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Tomasz SOSULSKI[1] and Stanisław MERCIK[1]

DYNAMICS OF MINERAL NITROGEN MOVEMENT IN THE SOIL PROFILE IN LONG-TERM EXPERIMENTS

DYNAMIKA PRZEMIESZCZANIA SIĘ AZOTU MINERALNEGO W PROFILU GLEBOWYM W WARUNKACH WIELOLETNICH DOŚWIADCZEŃ NAWOZOWYCH

Abstract: Results presented in this paper come from long term fertilization experiments (5-field crop rotation: potatoes (30 Mg FYM ha^{-1}), s. barley, r. clover, w. wheat, rye; arbitrary rotation without FYM and without legumes) carried out in Skierniewice (since 1923). Content of mineral nitrogen ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) was measured using Skalar San Plus Flow Analizer, after fresh soil extraction in 0.01 M $CaCl_2$. In all crop rotation systems and merely all fertilizer treatments the soil content of mineral nitrogen was higher in late autumn than in spring and than in summer. Among the examined soil profiles the highest content of mineral nitrogen was shown in the soil treated with FYM (5-field crop rotation – E). The soil content of mineral nitrogen was significantly higher in the soil fertilized with nitrogen (CaNPK, NPK) than in the unfertilized one (CaPK, PK). Migration of mineral nitrogen from the top soil layer into deeper layers was bigger in the FYM fertilized fields with legumes cultivation in crop rotation than in the field not fertilized with manure and without legumes cultivation.

Keywords: long-term experiment, fertilization, soil nitrogen

Depending on the amount of fertilization, plant species or physicochemical soil properties, plants uptake usually about 60 % of the fertilizer nitrogen dose [1]. Thus in the defined agrotechnical and climatic conditions the amount of nitrogen not consumed by plants may be quite large [2, 3]. In the soils of moderate climate the shift of mineral nitrogen below the topsoil takes place. The movement of components down the soil profile is connected with the vertical movement of water. Thus the amount and distribution of precipitations is the primary factor shaping the dynamics of washing out the nitrogen [4]. The migration of nitrogen is also greatly affected by the granulometric composition and type of soil [5], choice of plants in crop rotation [6], management system of land [7, 8], form and dose of the applied fertilizers [9, 10].

[1] Department of Soil Environments Sciences, Warsaw University of Life Sciences, ul. Nowoursynowska 159, 02–686 Warszawa, Poland, phone: +48 22 593 26 30, email: tomasz_sosulski@sggw.pl

This paper aims at evaluating changes of mineral nitrogen content in soils with different chemical properties resulting from 80 year period of various applications of fertilizers and crop rotation.

Material and methods

The research were carried out in the years 1997–2001 in long term field experiments performed on Experimental Field in Skierniewice. The Experimetal Field belongs to the Department of Agricultural Chemistry of Warsaw Agricultural University – SGGW. Long term fertilizing experiments in that location have been carried out since 1923. The Experimental Field is located in the Central Poland where the average temperature is 8 ^{o}C and rainfall 520 mm (the highest precipitation in July and the lowest in January and February). The soil in Skierniewice region is podzolic, Haplic Luvisols with the clay and silt (Ø 0.02 mm) content equals to 15–17 % in Ap, 10–12 % in Eet and 25 % in Bt soil layers. Plants were cultivated in 2 different crop rotations:

– (A) arbitrary rotation without FYM and without legumes;
– (E) 5-field crop rotation: potatoes (30 Mg FYM ha^{-1}), s.barley, r.clover, w.wheat, rye.

Experiments were conducted in 3 (A) or 5 (E) repetitions. Plots fertilized without and with nitrogen (CaPK or PK and CaNPK + NPK) were chosen for the evaluation of each crop rotation. Mineral fertilizers were applied to all crops and within all crop rotations in the following doses: 90 kg N, 26 kg P and 91 kg K · ha^{-1}. Lime was applied every four years (1.6 Mg CaO · ha^{-1}) in the fields with A rotations and every five years (2 Mg CaO · ha^{-1}) in the field with E rotation. Nitrogen in the form of NH_4NO_3 was applied in a single dose in the spring before the beginning of vegetation.

Soil samples were collected three times a year during a five year period (1997–2001) from Ap, Eet and Bt soil layers (0–65 cm): in early spring – before the nitrogen treatment, in summer – after harvesting and late in the autumn. The content of mineral nitrogen (N-NH_4 and N-NO_3) was measured in fresh soil samples using the Skalar San Plus Analyzer after the fresh soil extraction in 0.01 M $CaCl_2$ (Standard ISO 11261:1995).

Results and discussion

The content of total nitrogen in the ploughing soil layer was higher than in the deeper soil layers. Fertilization with manure and cultivation of legumes in five-crops rotation (E) increased the total nitrogen content in the studied soil layers in relation to objects fertilized without manure and without legumes in crop rotation (A). On all objects with nitrogen fertilization the content of total nitrogen in soil was higher than on objects without this fertilization. The higher increase of nitrogen content in soil under nitrogen fertilization was obtained in field A than in field E. The total nitrogen content in soil on limed objects fertilized with nitrogen (CaNPK) was higher than on objects not treated with lime (NPK).

The amounts of mineral N in the 0–65 cm layer of the investigated soils varied depending on the system of fertilization and plant cultivation as well as the time of determination from 31–83 kg N · ha^{-1} in the field E, 18–41 kg N · ha^{-1} in the field A (Table 2, 3). Calculating the average from all the fertilization combinations the most mineral N in the soil profile down to 65 cm was found in the late autumn – at the beginning of November, less in the spring – prior to the application of nitrogen mineral fertilizers (March) and the least amount in August – directly after plants harvest (Table 2, 3). According to Labetowicz and Rutkowska, the decrease of the mineral N content in the soils fertilized with nitrogen observed between the time of fertilizer application and the time of harvest is caused mainly by the plant uptake of this component [11]. On the other hand, Fotyma reported that in the Polish soil and climatic conditions the highest content of mineral nitrogen in soil was obtained after harvest, lower in the late autumn and the lowest in the early spring [12].

Table 1

The content of total nitrogen [g N · kg^{-1}] in the three soil layers (Ap, Eet, Bt) depending on different ferilization and crop rotation

Crop rotation	Soil layers	Fertilization			
		PK	NPK	CaPK	CaNPK
E	Ap	—	0.702	0.643	0.712
(five crop-rotation with	Eet	—	0.296	0.305	0.315
FYM and with legumes)	Bt	—	0.331	0.342	0.361
A	Ap	0.392	0.464	0.362	0.491
(arbitrary rotation without	Eet	0.279	0.238	0.219	0.277
FYM and without legumes)	Bt	0.252	0.269	0.214	0.247

Table 2

The content of mineral nitrogen ($N\text{-}NH_4^{+}$+$N\text{-}NO_3^{-}$) in the soil layer of 0–65 cm deep [kg N · ha^{-1}] in the field with five field crop rotation with legumes and manure (E) at three terms (March, August, November) depending on long term fertilization

Terms of investigation (B)	Fertilization (A)			Mean	LSD
	CaPK	CaNPK	NPK		
March	55.4	79.2	72.2	68.9	A = 2.3
August	33.1	54.5	58.5	48.7	B = 2.3
November	72.6	83.1	68.4	74.7	A/B = 3.4
Mean	53.8	72.3	66.4	—	

Table 3

The content of mineral nitrogen ($N\text{-}NH_4^{+}$ +$N\text{-}NO_3^{-}$) in the soil layer of 0–65 cm deep [kg N·ha^{-1}] in the fields with arbitrary crop rotation without legumes and manure (A) at three terms (March, August, November) depending on long term fertilization

Terms of investigation (B)	Fertilization (A)				Mean	LSD
	PK	NPK	CaPK	CaNPK		
March	23.6	29.8	25.57	33.0	28.0	A = 1.7
August	18.0	27.6	19.79	29.4	23.7	B = 1.7
November	24.3	37.4	34.75	41..6	32.2	A/B = 2.9
Mean	22.0	31.6	26.7	31.2	—	

Independently from crop rotation, at all terms of investigations nitrogen fertilization (CaNPK and NPK) resulted in the increase of the amount of mineral N in the soil as compared with the objects not fertilized with this element – CaPK and PK (Table 2, 3). The gains of mineral N content in the soil in combinations of nitrogen fertilization (CaNPK and NPK) as compared with the control varied in particular fields depending on the term of determination in the following way: field E 14–65 %, field A 26–54 %. The described dependence was also observed by Sapek [4] as well as by Labetowicz and Rutkowska [11]. The effect of liming on the amount of mineral N in the soil during the whole year was not explicit. In the all investigated fields the amount of mineral N observed in the limed soils (CaNPK) was significantly higher as compared with the non-limed (NPK) objects. In the spring the significance of differences between the amount of mineral N in the limed and non-limed objects was proved in the both fields E and A. The amounts of mineral N after harvest in the limed and non-limed soils were similar.

In the soil of the E field (crop rotation with papilionaceous plants and manure) the amount of mineral N was on the average about twice higher than in the soils not fertilized with manure in which no legumes plants were cultivated – A. Sosulski et al report [13] that manure applied every year causes the increase of the mineral N content in the soil during the whole period of vegetation. In this study large amounts of organic nitrogen might have come from FYM and post-harvesting legumes residues, which were mineralized throughout the whole vegetation period over the few years after the fertilizer application and legumes cultivation.

The results of measurements of the mineral N content at the levels of Ap, Eet and Bt taken late in the autumn and in the spring allowed for the evaluation of differences in the translocation of mineral N in the soil profiles of the investigated fields. In November nearly in all the objects of five-field crop rotation (E) and in the limed objects CaPK and CaNPK in the field A a bigger amount of mineral N was found in the Ap level than in the Eet and Bt (Table 4). It was probably caused by an intensive mineralization of post-harvest remnents and manure taking place in the soil with higher content of total nitrogen and higher pH. On the other hand, in unlimed objects PK and NPK in the fields with arbitrary crop rotation (A) the least amounts of the mineral N were observed at the Ap level and the biggest amounts at the deepest level of the soil profile – Bt. It points to a smaller amount of post-harvest remnents and their slowed down mineralizationin the acid soils. Also Fotyma observed [2] a bigger amount of mineral N in the deeper soil layer than in the top soil during the period from the late autumn and early spring. In her investigations in the late autumn the most mineral N was in the soil layer of 20–40 cm. On the other hand in the early spring the amount of mineral N moved down into the soil profile which was probably caused by leaching out. In our own investigations changes were observed in the mineral N distribution in the soil profile in all the fields between the autumn and spring terms of analyses. In the field with five crop rotation (E) in the early spring a relatively big amount of mineral N was still present in the layer Ap. Changes in the distribution of mineral N in the profile of the fertilization objects concerned mainly the level Eet and Bt. As compared with the autumn less of mineral N was present in the layer Eet and significantly more in the layer Bt. It was most likely the effect of migration down the soil profile of bigger amounts of mineral N from more sandy Eet layer than from the humus Ap layer. In the field with arbitrary crop rotation (A) a slightly smaller dynamics of mineral nitrogen migration in the soil profile was observed than in the five crop rotation field (E). It is revealed by a similar as in the autumn the spring distribution of mineral N in the soil profile. The decrease of the content of mineral N in the soil which takes place between the autumn and spring and a small changes of arrangement of the N mineral in soil levels, was shown that in arbitrary rotation nitrogen is leached almost evenly from the Ap, Eet and Bt layers.

Table 4

Per cent distribution of mineral N in three layers of the soil profile (Ap, Eet, Bt) and distribution of $N\text{-}NO_3^-$ in soil N mineral in the field with five crop rotation (E) and with arbitrary crop rotation (A) in the late autumn and spring depending on long term fertilization

Crop rotations	Fertilization	Soil layers	Autumn		Spring	
			N_{min} in layers	% $N\text{-}NO_3^-$ in N_{min} in 0–65 cm layer	N_{min} in layers	% $N\text{-}NO_3^-$ in N_{min} in 0–65 cm layer
E (five-crop-rotation with FYM and with legumes)	CaPK	Ap Eet Bt	47 % 31 % 22 %	63 %	40 % 18 % 42 %	35 %
	CaNPK	Ap Eet Bt	41 % 33 % 26 %	65 %	44 % 19 % 37 %	45 %
	NPK	Ap Eet Bt	46 % 28 % 26 %	58 %	39 % 20 % 41 %	34 %
A (arbitrary rotation without FYM and without legumes)	PK	Ap Eet Bt	24 % 36 % 40 %	49 %	31 % 35 % 34 %	38 %
	NPK	Ap Eet Bt	31 % 33 % 36 %	54 %	39 % 35 % 34 %	37 %
	CaPK	Ap Eet Bt	38 % 34 % 28 %	56 %	38 % 29 % 33 %	46 %
	CaNPK	Ap Eet Bt	39 % 34 % 27 %	61 %	39 % 28 % 33 %	51 %

The described changes in the content and distribution of mineral N in the studied soil profiles between autumn and spring went along with changes in shares of $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ in N mineral in soil. In almost all objects of five-field crop rotation (E) and in field A with arbitrary rotation the share of $N\text{-}NO_3^-$ in N mineral in the 0–65 cm soil layer in the autumn was higher than the $N\text{-}NH_4^+$ share. Only on unlimed object PK the distribution of $N\text{-}NO_3^-$ in soil profile was similar to that of $N\text{-}NH_4^+$. The decrease of mineral nitrogen in soil and changes in its distribution in soil layers between November and March was accompanied by a decrease in the share of $N\text{-}NO_3^-$ in N mineral in soil profile. This leads to the conclusion, that $N\text{-}NO_3^-$ plays a bigger role in the nitrogen migration down the soil profile than $N\text{-}NH_4^+$.

Conclusion

1. Fertilization with farmyard manure and legumes cultivation increases the content of total nitrogen and mineral nitrogen in the soil layer of 0–65 cm deep.
2. The content of mineral nitrogen in soil is the lowest after the harvest and the highest in the late autumn. Between the autumn and spring the content of N mineral in soil decreases.
3. Migration of mineral nitrogen from the top soil layer into deeper layers is bigger in the FYM fertilized fields with legumes cultivation in crop rotation than in the field not fertilized with manure and without legumes cultivation.

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DYNAMIKA PRZEMIESZCZANIA SIĘ AZOTU MINERALNEGO W PROFILU GLEBOWYM W WARUNKACH WIELOLETNICH DOŚWIADCZEŃ NAWOZOWYCH

Katedra Nauk o Środowisku Glebowym,
Szkoła Główna Gospodarstwa Wiejskiego w Warszawie

Abstrakt: Wyniki badań zamieszczone w pracy zostały uzyskane w oparciu o materiał zebrany trwałych doświadczeniach nawozowych (ze zmianowaniem pięciopolowym z rośliną motylkową i obornikiem i doświadczeniu ze zmianowaniem dowolnym bez rośliny motylkowej i bez obornika) prowadzonych od 1923 r. w Skierniewicach. Zawartość azotu mineralnego w glebie ($N\text{-}NH_4^+$ and $N\text{-}NO_3^-$) była zmierzona przy użyciu aparatu Skalar San Plus Flow Analizer, po ekstrakcji gleby w 0,01 M $CaCl_2$. Niemal na wszystkich obiektach nawozowych badanych pól zawartość azotu mineralnego w glebie była większa w okresie późnej jesieni niż wiosną i latem. Większą zawartość azotu mineralnego stwierdzono w glebie nawożonej obornikiem na polu ze zmianowaniem pięciopolowym niż w glebie pod zmianowanie dowolnym bez rośliny motylkowej i bez obornika. Zawartość azotu mineralnego w glebie na obiektach nawożonych azotem (CaNPK, NPK) była większa niż na obiektach nienawożonych tym składnikiem (CaPK, PK). Większe przemieszczanie azotu z wierzchniej warstwy gleby do jej głębszych poziomów stwierdzono w warunkach doświadczenia ze zmianowaniem pięciopolowym z rośliną motylkową i obornikiem niż ze zmianowaniem dowolnym bez rośliny motylkowej i bez obornika.

Słowa kluczowe: doświadczenia wieloletnie, nawożenie, azot w glebie