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Effect of nitrogen rate and forecrop on nitrogen use efficiency in winter wheat (*Triticum aestivum*)

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Abstract. Application of plant nutrient is one of the most important measures increasing grain yield and yield quality. Excessive application of nitrogen fertilizers leads to nitrogen leaching and it affects the quality of groundwater and surface water. The objective of this research was to evaluate the effect of nitrogen fertilizer rate on nitrogen use efficiency in winter wheat after two forecrops. The experiment was conducted at the Research and Study farm 'Pēterlauki' of Latvia University of Life Sciences and Technologies (56° 30.658' N and 23° 41.580' E) in four growing seasons: 2014/2015, 2015/2016, 2016/2017 and 2017/2018. Researched factors were crop rotation (wheat/wheat and oilseed rape (*Brassica napus* ssp. *oleifera*/wheat) and five nitrogen fertilizer rates (kg ha^{-1}): N0 or control, N60, N120(90+30), N180(90+60+30) and N240(120+60+60). Nitrogen fertilizer affected winter wheat grain yield significantly ($P < 0.001$) and average grain yield increased significantly ($P < 0.049$) until nitrogen rate N180. But analyzing it after each forecrop separately, yield increased significantly ($P < 0.05$) until N120 after both forecrops. Nitrogen fertilizer affected nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUpE), nitrogen utilization efficiency (NUtE) and protein content significantly ($P < 0.001$). When increasing nitrogen fertilizer rate NUE, NUpE and NUtE decreased, and higher results were observed at the lowest nitrogen rates. Increased nitrogen fertilizer rate also increased crude protein content in grain, and for bread baking suitable grain was obtained only with the highest N rate: N 240. Forecrop did not affect winter wheat grain yield, however, it affected NUtE ($P < 0.01$), NUE ($P < 0.001$) and nitrogen harvesting index ($P < 0.001$) significantly; higher results were observed when wheat was grown after wheat.

Key words: forecrop, nitrogen fertilizer, winter wheat, nitrogen use.

INTRODUCTION

The growth and development of any plant requires optimal supply of plant nutrients. The amount of nutrients in the soil and organic fertilizers cannot provide enough nutrients to produced high grain yields with appropriate quality for processing. Therefore, the use of mineral fertilizers as additional source of plant nutrients plays an important role in agriculture. Nitrogen shows the most apparent effect on yield and quality formation. At the same time, excessive application of nitrogen containing fertilizers not only increases production costs, but also leads to leaching of nitrogen from the soil. In its turn, leaching affected the quality of surface water and groundwater quality.

Nitrogen use efficiency is important indicator showing the amount of grain obtained on the nitrogen unit consumed. Nitrogen use efficiency depends on several factors. The most important factors are: meteorological conditions in growing season and applied cultivation technology. Nitrogen efficiency affected applied fertilizer – type of fertilizer, fertilizer rate and timing of fertilizer application (Haile et al., 2012). Previous studies in Latvia indicate that winter wheat grain yield increased significantly until nitrogen fertilizer rate N120 and with each next nitrogen fertilizer rate nitrogen fertilizer return decreased (Ruža et al., 2003). Other studies also contain information that increasing nitrogen rate decreased nitrogen use efficiency (Rahimizadeh et al., 2010; Haile et al., 2012). However, when changing crop varieties and using intensive cultivation technologies, farmers also use higher fertilizer rates. Therefore, it is important to find out nitrogen fertilizer rates which are agronomically justified. The aim of this paper is to evaluate the effect of nitrogen fertilizer rate on nitrogen use efficiency (NUE) of winter wheat after two forecrops.

MATERIALS AND METHODS

The experiment was conducted at the Research and Study farm 'Pēterlauki' of Latvia University of Life Sciences and Technologies (56° 30.658` N and 23° 41.580` E). Trial was repeated four years: 2014/2015, 2015/2016, 2016/2017 and 2017/2018, and it was arranged using split plot design in four replications, plot size was 25 m^2. As previously described, the researched factors were crop rotation (wheat/wheat and oilseed rape (*Brassica napus* ssp. *oleifera)*/wheat) and nitrogen fertilizer rate (altogether five rates: N0 or control, N60, N120 (90+30), N180 (90+60+30) and N240 (120+60+60). Totally, eight nitrogen rates were used in the trial (in addition to the mentioned: N 90, N150(90+60) and N210(90+70+50) (Litke et al., 2018)), but NUE and other parameters related to nitrogen use by crop (described below) were calculated and analysed only taking into account five rates. Traditional soil tillage with mould-board ploughing at depth of 20–22 cm was used. Straw of both forecrops was incorporated in the soil.

Table 1. Soil agrochemical characteristics depending on forecrop and growing season in winter wheat trial

Growing year and forecrop	pH KCl	Organic matter content, g kg^{-1}	P_2O_5 content, mg kg^{-1}	K_2O content, mg kg^{-1}
2014/2015				
wheat after oilseed rape	6.3	31	69	158
wheat after wheat	6.7	24	237	224
2015/2016				
wheat after oilseed rape	6.9	24	247	328
wheat after wheat	6.7	23	131	195
2016/2017				
wheat after oilseed rape	7.2	32	171	207
wheat after wheat	6.8	21	187	225
2017/2018				
wheat after oilseed rape	6.5	37	112	189
wheat after wheat	6.9	38	175	300

Note: pH KCL was detected potentiometrically in 1 *M* KCl suspension; organic matter content – oxidizing the soil with potassium dichromate ($K_2Cr_2O_7$); P_2O_5 and K_2O content was detected using Egner–Riehm (DL) method.

Soil at the site was loam, *Endocalcaric Abruptic Luvisol* (Cutanic, Hypereutric, Ruptic, Silitic, Protostangnic Epiprotovertic). Soil agrochemical characteristics are described in Table 1.

In the trial, cultivar 'Skagen' was used. This is one of the most commonly used cultivars in Latvia and it is characterized by good winterhardiness, which is combined with disease resistance and baking quality of grain, notably high and stable falling number. Sowing rate depended on sowing time and trial meteorological conditions: 450 germinable seed per m^2 in 2014/2015 (after oilseed rape), 2015/2016 (after both forecrops), but 500 germinable seed m^2 in 2014/2015 (after wheat), 2016/2017 and 2017/2018 (after both forecrops).

In spring, when the vegetation had renewed, nitrogen fertilizer (NH_4NO_3; N 34%) was applied for all variants, except the control variant N0. Second top-dressing was done at GS 29–31 of winter wheat with ammonium sulphate ($(NH_4)_2SO_4$; N 21%, S 24%) at the rate 100 kg ha^{-1} and remaining amount of needed nitrogen was added using ammonium nitrate. The third top-dressing was done at GS 47–51 using ammonium nitrate. The whole rate of fertilizer was applied once for variant N60 and N90; rate was divided into two application for variants N120 and N150, but into three application – for variants N180, N210 and N240. Grain yield was harvested at GS 90–91 using combine Sampo 130. After harvesting, grain was weighted, grain purity and moisture content detected and yield data was recalculated to standard moisture (14%) and 100% purity. Before yield harvesting, plant samples were taken from each plot (from 0.18 m^2) to calculate straw and main root mass (plants were dug out from the top-soil layer) in t ha^{-1}. Samples of grain, straw and roots were used to determine the content of NPK in them. The analysis of N, P, K content was carried out at the Scientific Laboratory of Biotechnology Department of Agronomic Analysis of the Latvia University of Life Sciences and Technologies determining the content of N according the Kjeldahl method (LVS EN ISO 5983–2:2009), P – according the Spectrometric method (ISO 6491:1998), and K – using atomic absorption spectrometry (LVS EN ISO 6869:2002). To convert elements' P and K concentration to oxide, P_2O_5 and K_2O coefficients were used: $P_2O_5 = P \times 2.291$ and $K_2O = K \times 1.204$. Nutrients' removal was calculated using grain, straw and root mass and concentration of nutrient in them. Protein content was calculated by multiplying nitrogen content in grains by coefficient 5.75. Nitrogen use efficiency was calculated according to the following formulas:

$$\text{Nitrogen use efficiency (NUE, kg kg}^{-1}) = G_y / N_{supply}, \quad (1)$$

where G_y – grain yield, kg ha^{-1}; N_{supply} – sum of nitrogen used from soil in control variant (N-0) and from nitrogen fertilizer, kg.

$$\text{Nitrogen uptake efficiency (NUpE, kg kg}^{-1}) = N_t / N_{supply} \quad (2)$$

where N_t – total plant N uptake, kg; N_{supply} – explained below formula (1)

$$\text{Nitrogen utilization efficiency (NUtE, kg kg}^{-1}) = G_y / N_t \quad (3)$$

where G_y – grain yield, kg ha^{-1}; N_t – total plant N uptake, kg

$$\text{Nitrogen harvesting index (NHI, \%)} = (N_g / N_t) \times 100 \quad (4)$$

where N_g – total grain N uptake; N_t – total plant N uptake, kg.

Meteorological conditions of three years (2014/2015; 2015/2016 and 2016/2017) were described in detail in our previous paper (Litke et al., 2018). Conditions differed significantly during the last trial year (2017/2018). Meteorological conditions of growing season 2017/2018 differed significantly also from the long-term average data. Autumn of 2017 was warm and excessively rainy. Prolonged drought period started during May 2018. The drought period lasted until yield harvesting. This affected the plant growth and development and use efficiency of applied fertilizer.

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

RESULTS AND DISCUSSION

Nitrogen fertilizer is important for wheat growing and yield production. According to the research results, nitrogen has great influence on wheat, and different amount of nitrogen fertilizer has different effects on wheat grain yield (Liu & Shi, 2013). Results of our trials also indicated that the nitrogen fertilizer application significantly ($P < 0.001$) increased winter wheat grain yield. Even lower nitrogen fertilizer rates gave a significant yield increase, if compared with control (N0). Average four year winter wheat grain yield (after both forecrops) was 4.72 (N0)–8.96 (N240) t ha^{-1} and significant ($P = 0.049$) increase was observed until nitrogen rate N180 (Fig. 1). If we analyze the grain yield after each forecrop separately, important yield increase was also observed until the rate N180 (8.87 t ha^{-1} after rape, increase +0.67, if compared with N120; 8.69 t ha^{-1} after wheat, increase +0.62 t ha^{-1}, if compared with N120), but this increase, if compared with variant N120, was not mathematically significant ($P = 0.569$ and $P = 0.404$, respectively) (Fig. 1).

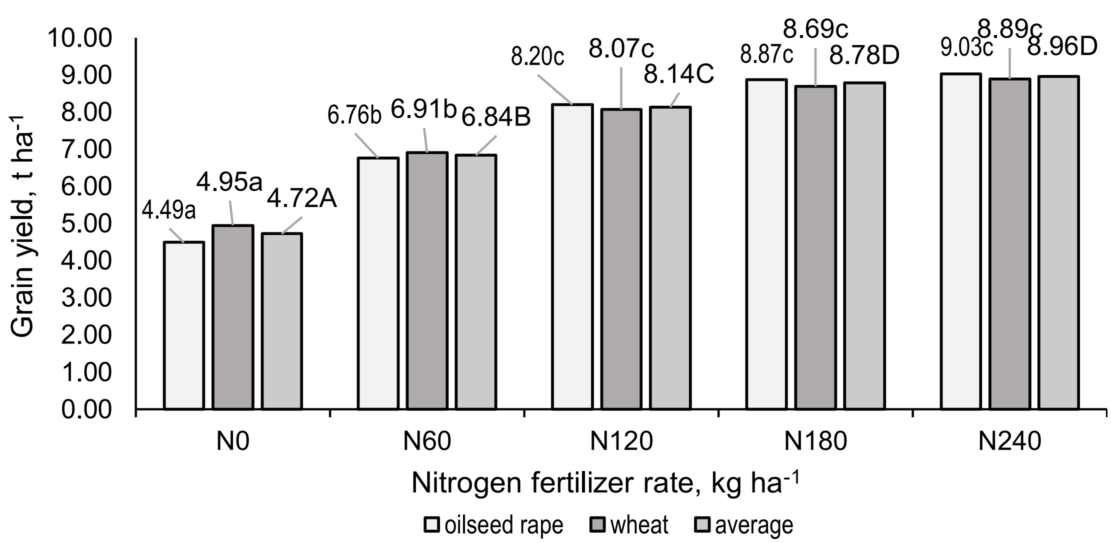

Figure 1. Average four year winter wheat grain yield depending on nitrogen fertilizer rate and forecrop (^{a,b,c} – yields labelled with different small letters are significantly different after specific forecrop depending on N rate.; ^{A,B,C} – average yields labelled with different capital letters are significantly different depending on N rate).

Yield changes in the first three trial years, including calculation of all eight N rates and also effect of soil tillage, were described more in detail in our previous publication (Litke et al., 2018), in which we also showed significant yield increase until the rate N180. But similar studies in Latvia showed that the grain yield increased significantly until nitrogen fertilizer rate N120 (Ruža et al., 2003; Kārkliņš, Līpenīte & Ruža 2017). This can be explained with different agro-meteorological conditions of previous trials, and in addition, average results per 10 winter wheat varieties were described in paper written by Ruža et al. (2003).

Nutrient removal

Nutrient removal is the quantity of nutrients, which are removed with plant material from the field. Nutrient removal with plant material is depending on the size of the harvested yield and its nutrient content. Nutrient removal by harvested yield is one of the ways how nutrients from the soil and given fertilizers leave the field. In our trial, nitrogen fertilizer affected N, P and K content in grain significantly ($P < 0.001$). Results showed that the nitrogen fertilizer rate affected N, P_2O_5 and K_2O removal with grain yield significantly ($P < 0.001$) (Table 2). Results also showed that the increase of nitrogen rate increases also nutrient removal. Nutrients' removal was higher when higher fertilizer rates were used. Depending on nitrogen fertilizer rate, N removal was 66.29–206.05 kg ha^{-1}. Significant increase, depending on forecrop, was observed until nitrogen rate N180 (if forecrop was wheat) – N240 (if forecrop was oil-seed rape). Average P_2O_5 removal with grain yield was 35.26–62.58 kg ha^{-1}, and P_2O_5 removal significantly increased until nitrogen rate N60–N120. Average K_2O removal, depending on nitrogen rate, was 24.68–46.12 kg ha^{-1}, and significant increase of K_2O removal after both forecrops was observed until nitrogen rate N120 (Table 2).

Table 2. Nutrient removal, kg ha^{-1}, with grain yield depending on forecrop and applied N rate on average per trial period

N rate	N removal, kg ha^{-1}		P_2O_5 removal, kg ha^{-1}		K_2O removal, kg ha^{-1}	
	oilseed rape	wheat	oilseed rape	wheat	oilseed rape	wheat
N0	66.29^{a}	68.36^{a}	35.26^{a}	37.90^{a}	26.12^{a}	24.68^{a}
N60	102.24^{b}	105.00^{b}	49.79^{b}	50.43^{ab}	38.40^{b}	36.61^{b}
N120	128.68^{b}	144.91^{c}	56.88^{bc}	56.67^{b}	46.12^{c}	41.23^{bc}
N180	177.28^{c}	181.85^{d}	60.70^{c}	59.22^{b}	44.42^{bc}	43.28^{c}
N240	206.05^{d}	202.12^{d}	62.58^{c}	60.25^{b}	44.21^{bc}	43.48^{c}

^{a,b,c,d,e} – indicators labelled with different letters are significantly different in columns depending on N rate.

Results showed that the forecrop had no significant impact on N ($P = 0.296$, P ($P = 0.545$) and K ($P = 0.612$) content in wheat grain. It coincides with other findings where forecrop had no effect on P and K in wheat grain (Wanic et al., 2018). Results showed that the forecrop affected significantly ($P < 0.05$) only K_2O removal with grain yield. Higher K_2O removal with grains was observed, when wheat was grown after oilseed rape, if compared with wheat growing after wheat. Forecrop did not show any significant effect on N ($P = 0.082$) and P_2O_5 ($P = 0.889$) removal.

Nitrogen fertilizer significantly ($P < 0.001$) affected N and K content in wheat straw, but had no impact ($P = 0.910$) on P content in straw. Ruža et al. (2013) found that by increasing nitrogen rate also K_2O content increased rapidly in straw of barley, and in its turn also its removal increased. Wheat straw contains the least amount of P_2O_5 and N, but the most amount of K_2O. As a result, straw mass removes the most amount of K_2O from the soil, but the least amount of P_2O_5. Nutrients' (N, P_2O_5, K_2O) removal with straw mass was significantly ($P < 0.001$) affected by nitrogen fertilizer rate. The increase of nitrogen fertilizer rate increases the nutrient removal with straw. Depending on nitrogen fertilizer rate, N removal with straw was 13.41–53.94 kg ha^{-1} (Table 3), P_2O_5 removal was 5.41–10.15 kg ha^{-1}, but K_2O 30.43–138.54 kg ha^{-1}

Table 3. Nutrient removal, kg ha^{-1}, with wheat straw mass depending on forecrop and N rate on average per trial period

N rate	N removal, kg ha^{-1}		P_2O_5 removal, kg ha^{-1}		K_2O removal, kg ha^{-1}	
	oilseed rape	wheat	oilseed rape	wheat	oilseed rape	wheat
N0	13.49^{a}	13.41^{a}	5.78^{a}	5.41^{a}	31.72^{a}	30.43^{a}
N60	22.59^{ab}	21.52^{ab}	6.48^{a}	6.44^{a}	54.67^{b}	49.37^{ab}
N120	35.55^{bc}	28.45^{ac}	7.55^{ab}	7.97^{a}	86.33^{c}	72.51^{bc}
N180	42.62^{cd}	37.27^{bc}	8.62^{ac}	8.54^{a}	108.36^{c}	95.19^{c}
N240	53.94^{d}	44.07^{c}	10.15^{bc}	9.30^{a}	138.54^{d}	91.64^{c}

$^{a,b,c,d.e}$ – indicators labelled with different letters are significantly different in columns depending on N rate.

Forecrop had no significant impact on N ($P = 0.182$), P ($P = 0.492$) and K ($P = 0.074$) content in wheat straw. Our results showed that forecrop had no significant ($P = 0.536$) impact on P_2O_5 removal with straw mass, but it had a significant ($P < 0.001$) impact on N and K_2O removal with straw. When growing wheat after oilseed rape, N and K_2O removal with straw was higher, if compared with the variant where wheat was grown after wheat.

Nitrogen fertilizer affected significantly N ($P < 0.001$) and P ($P < 0.01$) content in the main root mass, but significant impact was not observed on K ($P < 0.227$) content in main root mass. Winter wheat roots mostly remove N and K_2O from the soil, but P_2O_5 removal was the least. Depending on nitrogen rate and forecrop, N removal with main root mass was 2.06–5.05 kg ha^{-1} (Table 4), K_2O removal was 2.00–5.25 kg ha^{-1} and that of P_2O_5 was 0.67–0.96 kg ha^{-1}. Results showed that the nitrogen fertilizer rate had a significant ($P < 0.001$) impact on N and K_2O removal with winter wheat main root mass, but it had no significant ($P = 0.283$) impact on P_2O_5 removal. Increase of nitrogen fertilizer rate also increased N and K_2O removal with main root mass.

Table 4. Nutrient removal, kg ha^{-1}, with wheat main root mass depending on forecrop and N rate on average per trial period

N rate	N removal, kg ha^{-1}		P_2O_5 removal, kg ha^{-1}		K_2O removal, kg ha^{-1}	
	oilseed rape	wheat	oilseed rape	wheat	oilseed rape	wheat
N0	2.17^{a}	2.06^{a}	0.86^{a}	0.77^{a}	2.71^{a}	2.00^{a}
N60	3.26^{ab}	2.43^{ab}	0.96^{a}	0.83^{a}	3.58^{ab}	2.38^{a}
N120	3.65^{bc}	3.01^{bc}	0.85^{a}	0.73^{a}	3.82^{ac}	2.52^{a}
N180	4.54^{bd}	3.46^{c}	0.91^{a}	0.78^{a}	4.66^{bc}	3.19^{a}
N240	5.05^{cd}	3.66^{c}	0.89^{a}	0.67^{a}	5.25^{bc}	2.45^{a}

$^{a,b,c,d.e}$ – indicators labelled with different letters are significantly different in columns depending on N rate.

Forecrop affected significantly ($P < 0.001$) only K content in wheat roots. But forecrop affected significantly ($P < 0.001$) removal of all three nutritional elements with main root mass. Higher N, P_2O_5 and K_2O removal was observed when wheat was grown after oilseed rape, if compared to wheat growing after wheat.

The total removal of nutrients is the necessary amount of nutrients for crop yield production. Nitrogen fertilizer affected significantly ($P < 0.001$) total nutrients' removal. Increasing nitrogen rate increases also the grain yield, and in its turn – the total nutrient removal increases. Depending on nitrogen fertilizer rate, total N removal was 78.76–257.34 kg ha^{-1}, P_2O_5 removal was 40.86–71.29 kg ha^{-1} and K_2O removal was 56.47–181.47 kg ha^{-1} (Table 5).

Table 5. Total nutrient removal, kg ha^{-1}, with winter wheat biomass depending on forecrop and N rate on average per trial period

N rate	N removal, kg ha^{-1}		P_2O_5 removal, kg ha^{-1}		K_2O removal, kg ha^{-1}	
	oilseed rape	wheat	oilseed rape	wheat	oilseed rape	wheat
N0	78.76^{a}	79.30^{a}	40.86^{a}	42.36^{a}	60.01^{a}	56.47^{a}
N60	124.62^{b}	126.15^{b}	56.45^{b}	55.71^{ab}	98.14^{b}	87.52^{ab}
N120	161.84^{b}	174.32^{c}	63.78^{bc}	63.82^{ac}	134.64^{c}	115.47^{bc}
N180	220.06^{c}	218.29^{cd}	68.61^{bd}	66.60^{bc}	156.39^{cd}	141.10^{c}
N240	257.34^{c}	244.91^{d}	71.29^{cd}	68.52^{bc}	181.47^{d}	136.79^{c}

^{a,b,c,d,e} – indicators labelled with different letters are significantly different in columns depending on N rate.

Results indicated that the forecrop had a significant ($P < 0.001$) impact only on the total K_2O removal, but it had no significant impact on the total N ($P = 0.982$) and P_2O_5 ($P = 0.549$) removal. Higher total K_2O removal was observed when wheat was grown after oilseed rape.

The nitrogen use efficiency

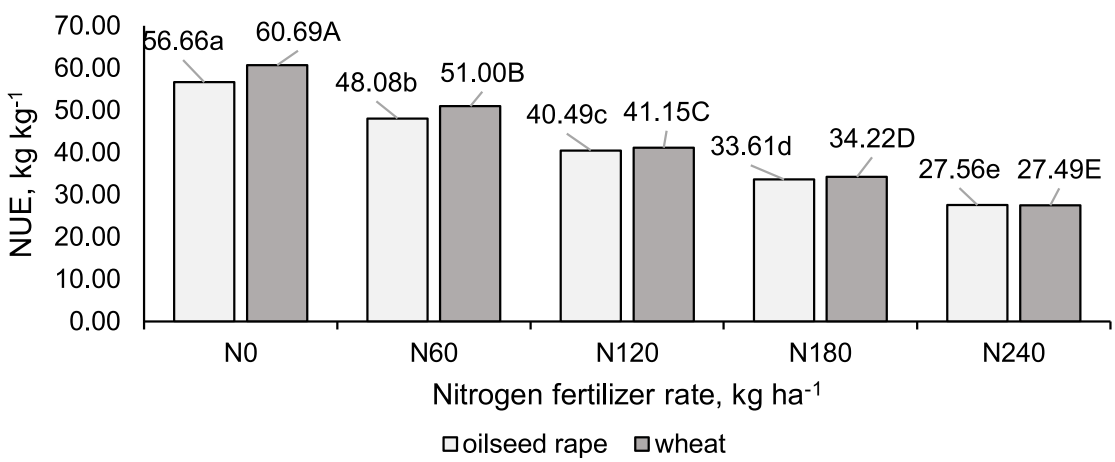

Figure 2. Average winter wheat nitrogen use efficiency (NUE) depending on nitrogen fertilizer rate and forecrop during 2014/2015–2017/2018 (^{a,b,c,d,e} – yield labelled with different letters are significantly different depending on N rate after oilseed rape, ^{A,B,C,D,E} – yields labelled with different letters are significantly different depending on N rate after wheat).

Nitrogen use efficiency (NUE) shows the capacity of given genotype to take advantage of the applied nitrogen and capacity to transform it in grains (Todeschini et al., 2016). Higher NUE of plants can not only enhance crop yields, but also reduce fertilizer input costs, decrease nutrient loss rate (Baligar et al., 2007). Our results indicated that the nitrogen fertilizer rate affected significantly ($P < 0.001$) NUE, and higher NUE was in the variants with the lowest nitrogen rates. NUE ranged between 27.49–60.69 kg kg^{-1}, depending on nitrogen rate (Fig. 2). In control (N0) variant, the highest NUE (56.66–60.69 kg kg^{-1}) was observed; crop used N only from the soil reserves in this variant. Increase of the nitrogen fertilizer rate decreases NUE. This result was similar with another study, in which it was also found that the increase of nitrogen fertilizer rate gradually decreased the return on 1 kg of nitrogen fertilizer (Haile et al., 2012; Maļecka & Ruža, 2013).

Forecrop has also a significant ($P < 0.001$) impact on NUE (Table 6). Higher NUE was obtained when wheat was grown after wheat. Similarly, Rahimizadeh et al. (2010) found that the forecrop affected NUE, but in his study, the lowest NUE of wheat was observed when wheat was grown after wheat. Our results are different also from the results of Lopez-Bellido Garrido & Lopez-Bellido (2001), who found that nitrogen use efficiency was considerably lower in repeated spring wheat sowings in Mediterranean climate, if compared with wheat growing in different crop rotations.

Table 6. The mean N uptake efficiency (NUpE), N utilization efficiency (NUtE), nitrogen use efficiency (NUE), N harvesting index (NHI) and grain protein content depending on forecrop and nitrogen fertilizer rate

Factor	NUpE, kg kg^{-1}	NUtE, kg kg^{-1}	NUE, kg kg^{-1}	NHI, %	Protein, %
Forecrop					
Oilseed rape	0.84 a	47.36a	41.28a	78.05a	10.1a
Wheat	0.88 a	48.74b	42.91b	81.61b	10.6a
N rate					
N0	0.99 a	58.49 a	58.49 a	80.31 a	8.3 a
N60	0.89 ab	55.13 ab	49.41 b	79.90 a	8.8 a
N120	0.82 b	49.85 b	40.79 c	78.74 a	9.6 a
N180	0.82 bc	41.09 c	33.89 d	80.27 a	11.8 b
N240	0.76 c	35.39 c	27.53 e	79.14 a	13.2 b

^{a,b,c,d,e} – indicators labelled with different letters are significantly different in columns depending on N rate or forecrop.

N uptake efficiency

N uptake efficiency (NUpE) can be defined as the amount of N taken up by the crop as a fraction of the amount available to the crop from all sources. NUpE associated with root structure and functioning. Early root development can promote N scavenge before fertilizer application, root development near to the soil surface enables capture of applied N, and later longer roots and deeper roots can access deeper N reserves and leached N (Hawkesford, 2014). It is mentioned in the literature that the availability of N in soil plays an important role in regulating N uptake by plant roots and the amount of N supply, and dryness in soil constrains the rate of N uptake in crop plants (Keulen & Seligman, 1987). Results showed that the nitrogen fertilizer affected significantly ($P < 0.001$) NUpE and, depending on nitrogen fertilizer rate, average NUpE ranged between 0.76–0.99 kg kg^{-1} (Table 6), decreasing when N rate was increased. Similar results were observed in other studies, where it was found that the nitrogen uptake efficiency was significantly influenced by nitrogen fertilizer rate, and N uptake efficiency was higher at lower rates of N; it decreased drastically with further increases in the rate of fertilizers (Haile et al., 2012). Forecrop had no significant ($P = 0.354$) impact on NUpE. When growing wheat after wheat, the average NUpE was 0.88 kg kg^{-1}, but growing wheat after oilseed rape – 0.84 kg kg^{-1}. This result differs from other study, where it was found that wheat NUpE was affected by forecrop and the lowest NUpE was observed when growing wheat after wheat (Rahimizadeh et al., 2010).

The nitrogen utilization efficiency

The nitrogen utilization efficiency (NUtE) is the relationship between crop yield and total N absorbed by the plant. Results indicated that the nitrogen fertilizer affected NUtE significantly ($P < 0.001$). It coincides with the results of another study (Haile et al., 2012). In our trial, NUtE was 35.39–58.49 kg kg^{-1}, depending on nitrogen fertilizer rate. Higher average NUtE was observed at lower nitrogen fertilizer rate, and with the increase of nitrogen fertilizer rate NUtE decreased. Forecrop had a significant ($P < 0.01$) influence on NUtE. When growing wheat after wheat, average NUtE was 48.74 kg kg^{-1}, but when growing wheat after oilseed rape the average NUtE was 47.36 kg kg^{-1}.

Nitrogen harvesting index

Nitrogen harvesting index (NHI) is defined as the relation between nitrogen amount in grain to total nitrogen uptake (Rahimizadeh et al., 2010). In our trial, nitrogen fertilizer did not have a significant ($P = 0.3033$) impact on NHI. This result coincides with the results of other authors' research, where it was also found that nitrogen fertilizer did not affect NHI (Rahimizadeh et al., 2010; Haile et al., 2012).

Forecrop affected NHI significantly ($P < 0.001$). Similar results were observed in other study, where it was found that the NHI of wheat varied significantly depending on forecrop (Rahimizadeh et al., 2010).

Protein content

From the economic point of view, grain yield is not the only factor affecting income. Quality of the harvested grains is also important. One of the quality indicators, which is closely related to the applied nitrogen fertilizer rate, is the crude protein (CP) content of grains. In our trial, nitrogen fertilizer affected the CP content significantly ($P < 0.001$). Similar results were obtained by many other researchers (e.g. Rahimizadeh et al., 2010; Abedi et al., 2011; Haile et al., 2012), who found that the grain protein content was significantly affected by N rates. Our results showed that with the increase of nitrogen fertilizer rate, also the CP content of the grains increases significantly ($P < 0.001$). Average grain CP content under different N application rates ranged from 8.3 (N0) to 13.2% (N240). According to the demands of grain milling companies, only the CP content above 12% is suitable for bread baking and for such grain higher price can be obtained. Such appropriate average CP content was provided only by N rate 240 kg ha^{-1}.

Results showed that the forecrop had no significant ($P = 0.215$) impact on the CP content in winter wheat grains (Table 6). This result agrees with the finding of other researchers, where it was found that the choice of forecrops had no significant influence on the protein content of wheat grain (Jankowski et al., 2015).

CONCLUSIONS

Nitrogen fertilizer affected winter wheat grain yield significantly ($P < 0.001$) and average grain yield increased significantly ($P < 0.049$) until nitrogen rate N180. Grain yield increased importantly until N180 also analyzing it separately after every forecrop, but mathematically significant this increase was until N120.

Results indicated that with increasing nitrogen fertilizer rate also removal of N, P_2O_5 and K_2O with wheat biomass increased significantly ($P < 0.001$). Significant increase of nitrogen removal with winter wheat grain yield depending on forecrop was observed until nitrogen fertilizer rate N180–N240, P_2O_5 removal significantly increased until N60 – N120, and K_2O removal significantly increased until nitrogen rate N120.

Nitrogen fertilizer affected nitrogen use efficiency (NUE), nitrogen uptake efficiency (NUpE), nitrogen utilization efficiency (NUtE) and crude protein content significantly ($P < 0.001$), but it did not have any significant ($P = 0.303$) impact on nitrogen harvesting index (NHI). When increasing nitrogen fertilizer rate NUE, NUpE and NUtE decreased, and higher results were observed at the lowest nitrogen rates. Increase in nitrogen fertilizer rate also increased protein content in grain, and suitable for bread baking grain was obtained only with the highest N rate: N 240.

Forecrop did not affect winter wheat grain yield, however, it affected significantly NUtE ($P < 0.01$), NUE ($P < 0.001$) and NHI ($P < 0.001$); higher results were observed when wheat was grown after wheat.

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REFERENCES

Abedi, T., Alemzadeh, A. & Kazemeins, S.A. 2011. Wheat yield and grain protein response to nitrogen amount and timing. *Australian Journal of Crop Science* **5**(3), 330–336.

Baligar, V.C., Fageria, N.K. & He, Z.L. 2007. Nutrient use efficiency in plants. *Communications in Soil Science and Plant Analysis* **32**(7–8), 921–950.

Haile, D., Nigussie, D. & Ayana, A. 2012. Nitrogen use efficiency of bread wheat: Effects of nitrogen rate and time of application. *Journal of Soil Science and Plant Nutrition* **12**(3), 389–409.

Hawkesford, M.J. 2014. Reducing the reliance on nitrogen fertilizer for wheat production. *Journal of Cereal Science* **59**(3), 276–283.

Jankowski, K.J., Kijewski, L. & Dubis, B. 2015. Milling quality and flour strength of the grain of winter wheat grown in monoculture. *Romanian Agricultural Research* **32**, 191–200.

Kārkliņš, A., Līpenīte, I. & Ruža, A. 2017. N fertilizer use and grain yield in Saldus experimental field. In *Proceedings of the Scientific and Practical Conference. Harmonious Agriculture.* Latvia University of Agriculture, Jelgava, Latvia, pp. 42–49 (in Latvian).

Keulen Van, H. & Seligman, N.G. 1987. *Simulation of wheat use nitrogen nutrition and growth of a spring wheat crop. Simulation Monographs*. PUDOC, Wageningen, 310 pp.

Litke, L., Gaile, Z. & Ruža, A. 2018. Effect of nitrogen fertilization on winter wheat yield and yield quality. *Agronomy Research* **16**(2), 500–509.

Liu, D. & Shi, Y. 2013. Effects of different nitrogen fertilizer on quality and yield in winter wheat. *Advance Journal of Food Science and Technology* **5**(5), 646–649.

Lopez-Bellido Garrido, R.J., Lopez-Bellido, L. 2001. Effects of crop rotation and nitrogen fertilizer on soil nitrate and wheat yield under rainfed Mediterranean conditions. *Agronomie* **21**(6–7), 509–516.

Maļecka, S. & Ruža, A. 2013. The impact of nitrogen fertilizer norm on the indicators of nutrient use for spring wheat. In *Proceeding of the Scientific and Practical Conference. Agricultural Science for Successful Farming.* Latvia University of Agriculture, Jelgava, Latvia, pp. 232–237 (in Latvian).

Rahimizadeh, M., Kashani, A., Zare-Heizabadi, A., Koocheki, A. & Nassiri-Mahallati, M. 2010. Nitrogen use efficiency of wheat as affected by preceding crop, application rate of nitrogen and crop residues. *Australian Journal of Crop Science* **4**(5), 363–368.

Ruža, A., Kreita, Dz., Krotovs, M., Maļecka, S., Stramkale, V. 2003. Nitrogen fertilizer use efficiency in winter wheat trials. *Environment. Technology. Resources* **1**, 232–237.

Ruža, A., Kreita, Dz., Katamadze, M., Skrabule, I., Vaivode, A. & Maļecka, S. 2013. The impact of nitrogen fertilizer norm on the indicators of nutrient use in spring barley. In *Proceeding of the Scientific and Practical Conference. Agricultural Science for Successful Farming.* Latvia University of Agriculture, Jelgava, Latvia, pp. 56–60 (in Latvian).

Todeschini, M.H., Milioni, A.S., Trevizan, D.M., Bornhofen, E., Finatto, T., Strock, L. & Benin, G. 2016. Nitrogen use efficiency in modern wheat cultivars. *Soil and Plant Nutrition* **75**(3), 351–361.

Wanic, M., Denert, M. & Treder, K. 2018. Effect of forecrops on the yield and quality of common wheat and spelt wheat grain. *Journal of Elementology* **24**(1), 369–383.