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The influence of cultivar, weather conditions and nitrogen fertilizer on winter wheat grain yield

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Abstract. Winter wheat *(Triticum aestivum* L.) is one of the most productive and significant cereal species in Latvia used for food grain production. The aim of the research was to evaluate winter wheat grain yield depending on nitrogen fertilizer rate, crop-year (meteorological conditions) and cultivar and determine the impact and interaction of research factors on grain yield. Field experiments with winter wheat cultivars 'Bussard' and 'Zentos' were conducted at the Latvia University of Agriculture, Study and Research farm Peterlauki during a three year period (2009/2010, 2010/2011 and 2011/2012). Nitrogen (N) was applied (N60, N90, N120, N150 kg ha^{-1}) in spring after resumption of vegetative growth. Assessment of both winter wheat cultivars showed that crop-year, cultivar, nitrogen fertilizer, crop-year × cultivar had a significant ($p < 0.05$) impact on grain yield. Nitrogen fertilizer did significantly ($p < 0.05$) affect the grain yield of winter wheat, treatment with N90 showed of yield increase, compared to N60, while further use of increasing amounts of N fertilizer did not increase grain yields significantly. Results suggest, that winter wheat grain yield by 34% depended on cultivar, by 33% on crop-year (weather conditions), and by 13% on crop-year × cultivar. Influence of the nitrogen fertilizer effect was small – 3%. Medium strong positive correlation was found between HTC in the vegetation period from winter wheat heading to grain ripening.

Key words: grain yield, nitrogen fertilizer, hydrothermic coefficient.

INTRODUCTION

Winter wheat *(Triticum aestivum* L.) is the main cereal crop used for human consumption in many areas worldwide. In 2014, according to FAO data (FAOSTAT, 2017) 221 million ha were the total sown area by wheat in the world, while the harvested yield exceeded 730 million tonnes of grain, but the average yield of wheat was 3.3 t ha^{-1}. The total amount of grain in different parts of the world varies annually, mainly due to changing climatic conditions owing to drought or excessive moisture.

In Latvia, winter wheat (*Triticum aestivum* L.) is the most widely grown crop. The sown area, grain yield per ha and the total harvested yield tends to increase. According to statistical data, 256 thousand ha were under winter wheat in 2008, whereas in 2011 it occupied 200 thousand ha, but in 2012 the sown area reached 258 thousand ha. In 2015, the area sown to wheat occupied 448 thousand ha including 291 thousand ha devoted to winter wheat, which was 43% of the total sown area planted with cereals. Winter wheat is the most productive cereal in Latvia, high yield was achieved in 2008 – 4.35 t ha^{-1}, in 2011 the average yield was lower – 3.1 t ha^{-1}, but in 2012 – 4.7 t ha^{-1} were obtained, while the highest winter wheat yield was achieved in 2015 – 5.5 t ha^{-1} as influenced by favourable meteorological conditions during vegetation period (Graudu statistikas dati, 2015).

Wheat yield is influenced by the interaction of a number of factors including cultivar, soil, climate, and cropping practices (Shejbalova et al., 2014; Jonczuk & Stalenga, 2016). Wheat grain yield depends on weather conditions in the investigation years (Skudra & Linina, 2011; Fetere & Strazdina, 2014; Faměra et al., 2015, Karklins & Ruza, 2015; Alijošius et al., 2016). Wheat is sensitive to the prevailing weather conditions, such as precipitation. In Hungary Márton, L. (2008) found significant correlation between winter wheat yield and precipitation in vegetative period. He concludes that optimum yields develop in response to rainfall in the 450–500 mm range. Above or below this rainfall yields reduce. While results in Poland (Bujak et al., 2013) suggest that no correlation has been found between the yields and the total precipitation. The soil type proved to be the environmental factor of particular importance in determining winter wheat yields.

The lowest grain yield was harvested, when wintering of wheat was problematic, in rather dry weather conditions prevailing during filling of grain, and when the temperature in July (in grain ripening period) was higher than the long-term average (Jansone & Gaile, 2013). The influence of the crop-year on grain yield was observed best with seven winter wheat cultivars investigated in 2002–2004 at the State Stende Plant Breeding station in Latvia (Malecka, Bremanis & Miglane, 2005), and 13 winter wheat cultivars investigated across four locations and two years in Lithuania (Tarakanovas & Ruzgas, 2006). During ripening wheat plants require moderate moisture and warm weather conditions. These conditions secure biological maturity and acceptable technological properties of grain (Linina & Ruza, 2012; Fetere & Strazdina, 2014; Faměra et al., 2015; Rozbicki et al*.,* 2015).

Winter wheat yield is related to nitrogen supply levels. Under temperate climate, nitrogen is a limiting factor of winter wheat growth and yield (Povilaitis & Lazauskas, 2010). Positive correlation between grain yield and nitrogen fertilizer was found by several researchers in Croatia (Svečnjak et al., 2013), in Czech Republik (Šip et al., 2000), in USA (Farrer et al., 2006) and also in Australia (Savin, Sadras & Slafer, 2006).

Grain yield significantly varied depending on the cultivars as previously observed (Márton, 2008; Skudra & Linina, 2011; Jansone & Gaile, 2013; Kaya & Akcura, 2014; Alijošius et al*.,* 2016).

The aim of the research was to evaluate winter wheat grain yield depending on nitrogen fertilizer rate, crop-year (meteorological conditions) and cultivar and determine the impact and interaction of research factors on grain yield.

MATERIALS AND METHODS

Field experiments. A field trial was carried out in Study and Research farm Peterlauki (56º 30.658’ N and 23º 41.580’ E) of the Latvia University of Agriculture (LLU) during a three-year period: 2009/2010, 2010/2011 and 2011/2012. Soil at the site was Endocalcaric Abruptic Luvisol (by World Reference Base for Soil Resources) silt loam. Soil agro-chemical parameters were different on a year (Table 1). Such conditions were suitable for winter wheat growing.

Table 1. Soil parameters at trial site depending on year

Parameter	Year		
	2010	2011	2012
Soil pH KCL	6.9	6.6	7.0
Available P mg kg^{-1} (by Egner – Riehm method)	182	118	121
Available K mg kg^{-1} (by Egner – Riehm method)	171	191	153
Organic matter, g kg^{-1} of soil (by Tyurin's method)	27	31	27

In trial traditional soil treatment was used, which involves soil ploughing. Winter wheat was sown (13 September in 2009, 25 September in 2010 and 12 September in 2011) using a sowing machine Junkkari Simulta 2500 T. In the Study and Research farm Peterlauki have eight field crop sequence and winter wheat always sown after black fallow. The trial included two winter wheat cultivars 'Bussard' and 'Zentos' (released in Germany), because these cultivars from 2008 to 2012 was the most popular in Latvian farms.

Both wheat cultivars are of high bread–making quality (Elite cultivars), differing in their high molecular weight (HMW) glutenin composition. Wheat 'Bussard' possesses subunit 1 at Glu – A1 locus α allele, and 'Zentos' possesses subunit 0, respectively. Both cultivars have the same patterns 7 + 9 at Glu – B1 c and 5 + 10 at Glu – D1 locus d alleles (Mašauskienė et al., 2002).

These cultivars were grown in four replications with a plot size of 36 m^2, at the rate of 450 germinating seeds per m^2. Treatments were arranged in a randomized block design. The fertilizer background was P_2O_5 – 70 kg ha^{-1} and K_2O – 90 kg ha^{-1}. Nitrogen was applied in spring after resumption of vegetative growth. Nitrogen (N) top-dressing rates were as follows: N60, N90, N120 and N150. All the necessary plant protection measures (herbicides, plant growth regulators and fungicides) were performed. Wheat grain was harvested at full ripening (GS 90 – 92) with harvester Sampo Rosenlew-130 on 4 August in 2010, on 5 August in 2011 and on 3 August in 2012. The yield of winter wheat grain was recalculated in t ha^{-1} at 14% moisture and 100% purity.

Weather conditions. During three investigation years weather conditions were different. Winter wheat in all three years overwintered successfully. The duration of winter wheat growth from spring after the resumption of vegetative growth to harvesting was different in the trial years: in 2010 and 2011 – 126 and 121 days, respectively; in 2012 – 111 days (because that year, the vegetation period began later – on April 15) (Table 2). Precipitation in grain filling period in July, which is most decisive for grain quality formation, was 298, 179, and 197 mm in 2010, 2011, and 2012, respectively, which significantly exceeded the long-term average (81.7 mm). The sum of active temperatures (above +5 °C) in the winter wheat vegetation period in 2010 and 2011 was 1,777 and 1,769 °C, respectively, while the year 2012 was cooler with a lower active temperature – 1,561 °C.

To evaluate the conditions of dampness of the area, the Seljanin's hydrothermal coefficient (HTC) was used, which shows the relationship between the amount of precipitation and the air temperature (above +10 °C) in the vegetation period. It is given by the following relation:

$$\text{HTC} = \frac{\sum N}{\sum t} \times 10$$

where $\sum$ N – is the sum of precipitation (mm) during period; $\sum t$ – the sum of average daily temperatures (°C) during the same period; 10 – coefficient.

In the vegetation period of 2010 and 2012, excessive moisture was observed, and HTC was 2.79 and 2.65, respectively. In 2011, HTC was 1.92, which indicates a sufficient amount of moisture.

Table 2. Duration of winter wheat growth stages and description of weather conditions in 2010–2012

Traits	Year	Zadoks growth stages (GS)*			
		24–91	24–30	31–0	51–91
Duration of the period, days	2010	126	45	29	52
	2011	121	42	20	61
	2012	111	31	19	61
Sum of active temperatures (+ 5 °C)	2010	1,777	360	424	994
	2011	1,769	363	296	1,111
	2012	1,561	310	236	1,016
	2010	14.1	8.0	14.6	19.1
Mean daily temperature, °C	2011	14.5	8.9	14.8	18.2
	2012	14.7	10.0	12.4	16.7
	2010	495	107	52	337
Sum of precipitation, mm	2011	339	71	13	255
	2012	414	89	35	289
	2010	2.79	2.96	1.23	3.24
Hydrothermic coefficient (HTC)	2011	1.92	1.96	0.43	2.26
	2012	2.65	2.88	1.50	2.75

* Zadoks growth stages (GS); 24–91 (from tillering (main shoot and 4 tillers) to ripening); 24–30 (from main shoot and 4 tillers to stem elongation); 31–50 (from stem elongation (1st node detectable) to heading; 51–91 (from heading to ripening) (Zadoks, Chang & Konzak, 1974).

Statistical analysis. Experimental data evaluation was done using three – factor (SPSS) analysis of variance by Fisher's criterion ($p < 0.05$) and least significant difference ($LSD_{0.05}$). Influence (ŋ, %) of each factor (crop-year, nitrogen fertilizer, cultivar and interaction of them) was calculated of three – factor analysis of variance for winter wheat grain yield. It was expressed as percentage to the total variance. Correlation (r) and determination coefficient (R^2), regression equation between grain yield and hydrothermic coefficient were also carried out.

RESULTS AND DISCUSSION

Influence of weather conditions on grain yield. In total, obtained grain yields of both investigated winter wheat cultivars, averaged over three years, were 6.22 ± 0.11 t ha^{-1} (within the range (min-max) of 5.13 to 6.92 t ha^{-1}) with a coefficient of variation (V, %) 8%.

According to Fisher's criterion, the influence of weather conditions (2010–2012 crop-years) on winter wheat grain yield was significant ($p < 0.05$). According to the results of our research, significantly ($p < 0.05$) lower grain yield was obtained in 2011 (5.84 t ha^{-1}) (Fig. 1), when the average amount of precipitation in the vegetation period was lower (339 mm, HTC 1.92) (Table 1). There was a significant disturbance in plant nutrition (HTC 0.43) in GS 31–51, also the relatively high average temperatures in June (17.2 °C) and July (19.5 °C) negatively affected the ripening process and grain yield of winter wheat.

The higher grain yield was obtained in 2010 crop-year – 6.60 t ha^{-1}. The vegetation period in 2010 was rainy and HTC was the highest – 2.3, compared with others trial years (Table 2). The period from stem elongation to heading (GS 31–51) in this year was 29 days, which was by 5 and 15 days longer compared to the years 2011 and 2012 respectively, but HTK was 1.2, indicating that wheat plants had enough moisture and warmth, which positively influenced the growth and development of wheat plants. Increased rainfall greatly influenced the process of grain formation having a positive effect on grain yield, but negative effect on the quality of grain.

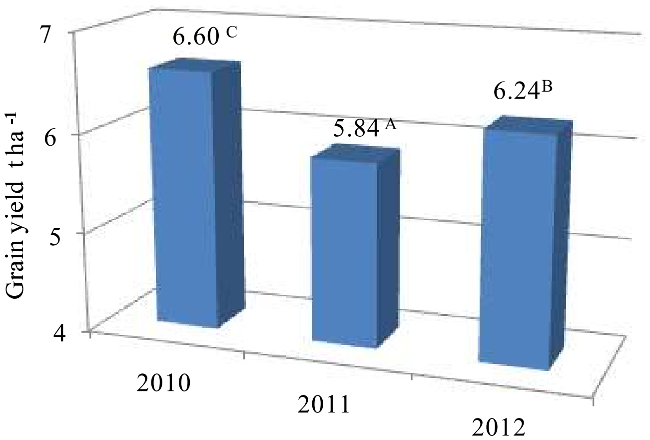

Figure 1. Influence of weather conditions on winter wheat grain yield (t ha^{-1}), 2010–2012 on average; ^{ABC} columns marked with different letter did differ significantly ($p < 0.05$).

Winter wheat yield significantly varied depending on the differences among cultivars (Cesevičienė et al., 2012; Kaya & Akcura, 2014). Investigation results in Lithuania (2000–2007) show that the average grain yield of the cultivar 'Zentos' was 6.6 t ha^{-1} (Liatukas et al., 2012) which is consistent with our results. The research data from other scientists show that winter wheat yield in favourable years was 8 – 10 t ha^{-1} (Tarakanovas & Ruzgas, 2006; Jansone & Gaile, 2011; Jansone & Gaile, 2013; Fetere & Strazdina, 2014; Alijošius et al., 2016; Gaile et al., 2017), while in adverse year 3 – 5 t ha^{-1} (Ivanova & Tsenov, 2012; Jablonskytė-Raščė, et al., 2013; Skudra & Ruza, 2016). Wheat productivity largely depends on climatic conditions, in particular on the total precipitation and temperature in the trial year (Bujak et al., 2013; Faměra et al., 2015; Karklins & Ruza, 2015). Similar results were obtained in our research. When the growing conditions are dry and warmer, compared with the long-term mean, wheat grain yield is poorest (Teesalu & Leedu, 2001; Cesevičienė, Leistrumaitė & Paplauskienė, 2009; Kozlovsky et al., 2009) while the grain quality is improving (Cesevičienė et al., 2012). In our investigation it was determined, that in 2010 and 2011 crop-years there were lower winter wheat grain yields but better grain quality, compared to 2012 crop-year, as described in our previous paper (Liniņa & Ruža, 2012; Linina & Ruza, 2015).

Interaction of hydrothermic coefficient (HTC) and wheat grain yield. HTC is one of the interpretations of humidity on plant development used in wheat and other crops. Statistically medium strong positive correlation was found between HTC in the vegetation period from winter wheat heading to grain ripening (GS 51–91) and grain yield $r = 0.577$ (significant at 99%) ($n = 24$, $\alpha_{0.01} = 0.515$) $R^2 = 0.37$, $p = 0.026$. As shown, the increase in HTC in 37% cases resulted also in grain yield increase (Fig. 2).

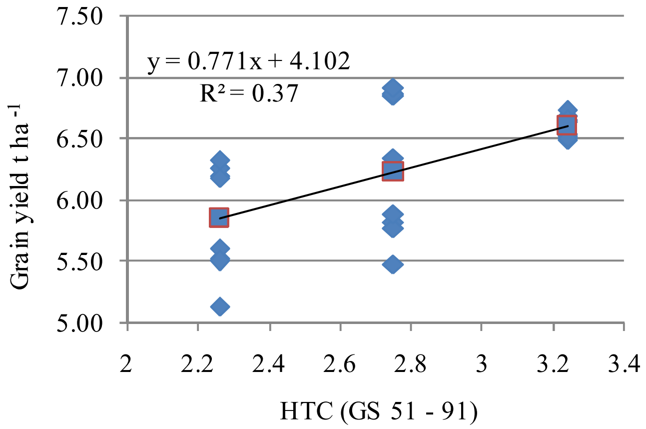

Figure 2. Correlation between wheat grain yield and hydrothermic coefficient (HTC), 2009/2010, 2010/2011 and 2011/2012 crop-years (GS 51–91).

Influence of nitrogen fertilizer on grain yield. In the current research nitrogen fertilizer was significantly ($p < 0.05$) increasing winter wheat grain yield. It should be noted that the lowest winter wheat grain yield was obtained using nitrogen fertilizer N60 – 6.08 t ha^{-1} (Fig. 3). Grain yield increase with N90 compared to N60, while further use of increasing amounts of N fertilizer did not increase grain yields significantly.

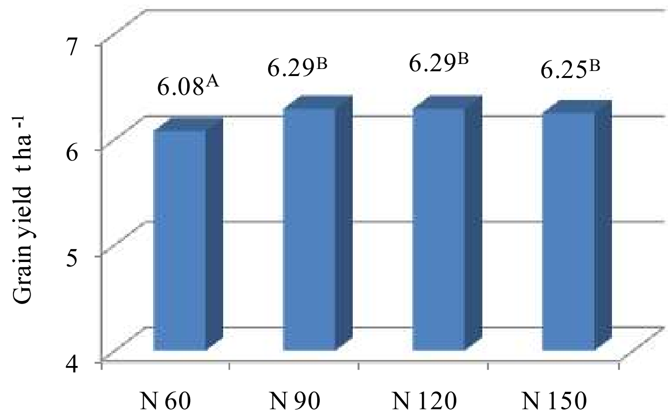

Figure 3. Influence of nitrogen fertilizer norm on winter wheat grain yield (t ha^{-1}), 2010–2012 on average, ^{ABC} columns marked with different letter did differ significantly ($p < 0.05$).

Grain yield significantly varied depending on the nitrogen fertilizer as previously observed (Cesevičienė et al., 2012; Jablonskitė-Raščė et al., 2012; Márton, 2008, Shejbalova et al., 2014; Skudra & Ruza, 2016). The nitrogen fertilizer is an important factor that stabilises the grain yield of winter wheat. However, the nitrogen effect is small compared to crop-year and cultivar influences (Teesalu & Leedu, 2001) and it is in agreement with our investigation. The effect of fertilizer depends on weather conditions during investigation year.

Influence of cultivar, crop-year and nitrogen fertilizer on grain yield. Influence (ŋ, %) of each factor (crop-year, nitrogen fertilizer, cultivar and interaction of them) was calculated of three – factor analysis of variance for winter wheat grain yield. It was expressed as percentage to the total variance. Results suggest, that winter wheat grain yield by 34% depended on cultivar, by 33% on crop-year (weather conditions), and by 13% on crop-year × cultivar. Influence of the nitrogen fertilizer effect was small – 3% (Table 3).

Table 3. Analyses of variance of winter wheat grain yield for two cultivars grown in three crop-years (2010–2012)

Source	DF	SS	MS	ŋ, %
Total	95	28.21	–	–
Crop-year (A)	2	9.18	4.59*	33
N fertilizer (B)	3	0.74	0.25*	3
Cultivar (C)	1	9.63	9.63*	34
A × C	2	3.66	1.83*	13
B × C	3	0.03	0.01	0 (ns)
A × B	6	1.00	0.17	4 (ns)
A × B × C	6	0.25	0.04	1 (ns)
Error	72	3.72	0.05	–

* – significant at the 0.05 probability level; DF – degree of freedom; SS – sum of squares; MS – mean square; ns – not significant at the 0.05 probability level.

There are not significant effect cultivar × nitrogen fertilizer, crop-year × nitrogen fertilizer and cultivar × nitrogen fertilizer × crop-year on winter wheat grain yield. Grain yield was affected most by the weather conditions during experimental year, but the genotype of the cultivar had some impact on the variation as well (Tarakanovas & Ruzgas, 2006) as it confirmed in the present trial.

Several authors have determined the effect of the cultivar, crop-year and interaction on the winter wheat grain yield (Rozbicki et al., 2015). The influence of the crop-year on grain yield was most important also in research results reported from Lithuania (Tarakanovas & Ruzgas, 2006; Cesevičienė et al., 2012). Only a few authors have studied nitrogen fertilizer, crop-year, and cultivar effects (impact factor – ŋ, %) on winter wheat grain yield. Results (2002–2004) at the State Stende Plant Breeding station in Latvia suggest, that winter wheat grain yield by 23% depended on crop-years (weather conditions), by 16% on nitrogen fertilizer, by 29% on nitrogen fertilizer × cultivar and by 3% on cultivar (Malecka, Bremanis & Miglane, 2005), while in the current research the nitrogen effect was smaller (Table 3).

CONCLUSION

1. The grain yield of winter wheat was affected mainly by cultivar and crop-year, less effect was to nitrogen fertilizer and interaction between these factors.
2. Insufficient precipitation and higher daily temperature from the stem elongation to heading of wheat resulted in lower grain yield.
3. Medium strong positive correlation was found between HTC in the vegetation period from winter wheat heading to grain ripening.

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