate, soil tillage, conditions of growing year ($p < 0.001$) and forecrop ($p < 0.05$). Average yield increased significantly until the nitrogen fertilizer rate N180. Significantly higher average grain yield was obtained under traditional soil tillage and in variants where the forecrop was oilseed rape.

Increase of nitrogen fertilizer rate increased significantly almost all tested yield quality indicators ($p < 0.001$), except starch content, after both forecrops and in both soil tillage variants.

Crude protein and gluten content in grain increased on average until nitrogen fertilizer rate N210. However, protein and gluten content conforming to lowest food quality demands was obtained from nitrogen fertilizer rate N180. Significant increase of volume weight was observed until fertilizer rate N150, but that of falling number – until nitrogen fertilizer rate N180; both quality indicators conform for food quality in all fertilization variants, even in control variant.

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