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Effect of nitrogen fertilization management on mineral nitrogen content in soil and winter wheat productivity

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Abstract. In recent years farmers must use integrated crop growing principles. One of the most important principle is to balance usage of mineral elements in crop cultivation, especially nitrogen management. Excessive and unbalanced usage of nitrogen fertilizer reduces nitrogen use efficiency and increases nitrate leaching in surface and groundwater. The dynamics of nitrogen forms in soil at different depths and different plant growth stages are studied to increase the productivity of winter wheat, promoting nitrogen uptake in plants and reducing nitrogen leaching during the vegetation period. Field experiments were carried out at the Research and Training Farm Vecauce of the Latvia University of Life Science and Technologies from 2012 till 2015. Researched factors were nitrogen (N) fertilizer rate: 0 – control, 85, 153, 187, and N rate determined by chlorophylmeter (Yara N-tester) 180 (2012/2013), 150 (2013/2014), 205 (2014/2015) N kg ha^{-1}, nitrogen and sulphur (S) fertilizer rate – N175+S21 kg ha^{-1}, and conditions of the growing seasons: 2012/2013, 2013/2014 and 2014/2015. The content of nitrate (NO_3–N) nitrogen and ammonium (NH_4–N) nitrogen was determined in the soil layers 0–20 cm, 20–40 cm and 40–60 cm at the growth stages (GS) 30–32, 49–51, 69 and 90–92. All trial years the amount of nitrate nitrogen and ammonium nitrogen in soil decreased during vegetation, but increased with increasing fertilization dose. Nitrate nitrogen content was significantly influenced by year in 0–40 cm soil layer ($P < 0.01$) and by nitrogen fertilizer in the 20–40 cm soil layer. Ammonium nitrogen content had significant influence only on nitrogen fertilizer at 20–40 cm soil layer ($P < 0.05$). Average grain yields did not show significant correlation with the nitrate nitrogen and ammonium nitrogen in different soil layers and plant growth stages, except nitrate nitrogen content in soil layer 40–60 cm at GS 30–32 and ammonium nitrogen content in soil layer 40–60 cm at GS 69 and GS 90–92.

Key words: ammonium nitrogen, nitrate nitrogen, fertilizer, wheat.

INTRODUCTION

In recent years farmers must use integrated crop growing principles. Integrated crop management based on high crop yield obtaining with lower inputs based on an understanding of high yield traits and better managing (Dianjun et al., 2016). The most important factors in integrated wheat fertilization are nutrient demands of macro- and micro-elements, dynamics of nutrient uptake in vegetation period and weather conditions (Pepo, 2002). One of the most important principle is balanced usage of mineral elements in wheat fertilization, especially nitrogen management. Excessive and unbalanced nitrogen fertilizer usage reduced nitrogen use efficiency and increased nitrate leaching in surface and groundwater. The European Union Nitrate Directive (91/676/EEC) also requires Member States to implement restrictive measures for minimazing water and soil contamination with nitrates from agriculture sources (Council Directive, 1991). High efficiency of nutrient use improves physical, chemical, biological properties of soil and enhances crop productivity and reduces soil contamination (Zhang et al., 2012, Dianjun et al., 2016). Weather, soil conditions and agrotechnics influenced organic compound mineralization, which include nitrogen availability for the crops (Ruza & Kreita, 2006, Osvalde, 2011, Līpenīte et al., 2016, Linina & Ruza, 2018). The amount of mineral nitrogen in soil substantially contributes to the nitrogen nutrition of the crops during the growth period (Olfs et al., 2005). Mineral nitrogen compounds in soil are very dynamic, plants can use them easily, but nitrogen may reduce losses from soil-plant system substantially and also soil-microbial nitrogen immobilization (Olfs et al., 2005, Līpenīte et al., 2016). Previous research in Latvia show that in spring at the wheat regrowth time, the ammonium and nitrate nitrogen forms in soil were observed aproximatelly in equal amount, but at the active vegetative growth period (in June) nitrate nitrogen reached it's highest amount (74%), but ammonium nitrogen (84%) – in July (Timbare, Bušmanis & Reinfelde, 2001). Determination of mineral nitrogen amount in soil at the vegetative growth period can help to understand plant provision with nitrogen and necessity of fertilizers.

The dynamics of nitrogen forms in soil at different depths and different plant growth stages is studied for increasing the productivity of winter wheat (*Triticum aestivum* L.), promoting nitrogen uptake in plants and reducing nitrogen leaching during the vegetation period. The hypothesis of the study was the soil nitrogen availability by plant affected wheat grain productivity. The aim of this study was to assess the effect of nitrogen fertilizer application timing on soil nitrogen availability for winter wheat high grain yield.

MATERIALS AND METHODS

Field trials with winter wheat variety 'Kranich' were carried out at the Research and Training Farm Vecauce (latitude: N 56° 48', longitude: E 22° 87') of the Latvia University of Life Science and Technologies from 2012 till 2015. In 2012, and 2013 the pre-crop was oilseed rape, but in 2014 – spring wheat. Trials were arranged randomly in four replications. Soil at the trial site was loam in 2012 and 2013, and sandy loam in 2014. Soil is characterized by the following agro-chemical parameters depending on the years: organic matter content 17–25 g kg^{-1} (Tiurin's method), soil exchange reaction pH KCl 6.6–7.2, phosphorus (P) content 50–153 mg kg^{-1} (Egner-Riehm's method) and potassium (K) content 118–150 mg kg^{-1} of the soil (Egner-Riehm's method). Wheat was fertilised with compound mineral fertilizer at the rate: nitrogen (N) 11–18, P 20–34, K 45–75 kg ha^{-1} before sowing depending on the years and agro-chemical properties. Wheat was sown in optimal time – the second decade of September, at the rate 450 germinal seeds per m^2. Weeds and diseases were controlled by using plant protection products in all trial years.

In spring, when the vegetation had renewed the first top-dressing of nitrogen fertilizer was applied. The second top-dressing was done at the stem elongation growth stage (GS 30–32) (Zadoks et al., 1974) of winter wheat and the third – at the beginning of heading (GS 49–51).

Researched factors were nitrogen (N) fertilizer rate: 0 – control, 85, 153, 187, and N rate determined by chlorophylmeter (Yara N-tester) 180 (2012/2013), 150 (2013/2014), 205 (2014/2015) N kg ha^{-1}, nitrogen and sulphur (S) fertilizer rate – N175+S21 kg ha^{-1}, and conditions of the growing seasons: 2012/2013, 2013/2014 and 2014/2015. Different nitrogen fertilizer rates were used according farmers traditional practice. The chlorophylmeter was used for determination nitrogen rate necessity in one variant, it's differ from year to year.

The content of ammonium nitrogen NH_4–N and nitrate nitrogen NO_3–N was determined in the soil layers 0–20 cm, 20–40 cm and 40–60 cm at the growth stages GS 30–32, 49–51, 69 and 90–92. Samples were analysed at the Agrochemical Laboratory of the Latvia State Plant Protection Service using standard method set out by LVS ISO/TS 14256–1 (determination of nitrate and ammonium in field-moist soils by extraction with potassium chloride solution). After harvesting grain yield was determined at 100% purity and 14% humidity in four recurrences.

Statistical analyses: standard errors, *Student's t-test*, impact factors influence (η^2), ANOVA procedures, correlation and regression analyses were done using software MS Excel. The differences were considered statistically significant when $P < 0.05$.

During the field trial years meteorological conditions differed considerably. Autumn in all trials years was warm and dry. Winter in 2012/2013 and 2014/2015 was good for wheat overwintering. In 2013/2014, wheat got serious wintering problems. Temperature below zero were observed only in the middle of January, soil frosted, but without snow. Frost continue until six of February, sometimes temperature dropped to -25 °C. Part of plants did not survive. In 2013, the vegetation renewed very late – at the end of April, but in 2014 and 2015 – at the end of March. Spring of 2013 and 2014 was wormer and dryer than obtained in long-term observations. In 2014, May was dry, but in 2013 was very rainy – rainfall exceeded long-term observations 2.6 times. In summer, June was dry in 2013 and 2015, and air temperature was lower than long-term observations in 2014 and 2015. July in 2014 was warm, average air temperature exceeded long-term observations per +2.9 °C. The beginning of August in all trial years was warm and dry, and it was favourable for wheat harvesting. Overall, meteorological conditions were suitable for winter wheat growing.

The effect of temperature and humidity presented by the hydrothermal coefficient (HTC) by Selianinov (Čirkovs, 1978).

$$HTC = \frac{\sum p}{\sum t_{>10^\circ C}} \cdot 10 \qquad (1)$$

Where $\sum p$ is the sum of precipitation in crop growth period, mm, $\sum t_{>10\ °C}$ is the sum of active (> 10 °C) air temperature of the same period. Optimal value of the coefficient indicate 1, values below and above 1 – drought and humid period respectively.

During the vegetation period an average drought (HTC 0.59–0.80) were recorded in 2013 GS 51–69, 2014 GS 30–51 and 2015 GS 51–90, but humid period (HTC 2.15–9.52) – in 2013 GS 24–51, 2014 GS 24–30 and GS 51–69, and in 2015 GS 24–30 (Fig. 1).

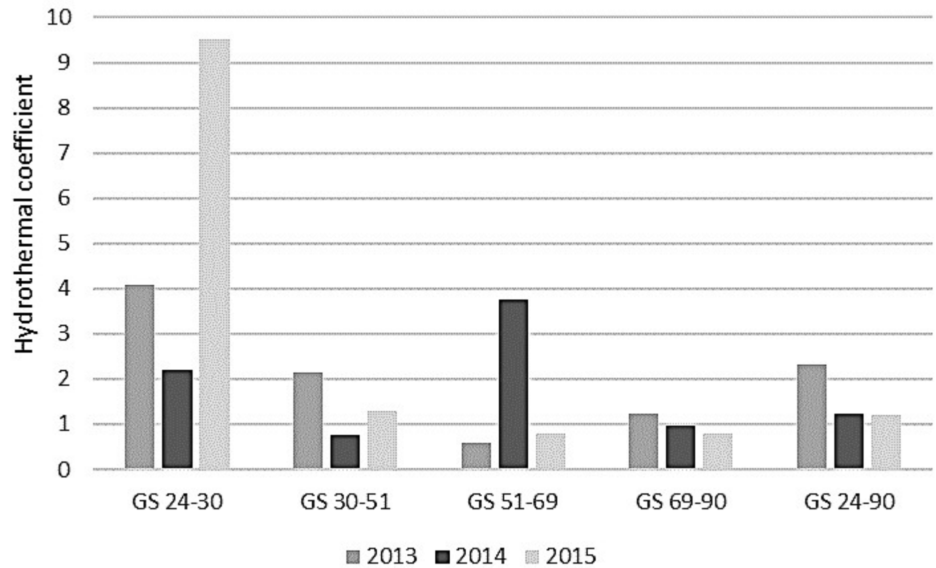

Figure 1. Values of the hydrothermal coefficient in wheat vegetation period, 2013–2015.

RESULTS AND DISCUSSION

The ammonium and nitrate nitrogen accumulation in soil were different in all trial years. Across 3 trial years at the end of winter period, in spring 2013, the highest ammonium and nitrate nitrogen content were obtained 54.72 and 55.68 kg ha^{-1} respectively, in soil layer 0–60 cm (Figs 2, 3). In 2013 plant wintering conditions was favourable, winter was stable with snow and soil was frozen long period, vegetation started very late – at the end of April. According literature data (Timbare, Bušmanis & Reinfelde, 2001, Ruza, & Kreita, 2006, Staugaitis et al., 2015) nitrogen content in soil are affected by precipitation level, soil and air temperature, soil texture and other factors. In 2014 absolute minimum of NO_3–N was recorded at GS 49–51 with 2.88 kg ha^{-1} for the treatment with 85 kg N ha^{-1}, while the maximum value (139.92 kg NO_3–N ha^{-1}) was determined for a plot fertilized with 150 kg N ha^{-1} at stem elongation stage in the same year. In 2013 at the end of vegetation (GS 90–92) NH_4–N content minimum (6.72 kg ha^{-1}) obtained for the treatment with 85 kg N ha^{-1}, but maximum (73.68 kg ha^{-1}) at GS 69 for the treatment with 187 kg N ha^{-1} in comparison with other trial years.

Our trials showed that year meteorological conditions had a significant influence on nitrate nitrogen content at 0–40 cm soil layer ($P < 0.01$), but not significant on ammonium nitrogen content in soil. Nitrate and ammonium nitrogen content in soil 20–40 cm layer were significantly dependant on the level of nitrogen fertilizer ($P < 0.05$).

In 2013 from the renewal of vegetation NO_3–N and NH_4–N content decrease till GS 49–51 and minimum value (4.56 and 10.80 kg ha^{-1} respectively) obtained in treatment of 180 kg N ha^{-1}, further NO_3–N and NH_4–N content increase till GS 69 – maximum value (53.04 and 73.68 kg ha^{-1} respectively) obtained in treatment of 187 kg N ha^{-1} in the soil layer 0–60 cm. Similar results were obtained in other trials (Corbeels et al., 1999, Līpenīte et al., 2016), where found that ammonium and nitrate nitrogen content rapid decrease in soil during plant vegetation due to its consumption. The NO_3–N and NH_4–N content varied depending on the fertilizer treatment and sampling time, it's also reported in other trials (Līpenīte et al., 2016, Jurišč et al., 2014). The highest content of NO_3–N and NH_4–N were observed in the top layer (0–20 cm) from GS 30–32 till GS 49–51, further on till the end of flowering stage NO_3–N content increase in deeper layer (40–60 cm) and get greatest value 35.76 kg ha^{-1} for the treatment with 180 kg N ha^{-1}, but NH_4–N – 73.5 kg ha^{-1} for the treatment with 187 kg N ha^{-1} at the GS 69. Similar findings were reported in studies by Ruza & Kreita (2006). In 2013 it was found that wheat growth stage significantly influenced ($P < 0.05$) NO_3–N and NH_4–N content in all soil layers, except NH_4–N content in 20–40 cm.

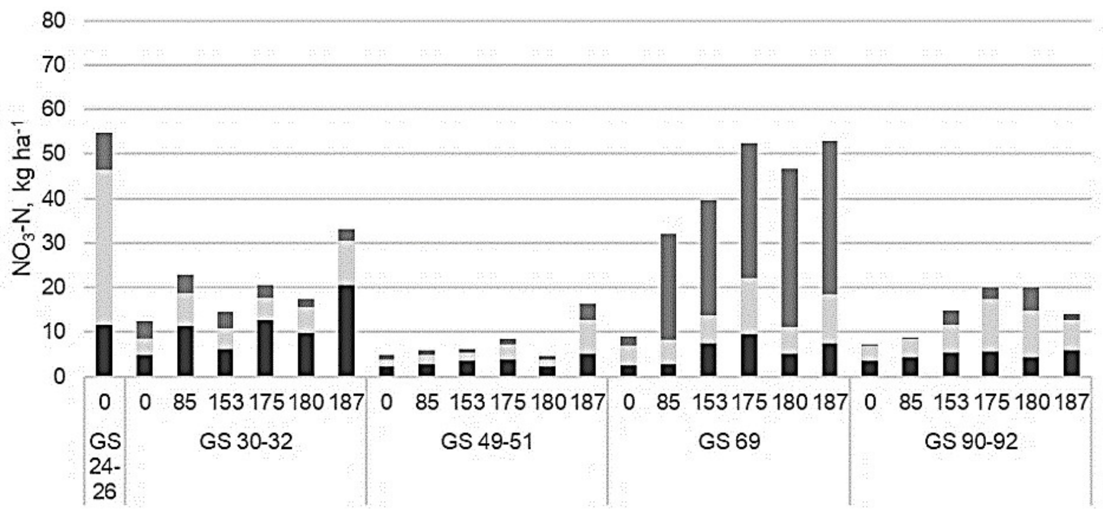

Figure 2. NO_3–N nitrogen accumulation in different soil layers in vegetation period 2013, kg ha^{-1}. (0, 85, 153, 175, 180, 187 – N norm, growth stage; ■ – 0–20 cm; $LSD_{0.05}$ = 3.96; ■ – 20–40 cm; $LSD_{0.05}$ = 3.36; ■ – 40–60 cm*); *not significant at the probability level 0.05.

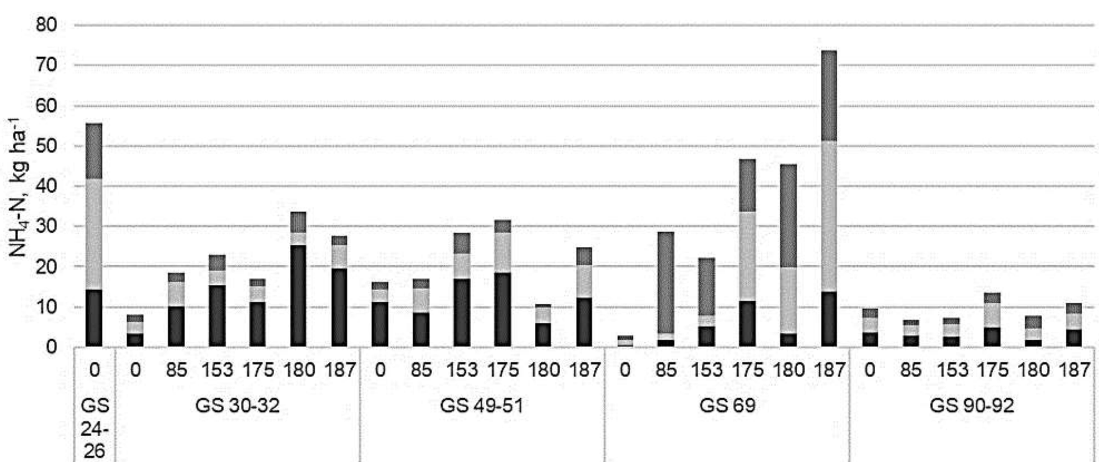

Figure 3. NH_4–N nitrogen accumulation in different soil layers in vegetation period 2013, kg ha^{-1}. (0, 85, 153, 175, 180, 187 – N norm, growth stage; ■ – 0–20 cm*; ■ – 20–40 cm*; ■ – 40–60 cm*); *not significant at the probability level 0.05

During the 2014 growing season the amount of nitrate and ammonium nitrogen decrease from stem extension till full ripening in 0–60 cm soil layer. Maximum content of NO_3–N (140 kg ha^{-1}) was determined in GS 30–32 in the fertilised plot with

150 kg N ha^{-1}, where chlorophyllmeter was used to determine needed nitrogen fertilizer (Fig. 4). Highest NH_4–N content (67 kg ha^{-1}) also was observed in the same growth stage in variant N187 (Fig. 5). The optimal temperature and moisture conditions in vegetation renew period activated rapid increase of NO_3-N nitrogen content in soil. Similar results were reported by Līpenīte et al. (2016) where in mucky – humus gley soil nitrate nitrogen content decrease from GS 30–32, when plants intensive consumes nitrogen. Jurišč et al. (2014) reported that winter wheat at steam extension and ripening growth stage consumes more nitrates from soil and less nitrate-nitrogen was presented in lysimeter outflow. In our trial the highest values of nitrate and ammonium nitrogen content were observed in the top layer (0–20 cm) all vegetation period in 2014, and it decrease in deeper soil layers. Karkliņš et al. (2017) also reported NO_3–N main amount was placed in the 0–30 cm soil layer. In our experiment in 2014 it was found that wheat growth stage significantly influenced ($P < 0.05$) NO_3–N and NH_4–N nitrogen content in all soil layers.

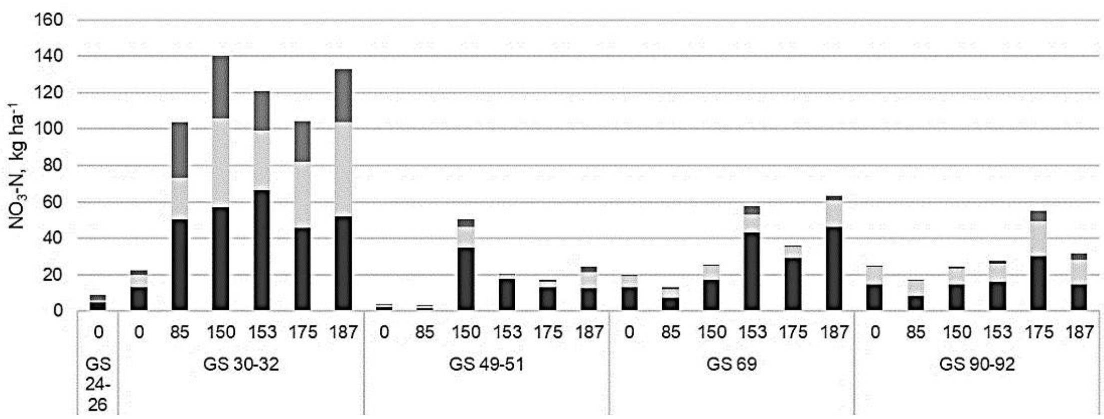

Figure 4. NO_3–N nitrogen accumulation in different soil layers in vegetation period 2014, kg ha^{-1}. (0, 85, 150, 153, 175, 187 – N norm, growth stage; ■ – 0–20 cm*; ■ – 20–40 cm*; ■ – 40–60 cm*); *not significant at the probability level 0.05.

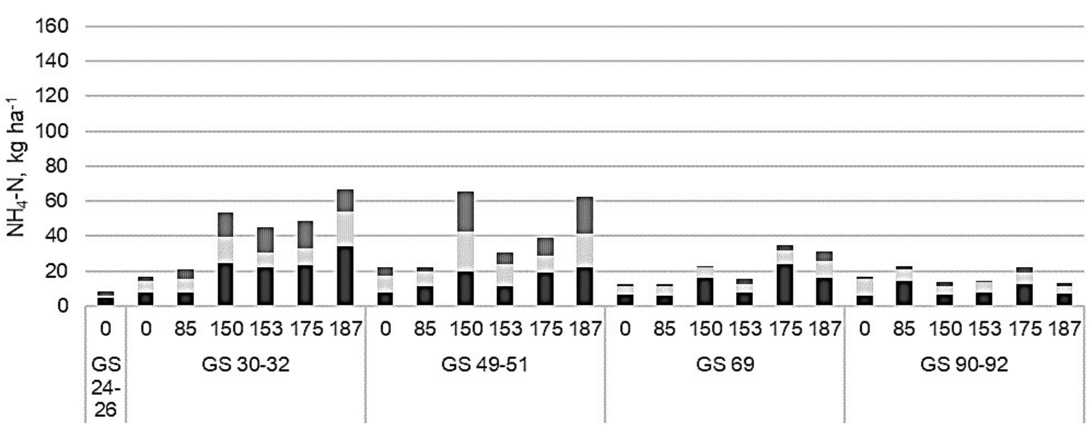

Figure 5. NH_4–N nitrogen accumulation in different soil layers in vegetation period 2014, kg ha^{-1}. (0, 85, 150, 153, 175, 187 – N norm, growth stage; ■ – 0–20 cm; $LSD_{0.05}$ = 8.31; ■ – 20–40 cm*; ■ – 40–60 cm*); *not significant at the probability level 0.05

Rapid nitrate and ammonium nitrogen content increase in soil layer 0–60 cm was observed from the renew vegetation till the GS 49–51 in 2015 (Figs 6, 7). During the subsequent growth period, decline of nitrate and ammonium nitrogen content was observed in all variants, except N187 and N205, where content increased till GS 69. Chlorophyllmeter was used to determine needed amount of fertilizer in variant N205. Nitrogen fertilizer uptake in wheat was affected negatively because of dry weather conditions and lower air temperatures than long-term observations at the end of flowering stage and it influenced plant mineral nutrition. Corbeels et al. (1999) reported that nitrification process was considerably reduced at low soil moisture level.

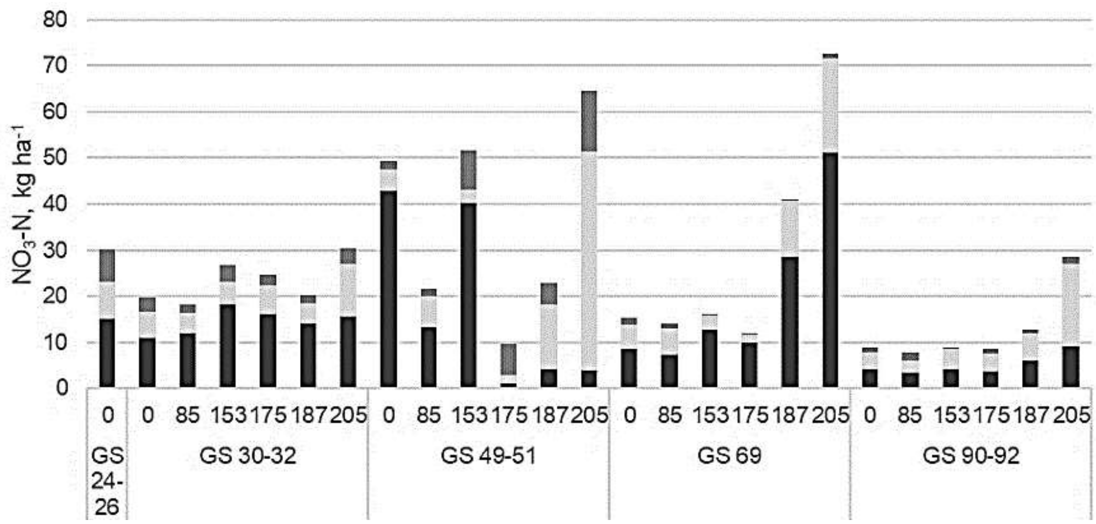

Figure 6. NO_3–N nitrogen accumulation in different soil layers in vegetation period 2015, kg ha^{-1}. (0, 85, 153, 175, 187, 205 – N norm, growth stage; ■ – 0–20 cm*; ■ – 20–40 cm; $LSD_{0.05}$ = 10.04; ■ – 40–60 cm*); *not significant at the probability level 0.05.

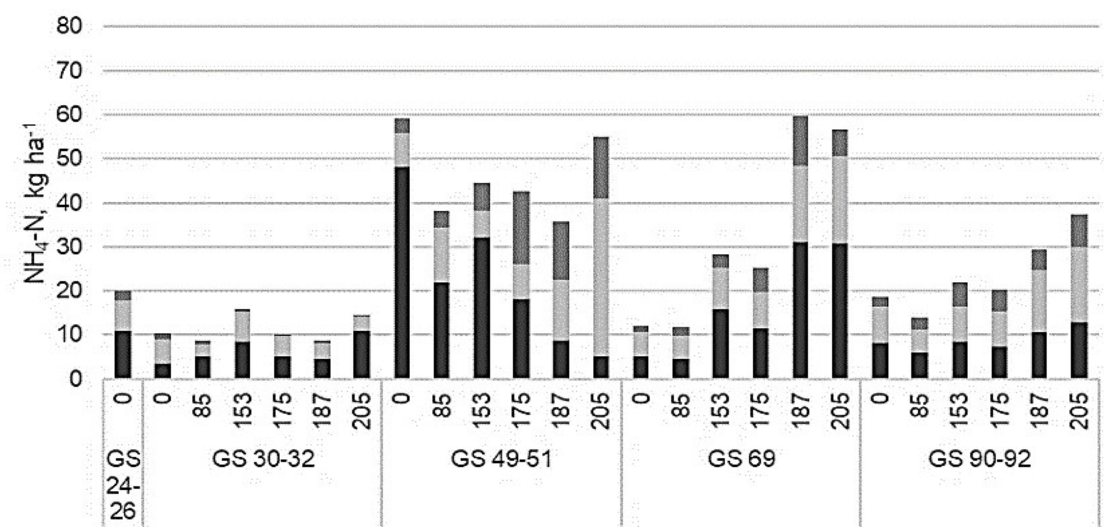

Figure 7. NH_4–N nitrogen accumulation in different soil layers in vegetation period 2015, kg ha^{-1}. (0, 85, 153, 175, 187, 205 – N norm, growth stage; ■ – 0–20 cm*; ■ – 20–40 cm; $LSD_{0.05}$ = 8.11; ■ – 40–60 cm*); *not significant at the probability level 0.05.

In 2015 was similar situation like in 2013 when nitrate and ammonium nitrogen content highest values were observed in the top layer (0–20 cm) from the renew of vegetation till GS 69, except variants with high nitrogen application doses (N175, 187, 205) in GS 49–51. Further on till the ripening stage NO_3–N and NH_4–N nitrogen content increase in deeper soil layer (20–40 cm). In 2015 it was found that wheat growth stage significantly influenced ($P < 0.05$) NO_3–N and NH_4–N nitrogen content in soil 40–60 cm layer.

Nitrogen surplus in soil at the end of vegetation is harmful to the environment. Data obtained in our experiments shows that maximum nitrate content at the end of vegetation GS 90-91 (2.3–12.6 mg kg^{-1}) did not exceed the Nitrate directive determined NO_3–N norm – 50 mg kg^{-1}.

In our research the linear relation between the mineral nitrogen (NO_3–N and NH_4–N) content in the soil layer 0–60 cm and climatic conditions according to HTC during the growing season was statistically significant ($P < 0.05$) in 2013 variants with high nitrogen application norm (> 153 kg N ha^{-1}) and in 2015 N175 (Table 1). In 2013 plants overwintering was very good, spring was late and period of plant active growth was warm and wet. Precipitation in May was high – 2.5 times over annual data, air temperature 3 °C above annual data. 2013 vegetation period was high moisture availability: HTC – 2.33. Research data correspondent with data Timbare et al. (2001) where was found relationship between the content of mineral nitrogen in soil and the value of HTC (0.5–4.2) in depth 0–40 cm. A significant correlation was not found in 2014, when part of plants did not survive after wintering. The effect of temperature and precipitation on nitrate and ammonia nitrogen content in soil are not simple, it means that non-controllable factors such us mineralization of soil organic matter, nitrification and soil aerobicity were affecting results (Haynes et al., 1986, Līpenīte et al., 2016).

Table 1. Dependence of mineral nitrogen (N_{min}) content (0–60 cm soil layer) in relation of fertilizer norm on HTC in vegetation period, 2013–2015

Fertilization norm, Kg N ha^{-1}	Year/ coefficient of correlation			Regression equation
	2013	2014	2015	
Control – without fertilizer	0.808	0.496	0.898	n/s
85	0.949	-0.248	0.917	n/s
153	0.952*	-0.553	0.942	y = 4.5645x+18.637
175	0.989*	-0.268	0.961*	y = 10.231x+5.8067 (2013) y = 46.305x-5.6493 (2015)
180 (2013), 150 (2014), 205 (2015)	0.991*	-0.517	0.792	y = 11.814x+2.6637
187	0.998*	-0.663	0.429	y = 8.8617x+15.793

*Significant at probability level 95%, n/s – not significant, n = 4.

Influence (η^2) of factors: growth stage and fertilizer application were calculated for nitrogen forms (NO_3–N and NH_4–N) content on soil different layers in all trial years (Table 2). Results suggest, that growth stage had highest factors influence – 76% on NO_3-N content in 2013 and 2014 in soil 40–60 cm layer, and 66% on NH_4–N content in the same soil layer in 2013. Growth stage smallest influence on NO_3–N and NH_4–N content were found (9% and 7% respectively) in the soil 20–40 cm layer in 2015. The fertilizer application highest influence on NO_3-N and NH_4–N content (61% and 40% respectively) was observed in soil 20–40 cm layer in 2015. The lowest value (7%) of fertilizer application influence on NO_3-N content were found in the soil 40–60 cm layer in 2013, but on NH_4–N content – 6% in the soil top layer (0–20 cm) in 2015.

Table 2. Influence of growth stage and fertilizer application on NO_3–N and NH_4–N content in soil different layers, 2013–2015, %

	2013		2014		2015	
Soil layers, cm	growth stage	fertilizer application	growth stage	fertilizer application	growth stage	fertilizer application
NO_3–N						
0–20	49	26	52	23	18	13
20–40	31	38	64	16	9	61
40–60	76	7	76	8	50	14
NH_4–N						
0–20	45	19	41	27	32	6
20–40	25	25	41	23	23	40
40–60	66	9	47	23	48	25

Winter wheat grain yield ranged from 4.07–7.64 t ha^{-1} ($LSD_{0.05}$ = 0.47), in 2013, from 2.79–5.20 t ha^{-1} ($LSD_{0.05}$ = 0.12) in 2014, and 4.23–10.20 t ha^{-1} ($LSD_{0.05}$ = 0.81) in 2015. In 2013 and 2015 the highest grain yield (7.64 and 10.20 t ha^{-1} respectively) were observed in variant with fertilizer norm 175 kg N ha^{-1}, but in 2014 – N187 (5.20 t ha^{-1}). In 2015 highest amount of nitrogen fertilizer (205 kg N ha^{-1}) determined by chlorophylmeter not provide high grain yield (7.27 t ha^{-1}), because of dry weather conditions. Trial years average grain yields did not showed significant correlation with the nitrate and ammonium nitrogen content in different soil layers and plant growth stages, except nitrate nitrogen content in soil layer 40–60 cm at GS 30–32 where obtain negative correlation -0.52 and ammonium nitrogen content in soil layer 40–60 cm at GS 69 and GS 90–92 (0.54 and 0.58 respectively) at probability level 95% (Table 3). Scientists Joseph & Prasad (1993) have found close correlation between wheat yield and nitrate nitrogen content in soil at 30, 45 and 60 days after sowing, but ammonium nitrogen content at 15 and 30 days after sowing. Staugaitis et al. (2007) observed similar results: crop yield correlated less with nitrate nitrogen and least with ammonia nitrogen.

Table 3. Correlation between winter wheat grain yield and ammonium nitrogen and nitrate nitrogen content in soil different levels

Growth stage	NO_3–N			NH_4–N		
	0–20 cm	20–40 cm	40–60 cm	0–20 cm	20–40 cm	40–60 cm
GS 24	0.96	0.59	0.93	0.89	0.58	0.41
GS 30–32	-0.43	-0.40	-0.52*	-0.08	-0.37	-0.42
GS 49–51	-0.23	0.17	0.47	-0.09	0	0.14
GS 69	-0.09	0.10	0.42	0.23	0.45	0.54*
GS 90–92	-0.46	-0.15	0.15	-0.26	0.07	0.58*

*Significant at probability level 95%.

CONCLUSIONS

Trials results indicate that the soil NO_3–N and NH_4–N content significantly varied depending on the fertilizer treatment and sampling time. The content of ammonium nitrogen NH_4–N and nitrate nitrogen NO_3–N in the soil layers 0–20 cm, 20–40 cm and 40–60 cm mostly years decreased during vegetation and increased with increasing nitrogen dose. Year meteorological conditions had significant influence on nitrate nitrogen content at 0–40 cm soil layer ($P < 0.01$). Nitrate and ammonium nitrogen content in 20–40 cm soil layer were significantly dependant on the level of nitrogen fertilizer ($P < 0.05$). Average grain yields showed significant correlation with the nitrate nitrogen content in soil layer 40–60 cm at GS 30–32 and ammonium nitrogen content in soil layer 40–60 cm at GS 69 and GS 90–92. Nitrogen fertilizer management based on mineral nitrogen amount in soil can improve wheat nitrogen use efficiency and can reduce potential pollution of ground water with nitrogen compounds.

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