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NITRATE NITROGEN IN THE SOILS OF EASTERN POLAND AS INFLUENCED BY TYPE OF CROP, NITROGEN FERTILISATION AND VARIOUS ORGANIC FERTILISERS

WPŁYW RODZAJU UPRAWY, NAWOŻENIA AZOTEM I ZRÓŻNICOWANEGO NAWOŻENIA ORGANICZNEGO NA ZAWARTOŚĆ AZOTU AZOTANOWEGO W GLEBACH WSCHODNIEJ POLSKI

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ABSTRACT

This paper describes the influence of nitrogen and organic fertilisation and the type of crops on the contents of NO_3-N in arable land. The large-scale environmental research was carried out in 2004-2006. Soil samples were taken from 411 places throughout the Lublin region in two seasons: spring and autumn.

The concentration of nitrate(V) depended on fertilisation and crops. It was found that application of N-fertiliser above 121 kg N ha^{-1} caused a significant increase in the nitrate(V) concentration in the surface soil layer. The distribution of NO_3-N in the soil profile indicated a possibility of nitrate(V) leaching during winter and early spring. On fields treated with a liquid organic fertilizer, the content of NO_3-N was considerably higher than on the other fields. The lowest NO_3-N was observed in straw treatments. A higher content of NO_3-N was noted in sugar beet and vegetable objects, while fallow, rye or rough grazing decreased accumulation of nitrate(V) in the soil profile.

KEYWORDS: content of nitrate(V) nitrogen in soil, type of crop, season, nitrogen fertilisation, organic fertilisation

STRESZCZENIE

Praca przedstawia wpływ nawożenia azotem, zróżnicowanego nawożenia organicznego oraz rodzaju uprawy na zawartość N-NO_3 w profilu gruntów ornych.

Szeroko zakrojone badania środowiskowe był prowadzone we wschodniej Polsce w latach 2004 -2006. Próby glebowe pobierane były z 411 punktów rozlokowanych na terenie województwa lubelskiego do głębokości 90 cm dwukrotnie w ciągu roku – wiosną i jesienią.

Otrzymane rezultaty pokazują dużą zmienność zawartości azotanów(V) w zależności od nawożenia azotem, nawożenia organicznego oraz rodzaju uprawianej rośliny. Stwierdzono, że dawka azotu w ilości przekraczającej 121 kg N ha^{-1} powodowała istotne zwiększenie koncentracji azotanów(V) w wierzchniej warstwie gleby. Rozmieszczenie N-NO_3 w profilu glebowym wskazuje na możliwość wymycia tej formy azotu w okresie zimy i wczesnej wiosny. Stwierdzono, że na polach nawożonych płynnymi nawozami organicznymi zawartość N-NO_3 była istotnie większa w porównaniu z innymi obiektami. Najwyższą zawartość N-NO_3 w profilu gleby zauważono na obiektach, na których uprawiano burak cukrowy i warzywa, podczas gdy ugór, żyto oraz użytek zielony obniżały akumulację azotanów(V) w profilu glebowym.

SŁOWA KLUCZOWE: zawartość azotu azotanowego w glebie, rodzaj uprawy, termin. nawożenie azotem, nawożenie organiczne

DETAILED ABSTRACT

Podstawą określenia wpływu uprawy rośliny oraz nawożenia organicznego i azotowego na występowanie azotu azotanowego(V) (N-NO_3) w glebie były badania środowiskowe przeprowadzone na gruntach ornych województwa lubelskiego. Próby glebowe pobierane były z 411 punktów (rys. 1), w dwóch terminach – wiosennym (przed zastosowaniem nawożenia, tuż przed siewem lub przed rozpoczęciem wegetacji roślin ozimych) oraz jesienią (po zbiorach roślin uprawnych). Badania prowadzone były w latach 2004-2006. W glebie oznaczono zawartość N-NO_3 w trzech poziomach gleby (0-30 cm, 31-60 cm, 61-90 cm). Wielkość nawożenia azotem oraz stosowany nawóz organiczny i rodzaj uprawianej rośliny ustalono na podstawie szczegółowej ankiety przeprowadzanej z rolnikami każdorazowo podczas pobierania prób glebowych. Nawożenie organiczne w istotny sposób modyfikowało zawartość azotu azotanowego(V) w glebie. Stosowanie ciekłych nawozów organicznych dodatnio wpłynęło na ilość N-azotanowgo(V) w profilu. Zawartość tej formy azotu po zastosowaniu gnojowicy zwiększyła się ponad 2-krotnie (18,8 mg N kg^{-1}) w stosunku do pól, na których nie stosowano nawozów organicznych (7,9 mg N kg^{-1}). Stwierdzono także obniżone zawartości N-NO_3^- na polach, które nawożono słomą (5,0 mg N kg^{-1}). Wzrastające dawki nawożenia azotem w istotny sposób zwiększały zawartość azotanów(V) w badanych glebach. Rezultaty badań wykazały mniejszą mobilność azotanów(V) z pól nawożonych obornikiem oraz azotem w dawce powyżej 120 kg N ha^{-1} w porównaniu z glebami nawożonymi jedynie azotem. Gleby, na których prowadzono uprawę buraków cukrowych (14,1 mg N kg^{-1}), a także warzyw (14,0 mg N kg^{-1}), charakteryzowały się istotnie wyższą zawartością azotu azotanowego(V) w porównaniu z gruntami, które były odłogowane (1,1 mg N kg^{-1}), na

których prowadzono uprawę żyta (4,6 mg N kg^{-1}) lub stanowiły użytek zielony (5,6 mg N kg^{-1})

INTRODUCTION

Most total N in soil is bound in organic compounds (95 %), the rest is in inorganic forms, mainly as nitrate(V) and ammonium (NO_3-N, NH_4-N) [9]. Stenger et al. (1998) indicate that the content of mineral nitrogen (N_{min}) in the soil is one of the most important factors with a decisive role in high crop yields and a potential risk of environmental pollution. Determination of N_{min} contents in agricultural soils in spring is a useful tool to assess requirements for nitrogen fertilisation, while the distribution of NO_3-N in soil in autumn evaluates possible nitrogen losses by leaching during winter [22]. Goss et al. (1988) suggest that the N_{min} distribution is a key in improvement of nitrogen management practices. To avoid leaching of NO_3-N and simultaneously maintain yielding of crops, it is appropriate to recognise variables affecting the N_{min} amount in the soil profile. Its distribution is the result of natural soil properties, climatic conditions and human activity [16, 24]. Particularly, agricultural operations have a great effect on the inorganic nitrogen pool. Earlier studies have demonstrated that application of nitrogen fertilizer alone or with organic manures contributed towards the N_{min} increase in soil [21]. Ondrišík et al. (2009) point out that soil cultivation influences the activity of microorganisms which participate in various nitrogen transformation processes in soil. Besides, the changes that have appeared in agriculture during the past few decades additionally complicated nitrogen management. These changes include over-fertilisation, little varied crop rotation, drainage of agricultural soils and animal production press could lead to an increase in N movement from agricultural sources into surface and ground waters [7]. Several authors have reported that the N_{min} content in the soil depends on the crop species [15]. It is obvious that the type of growing crops is connected with N uptake, microbiological activity [29], tillage, harvested crop remains and, indirectly, with the mineral and organic fertilisation requirement. All these factors have a considerable role in nitrogen transformation and distribution of N_{min} in the soil profile. Some studies show that evaluation of the influence of the species type on nitrate(V) dynamics is a combination of various factors, including plant uptake [14] crop rotation [5], and density of plant cover [27].

SITES AND METHODS

Changes in the content of NO_3–N and NH_4-N in the soil profile were observed in eastern Poland in 2004 – 2006. The study area is located in the Lublin region within about 130 km around Lublin between the Vistula and the Bug river (52°29 – 50°32´ N; 21°87 – 24°07´ E). The Lublin region is an important agricultural region in Poland. It is characterised by diversified cropping systems and varied soil types. In this paper, we present analyses of soil in which rye, potatoes, spring wheat, winter wheat, sugar beet, vegetables, winter rape and maize were cultivated, as well as from rough grazing or fallow land. The climate of the region is continental with annual precipitation 550-650 mm, average annual temperature -3.6°C in January and 17.9 °C in July and with the growing season 205-210 days. The average monthly precipitation and temperatures observed in Lublin (51°13´ N, 22°39´ E) during the study years are given in Table 1.

Table 1. Average monthly temperature and sum of monthly precipitation from January 2004 to October 2006 and the 49-yr mean in the Lublin Region
Tabela 1. Średnia miesięczna temperatura oraz suma opadów występująca w województwie lubelskim od stycznia 2004 do października 2006 oraz średnia z 49 lat

Month Miesiąc	Average monthly temperatures in Celsius degrees Średnia miesięczna temperatura w stopniach Celsjusza				Sum of monthly precipitation in mm Miesięczna suma opadów w mm			
	1951-2000	2004	2005	2006	1951-2000	2004	2005	2006
I	-3.6	-5.8	0.1	-7.4	21.7	32.7	41.6	15.7
II	-2.8	-1.1	-3.8	-4.5	24.8	52.5	26.0	26.7
III	1.0	2.7	-0.2	-1.2	25.8	33.9	48.0	47.0
IV	7.5	7.9	9.1	8.7	40.8	38.1	18.6	30.3
V	13.0	11.9	13.1	13.6	58.3	38.0	98.0	59.5
VI	16.5	15.9	16.0	16.9	65.8	49.9	55.9	37.9
VII	17.9	18.0	19.8	21.6	78.0	90.5	109.8	6.8
VIII.	17.3	18.3	16.9	17.4	69.7	48.5	108.7	197.3
IX.	12.9	12.8	14.9	15.7	52.1	14.2	18.0	11.0
X	7.9	9.7	8.8	10.1	40.3	19.1	8.6	14.2
XI	2.5	3.1	2.7	-	39.1	58.2	21.7	-
XII	-1.4	1.6	-0.8	-	31.5	17.1	54.5	-

The 411 measurement points were spread on a surface area of 25 000 km^2 (Fig. 1). Soil samples were taken to the depth of 90 cm, which was sectioned into three layers – 0-30 cm; 31-60 cm; and 61-90 cm each year (2004 – 2006) in two seasons (spring – before any N fertilisation started and autumn – after harvest). The samples were collected from arable lands. Fresh soil samples from 10 or 15 (if manure was employed) sites were collected from the experimental fields whose size did not exceed 4 ha. The composite soil (200 g) samples were thoroughly mixed, placed in polyethylene bags and stored in the refrigerator prior to the N inorganic analysis. NO_3-N and NH_4-N were determined colorimetrically using a San Plus Segmented Flow Analyser after extraction with 1% K_2SO_4. Among the types of organic fertilisation we specified: dungstead manure, liquid manure, swine manure, cattle manure, mixed manure, and straw. The rate of the nitrogen, type of organic fertiliser and species of crops were determined on the basis of an interview with farmers at each sampling site. A more detailed description of the sites and methods can be found in Dresler (2009).

The effects of the nitrogen rate, type of organic fertilisation or type of crop on the NO_3-N and NH_4-N content in soil were determined using ANOVA. The nitrogen fertilisation rates were grouped in two ways: 1) A – 0-30; B – 31-60; C – 61-90; D – 91-120; E – 121-150; F – above 151 kg N ha^{-1} and in this case the three-way ANOVA was used - season*nitrate(V) rate*depth of sampling, 2) N0 – no N-fertiliser; N1 – 60-120; N2 above 120 kg N ha^{-1} ; the three-way ANOVA was also used here but with differ factors - manure*nitrate(V) rate*depth of sampling. Differences between the levels were determined with the Tukey honest significance difference (HSD) at the 0.05 probability level. The data were analyzed using Statistica ver. 6 (StatSoft, Inc. 2004).

Fig. 1. Location of the study area and distribution of the measurement points
Ryc. 1. Lokalizacja terenu badań i rozmieszczenie punktów pomiarowych

RESULTS AND DISCUSSION

As shown in Fig.2, the amount of NO_3-N in the soil profile was influenced by annual applications of nitrogen fertilisation. The highest content of nitrate(V) nitrogen was found in the 0-30 soil layers with above 151 kg N ha^{-1} fertilisation. The data indicate that the effect of N-fertilizer on the nitrate(V) concentration in the surface layer is not linear (Fig. 3). No significant increase in the NO_3-N content was observed after nitrogen fertilisation under 120 kg N ha^{-1}; however, when the N rate exceeded this value, the concentration of nitrate(V) increased significantly above 15 mg N kg^{-1}. Similar results were reported by Chmielewska and Dechnik (1987) in their previous field trial study. According to Chaney (1990), the non-linear effect of N-fertilisation on the nitrate(V) content in soil has environmental and economic implications. Powlson et al. (1992) indicate that over-fertilization will not only be wasteful but may also lead to ground and surface water pollution.

The increasing nitrogen rate positively affected the NO_3-N content in all the soil profiles in the two seasons. However, the nitrate(V) concentration in the 31-90 cm soil layers in spring was higher than in autumn. This fact is probably the result of many reasons – crop uptake during vegetation season [6], flush organic matter mineralization at the beginning of spring [10] or nitrate(V) leaching during winter and early spring [20]. There are a lot of studies which have proved that the soil NO_3-N can easily move through the soil profile [7, 9]. Ions of NO_3-N are not absorbed by mineral-organic colloids. Thus, during winter, when there is low evapotranspiration, high precipitation and no plant growth, nitrate(V) ions from fertilisation moved into the 31-90 cm soil layers.

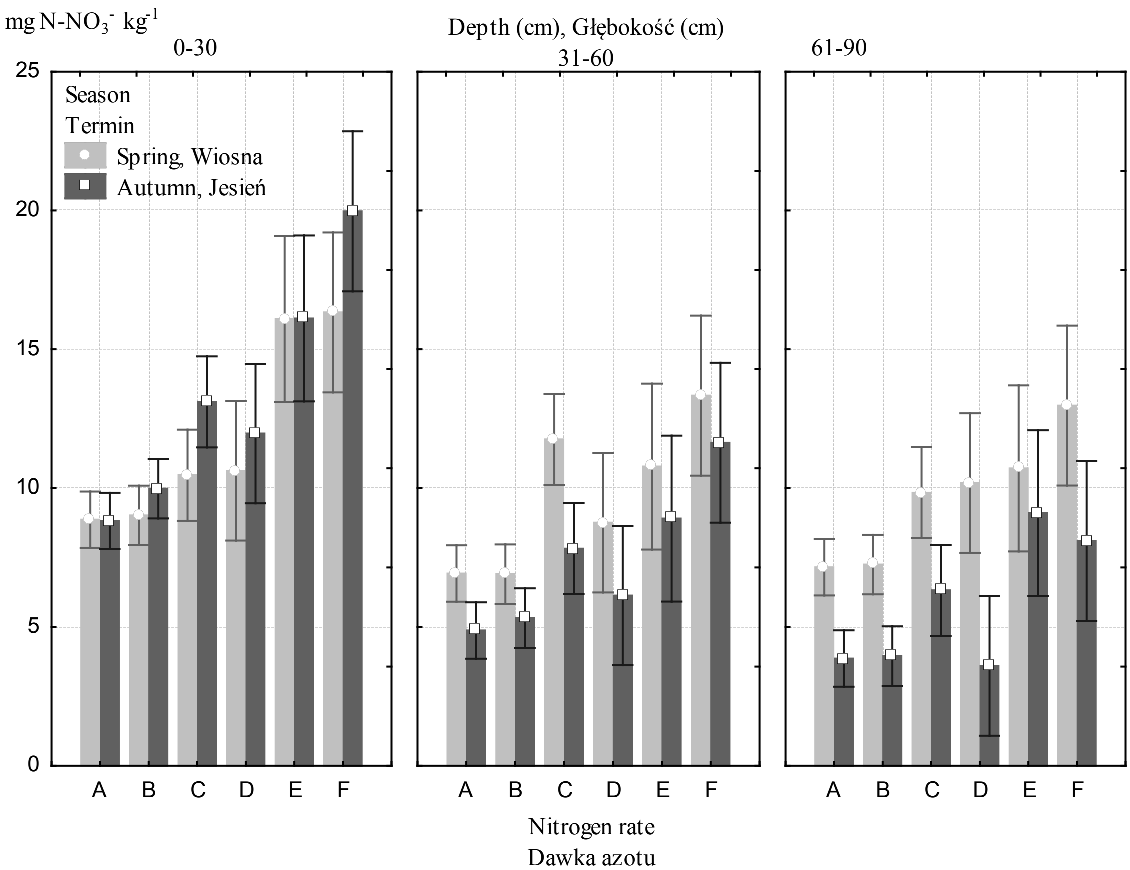

Fig. 4. Content of NO_3-N (mg N kg^{-1}) in the soil profile in spring and autumn depending on the N-fertilisation rate (A – 0-30; B – 31-60; C – 61-90; D – 91-120; E – 121-150; F – above 151 kg N ha^{-1}).
Ryc. 4. Zawartość N-NO_3 (mg N kg^{-1}) w profilu gleby wiosną i jesienią w zależności od dawki nawożenia azotem (A – 0-30; B – 31-60; C – 61-90; D – 91-120; E – 121-150; F – powyżej 151 kg N ha^{-1}).

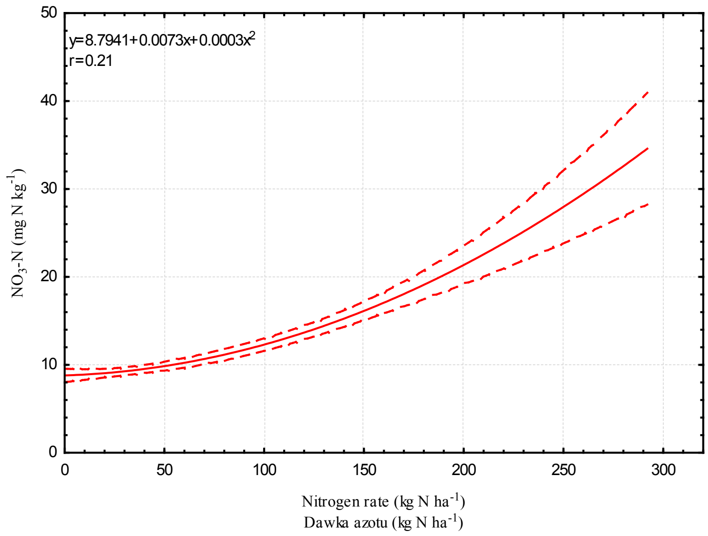

Fig. 3. The content of NO_3-N in the surface soil layer (0-30 cm) depending on the nitrogen rate
Ryc. 3. Zawartość N-NO_3 w wierzchniej warstwie gleby (0-30 cm) w zależności od dawki azotu

The data obtained showed large variations in the distribution of NO_3-N in the soil profiles of different types of organic fertilisation (table 2). The values indicate a trend of higher N-NO_3^- in soil after dungstead and liquid manure application. Particularly, after liquid manure, the content of nitrate(V) in soil profile (0-90 cm) increased significantly up to 18.8 mg NO_3-N·kg^{-1}.

Table 2. Content of NO_3-N (mg N kg^{-1}) in the soil profile depending on application of an organic fertiliser
Tabela 2. Zawartość N-NO_3^- (mg N kg^{-1}) w profilu glebowym w zależności od nawożenia organicznego

Depth (cm) Głębokość (cm)	Organic fertiliser types – Rodzaj nawożenia organicznego						
	No organic fertilisation Brak nawożenia organicznego	Dungstead Gnojówka	Liquid manure Gnojowica	Swine manure Obornik świński	Cattle manure Obornik bydlęcy	Mixed manure Obornik mieszany	Straw - Słoma
0-30	10.20 bc*	15.52 ns**	21.73 ce	9.37 ns	8.70 ns	11.34 c	8.04 ns
31-60	7.02 ade	10.12 ns	20.33 b-e	5.35 ade	4.31 abde	8.07 abde	4.07 abd

61-90	6.44 ade	5.07 ns	14.46 ns	3.32 a	3.25 ad	7.40 ade	2.90 ad
0-90	7.89 AB	10.23 ns	18.83 C	6.02 A	5.42 A	8.93 B	5.01 A

* homogenous group – grupy homologiczne
** non significant – nieistotne statystycznie
The total number of measures = 7398 – Całkowita liczba pomiarów = 7398

Various forms of manure compared with no organic fertilisation did not significantly influence the nitrate(V) concentration. On the other hand, the lowest NO_3-N content was observed after straw application. It is evident that the changing nitrate(V) amount in the soil after organic fertilisation depends on the C:N ratio. Liquid manure or dungstead with a low carbon to nitrogen ratio, increased the content of nitrate(V) whilst after straw application (wide C:N ratio) the content of nitrate(V) decreased. It is commonly known that the amount of N-NO_3^- in soil is determined by the net balance between the rate of nitrogen mineralized from organic matter and rate of N immobilization by growth of soil microbes [13]. This balance is strongly influenced by the C:N ratio of the decaying organic matter. Mary et al. (1996) indicate that an organic fertiliser with a wide C:N ratio (greater than 30:1) such as fresh manure or straw may temporarily reduce the available nitrogen pool. However, several authors have reported a considerable increase in NO_3-N and a possibility of nitrate(V) leaching after liquid organic fertilisation [1].

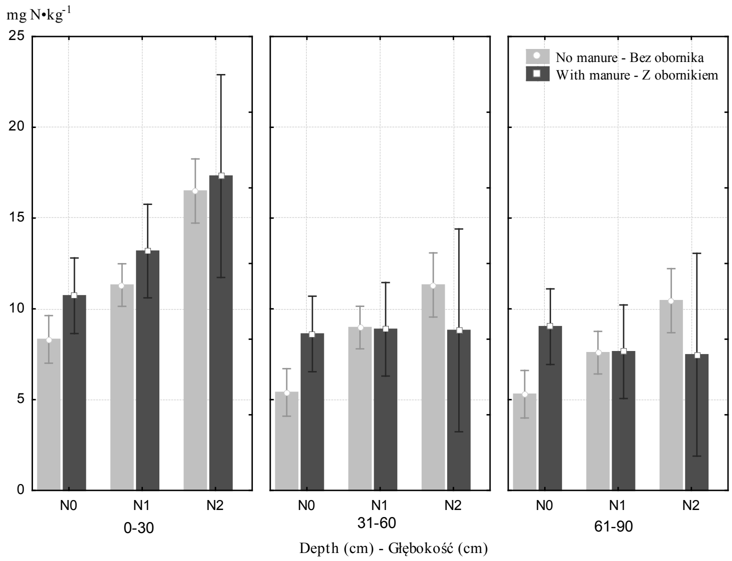

Fig. 3. Content of NO_3-N (mg N kg^{-1}) in the soil profile depending on the N-fertilisation rate and manure application (N0 – no N-fertiliser; N1 – 60-120; N2 above 121 kg N ha^{-1})
Ryc. 3. Zawartość N-NO_3 (mg N kg^{-1}) w profilu glebowym w zależności od dawki

nawożenia azotem oraz nawożenia obornikiem (N0 – bez nawożenia azotem; N1 – 60-120; N2 powyżej 121 kg N ha^{-1})

The analysis of the nitrate(V) content in soil in different variants of N-mineral and manure fertiliser combination showed an interaction between these two factors in the 31-90 cm soil layer (Fig. 3). In the manure treatments, we did not observe any changes in the nitrate(V) concentration under the 30 cm soil level after various nitrogen rates, compared with the increased NO_3-N amount only in the N-fertilized object. Furthermore, manure application objects were characterised by a slightly higher nitrate(V) content in the surface soil layer compared with no manure. These findings suggest that when manure was applied together with the N-fertilizer, the movement of nitrate throughout the soil profile was decreased, compared with objects without manure. Earlier, Tong et al. (1997) found that manure applied in combination with a mineral fertilizer could reduce the mass of NO_3-N. In turn, Yang et al. (2004) indicated that in order to reduce the risk of nitrate(V) leaching and groundwater pollution, manure should be applied together with a mineral fertilizer.

It was found in our studies that the nitrate(V) content in the soil profile varied according to the plant species (table 3). The highest levels of nitrates(V) were found in vegetables, sugar beet, winter rape and winter wheat objects. The species mentioned above have high soil quality and high agro-technical level requirements. Cultivation of these crops was generally connected with the mineral and organic fertiliser. Besides, ploughing accompanying of this crops is favourable for the nitrification process [2], mineralisation of organic nitrogen [12] and a decrease in the denitrification process [25]. In contrast, fallow, rye or rough grazing significantly decreased this N-form in the soil profile. This probably results from the low N-fertilisation level required in this kind of soil utilisation. It is worthy to note that, in grassland or fallow, lower mineralisation and high nitrate(V) losses by denitrification occur [2, 23].

Table 3. Content of NO_3-N (mg N kg^{-1}) in the soil profile depending on the type of crops grown
Tabela 3. Zawartość N-NO_3 (mg N kg^{-1}) w profilu glebowym w zależności od rośliny uprawnej

Depth (cm) Głębokość (cm)	Crops type – Rodzaj uprawy									
	Fallow Odłóg	Rye Żyto	Rough grazing Użytek zielony	Potato Ziemniaki	Spring wheat Pszenica jara	Maize Kukurydza	Winter rape Rzepak ozimy	Winter wheat Pszenica ozima	Sugar beet Burak cukrowy	Vegetables Warzywa
0-30	1.86 ns**	7.33 b-e*	7.30 a-eg	10.50 d-i	11.69 d-j	14.61 ehij	14.86 ej	13.44 fij	16.88 j	16.14 ij
31-60	1.00 ns	3.83 ab	4.74 abc	7.54 b-eg	7.89 a-h	10.09 b-j	8.58 ns	10.30 d-i	13.46 f-j	12.39 d-j

61-90	0.50 ns	2.65 a	4.87 abc	6.66 abcd	7.97 a-h	6.92 a-egh	11.88 c-j	8.43 cdegh	11.88 d-j	13.34 e-j
0-90	1.12 ABC	4.60 A	5.64 ABD	8.24 B-E	9.13 CEF	10.54 EFG	11.77 EFG	10.72 F	14.08 G	13.96 G

* homogenous group – grupy homologiczne
** non significant – nieistotne statystycznie
The total number of measures = 7398 – Całkowita liczba pomiarów = 7398

CONCLUSIONS

Although the basic mechanisms of the nitrogen dynamics in soil have been clearly indentified, there is a need for agro-technical practice improving nitrogen management under field conditions. The large-scale study results generally show that the concentration of nitrate(V) in the soil was affected by the high nitrogen fertilisation. Considerably higher amounts of soil nitrate(V) after nitrogen fertilisation above 120 kg N ha^{-1} were found. The amount of NO_3-N in the soil profiles in the two seasons showed a possibility that nitrate(V) was transported to deeper layers in the soil during winter and early spring. The influence of various types of organic fertiliser on changes in the soil nitrate(V) content was significant. Application of a liquid organic fertiliser to the soil increased the soil nitrate(V) content, whilst decreased NO_3-N were observed after straw application. There are important implications of this observation: the amount of nitrate(V) was determined by the C:N ratio in the organic fertiliser. The low C:N ratio in the liquid manure is more favourable for the high nitrate(V) concentration, whilst the wide C:N ratio in straw encourages microorganism growth and nitrogen immobilisation. Combined applications of N-fertilizer and manure reduced soil nitrate(V) accumulation in the 31-90 cm soil layer, compared with N-fertilisation alone. Additionally, we observed higher NO_3-N accumulation in the surface soil layer after manure, compared with no manure, regardless of the N rate. It appears that the concentration of this N-form depended on the net balance between the rate of immobilization and mineralisation. The metastable equilibrium between these two processes depended, besides C:N ratio, on tillage and the type of crop cultivation. It was found that soil with plants which do not need ploughing or a high level of nitrogen fertilisation (grassland or fallow) contains much less nitrate(V) than soil with deep tillage. This finding suggests that soil aeration conditions affect nitrogen mineralisation and nitrification.

REFERENCES

[42] Bakhs A., Kanwar R. S., Karlen D. L., Effects of liquid swine manure applications on NO3-N leaching losses to subsurface drainage water from loam soils in Iowa, Agric. Ecosyst. Environ. (2005) 109:118-128

[43] Barabasz W., Mikrobiologiczne przemiany azotu glebowego. II Biotransformacja azotu glebowego, Post Mikrobiol. (1992) 31:3-33

[44] Chaney K., Effect of nitrogen fertilizer rate on soil nitrate nitrogen content after harvesting winter wheat, J. Agri. Sci. Cambridge, (1990) 114:171-176

[45] Chmielewska B., Dechnik J., Wpływ nawożenia mineralnego na zawartość niektórych form azotu w brunatnej glebie lessowej, Rocz. Nauk Roln., (1987) 106:197-205

[46] Czekała J., Owczarzak W., Jakubus M., Szukała J., Wpływ zmianowania roślin, deszczowania i nawożenia azotem na zawartość mineralnych form azotu w glebie, Zesz. Probl. Nauk Rol. (2002) 484:101-108

[47] Dechnik I., Bednarek W., The dynamics of nitrogen forms in soil and their interrelations with vegetational mass of spring barley., Pol. J. Soil. Sci., (1989) 22/2, 67-71

[48] Dinnes D. L., Karlen D. L., Jaynes D. B., Kaspar T. C., Hatfield J. L., Colvin T. S., Cambardella C A Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils, Agron J. (2002) 94:153-171

[49] Dresler S., The effect of the natural and anthropogenic factors on the amount of mineral nitrogen forms in soil, Ph.D Theses, Univer. Life Sci. in Lublin, Poland (2009) pp. 1-149

[50] Follett R. F., Transformation and transport processes of nitrogen in agricultural systems. In: Hatfield J. L. and Follett R. F. (Eds.) Nitrogen in The Environment: Sources, Problems and Management, Elsevier, The Nederlands, (2008) pp. 19-50

[51] Frąckowiak H., Mineralizacja związków azotowych na tle zróżnicowania gleb Doliny Kanału Bydgoskiego, Prace Kom. Nauk Rol. i Biol., (1972) Ser. B, 12, 97-149

[52] Goss M. J., Colbourn P., Harris G. L., Howse K. R., Leaching of nitrogen under autumn-sown crops and the effects of tillage In: Jenkinson D. S. and Smith K. A. (Eds.) Nitrogen Efficiency in Agricultural Soils, Elsevier Appl. Sci., England, (1988) pp. 269-282

[53] Halvorson A. D., Wienhold B. J., Black A. L., Tillage and nitrogen fertilization influences on grain and soil nitrogen in a spring wheat-fallow system, Agron J. (2001) 93:836-841

[54] Kaye J. P., Hart S. C., Competition for nitrogen between plants and soil microorganisms, Trends Ecol. Evol. (1997) 12:139-143

[55] Ma B. L., Subedi K. D., Costa C., Comparison of crop-based indicators with soil nitrate test for corn nitrogen requirement, Agron J. (2005) 97:462-471

[56] Macdonald A. J., Poulton P. R., Powlson D. S., Jenkinson D. S., Effects of season, soil type and cropping on recoveries, residues and losses of 15N-labelled fertilizer applied to arable crops in spring, J. Agric. Sci. Cambridge, (1997) 129:125-154

[57] Malhi S. S., McGill W. B., Nitrification in three Alberta soil: Effect of temperature, moisture and substrate concentration, Soil Biol Biochem. (1982) 14:393-399

[58] Mary B., Recous S., Darwis D., Robin D., Interactions between decomposition of plant residues and nitrogen cycling in soil, Plant and Soil, (1996) 181:71-82

[59] Ondrišík P., Porhajašová J., Urminská J., Ňaršanská M., The effect of agrotechnical interventions on seasonal changes of inorganic nitrogen content in soil, J. Cent. Eur. Agric. (2009) 10:101-108

[60] Powlson D. S., Hart P. B. S., Poulton P. R., Johnston A. E., Jenkinson D. S., Influence of soil type, crop management and weather on the recovery of 15N-labelledfertilizer applied to winter wheat in spring, J. Agri. Sci. Cambridge, (1992) 18:83-100

[61] Randall G. W., Goss M. J., Nitrate losses to surface water through subsurface tile drainage. In Hatfield J L, Follett R F (Eds.), Nitrogen in the Environment: Sources, Problems, and Management. Elsevier, The Nederlands 2008 pp. 145-175

[62] Reddy K. S., Singh M., Tripathi A. K., Singh M., Saha M. N., Changes in amount of organic and inorganic fractions of nitrogen in an Eutrochrept soil after long-term cropping with different fertilizer and organic manure inputs, J. Plant Nutr. Soil Sci. (2003) 166:232-238

[63] Rutkowska A., Fotyma M., Calibration of soil test for mineral nitrogen in Poland, Commun. Soil. Sci. Plant Anal. (2009) 40:987-998

[64] Sapek B Mineralizacja materii organicznej w glebach łąkowych jako źródło azotu. Zesz Naukowe IMUZ Falenty. (1996) 1:75-85

[65] Shaffer M J, Delgado J A Essentials of a national nitrate leaching index assessment tool. J Soil Water Conserv. (2002) 57:327-335

[66] Soon Y K, Clayton G W, Rice W A Tillage and previous crop effects on dynamics of nitrogen in a wheat – soil system. Agron J. (2001) 93:842-849

[67] Stenger R, Priesack E, Beese Distribution of inorganic nitrogen in agricultural soils at different dates and scales. Nutr Cycl Agroecosys (1998) 50:291-297

[68] Suchorska-Orłowska J Influence of organic-mineral fertilizer and manure on the content of inorganic nitrogen compounds in the soil. Acta Agrophysica. (2001) 52:271-283

[69] Tong Y, Ove E, Lu D, Harald G Effect of organic manure and chemical fertilizer on nitrogen uptake and nitrate leaching in a Eum-orthic anthrosols profile. Nutr Cycling Agroecosyst (1997) 48:225-229

[70] Wyczółkowski A I, Dąbek-Szreniawska M, Bieganowski A, Zimon A Aktywność enzymów biorących udział w mineralizacji azotu organicznego w glebie pod różnymi roślinami. Acta Agrophysica. (2006) 7:1035-1041

[71] Yang S, Li F, Malhi S S, Wang P, Suo D, Wang J Long-term fertilization effects on crop yield and nitrate nitrogen accumulation in soil in Northwestern China. Agron. J. (2004) 96:1039-1049