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Effect of Nitrogen Fertilization and Microbial Preparations on N_{min} Content in Soil after Potato Harvesting

M. Kołodziejczyk[1]

ABSTRACT

A three-year field experiment was conducted under conditions of Luvic Chernozem soil. Diversified nitrogen fertilization with 0, 60, 120, and 180 kg N ha^{-1}, and microbial preparations improving soil properties were applied to potatoes, *cv.* 'Satina', cultivation. N–NO_3 concentration in the soil profile (0–0.9 m) in autumn after potato harvesting fluctuated from 28 kg N ha^{-1} in the N_0 treatment to 70 kg N ha^{-1} in the N_{180} treatment, whereas N–NH_4 content varied from 22 to 48 kg N ha^{-1}, respectively. The level of nitrogen fertilization also had a significant effect on the change in soil N–NO_3 content during the autumn-winter period. The decrease in N–NO_3 content in the N_0 treatments was 7% compared to 24% in the N_{180} treatments. Application of microbial preparations to potato cultivation caused an increase in N_{min} content in soil after crop harvesting. However, after the autumn-winter period, a lower amount of N–NO_3, compared to the control treatment, was found in the treatments where microbial preparations had been used.

Keywords: Ammonium nitrogen, Nitrate nitrogen, Loss of N–NO_3, *Solanum tuberosum*.

INTRODUCTION

Mineral nitrogen content in soil after crop harvesting evidences the effectiveness of fertilization with this nutrient element and is an indicator of environmental hazard resulting from an excessive nitrate concentration in soil. High doses of natural and mineral, particularly nitrogen fertilizers, are usually applied to potato cultivation. However, nitrogen utilization by potato plants is still low, most often reaching 40-60% and decreasing with increasing level of fertilization with this element (Zvomuya *et al*., 2003; Vos, 2009). A low effectiveness of nitrogen fertilization is determined, among others, by shallow root system of potato plants, its cultivation in sandy soil, and excessive or insufficient rainfall amount during vegetation period (Stalham and Allen, 2001; Zebarth and Rosen, 2007). Nitrogen unabsorbed by crops or soil microorganisms undergoes many processes and, in effect, its considerable portion is lost, particularly in light soils (Gasser *et al*., 2002; Neumann *et al*., 2012). N–NO_3 leaching and N_2O, NO, and NH_3 emission pose a special hazard to the environment (Mosier, 1998; Munoz *et al*., 2005; Davenport *et al*., 2005). Nitrogen losses in potato cultivation happen both during the plants vegetation period and after their harvest. During their vegetation, the highest nitrate leaching from potato root zone occurs during the period from planting until the intensive development of the plant aboveground parts, i.e. about 45th day of vegetation (Zebarth and Milburn, 2003). However, the risk of nitrogen losses after the crop harvesting is greater than during their vegetation period (Vos and Mackerron, 2000). In the research of Neumann *et al*. (2012), total nitrogen losses, i.e. both during potato vegetation and after its harvesting (April-May) ranged from 13 to 27 kg N ha^{-1}. Considerable nitrogen losses in potato

[1] Department of Crop Production, University of Agriculture in Krakow, Krakow, Poland. e-mail: m.kolodziejczyk@ur.krakow.pl

cultivation were reported also by Arriaga *et al*. (2009) and Shrestha *et al*. (2010). According to Zebarth and Rosen (2007), the basic mechanism of N loss in potato production is nitrate leaching. $N–NO_3$ losses in potato-cereal crop rotation estimated by Gasser *et al*. (2002) ranged from 87 to 132 kg N ha^{-1} per year and exceeded N uptake by plants during harvesting by at least 20 kg N ha^{-1}.

Moreover, in the soil environment, nitrogen strongly influences the number and qualitative selection of soil microorganisms (Barabasz *et al*., 2002). It may lead to disturbance of microbiological balance and, as a result, soil degradation. Improvement of chemical properties and soil biological activity may be achieved owing to the application of microbial preparations (Kaczmarek *et al*., 2008). However, results of research on the effect of these preparations on the amount and quality of yield, and soil properties are not unanimous. Proponents of microbial preparations application prove their advantageous effect on crop yield and soil properties (Shah *et al*., 2001; Emitazi *et al*., 2004, Kumar *et al*., 2014), whereas the sceptics point to a low reliability of results because of a short period of investigations, their local range, and methodological errors of the conducted experiments (Priyadi *et al*., 2005; Còndor-Golec *et al*., 2007).

The present investigations were conducted to determine the effect of nitrogen fertilization and microbial preparations on mineral nitrogen content in soil after potato harvesting and $N–NO_3$ losses over the autumn-winter period.

MATERIALS AND METHODS

Experimental Designs and Agronomic Management

The research was conducted in 2006-2008 at the Experimental Station in Prusy near Krakow (50°07'N and 20°05'E, 271 m asl). The field experiment was set up in a split-block design in 4 replications on a Luvic Chernozem soil developed from loess. The experimental factors were nitrogen fertilization levels: 0, 60, 120 and 180 kg N ha^{-1} and microbial preparations improving soil properties: BactoFil B 10 (3 L ha^{-1}), Effective Microorganisms EM (3 L ha^{-1}) and UGmax soil fertilizer (0.9 L ha^{-1}) applied to the soil after harvesting the previous crop and prior to spring soil tillage. Hereafter, the fertilizer treatments will be referred to as N_0, N_{60}, N_{120} and N_{180}, and the microbial preparation as, respectively, B, EM, and UGmax. The characteristics of the microbial preparations was presented in the paper by Kołodziejczyk (2014). Urea (46% N) was applied as nitrogen fertilizer. In N_{60} and N_{120} treatments, the whole nitrogen dose was supplied to the soil before planting, while in N_{180} treatment, 120 kg N ha^{-1} was applied before planting and the remaining part (60 kg N ha^{-1}) as top dressing before the last covering (BBCH 18-19). Phosphorus fertilization, with 60 kg P_2O_5 ha^{-1} (Triple superphosphate: 40% P_2O_5) and potassium, 210 kg K_2O ha^{-1} (Potassium salt: 60% K_2O) were applied in early spring under cultivator.

The previous crop for 'Satina' potato was winter wheat and, after its harvesting, white mustard was sown as the catch crop. The area of harvested plot was 24.0 m^2. The planting date was in the second decade of April, and harvest was in the third decade of September.

Soil and Weather Conditions

The arable layer of soil, with granulometric composition of silt, revealed a slightly acid pH, medium abundance in potassium, but high abundance in phosphorus and magnesium (Table 1). The content of N_{min} assessed in the 0–0.9 m soil profile before potato planting in the respective years and experimental treatments ranged from 64 to 80 kg N ha^{-1}.

The weather conditions in individual years of the experiment were diversified (Figure 1). The lowest rainfall amount (281 mm)

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Table 1. Soil characteristics of Luvic Chernozem from trial location (0–0.25 m layer).

Properties	Value
pH_{KCl}	6.4
Total organic C (g kg^{-1})	12.2
Total N (g kg^{-1})	1.14
C:N ratio	10.7
P_2O_2 (mg kg^{-1})	152.3
K_2O (mg kg^{-1})	175.4
MgO (mg kg^{-1})	112.1
Sand (g kg^{-1})	100
Silt (g kg^{-1})	550
Clay (g kg^{-1})	350

and the highest mean air temperature (16.5°C) were noted during potato growing season (April-September) in 2006. On the other hand, the greatest amount of rainfall (540 mm) during potato vegetation was registered in 2007. A particularly large amount of rainfall was noted by the end of potato vegetation period in August and September. Rainfall totals after potato harvesting in the autumn-winter period (October-March) in the respective years were little diversified, ranging from 250 to 255 mm. On the other hand, thermal conditions after potato harvesting during the autumn-winter period were more diversified than rainfall conditions. The highest mean air temperature over this period (5.2°C) was registered at the turn of 2006 and 2007, while the lowest (2.5°C) at the turn of 2008 and 2009.

Soil Analysis

The content of nitrate and ammonium forms of nitrogen were assessed in the soil collected in spring before the fertilizers application, in autumn when plant vegetation was completed (immediately after potato tubers harvesting), and after the autumn-winter period, i.e. in March of the following year. The soil samples (c.a. 400 g) were collected from the 0–0.3 m, 0.3–0.6 m and 0.6–0.9 m layers, using Egner's stick in four points at each plot and placed in foil bags, then kept frozen until analysis. Analysis of nitrate (NO_3^-) and ammonium (NH_4^+) ions was conducted using colorimetric method. The obtained results were converted into N–NO_3 and N–NH_4 content in dry soil mass and then the content of N_{min} was computed per kg N ha^{-1}.

Statistics

The obtained research results were

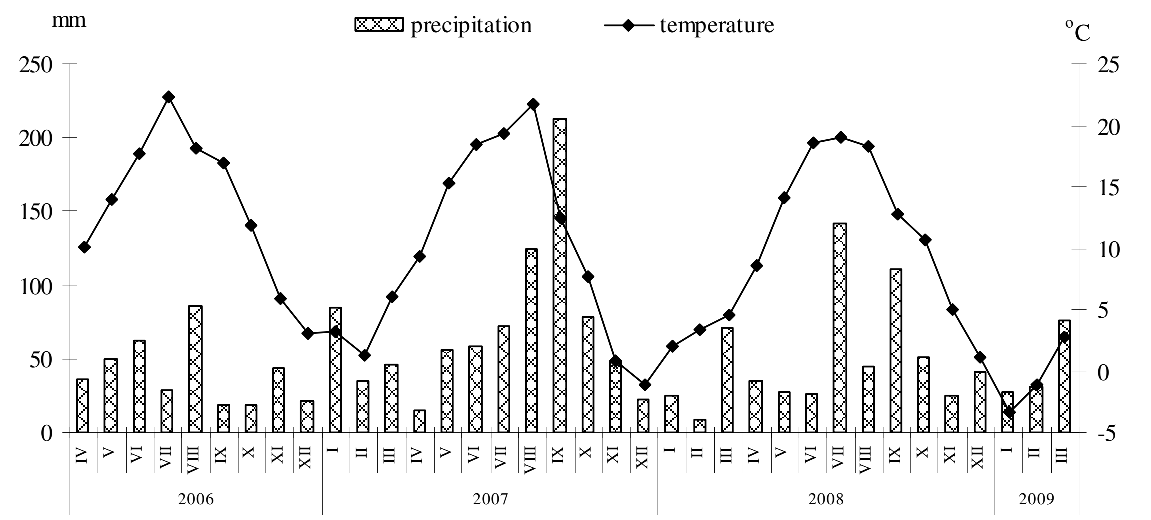

Figure 1. Characteristic of weather conditions during the study.

subjected to statistical analysis using the analysis of variance. Honestly significant difference (HSD) for content of N–NO_3 and N–NH_4 in soil were verified using the Tukey's test at significance level *P*= 0.05. The relationships between nitrogen doses and N_{min} content in soil after potato harvesting were assessed using analysis of regression.

RESULTS AND DISCUSSION

N_{min} Content in Autumn

N_{min} content in soil after potato harvesting was significantly dependant on the level of nitrogen fertilization, application of microbial preparations, and the weather conditions during the plant vegetation period (Table 2). The dominant nitrogen form was N–NO_3, best available to plants, whose share in the total N_{min} content ranged from 54 to 63%. Irrespective of the experimental factors, mean content of N–NO_3 in the 0–0.9 m soil layer was on the level of 50 kg N ha^{-1}, whereas N–NH_4 was 36 kg N ha^{-1}. The relationships between these individual nitrogen forms are compatible with the results reported by other authors (El-Galil, 2006; Fan, 2010). On the other hand, research conducted by Zebarth *et al*. (2003) has proved that N–NO_3 content in the 0–0.3 m soil layer after potato harvesting may be even 5-fold higher than N–NH_4 concentration.

N_{min} content in the individual layers of soil profile was diversified (Table 2). The biggest amount of N_{min}, on average 42 kg N ha^{-1}, was recorded in the 0–0.3 m soil layer, whereas the smallest i.e. 15 kg N ha^{-1}, was found in the 0.6–0.9 m layer. N–NO_3 content distribution in the soil profile was similar to the distribution of total N_{min} content, i.e. 49% of N–NO_3 was registered in the upper layer of the profile, 33% in the middle layer and 18% in the lower layer.

The amount of N_{min} in soil after plant harvesting increased with increasing level of nitrogen fertilization, particularly in the upper part of soil profile (Table 2). The smallest content of N–NO_3 and N–NH_4 at the depth up to 0.3 m was registered in N_0 treatment as, respectively, 13 and 10 kg N ha^{-1}, while the highest was observed in N_{180} treatment as, respectively, 35 and 24 kg N ha^{-1}. In the middle layer of the soil profile, N–NO_3 content increased from 10 to 23 kg N ha^{-1}, whereas N–NH_4 increased from 8 to 16 kg N ha^{-1}, respectively. In the lower layer

Table 2. Content of N–NO_3 and N–NH_4 in the soil after potatoes harvesting (kg N ha^{-1}).[a]

Treatment	N–NO_3[*]				N–NH_4			
	Soil layer (m)				Soil layer (m)			
	0–0.3	0.3–0.6	0.6–0.9	0–0.9	0–0.3	0.3–0.6	0.6–0.9	0–0.9
Microbial preparation								
control	23 [b]	16 [a]	9 [a]	48 [b]	16 [b]	12 [ab]	6 [a]	34 [b]
B	25 [a]	16 [a]	10 [a]	51 [a]	19 [a]	11 [b]	6 [a]	36 [a]
EM	24 [ab]	17 [a]	9 [a]	50 [a]	18 [a]	13 [a]	6 [a]	37 [a]
UGmax	25 [a]	16 [a]	9 [a]	50 [a]	18 [a]	12 [ab]	6 [a]	36 [a]
N rate (kg ha^{-1})								
N_0	13 [d]	10 [d]	5 [d]	28 [d]	10 [d]	8 [d]	5 [d]	22 [d]
N_{60}	21 [c]	14 [c]	9 [c]	44 [c]	16 [c]	12 [c]	6 [c]	34 [c]
N_{120}	28 [b]	19 [b]	10 [b]	57 [b]	20 [b]	13 [b]	7 [b]	40 [b]
N_{180}	35 [a]	23 [a]	12 [a]	70 [a]	24 [a]	16 [a]	8 [a]	48 [a]
Year								
2006	27 [a]	17 [a]	10 [a]	54 [a]	17 [a]	11 [b]	6 [a]	34 [b]
2007	24 [b]	15 [b]	10 [a]	49 [b]	18 [a]	10 [b]	6 [a]	34 [b]
2008	22 [c]	18 [a]	8 [b]	48 [b]	18 [a]	15 [a]	6 [a]	40 [a]

[a] Values followed by the same letters do not differ at 5% level of significance.

of the soil profile, higher nitrogen doses applied to potato cultivation caused an increase in N–NO_3 content ranging from 5 to 12 kg N ha^{-1}, whereas N–NH_4 was raised from 5 to 8 kg N ha^{-1}. Zebarth *et al*. (2003), based on many observations, stated that in the cultivation of potato fertilized with nitrogen rates up to 180 kg N ha^{-1}, after crop harvesting, mean contents of N–NO_3 and N–NH_4 in the 0-0.3 m soil layer were, respectively, 44 and 10 kg N ha^{-1}. On the other hand, in the investigations of Bélanger *et al*. (2003), the content of nitrate nitrogen form after potato harvest ranged much more widely: from 33 kg N ha^{-1} in the control treatment to 160 kg N ha^{-1} following application of 250 kg N ha^{-1}. Moreover, the authors claim that a safe amount of N–NO_3 in the 0–0.9 m soil profile after crop harvesting should not exceed 70 kg N ha^{-1}. In this author's own research, N–NO_3 content close to the limit value stated by Bélanger *et al*. (2003) was registered only in the treatments fertilized with a dose of 180 kg N ha^{-1}.

Linear regression analysis confirmed the existence of significant relationships between the nitrogen application rate and N–NO_3 and N–NH_4 content in soil after potato harvesting (Figure 2). The relationships were most apparent in the upper layer of the soil profile. Value of the coefficient of determination (R^2) proves that 87% of the N_{min} content in the 0–0.9 m soil layer can be explained by nitrogen rate for N–NO_3 and 79% in the case of N–NH_4. Increasing doses of nitrogen applied as urea caused a greater accumulation of N–NO_3 in the soil profile than N–NH_4. Also El-Galil (2006) and Fan (2010), who applied mineral fertilizers in the form of ammonium nitrate and urea, demonstrated a similar relationship.

The content of N_{min} in soil after plant harvesting may rise under the influence of organic matter mineralization. Decaying biomass of soil microorganisms may also play an important role. In research of Kołodziejczyk (2013), the quantity of N_{min}

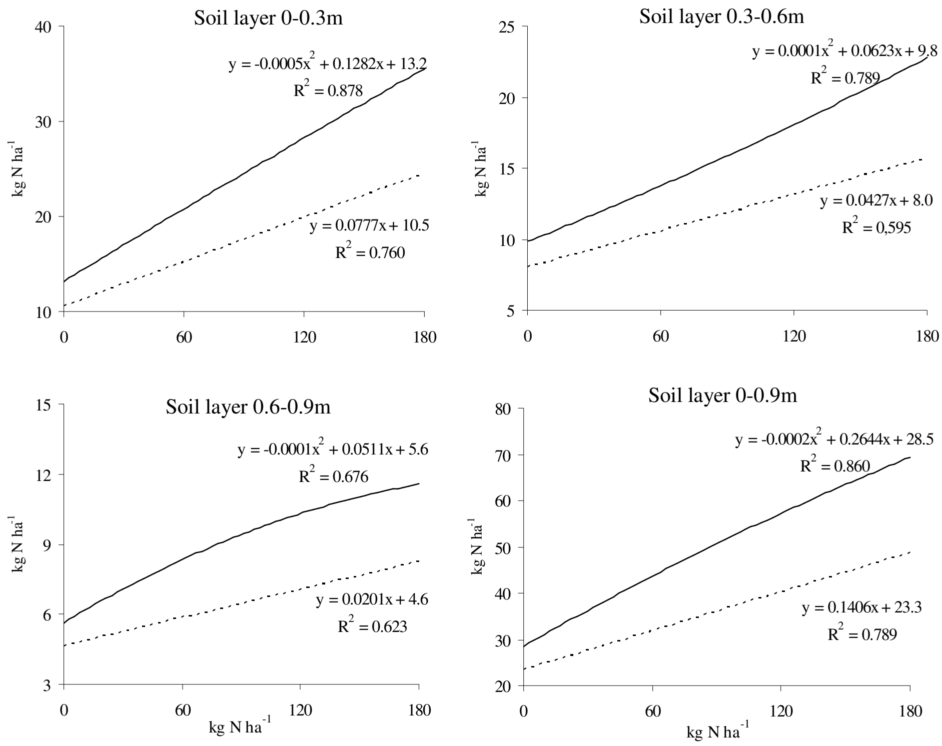

Figure 2. The relationship between the level of nitrogen fertilization and mineral nitrogen content in soil (kg N ha^{-1}), (—— N–NO_3, - - - N–NH_4) after harvest potatoes, (mean for 2006–2008).

assessed after wheat harvesting in the treatments where microbial preparations were applied, was lower than in the control. It might have resulted from a partial immobilization of nitrogen by soil microorganisms. However, the results of analyzed research point to a different dependence. Application of microbial preparations in potato cultivation led to increased N_{min} content in the soil after plants harvesting (Table 2). A different influence of microbial preparations on N_{min} concentrations in soil after plant harvesting resulted from a different length of wheat and potato vegetation periods and the date of soil sampling. The obtained results are compatible with these reported by Jakubus *et al*. (2010) who demonstrated a significant increase in N_{min} in Lessive soils incubated with EM-A preparation. The effect of microbial preparations on N–NO_3 and N–NH_4 content in soil after potato harvesting was ambiguous (Figure 3). A marked increase in N–NO_3 after B preparation application was registered in the upper layer of the soil profile in N_{60} fertilizer treatment and in the lower layer of the soil profile of the N_{180} treatment. On the other hand, in the middle part of the soil profile a significant effect of UGmax preparation on N–NO_3 content was observed. The influence of microbial preparations on N–NH_4 amount after potato harvesting was small and pronounced only in the upper soil layer. A significantly elevated N–NH_4 content was observed after the application of B preparation in N_{120} treatment and following the application of UGmax preparation in N_{180} treatment. In the middle and lower parts of the soil profile, no interactive effect of nitrogen doses or microbial preparations on N–NH_4 content was noted.

N_{min} concentrations in soil after potato harvesting depended on the weather conditions. The highest quantities of N–NO_3 were found in 2006 characterized by the lowest (281 mm) rainfall during vegetation period (April-September). A markedly lower content of N–NO_3 was assessed in the soil profile in the years 2007 and 2008 when total rainfall was considerably higher (respectively 540 and 387 mm). Rainfall amount, excessive in relation to needs, in August and September 2007 and in September 2008 might have caused a greater leaching of N–NO_3 into the soil profile below 90 cm. Also Zebarth *et al*. (2004) demonstrated a significant effect of the weather conditions in the final period of potato vegetation on N–NO_3 content in soil after plant harvesting.

A Change in N–NO_3 Content during the Autumn-Winter Period.

N–NO_3 content in soil after the autumn-winter period (March) was lower than in autumn after potato harvesting (September), (Table 3). The differences in the N–NO_3 content in the 0–0.9 m soil profile ranged from 2 kg N ha^{-1} (7%) in the nitrogen unfertilized plots to 17 kg N ha^{-1} (24%) in the plots where the N–NO_3 content was highest after potato harvest, i.e. in the plots fertilized at a rate of 180 kg N ha^{-1}. The application of microbial preparations also significantly affected the change in soil N–NO_3 content during the autumn-winter period. In the treatments where microbial preparations were used, N–NO_3 content in spring was between 7 and 10 kg N ha^{-1} lower than in autumn, whereas in the control, the reduction was 6 kg N ha^{-1}. The magnitude of the change in soil N–NO_3 content in the individual autumn-winter periods varied in spite of similar total precipitation from October to March, which was from 250 to 255 mm in the individual seasons (Figure 1). The thermal conditions could have also had a significant effect on the change in soil N–NO_3 content. The highest decrease in N–NO_3 content was found at the turn of 2006/2007 when the average air temperature in the autumn-winter period was 5.2^{o}C, whereas the lowest decrease was found at the turn of 2008/2009 with an average air temperature of 2.5^{o}C. Regardless of the experimental factors, the average decrease in N–NO_3 content in the

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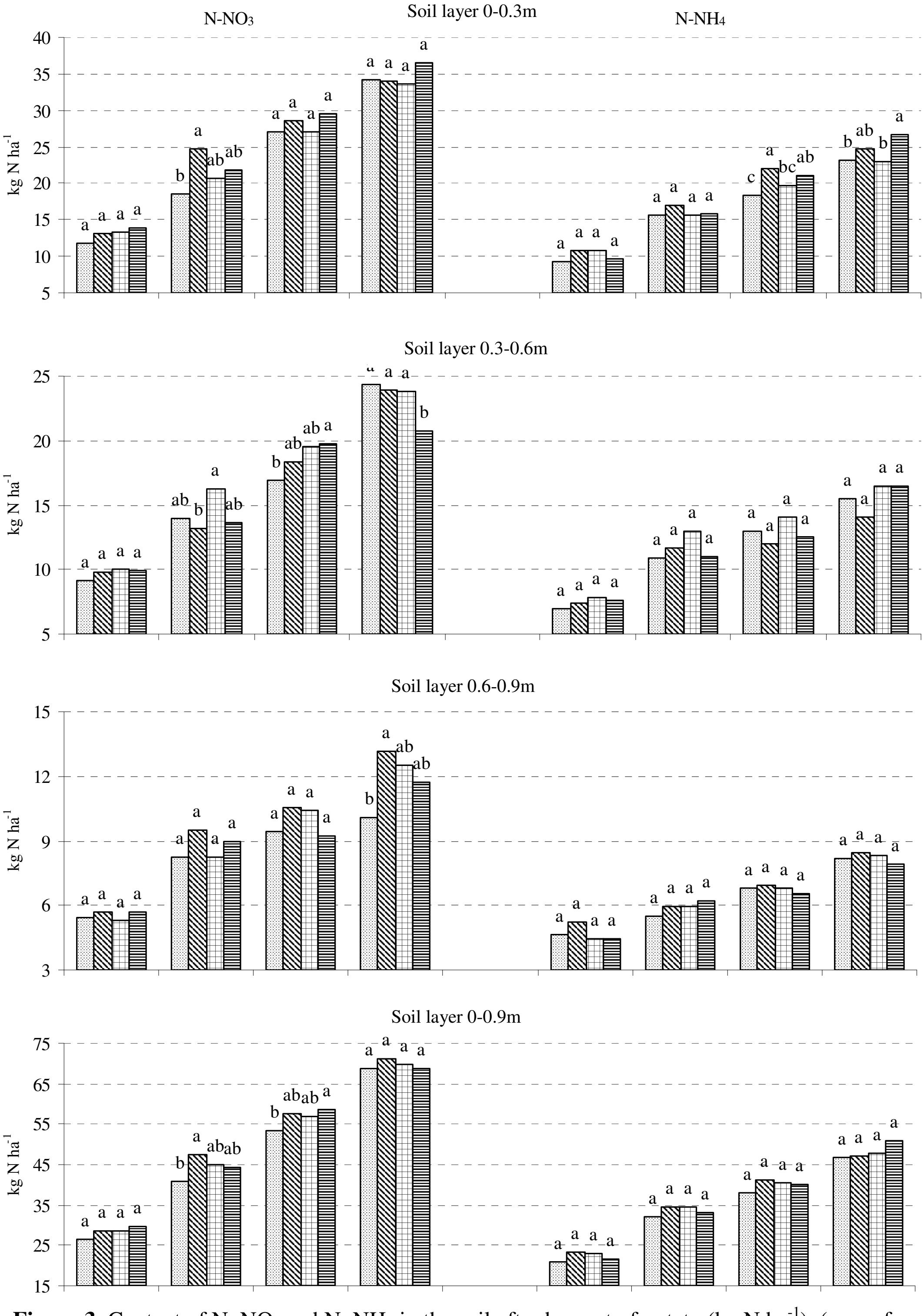

Figure 3. Content of N–NO_3 and N–NH_4 in the soil after harvest of potato (kg N ha^{-1}), (mean for 2006–2008).

Table 3. $N–NO_3$ content in spring and change of content of $N–NO_3$ in the autumn-winter period (kg N ha^{-1}).[a]

Treatment	$N–NO_3$ content				Change the content $N–NO_3$			
	Soil layer (m)				Soil layer (m)			
	0–0.3	0.3–0.6	0.6–0.9	0–0.9	0–0.3	0.3–0.6	0.6–0.9	0–0.9
Microbial preparation								
control	18^{a}	14^{ab}	10^{a}	42^{a}	-5^{b}	-2^{ab}	$+1^{ab}$	-6^{b}
B	17^{a}	15^{a}	10^{a}	42^{a}	-8^{a}	-1^{b}	0^{b}	-9^{a}
EM	17^{a}	13^{b}	10^{a}	40^{b}	-7^{ab}	-4^{a}	$+1^{ab}$	-10^{a}
UGmax	18^{a}	15^{a}	10^{a}	43^{a}	-7^{ab}	-1^{b}	$+1^{a}$	-7^{b}
N rate (kg ha^{-1})								
N_0	11^{d}	9^{d}	6^{d}	26^{d}	-2^{d}	-1^{b}	$+1^{b}$	-2^{c}
N_{60}	16^{c}	14^{c}	10^{c}	40^{c}	-5^{c}	0^{b}	$+1^{b}$	-4^{bc}
N_{120}	20^{b}	17^{b}	12^{b}	49^{b}	-8^{b}	-2^{b}	$+2^{a}$	-8^{b}
N_{180}	22^{a}	18^{a}	13^{a}	53^{a}	-13^{a}	-5^{a}	$+1^{b}$	-17^{a}
Year								
2007	19^{a}	14^{a}	11^{a}	44^{a}				
2008	16^{b}	14^{a}	10^{ab}	40^{b}				
2009	17^{b}	15^{a}	9^{b}	41^{b}				
2006/2007					-8^{a}	-3^{ab}	$+1^{b}$	-10^{a}
2007/2008					-8^{a}	-1^{b}	0^{b}	-9^{ab}
2008/2009					-5^{b}	-3^{a}	$+1^{a}$	-7^{b}

[a] Values followed by the same letters do not differ at 5% level of significance, +: Means an increase in the content of $N–NO_3$, -: Means the reduction of $N–NO_3$.

upper soil profile was 29%, while in the middle one it was 12%. Evaluating 228 potato plantations, Zebarth *et al.* (2003) found the $N–NO_3$ content in the upper soil layer to decrease in the range from 0 to 97%.

In conclusion, increasing nitrogen application rates caused a linear increase in soil N_{min} content after potato harvest and a decrease in the amount of $N–NO_3$ during the autumn-winter period. The dominant form of nitrogen in the soil was $N–NO_3$. Nitrogen fertilization of potato up to 180 kg N ha^{-1} did not cause the amounts of $N–NO_3$ to go above the safe amounts after the harvest. However, the way $N–NO_3$ levels change under the influence of increased doses of nitrogen might suggest that it is possible to exceed safe amounts of that form of nitrogen after the harvest of potato fertilized with higher than 180 kg N ha^{-1}. Due to high levels of N_{min} in the soil after the crop harvesting, especially in the condition of high nitrogen fertilization, it is advised to cultivate winter crops or intercrops as a way to limit the loss of the $N–NO_3$ in the autumn-winter period. The application of microbial preparations resulted in an increase in soil N_{min} content after potato harvest and a decrease in $N–NO_3$ content during the autumn-winter period.

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اثر کود نیتروژن و آموده های میکروبی روی محتوای نیتروژن معدنی خاک بعد از برداشت سیب زمینی

م. کلودزیجزیک

چکیده

این پژوهش سه ساله روی خاک چرنوزم لویک اجرا شد. مقادیر مختلف کود نیتروژن شامل صفر، ۶۰، ۱۲۰، و ۱۸۰ کیلوگرم نیتروژن در هکتار و نیز آموده های میکروبی برای بهبود ویژگی های خاک به مزرعه ای افزوده شد که زیر کشت سیب زمینی، کولتیوار ساتینا، بود. در پاییز، بعد از برداشت سیب زمینی، غلظت نیتروژن نیتراتی($N–NO_3$) در لایه ۰/۹-۰ متری بین $kgNha^{-1}$ ۲۸ در تیمار صفر(N_0) تا $kgNha^{-1}$ ۷۰ در تیمار N_{180} بود و درمورد $N–NH_4$، به ترتیب بین ۲۲ تا $kgNha^{-1}$ ۴۸ نوسان نشان داد. همچنین، مقدار کود نیتروژن اثر معنی داری روی تغییرات محتوای $N–NO_3$ در طی دوره پاییز و زمستان داشت به این صورت که مقدارکاهش $N–NO_3$ در تیمار N_0 برابر ۷ ٪ و در تیمار N_{180} برابر ۲۴٪ بود. افزودن آموده های میکروبی به مزرعه سیب زمینی منجر به افزایش نیتروژن معدنی خاک بعد از برداشت محصول شد. با این وجود، بعد از دوره پاییز-زمستان، در تیمارهایی که آموده های میکروبی دریافت کرده بودند، موجودی $N–NO_3$ خاک در مقایسه با تیمار شاهد کمتر بود.

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