

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

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### 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<sup>-1</sup>, and microbial preparations improving soil properties were applied to potatoes, cv. 'Satina', cultivation. N-NO<sub>3</sub> concentration in the soil profile (0–0.9 m) in autumn after potato harvesting fluctuated from 28 kg N ha<sup>-1</sup> in the N<sub>0</sub> treatment to 70 kg N ha<sup>-1</sup> in the N<sub>180</sub> treatment, whereas N-NH<sub>4</sub> content varied from 22 to 48 kg N ha<sup>-1</sup>, respectively. The level of nitrogen fertilization also had a significant effect on the change in soil N-NO<sub>3</sub> content during the autumn-winter period. The decrease in N-NO<sub>3</sub> content in the N<sub>0</sub> treatments was 7% compared to 24% in the N<sub>180</sub> 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<sub>3</sub>, 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<sub>3</sub>, *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<sub>3</sub> leaching and N<sub>2</sub>O, NO, and NH<sub>3</sub> 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 45<sup>th</sup> 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<sup>-1</sup>. Considerable nitrogen losses in potato

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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<sub>3</sub> losses in potato-cereal crop rotation estimated by Gasser *et al.* (2002) ranged from 87 to 132 kg N ha<sup>-1</sup> per year and exceeded N uptake by plants during harvesting by at least 20 kg N ha<sup>-1</sup>.

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<sub>3</sub> 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<sup>-1</sup> and microbial preparations improving soil properties: BactoFil B 10 (3 L ha<sup>-1</sup>), Effective Microorganisms EM (3 L ha<sup>-1</sup>) and UGmax soil fertilizer (0.9 L ha<sup>-1</sup>) 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<sub>0</sub>, N<sub>60</sub>, N<sub>120</sub> and N<sub>180</sub>, 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<sub>60</sub> and N<sub>120</sub> treatments, the whole nitrogen dose was supplied to the soil before planting, while in N<sub>180</sub> treatment, 120 kg N ha<sup>-1</sup> was applied before planting and the remaining part (60 kg N ha<sup>-1</sup>) as top dressing before the last covering (BBCH 18-19). Phosphorus fertilization, with 60 kg P<sub>2</sub>O<sub>5</sub> ha<sup>-1</sup> (Triple superphosphate: 40% P<sub>2</sub>O<sub>5</sub>) and potassium, 210 kg K<sub>2</sub>O ha<sup>-1</sup> (Potassium salt: 60% K<sub>2</sub>O) 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<sup>2</sup>. 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<sub>min</sub> 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<sup>-1</sup>.

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

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

Properties	Value
pH <sub>KCl</sub>	6.4
Total organic C (g kg <sup>-1</sup> )	12.2
Total N (g kg <sup>-1</sup> )	1.14
C:N ratio	10.7
P <sub>2</sub> O <sub>5</sub> (mg kg <sup>-1</sup> )	152.3
K <sub>2</sub> O (mg kg <sup>-1</sup> )	175.4
MgO (mg kg <sup>-1</sup> )	112.1
Sand (g kg <sup>-1</sup> )	100
Silt (g kg <sup>-1</sup> )	550
Clay (g kg <sup>-1</sup> )	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

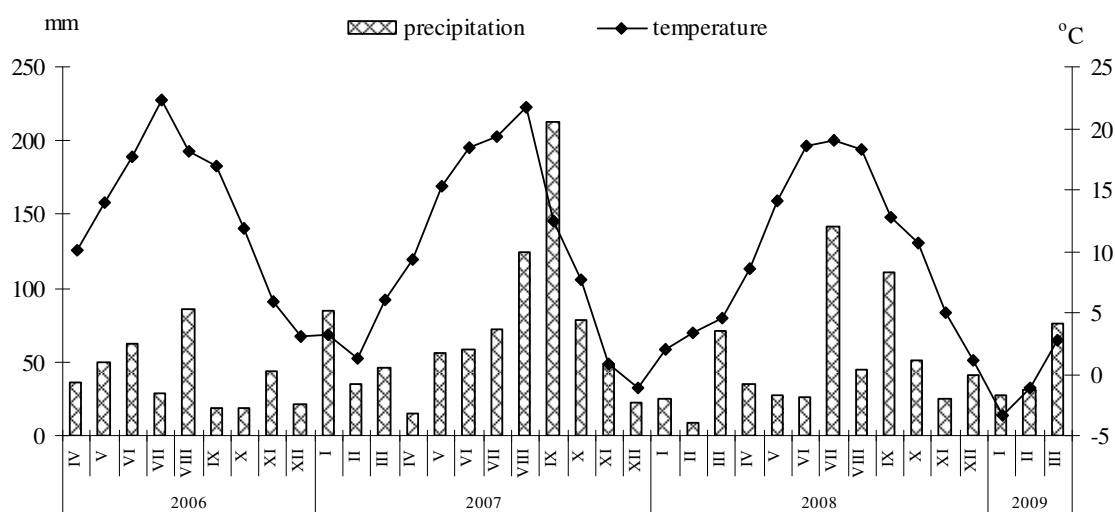
air temperature over this period (5.2°C) was registered at the turn of 2006 and 2007, while the lowest (2.5°C) at the turn of 2008 and 2009.

### 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<sub>3</sub><sup>-</sup>) and ammonium (NH<sub>4</sub><sup>+</sup>) ions was conducted using colorimetric method. The obtained results were converted into N–NO<sub>3</sub> and N–NH<sub>4</sub> content in dry soil mass and then the content of N<sub>min</sub> was computed per kg N ha<sup>-1</sup>.

### 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<sub>3</sub> and N-NH<sub>4</sub> in soil were verified using the Tukey's test at significance level  $P=0.05$ . The relationships between nitrogen doses and N<sub>min</sub> content in soil after potato harvesting were assessed using analysis of regression.

## RESULTS AND DISCUSSION

### N<sub>min</sub> Content in Autumn

N<sub>min</sub> 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<sub>3</sub>, best available to plants, whose share in the total N<sub>min</sub> content ranged from 54 to 63%. Irrespective of the experimental factors, mean content of N-NO<sub>3</sub> in the 0–0.9 m soil layer was on the level of 50 kg N ha<sup>-1</sup>, whereas N-NH<sub>4</sub> was 36 kg N ha<sup>-1</sup>. 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<sub>3</sub> content in the 0–0.3 m soil layer after potato harvesting may be even 5-fold higher than N-NH<sub>4</sub> concentration.

N<sub>min</sub> content in the individual layers of soil profile was diversified (Table 2). The biggest amount of N<sub>min</sub>, on average 42 kg N ha<sup>-1</sup>, was recorded in the 0–0.3 m soil layer, whereas the smallest i.e. 15 kg N ha<sup>-1</sup>, was found in the 0.6–0.9 m layer. N-NO<sub>3</sub> content distribution in the soil profile was similar to the distribution of total N<sub>min</sub> content, i.e. 49% of N-NO<sub>3</sub> was registered in the upper layer of the profile, 33% in the middle layer and 18% in the lower layer.

The amount of N<sub>min</sub> 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<sub>3</sub> and N-NH<sub>4</sub> at the depth up to 0.3 m was registered in N<sub>0</sub> treatment as, respectively, 13 and 10 kg N ha<sup>-1</sup>, while the highest was observed in N<sub>180</sub> treatment as, respectively, 35 and 24 kg N ha<sup>-1</sup>. In the middle layer of the soil profile, N-NO<sub>3</sub> content increased from 10 to 23 kg N ha<sup>-1</sup>, whereas N-NH<sub>4</sub> increased from 8 to 16 kg N ha<sup>-1</sup>, respectively. In the lower layer

**Table 2.** Content of N-NO<sub>3</sub> and N-NH<sub>4</sub> in the soil after potatoes harvesting (kg N ha<sup>-1</sup>).<sup>a</sup>

Treatment	N-NO <sub>3</sub> *				N-NH <sub>4</sub>			
	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 <sup>b</sup>	16 <sup>a</sup>	9 <sup>a</sup>	48 <sup>b</sup>	16 <sup>b</sup>	12 <sup>ab</sup>	6 <sup>a</sup>	34 <sup>b</sup>
B	25 <sup>a</sup>	16 <sup>a</sup>	10 <sup>a</sup>	51 <sup>a</sup>	19 <sup>a</sup>	11 <sup>b</sup>	6 <sup>a</sup>	36 <sup>a</sup>
EM	24 <sup>ab</sup>	17 <sup>a</sup>	9 <sup>a</sup>	50 <sup>a</sup>	18 <sup>a</sup>	13 <sup>a</sup>	6 <sup>a</sup>	37 <sup>a</sup>
UGmax	25 <sup>a</sup>	16 <sup>a</sup>	9 <sup>a</sup>	50 <sup>a</sup>	18 <sup>a</sup>	12 <sup>ab</sup>	6 <sup>a</sup>	36 <sup>a</sup>
N rate (kg ha <sup>-1</sup> )								
N <sub>0</sub>	13 <sup>d</sup>	10 <sup>d</sup>	5 <sup>d</sup>	28 <sup>d</sup>	10 <sup>d</sup>	8 <sup>d</sup>	5 <sup>d</sup>	22 <sup>d</sup>
N <sub>60</sub>	21 <sup>c</sup>	14 <sup>c</sup>	9 <sup>c</sup>	44 <sup>c</sup>	16 <sup>c</sup>	12 <sup>c</sup>	6 <sup>c</sup>	34 <sup>c</sup>
N <sub>120</sub>	28 <sup>b</sup>	19 <sup>b</sup>	10 <sup>b</sup>	57 <sup>b</sup>	20 <sup>b</sup>	13 <sup>b</sup>	7 <sup>b</sup>	40 <sup>b</sup>
N <sub>180</sub>	35 <sup>a</sup>	23 <sup>a</sup>	12 <sup>a</sup>	70 <sup>a</sup>	24 <sup>a</sup>	16 <sup>a</sup>	8 <sup>a</sup>	48 <sup>a</sup>
Year								
2006	27 <sup>a</sup>	17 <sup>a</sup>	10 <sup>a</sup>	54 <sup>a</sup>	17 <sup>a</sup>	11 <sup>b</sup>	6 <sup>a</sup>	34 <sup>b</sup>
2007	24 <sup>b</sup>	15 <sup>b</sup>	10 <sup>a</sup>	49 <sup>b</sup>	18 <sup>a</sup>	10 <sup>b</sup>	6 <sup>a</sup>	34 <sup>b</sup>
2008	22 <sup>c</sup>	18 <sup>a</sup>	8 <sup>b</sup>	48 <sup>b</sup>	18 <sup>a</sup>	15 <sup>a</sup>	6 <sup>a</sup>	40 <sup>a</sup>

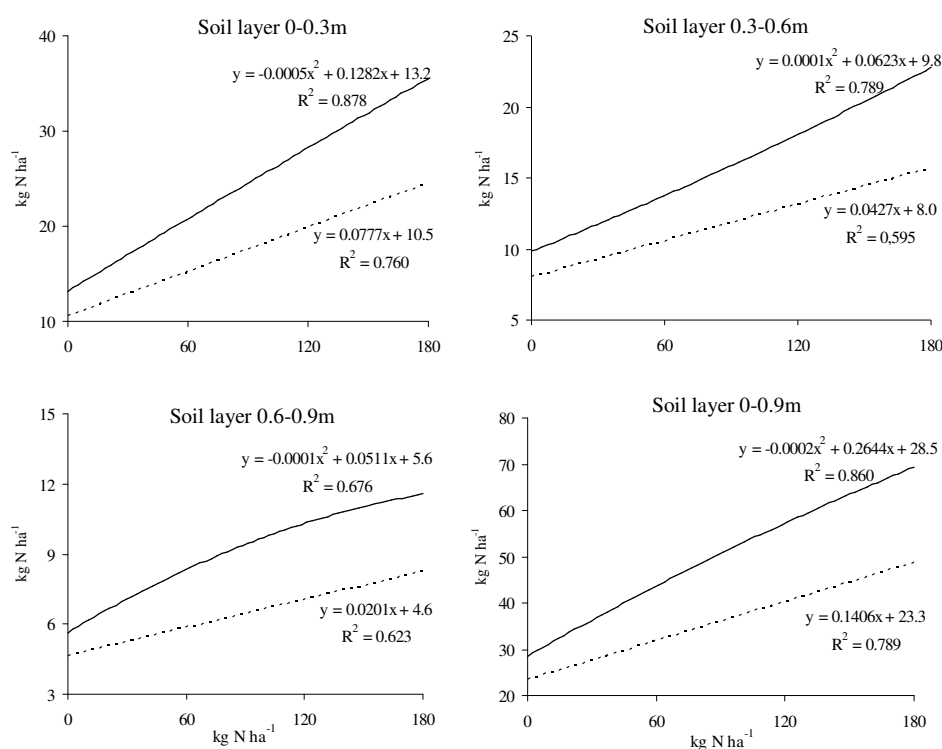
<sup>a</sup> Values followed by the same letters do not differ at 5% level of significance.

of the soil profile, higher nitrogen doses applied to potato cultivation caused an increase in N-NO<sub>3</sub> content ranging from 5 to 12 kg N ha<sup>-1</sup>, whereas N-NH<sub>4</sub> was raised from 5 to 8 kg N ha<sup>-1</sup>. 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<sup>-1</sup>, after crop harvesting, mean contents of N-NO<sub>3</sub> and N-NH<sub>4</sub> in the 0-0.3 m soil layer were, respectively, 44 and 10 kg N ha<sup>-1</sup>. 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<sup>-1</sup> in the control treatment to 160 kg N ha<sup>-1</sup> following application of 250 kg N ha<sup>-1</sup>. Moreover, the authors claim that a safe amount of N-NO<sub>3</sub> in the 0-0.9 m soil profile after crop harvesting should not exceed 70 kg N ha<sup>-1</sup>. In this author's own research, N-NO<sub>3</sub> 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<sup>-1</sup>.

Linear regression analysis confirmed the existence of significant relationships between the nitrogen application rate and N-NO<sub>3</sub> and N-NH<sub>4</sub> 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<sup>2</sup>) proves that 87% of the N<sub>min</sub> content in the 0-0.9 m soil layer can be explained by nitrogen rate for N-NO<sub>3</sub> and 79% in the case of N-NH<sub>4</sub>. Increasing doses of nitrogen applied as urea caused a greater accumulation of N-NO<sub>3</sub> in the soil profile than N-NH<sub>4</sub>. 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<sub>min</sub> 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<sub>min</sub>



**Figure 2.** The relationship between the level of nitrogen fertilization and mineral nitrogen content in soil (kg N ha<sup>-1</sup>), (— N-NO<sub>3</sub>, - - - N-NH<sub>4</sub>) 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<sup>-1</sup> (7%) in the nitrogen unfertilized plots to 17 kg N ha<sup>-1</sup> (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<sup>-1</sup>. 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<sup>-1</sup> lower than in autumn, whereas in the control, the reduction was 6 kg N ha<sup>-1</sup>. 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°C, whereas the lowest decrease was found at the turn of 2008/2009 with an average air temperature of 2.5°C. Regardless of the experimental factors, the average decrease in  $N-NO_3$  content in the

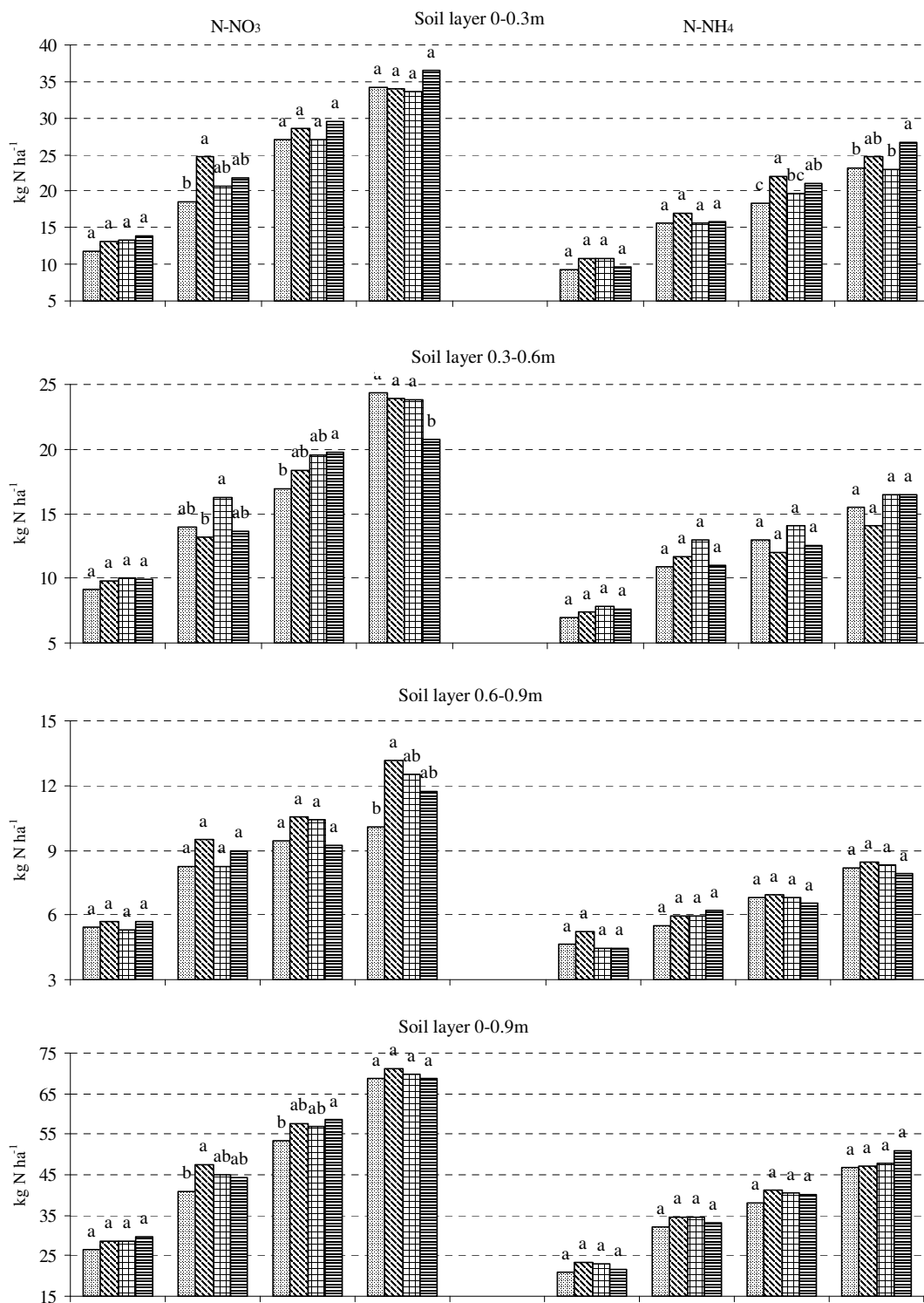


Figure 3. Content of N-NO<sub>3</sub> and N-NH<sub>4</sub> in the soil after harvest of potato (kg N ha<sup>-1</sup>), (mean for 2006–2008).



**Table 3.** N-NO<sub>3</sub> content in spring and change of content of N-NO<sub>3</sub> in the autumn-winter period (kg N ha<sup>-1</sup>).<sup>a</sup>

Treatment	N-NO <sub>3</sub> content				Change the content N-NO <sub>3</sub>			
	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 <sup>a</sup>	14 <sup>ab</sup>	10 <sup>a</sup>	42 <sup>a</sup>	-5 <sup>b</sup>	-2 <sup>ab</sup>	+1 <sup>ab</sup>	-6 <sup>b</sup>
B	17 <sup>a</sup>	15 <sup>a</sup>	10 <sup>a</sup>	42 <sup>a</sup>	-8 <sup>a</sup>	-1 <sup>b</sup>	0 <sup>b</sup>	-9 <sup>a</sup>
EM	17 <sup>a</sup>	13 <sup>b</sup>	10 <sup>a</sup>	40 <sup>b</sup>	-7 <sup>ab</sup>	-4 <sup>a</sup>	+1 <sup>ab</sup>	-10 <sup>a</sup>
UGmax	18 <sup>a</sup>	15 <sup>a</sup>	10 <sup>a</sup>	43 <sup>a</sup>	-7 <sup>ab</sup>	-1 <sup>b</sup>	+1 <sup>a</sup>	-7 <sup>b</sup>
N rate (kg ha <sup>-1</sup> )								
N <sub>0</sub>	11 <sup>d</sup>	9 <sup>d</sup>	6 <sup>d</sup>	26 <sup>d</sup>	-2 <sup>d</sup>	-1 <sup>b</sup>	+1 <sup>b</sup>	-2 <sup>c</sup>
N <sub>60</sub>	16 <sup>c</sup>	14 <sup>c</sup>	10 <sup>c</sup>	40 <sup>c</sup>	-5 <sup>c</sup>	0 <sup>b</sup>	+1 <sup>b</sup>	-4 <sup>bc</sup>
N <sub>120</sub>	20 <sup>b</sup>	17 <sup>b</sup>	12 <sup>b</sup>	49 <sup>b</sup>	-8 <sup>b</sup>	-2 <sup>b</sup>	+2 <sup>a</sup>	-8 <sup>b</sup>
N <sub>180</sub>	22 <sup>a</sup>	18 <sup>a</sup>	13 <sup>a</sup>	53 <sup>a</sup>	-13 <sup>a</sup>	-5 <sup>a</sup>	+1 <sup>b</sup>	-17 <sup>a</sup>
Year								
2007	19 <sup>a</sup>	14 <sup>a</sup>	11 <sup>a</sup>	44 <sup>a</sup>				
2008	16 <sup>b</sup>	14 <sup>a</sup>	10 <sup>ab</sup>	40 <sup>b</sup>				
2009	17 <sup>b</sup>	15 <sup>a</sup>	9 <sup>b</sup>	41 <sup>b</sup>				
2006/2007					-8 <sup>a</sup>	-3 <sup>ab</sup>	+1 <sup>b</sup>	-10 <sup>a</sup>
2007/2008					-8 <sup>a</sup>	-1 <sup>b</sup>	0 <sup>b</sup>	-9 <sup>ab</sup>
2008/2009					-5 <sup>b</sup>	-3 <sup>a</sup>	+1 <sup>a</sup>	-7 <sup>b</sup>

<sup>a</sup> Values followed by the same letters do not differ at 5% level of significance, +: Means an increase in the content of N-NO<sub>3</sub>, -: Means the reduction of N-NO<sub>3</sub>.

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<sub>3</sub> 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<sub>min</sub> content after potato harvest and a decrease in the amount of N-NO<sub>3</sub> during the autumn-winter period. The dominant form of nitrogen in the soil was N-NO<sub>3</sub>. Nitrogen fertilization of potato up to 180 kg N ha<sup>-1</sup> did not cause the amounts of N-NO<sub>3</sub> to go above the safe amounts after the harvest. However, the way N-NO<sub>3</sub> 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<sup>-1</sup>. Due to high levels of N<sub>min</sub> 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<sub>3</sub> in the autumn-winter period. The application of microbial preparations resulted in an increase in soil N<sub>min</sub> content after potato harvest and a decrease in N-NO<sub>3</sub> content during the autumn-winter period.

## REFERENCES

1. Arriaga, F. J., Lowery, B., and Kelling, K. A. 2009. Surfactant Impact on Nitrogen Utilization and Leaching in Potatoes. *Am. J. Pot. Res.*, **86**: 383-390.
2. Barabasz, W., Albińska, D., Jaśkowska, M. and Lipiec, J. 2002. Biological Effects of Mineral Nitrogen Fertilization on Soil Microorganisms. *Pol. J. Environ. Stud.*, **11**: 193-198.
3. Bélanger, G., Ziadi, N., Walsh, J. R., Richards, J. E. and Milburn, P. H. 2003. Residual Soil Nitrate after Potato Harvest. *J. Environ. Qual.*, **32**: 607-612.
4. Córdor-Golec, A. F., Pérez, P. G. and Lokare, Y. C. 2007. Effective



- Microorganisms: Myth or Reality? *Rev. Per. Biol.*, **14**: 315–319.
5. Davenport, J. R., Milburn, P. H., Rosen, C. J. and Thornton, R. E. 2005. Environmental Impacts of Potatoes Nutrient Requirements. *Am. J. Pot. Res.*, **82**: 321–328.
  6. El-Galil, A. A. 2006. Fertilizer-N Dynamics in the Soil and Yield Response of Potatoes as Affected by Methods of N-application. *J. App. Sci. Res.*, **2**: 613–623.
  7. Emitazi, G., Nader, A. and Etemadifar, Z. 2004. Effect of Nitrogen Fixing Bacteria on Growth of Potato Tubers. *Adv. Food Sci.*, **26**: 56–58.
  8. Fan, Y. 2010. The Effects of Irrigation and Nitrogen Management on Potato Tuber Yield, N Recovery and Leaching in Northeast Florida. University of Florida, 115 PP.
  9. Gasser, M. O., Laverdière, M. R., Lagacè, R. and Caron, J. 2002. Impact of Potato-cereal Rotation and Slurry Applications on Nitrate Leaching and Nitrogen Balance in Sandy Soils. *Can. J. Soil Sci.*, **82**: 469–479.
  10. Jakubus, M., Kaczmarek, Z. and Gajewski, P. 2010. Influence of Increasing Doses of EM-A Preparation on Properties of Arable Soils: Chemical Properties. *J. Res. App. Agric. Engin.*, **55**: 128–132.
  11. Kaczmarek, Z., Wolna-Maruwka, A. and Jakubas, M. 2008. Changes of the Number of Selected Microorganism Groups and Enzymatic Activity in the Soil Inoculated with Effective Microorganisms (EM). *J. Res. App. Agric. Engin.*, **53**: 122–127.
  12. Kołodziejczyk, M. 2013. Effect of Nitrogen Fertilization and Application of Soil Properties Improving Microbial Preparations on the Content of Mineral Nitrogen in Soil after Spring Wheat Harvesting. *J. Cent. Eur. Agric.*, **14**: 306–318.
  13. Kołodziejczyk, M. 2014. Effectiveness of Nitrogen Fertilization and Application of Microbial Preparations in Potato Cultivation. *Turk. J. Agric. For.*, **38**: (in Print).
  14. Kumar, S., Baudhdh, K., Barman, S. C., Singh, R.P. 2014. Organic Matrix Entrapped Bio-fertilizers Increase Growth, Productivity, and Yield of *Triticum aestivum* L. and Transport of  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ ,  $\text{NH}_4^+$  and  $\text{PO}_4^{3-}$  from Soil to Plant Leaves. *J. Agr. Sci. Tech.*, **16**: 315–329.
  15. Mosier, A. G. 1998. Soil Processes and Global Change. *Biol. Fert. Soil.*, **27**: 221–229.
  16. Munoz, F., Mylavarapu R. S. and Hutchison, C. M. 2005. Environmentally Responsible Potato Production Systems: A Review. *J. Plant Nutr.*, **28**: 1287–1309.
  17. Neumann, A., Gunnar, T. and Aronsson, H. 2012. Nitrogen and Phosphorus Leaching Losses from Potatoes with Different Harvest Times and Following Crops. *Field Crop. Res.*, **133**: 130–138.
  18. Priyadi, K., Hadi, A., Siagan, T. H., Nisa, C., Azizah, A., Raihani, N. and Inubushi, K. 2005. Effect of Soil Type, Applications of Chicken Manure and Effective Microorganisms on Corn Yield and Microbial Properties of Acidic Wetland Soils in Indonesia. *Soil Sci. Plant Nutr.*, **51**: 689–691.
  19. Shah, H.S., Saleem, M.F. and Shahid, M. 2001. Effect of Different Fertilizers and Effective Microorganisms on Growth, Yield and Quality of Maize. *Int. J. Agric. Biol.*, **3**: 378–379.
  20. Shrestha, R. A., Cooperband, L. R. and MacGuidwin, A. E. 2010. Strategies to Reduce Nitrate Leaching into Groundwater in Potato Grown in Sandy Soils: Case Study from North Central USA. *Am. J. Pot. Res.*, **87**: 229–244.
  21. Stalham, M.A. and Allen, E.J. 2001. Effect of Variety, Irrigation Regime and Planting Date on Depth, Rate, Duration and Density of Root Growth in the Potato (*Solanum tuberosum* L.) Crop. *J. Agric. Sci.*, **137**: 251–270.
  22. Vos, J. 2009. Nitrogen Responses and Nitrogen Management in Potato. *Pot. Res.*, **52**: 305–317.
  23. Vos, J. and Mackerron, D.K.L. 2000. Basic Concept of the Management of Supply of Nitrogen and Water in Potato Production. In: “*Management of Nitrogen and Water in Potato Production*”, (Eds.): Haverkart A. J. and Mackerron D. K. L. Wageningen Press, PP. 15–33.
  24. Zebarth, B. J., Leclerc, Y. and Moreau, G. 2004. Rate and Timing of Nitrogen Fertilization of Russet Burbank Potato: Nitrogen Use Efficiency. *Can. J. Plant Sci.*, **84**: 845–854.
  25. Zebarth, B. J., Leclerc, Y., Moreau, G., Gareau, R. and Milburn, P. H. 2003. Soil Inorganic Nitrogen Content in Commercial Potato Fields in New Brunswick. *Can. J. Soil Sci.*, **83**: 425–429.



26. Zebarth, B. J. and Milburn, P. H. 2003. Spatial and Temporal Distribution of Soil Inorganic Nitrogen Concentration in Potato Hills. *Can. J. Soil Sci.*, **83**: 183–195.
27. Zebarth, B. J. and Rosen, C. J. 2007. Research Perspective on Nitrogen BMP Development for Potato. *Am. J. Pot. Res.*, **84**: 3–18.
28. Zvomuya, F., Rosen, C. J., Russelle M. P. and Gupta, S. C. 2003. Nitrate Leaching and Nitrogen Recovery Application of Polyolefin-coated Urea to Potato. *J. Environ. Qual.*, **32**: 480–489.

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

### م. کلودزیجیک

#### 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 ۰-۰/۹ متری بین  $28 \text{ kgNha}^{-1}$  در تیمار صفر ( $N_0$ ) تا  $70 \text{ kgNha}^{-1}$  در تیمار  $N_{180}$  بود و در مورد  $N-NH_4$ ، به ترتیب بین ۲۲ تا  $48 \text{ kgNha}^{-1}$  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 مقدار کاهش  $N-NO_3$  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.