THE CHANGES IN NITROGEN CONTENT IN SOIL DEPENDING ON WINTER WHEAT (*TRITICUM AESTIVUM* L.) FERTILIZING SYSTEM

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Abstract
The objective of this study was to evaluate the main plant nutrient: mineral nitrogen (NH_4^+-N and NO_3-N) dynamic in soil under fertilizing for obtaining high grain yields of winter wheat (*Triticum aestivum* L.) and to determine relationships between nutrient uptake and winter wheat productivity. The field study was carried out at the Research and Study farm 'Vecauce' of the Latvia University of Agriculture for two years 2012/2013 and 2013/2014 with winter wheat variety 'Kranich'. Different nitrogen application rates (0, 85, 153, 150, 175, 180 and 187 kg ha-1) and timing were used for winter wheat. The content of nitrates NO_3-N and ammonium nitrogen NH_4-N was determined in the soil layers 0-0.20 m, 0.20-0.40 m, 0.40-0.60 m. Nitrogen management strategy during the plant growth period based on soil N_{min} evaluating can improve N use efficiency and reduce environmental contamination. The maximum of mineral nitrogen content in soil in the vegetation period was observed at the beginning of stem elongation with a tendency to decrease. A significant impact ($p < 0.05$) of nitrogen fertilizer application was noted on the mineral nitrogen content in soil layer 0-0.20 m deep in both trial years. The increasing doses of nitrogen fertilizer raised the amount of mineral N in the soil profile. The significant impact ($p < 0.001$) of nitrogen application and year conditions was observed on grain yield. Close positive correlation significant at 99% probability level was observed between the grain protein content and nitrogen concentration mostly in all soil layers, but it was not found between the grain yield and nitrogen content.
Key words: wheat, nitrates, ammonium nitrogen, fertilizers, soil, yield.

Introduction

The productivity of crop is largely limited by soil mineral nutrients. Nitrogen is the main element affecting the rate of cereal growth and yielding. Nitrogen content in the soil is controlled by climate (especially temperatures), soil management and crops, as reported by different authors (Convertini et al., 2001; Skudra and Ruza, 2002; Timbare and Busmanis, 2002; Ruza and Kreita, 2006). In crop growing it is very important to reduce losses of the ammonium and nitrate nitrogen through the leaching, which is a serious problem because of the possibility of ground and surface water pollution. The European Union Nitrate Directive (91/676/EEC) is intended to reduce soil contamination caused by nitrates from agricultural sources; the content of nitrate nitrogen should not exceed 50 mg kg^{-1} in soil (Council Directive, 1991). If soil nutrient conditions during the growing season could be controlled better, those resources could be more efficiently utilized (Tivy, 2014). Analyses of NO_3-N content can maximize the crop production and minimize environmental impact of nitrogen fertilization. Some authors (Timbare and Busmanis, 2002; Ruza and Kreita, 2006) observed that indices of soil N dynamics in the vegetation period were significantly affected by the temperature and precipitation as well as relationships of their distribution. M.Corbeels et al. (1999) determined that the high level of residual mineral nitrogen in the soil profile resulted from a low N plant uptake relative to the soil N supply and N fertilization, and masked the effect of N fertilization on dry matter accumulation. Nitrogen losses through leaching and denitrification occurred after a heavy rainfall, but were limited. For obtaining high and quality yields, nitrogen provision must correspond to the requirements of the plants and the use of nitrogen from the soil as well.

The objective of the study was to evaluate the main plant nutrient: mineral nitrogen (NH_4^+-N and NO_3-N) dynamics in soil under fertilizing for obtaining high grain yields of winter wheat and to determine the relationships between nutrient uptake and winter wheat productivity.

Materials and Methods

The field study was carried out at the Research and Study farm 'Vecauce' (latitude: N 56°28´, longitude: E 22°53´) of the Latvia University of Agriculture. The 2012/2013 and 2013/2014 experiments were carried out on the fields with rape seed as the previous crop. The soil at the site was *Endostagnic Phaeozem (Loamic)* (WRB, 2014) with humus content 17 – 23 g kg^{-1}, soil pH KCl – 6.6 – 7.2, plant available K – 118 – 150 mg kg^{-1} and P – 50 – 122 mg kg^{-1} and S – 0.67 – 1.34 mg kg^{-1}. The plot size was 20 m^2, with four replicates. Winter wheat variety 'Kranich' was used with sowing rate – 450 germinate able seeds per m^2. While sowing winter wheat, the compound fertilizer was added. In 2012, 300 kg of NPK 5-15-25 were used for fertilizing containing N – 15, P – 20, K – 62 kg ha^{-1}, but in 2013 the same amount of NPK 6-26-30 containing N – 18, P – 34, K – 75 kg ha^{-1}. Different mineral nitrogen rates and timing were used for winter wheat. In addition, nitrogen fertilizer NH_4NO_3 was applied at the rates of 85 kg ha^{-1} N and 153 kg ha^{-1} N in two splits (85+68). N application 175 kg ha^{-1} was applied in three splits (85+60+30): the first dose as NH_4NO_3, but the second and third as $(NH_4)_2SO_4$. Application 180 kg ha^{-1} N was applied in three splits (85+50+45) in 2013 according to chlorophylmeter (Yara N-tester, Konica Minolta Sensing, inc.) data (Markwell et al., 1995) and 150 kg ha^{-1} N in three splits (85+50+15) in 2014 according to chlorophylmeter data, 187 kg ha^{-1} N in three splits (85+68+34) as NH_4NO_3. The first dose of nitrogen was given in spring at the beginning of wheat regrowth, the second time at the stem elongation and the third time - at the beginning of heading. The BBCH identification key of growth stages was used (Meier, 2001). Herbicide and fungicide applications were made to prevent suboptimal plant growth conditions due to weed infestation or diseases. The crop was harvested at the BBCH 88-92 on August 6, 2013 and August 8, 2014; the yield of plots was dried, weighted and the moisture content was determined. Grain protein content was calculated multiplying the total nitrogen content by coefficient 5.7 determined by Kjeldahl method (ICC 105/2; Kjeltec system 1002, Foss Tecator AB, Sweden).

Soil samples were taken with gauge auger, first in spring during wheat renewing time and, then at different plant development stages: BBCH 32, 51, 69 and 91. The content of nitrates NO_3-N and ammonium nitrogen NH_4-N was determined in the soil layers 0-0.20 m, 0.20-0.40 m, 0.40-0.60 m, according to the method set out by LVS ISO/TS 14256-1. Analyses were done in the Agrochemical Laboratory of the State Plant Protection Service. Each mineral N concentration per unit bulk volume of soil was calculated to the quantity per ha.

Meteorological conditions of the research years differed year by year. The climatic conditions were favorable for the growth of wheat plants in the autumn of 2012 and 2013. The end of vegetation in autumn was observed at the beginning of November (usually they occur in mid-November) in 2012. The permanent snow cover of 5-10 cm lasted from December to February. In March and April the air temperature was lower by 2.6 °C and 1.3 °C than the average for many years (Fig.1.) The vegetation renewed very late – at the end of April. May was favorable for plant development; the air temperature was 3 °C higher than the long-term average and precipitation three times more than the long-term average (Fig. 2.). In June the air temperature exceeded norm by 2.1 °C, but sufficient precipitation was recorded – half the long-term average. In August the weather was favorable for harvesting.

In 2013, autumn weather conditions were comparably good for winter crops. In January of 2014 snow fell on an unfrozen land, but then entered the snow break. From the middle of January till the beginning of February black frost was observed and winter wheat plants partly did not survive. The regrowth of vegetation started early – at the end of March. Temperature in April exceeded norm and weather was warmer. April and May were characterized by lack of rainfall. Moisture in June was optimal for plant growing. At the time of harvesting the weather was dryer than the long-term.

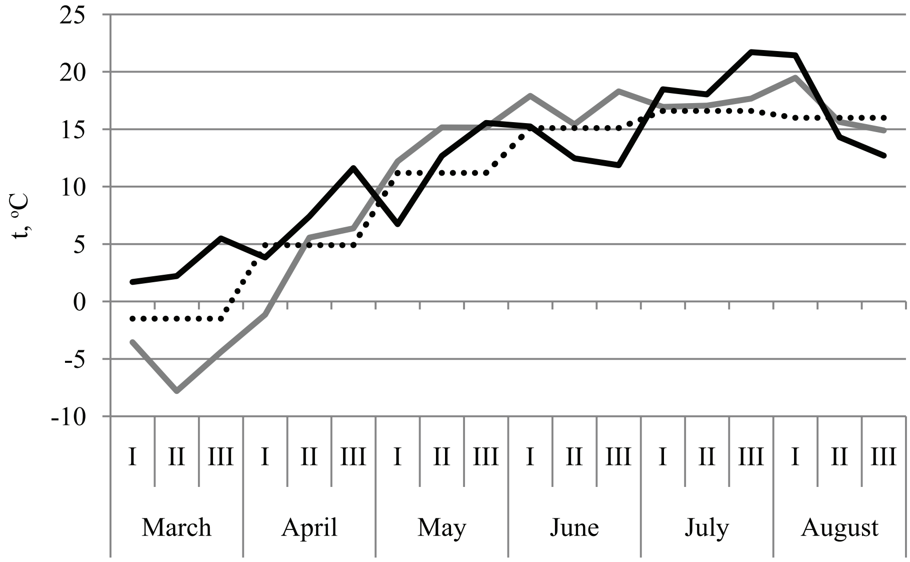

Figure 1. Mean air temperatures, Vecauce, 2013-2014, °C.
(– - 2013, – - 2014, …- long term average, I, II, III – ten day period).

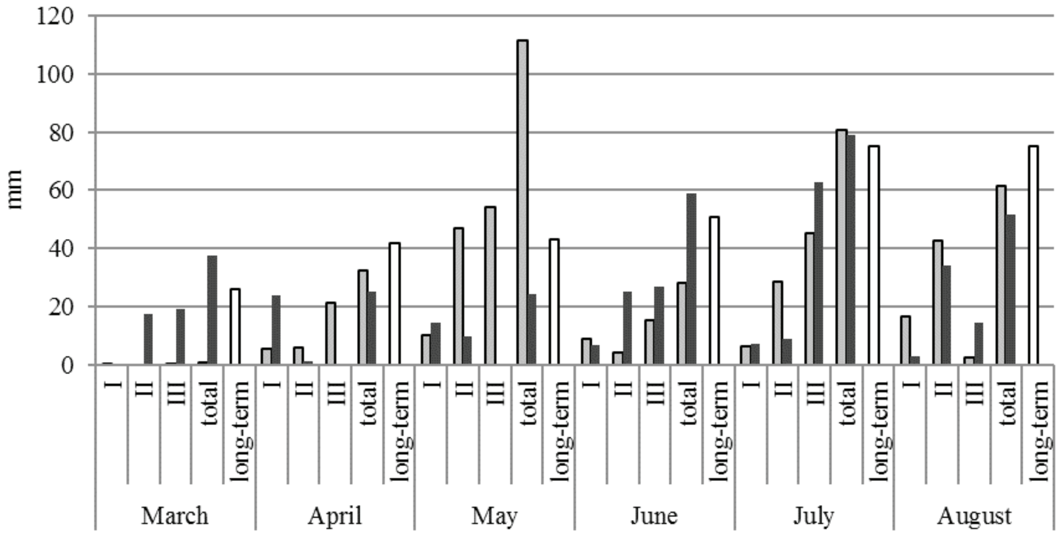

Figure 2. Amount of precipitation, Vecauce, 2013-2014, mm
(■– 2013, ■ – 2014, □ – long term average I, II, III – ten day period, monthly total).

Data were analyzed using ANOVA, correlation and regression analyses. The significance test was performed at probability level of $p<0.05$. Differences among treatment data and sampling dates were separated using Fisher's least significant difference procedure.

Results and Discussion

In 2013 at the regrowth of vegetation (22 April) the mineral nitrogen ($NH_4 + NO_3$) content was determined in the soil layer 0-0.20 m – 26 kg ha^{-1}, at 0.20-0.40 m – 62 kg ha^{-1} and in 0.40-0.60 m – 23 kg ha^{-1}. At this stage in the soil was observed maximum of mineral nitrogen content in vegetation period. Results coincided with A.M. Kibe et al. (2006) and K. Thorup-Kristensen (2009) reports that nitrogen compound is always present in the soil at the beginning of the vegetation period or is produced by mineralization during this period and there also occur losses of nitrogen due to volatilization, denitrification and leaching. The vegetation renewed very late – at the end of April, but in May there were very favorable climatic conditions (warm and wet) for plant development and for plant nitrogen uptake from the soil. As previously mentioned, in June sufficient precipitation was recorded – half a norm, which influenced the high amount of nitrogen in soil, at the BBCH 69 was observed 12-114 kg ha^{-1} (Fig. 3.), depending on fertilizer application. Under the low moisture conditions, the content of mineral nitrogen in topsoil could be a limiting factor with respect to the N nutrition of the plant. In such situation the root system is mainly active and plant N uptake generally occurs in the deeper soil layers (Corbels et al., 1999). Furthermore, in the vegetation period the nitrogen content in all soil layers decreases. Similar data were obtained with spring wheat (Jermuss, 2010).

There was observed a low mineral nitrogen content in the soil layers in the beginning of wheat regrowth in 2014: in the soil layer 0-0.20 m – 10 kg ha^{-1}, 0.20-0.40 m – 2 kg ha^{-1}, 0.40-0.60 m – 6 kg ha^{-1}. The mineral nitrogen content in soil maximum was obtained at the beginning of stem elongation – 39-199 kg ha^{-1} (Fig. 4). The rise of temperature and optimal moisture conditions in plant regrowth period resulted in a rapid increase of mineral N content in soil. During the next growth stages a rapid decline in N content was observed in all soil layers due to the plant uptake. The highest N_{min} content was found in the soil top layer (0-0.20 m) in both investigation years, except N_{min} content at the BBCH 69 in 2013. The nitrogen content in the soil was dependent not only on the duration of the vegetative growth, but also on the level of nitrogen fertilisation, - it was concluded also in the other research (Skudra and Ruza, 2002; Koodziejczyk, 2013). The amount of nitrogen content in the top layer (0-0.20 m) increased with the doses of fertilizers, similar data was obtained in Hungary (Ragasits et al., 1996). A significant impact ($p < 0.05$) of nitrogen fertilizer application was noted on the mineral nitrogen content in soil layer 0-0.20 m in both trial years (by 22% in 2013 and by 30% in 2014). Nitrogen fertilizer application on this parameter was not significant ($p > 0.05$) in soil layers 0.20-0.40 m and 0.40-0.60 m in both trial years. In 2014 a higher average N_{min} content was obtained in the soil layer 0-0.20 m deep (40.48 kg ha^{-1}) and in the 0.20-0.40 m layer (23.80 kg ha^{-1}) in comparison with data in 2013, where the nitrogen content in the top soil layer was lower: 25.29 kg ha^{-1} and 10.87 kg ha^{-1} in 0.20-0.40 m

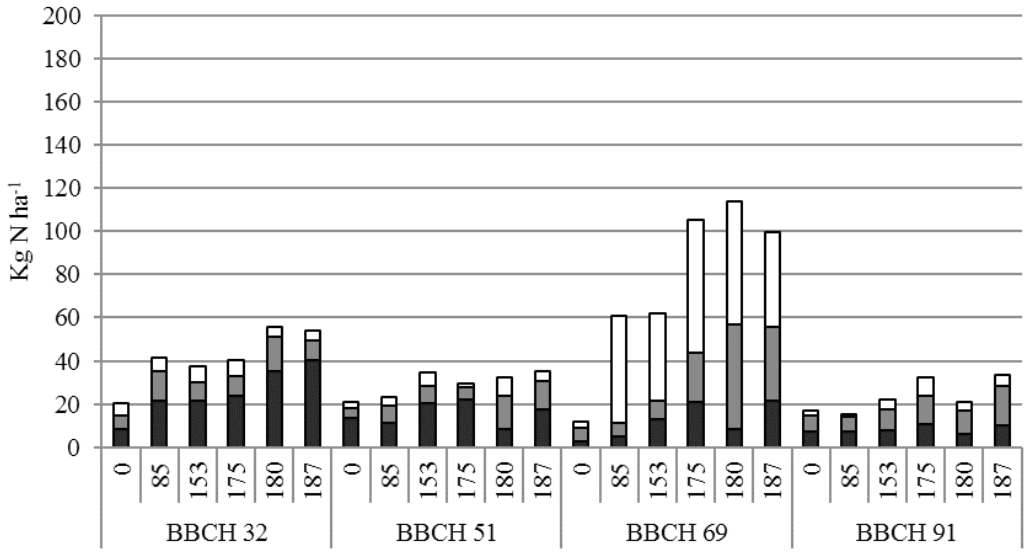

Figure 3. The content of mineral nitrogen in the soil layers in vegetation period 2013 (0, 85, 153, 175, 180, 187 – N norm, growth stage, ■ – 0-0.20 m $LSD_{0.05}$=7.7, ■ – 0.20-0.40 m $LSD_{0.05}$=11.8, □ – 0.40-0.60 m $LSD_{0.05}$=15.5).

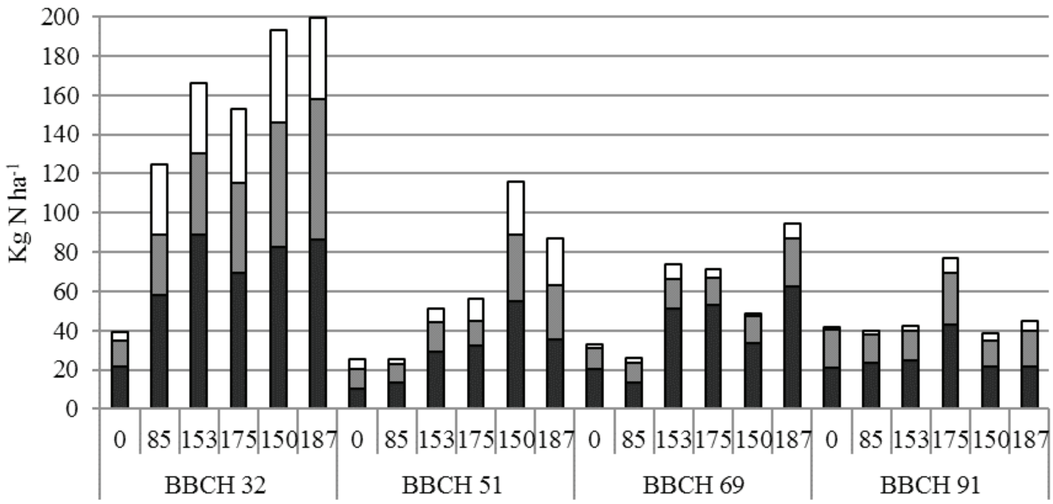

Figure 4. The content of mineral nitrogen in the soil layers in vegetation period 2014 (0, 85, 153, 175, 150, 187 – N norm, growth stage, ■ – 0-0.20 m $LSD_{0.05}$=20.7, ■ – 0.20-0.40 m $LSD_{0.05}$=15.7, □ – 0.40-0.60 m $LSD_{0.05}$=11.9).

layer. Average nitrogen content in the soil layer 0.40-0.60 m was similar in both investigation years (14.36 and 13.54 kg ha^{-1} accordingly). Differences could be explained by meteorological conditions and with differences in plant density – in 2014 after wintering the plant density was lower than in 2013. When the N-doses exceed the requirement of wheat, the soil pollution is significant, but in our investigation in 2014 the maximum NO_3 concentration at the BBCH 91 was 12.6 mg kg^{-1} and did not exceed the norm determined by the Nitrate directive (50 mg kg^{-1}).

In 2013 the winter wheat grain yield ranged between 4.07- 7.64 t ha^{-1} ($LSD_{0.05}$ = 0.47), and between 2.79 – 5.20 t ha^{-1} in 2014 ($LSD_{0.05}$ = 0.12) and had an increasing trend with increasing nitrogen dose. A significant impact ($p < 0.001$) of nitrogen application was observed on grain yield (increase from 2.77 to 3.88 t ha^{-1} in 2013 and increase from 0.52 to 2.41 t ha^{-1} in 2014). These findings are in accordance with other research (Abdin et al., 1996; Sestak et al., 2014) where nitrogen application for increasing grain yield was used. Nitrogen fertilizer norm had

Table 1

Correlation between N_{min} in soil layers and grain yield and protein content

BBCH	Soil layer, m	Correlation coefficients	
		grain yield	protein content
32	0-0.20	-0.28	0.90**
	0.20-0.40	-0.36	0.86**
	0.40-0.60	-0.46	0.81**
51	0-0.20	-0.12	0.78**
	0.20-0.40	-0.13	0.75**
	0.40-0.60	-0.15	0.74**
69	0-0.20	-0.23	0.91**
	0.20-0.40	0.52	0.21
	0.40-0.60	0.92**	-0.41
91	0-0.20	-0.56	0.73**
	0.20-0.40	-0.32	0.73**
	0.40-0.60	0.50	0.39

*- 0.05 probability level = 0.576, **- 0.01 probability level = 0.708

close linear correlation between grain yield (r=0.61, y=0.0587x+2.6521, $p < 0.05$). A significant impact ($p < 0.001$) of the year conditions was observed on grain yield. Another research (Sestak et al., 2014) reported that year properties significantly influenced N availability resulting in different responses of grain yield. A significant correlation was not found between mineral nitrogen content in soil and grain yield, except in soil layer 0.40-0.60 m at the BBCH69, where we got a positive correlation significant at 99% probability level (Table 1). R. Timbare and M. Bušmanis (2002) found a close correlation between grain yield at the variant without nitrogen application and mineral nitrogen in spring, but in our data we did not find such a correlation. It could be explained by diverse meteorological conditions year by year and we should get more data in the next year for a better data interpretation. A close positive correlation was observed between the grain protein content and nitrogen concentration in all soil layers at the all vegetative period significant at 99% probability level, except at BBCH 69 in 0.20-0.60 m layer and BBCH 91 at 0.40-0.60 m layer depth.

Conclusions

The maximum mineral nitrogen content in soil in vegetation period was observed at the beginning of stem elongation with a tendency to decrease. A significant impact ($p < 0.05$) of nitrogen fertilizer application was noted on the mineral nitrogen content in 0-0.20 m deep soil layer in both trial years. The increasing doses of nitrogen fertilizers raised the amount of mineral N in the soil profile. A significant impact ($p < 0.001$) of nitrogen application and year conditions on grain yield was observed. A close linear correlation was found between grain yield and nitrogen application rate. A close positive correlation was observed between the grain protein content and nitrogen concentration mostly in all soil layers, but it was not found between grain yield and nitrogen content. The nitrogen management strategy during plant growth period based on soil N_{min} evaluating can improve N use efficiency and reduce environmental contamination.

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