ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 8 2011

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# NITRATES(V) CONTENT IN POTATO TUBERS CULTIVATED UNDER VARIOUS FERTILIZATION SYSTEMS

## ZAWARTOŚĆ AZOTANÓW(V) W BULWACH ZIEMNIAKA UPRAWIANEGO W RÓŻNYCH SYSTEMACH NAWOŻENIA

**Abstract:** In a static field experiment established on brown soils in 1973, two types of natural fertilizers, farmyard manure (FYM) and liquid manure, mineral fertilizers (NPK) and combined organic and mineral fertilization were applied. Liquid manure was applied in two doses: rate I balanced with FYM and mineral fertilizers in the amount of nitrogen and rate II balanced in the amount of carbon. The experiment ran in two series: with and without liming. During the experiment, a 7-year plants rotation system was carried out.

It has been found that each fertilization system contributed to an increase in the amount of nitrate(V) nitrogen in potato tubers. The highest concentration of nitrates(V), exceeding from 2.1-fold (limed soil series) up to 2.3-fold (soil not limed) the permissible amount of these compounds, was determined in potato tubers fertilized with liquid manure in rate II and rate II + PK. Among the fertilizers with which equal amounts of nitrogen were introduced to soil, higher excess of the permissible concentration of nitrates(V) in potato tubers was caused by the application of mineral fertilizers and liquid manure in rate I than FYM. Supplementation of liquid manure with mineral fertilizers PK caused a further increase in the concentration of nitrates, whereas in the case of FYM the effect of PK was opposite. Soil liming differentiated the content of nitrates(V) in potato tubers but the effect of this treatment was ambiguous.

**Keywords:** fertilization, potato tubers, content of nitrates(V)

Nitrogen in plants appears primarily in the form of organic compounds and just small amounts of this element remain in the mineral form. Under increased content of mineral nitrogen in soil, where the process of reduction of nitrate(V) ions does not keep pace with their uptake, the mineral form of nitrogen may accumulate in plants. Accumulation of nitrates in plants is a complex process and depends on a number of factors, such as: genetic traits, soil and climatic conditions, fertilization and period of crop cultivation [1–5]. Genetic control of the content of nitrates may be a species – or even cultivar – specific trait but in many cases the ability to accumulate nitrates is relatively poorly inheritable [6]. The agronomic factor which mostly affects the accumulation of nitrates in plants is fertilization. High content of these compounds occurs mainly after

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unidirectional, excessive fertilization with nitrogen, introduced to soil with mineral or natural fertilizers [7–11].

Potato belongs to crops which do not tend to accumulate nitrates. Notwithstanding this, potato tubers grown experimentally or commercially are found to contain varied and often excessive amounts of nitrates. This is a disturbing finding because potato tubers make up a large share of foodstuffs in human diet [5, 7, 12].

The aim of this study has been to determine the effect of long-term application of three fertilization systems (organic, mineral and mixed organic and mineral) on the content of nitrates(V) in potato tubers.

## Material and methods

In a static field experiment set up in 1973 on brown acid soil formed from slightly loamy sand class IVb, two types of natural fertilizers, FYM and liquid manure, mineral fertilizers (NPK) and combined mineral and organic fertilization were applied*. Rate I of liquid manure, FYM and mineral fertilization were balanced every year with an appropriate amount of nitrogen while rate II of liquid manure was balanced with a dose of FYM by introducing an appropriate dose of organic carbon. The annual average quantities of nutrients (NPK) introduced to soil with natural and mineral fertilizers during the 37 years of the experiment were the following (per 1 ha):

| | | | |
|---|---|---|---|
| Liquid manure rate I | 133 kg N | 56 kg P | 84 kg K, |
| Liquid manure rate II | 393 kg N | 168 kg P | 240 kg K, |
| FYM | 133 kg N | 45 kg P | 108 kg K, |
| Mineral fertilizers NPK | 133 kg N | 43 kg P | 124 kg K. |

Against the background of natural fertilizers, supplementary mineral PK fertilization was carried out, equal 1/2 of the rate of these fertilizers introduced in the treatment with mineral fertilization (NPK). Phosphorus and potassium fertilizers were applied before sowing in the form of 46 % superphosphate and 60 % of potassium salt, respectively.

The amounts of total nitrogen and organic carbon in the soil sampled from the treatment which for 37 years had not been fertilized were, respectively, 53 mg · $kg^{-1}$ and 428 mg · $kg^{-1}$. As a result of the annual fertilization, the total nitrogen content rose from 5.7 % in soil fertilized with rate I of liquid manure to 32.1 % in soil enriched with rate II of liquid manure + PK, whereas the content of organic carbon increased from 14 % in soil treated with mineral fertilizers to 80.6 % in soil fertilized with FYM + PK. The value of soil reaction measured in KCl solution of the concentration equal 1 mol · $dm^{-3}$ ranged from 4.40 to 5.45.

The experiment was run in two series – with and without liming. Soil liming was carried out in 2006, ie 34 years after the experiment had been set up. A seven-year crop rotation system was maintained during the study period. The experimental plots were sown with crops in the following rotation sequence: potatoes, spring barley + red clover with grasses sown between barley, red clover with grasses, winter oilseed rape, winter wheat + aftercrop rye, maize grown for green mass, spring barley, winter wheat. Clover

* Long-term field experiment set up according to schema processed by professor Teofil Mazur.

with grasses was grown only in the first sequence of the rotation. This paper presents the results of our studies obtained during the sixth rotation. In 2009, edible potato, 'Cekin' cv., was grown. Potato tubers were harvested after 123 days of the growing season.

The total and protein nitrogen content in potato tubers was determined using Kjeldahl's method. Solution of trichloroacetic acid of the final concentration of 12 % was used to precipitate protein substances from the plant material.

The content of nitrates(V) in potato tubers was determined in fresh mass, according to the standard analytical method elaborated by Orion [13], using an Ionanlyzer® Orion Model 407 potentiometer and a Thermo Orion model 9307™ ionselective nitrogen electrode. The results of the analyses underwent statistical processing with STATISTICA version 9 software programme [14], at the level of significance $\alpha = 0.05$ using a two-factor analysis of variance ANOVA.

## Results and discussion

Potato tubers, apart from nutrients, may also contain compounds harmful to health, including some forms of nitrogen. The total content of this element and the forms in which it appears in potato tubers depends on the genetic traits of this plant and on some environmental conditions. High rates of fertilizers, particularly nitrogen, tend to raise the content of nitrates(V) and (III) and depress the nutritive value of this crop [4, 9, 15–17].

In the present experiment, the total content of nitrogen in potato tubers ranged from 0.91 to 1.42 % (Fig. 1), whereas that of protein nitrogen was between 0.58 to 0.74 % (Fig. 2).

Each fertilization system contributed to increasing the concentration of both forms of nitrogen compared with the control. In unlimed soil, the highest increase in the content of total nitrogen appeared in tubers of potato plants fertilized with rate II of liquid manure, with which nearly three-fold more nitrogen was introduced to soil than with the other fertilizers. This observation is confirmed by the data presented in papers by other

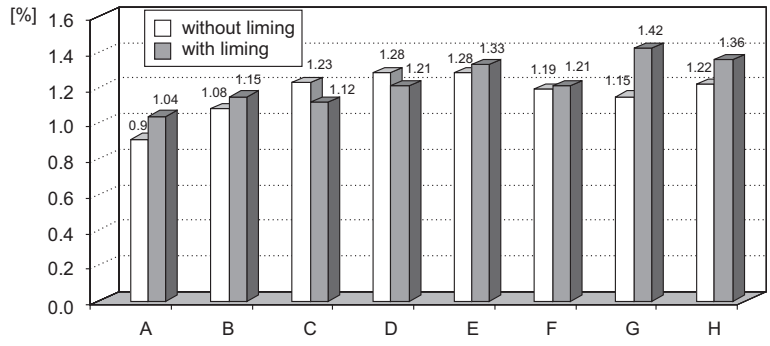


Fig. 1. Total nitrogen content in potato tubers: A – without fertilization; B – liquid manure rate I; C – liquid manure rate I + PK; D – liquid manure rate II; E – liquid manure rate II + PK; F – FYM; G – FYM+ PK; H – NPK; LSD: fertilization – 0.03; liming – 0.02; interaction – 0.05

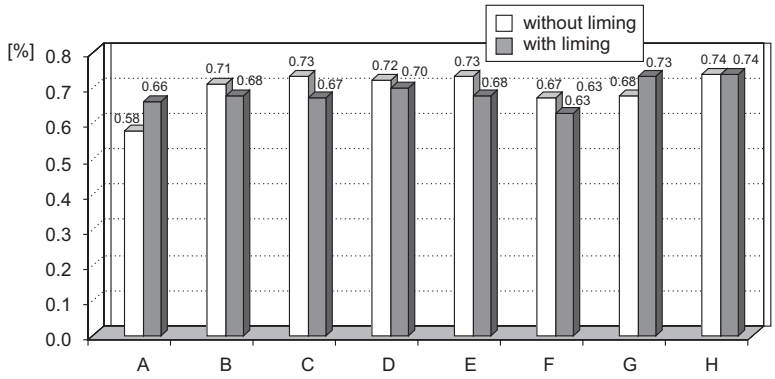


Fig. 2. Protein nitrogen content in potato tubers: A – without fertilization; B – liquid manure rate I; C – liquid manure rate I + PK; D – liquid manure rate II; E – liquid manure rate II + PK; F – FYM; G – FYM + PK; H – NPK; LSD: fertilization – 0.05; liming – 0. 01; interaction – 0.02

authors [4, 9, 11, 15], who report that increasing rates of nitrogen caused a significant increase in the content of this element in potato tubers, although the recorded increments were varied. Among the treatments where nitrogen balanced fertilizer rates were applied, higher concentrations of nitrogen were found in tubers of potatoes nourished with mineral fertilizers and FYM than the ones fertilized with liquid manure.

In the series with unlimed soil, the type of fertilizers or the rate of liquid manure did not have significant effect on the content of protein nitrogen in plants (Fig. 2). However, they significantly modified its share in the total nitrogen content (Table 1).

Table 1

Share of protein nitrogen in total nitrogen content [%]

| Fertilization | Unlimed soil | Limed soil |
|---|---|---|
| Without fertilization | 63.7 | 63.5 |
| Liquid manure rate I | 65.7 | 59.1 |
| Liquid manure rate I + PK | 59.3 | 59.8 |
| Liquid manure rate II | 56.3 | 57.9 |
| Liquid manure rate II + PK | 57.0 | 51.1 |
| FYM | 56.3 | 52.1 |
| FYM + PK | 59.1 | 51.4 |
| NPK | 60.7 | 54.4 |
| $LSD_{0.05}$ fertilization (I) | 2.1 | |
| liming (II) | 1.0 | |
| interaction (I · II) | 2.9 | |

In most of the fertilized treatments, the share of protein nitrogen in the total amount of this element was depressed, with the decline being larger after an application of FYM and liquid manure in rate II than after soil enrichment with mineral fertilizers. There was just one exception, namely potato tubers harvested from treatments fertilized with

rate I of liquid manure or rate I of liquid manure + PK, where the contribution of protein nitrogen to total nitrogen was 2 % higher than in the control.

No unambiguous effect was observed of the phosphorus-potassium fertilization applied in conjunction with natural fertilizers on the total nitrogen and protein nitrogen content in potato tubers. In most treatments, however, a tendency appeared for an increase in both forms of this element compared with the treatments receiving exclusively organic fertilization.

The soil liming treatment applied in the experiment added to a significant increase in the total nitrogen content in potato tubers except the treatments which were enriched with liquid manure in rate I + PK or liquid manure in rate II, where the content of nitrogen was higher compared to the unlimed series. With respect to protein nitrogen, liming did not have an unambiguous effect on the value of this parameter. In most treatments, there was a decreasing tendency regarding protein nitrogen in potato tubers compared with unlimed treatments.

Many authors [1, 4, 7, 16, 18] claim that as the amount of nitrogen introduced to soil under potatoes increases, so does – proportionately – the content of nitrates in potato tubers. Excessive accumulation of this form of nitrogen can be alleviated by more favourable weather conditions during the growth of potatoes [5]. According to Wojciechowska [6], under good insolation conditions it is possible to obtain a low content of nitrates in the crop yield, whereas low intensity of sunlight (autumn–winter) may raise their concentration several fold.

In the present research, the content of nitrate(V) nitrogen in potato tubers oscillated within 154.4–466.6 mg · $kg^{-1}$ fresh mass in the unlimed series and between 158.7 and 421.2 mg · $kg^{-1}$ fresh mass in the series where soil was limed (Fig. 3). In all the treatments, fertilization contributed to a significant increase in this form of nitrogen, up to the values exceeding their permissible quantities as established by the Ordinance of the Minister for Health of 13 January 2003 [19]. This threshold level was exceeded by 44.0 to 266.6 mg $NO_3^-$ · $kg^{-1}$ fresh mass.

Among the treatments where natural and mineral fertilizers were applied in rates balanced with respect to nitrogen introduced to soil, in both experimental series (limed and unlimed), a smaller increase in nitrates(V) in potato tubers occurred after

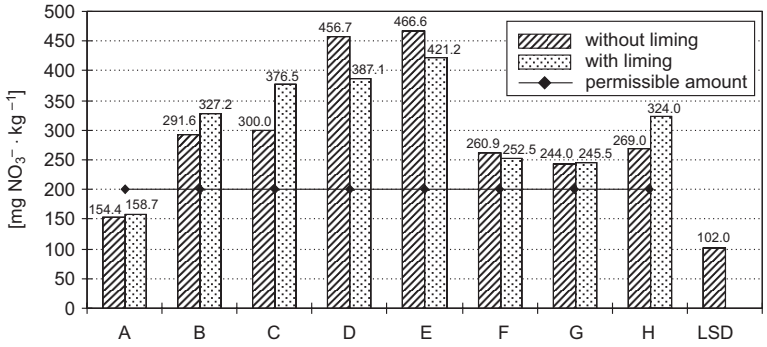


Fig. 3. Content of nitrates in potato tubers; A–H: key as in Figs. 1 and 2

fertilization with FYM and mineral fertilizers than after an application of liquid manure. An exceptionally high increase in the content of nitrates(V) was caused by fertilization with liquid manure rate II, balanced with FYM in respect of the amount of organic carbon introduced to soil. Three-fold more nitrogen was introduced with this fertilization system than with liquid manure rate I, FYM and mineral fertilizers.

The content of nitrates(V) was also affected by phosphorus-potassium fertilization applied in combination with natural fertilizers. When these fertilizers were used together with liquid manure, nitrate(V) nitrogen in potato tubers tended to increase but when the same fertilizers were applied alongside FYM, a non-significant decrease in this form of nitrogen in tubers appeared. Rogozinska et al [20], who emphasized the fact that potassium fertilization increased the content of nitrates in potato tubers, added that magnesium fertilization caused a reduction in the concentration of these compounds.

Soil liming did not have any significant effect on the increase in the content of nitrates(V) in potato tubers except the treatments with the second rate of liquid manure and FYM, where the effect of soil liming appeared as a significant increase in the concentration of the analysed form of nitrogen.

The results reveal large differentiation in the level of nitrates(V) in tubers of potatoes grown on soil fertilized with FYM versus the other types of fertilizers. The low content of nitrates(V) in tubers of potatoes fertilized with FYM is in accord with the data reported by other authors [4, 5, 8, 20, 21] but does not confirm the results of the author's previous experiment on grey-brown podsolic soil [22].

Numerous authors [12, 21, 23, 24] suggest that potatoes grown at organic farms, where FYM is mainly applied as a fertilizer, contain less nitrates compared with potatoes grown at conventional farms. In a study conducted by Murawa et al [12], organic potatoes contained two-fold less nitrates(V) and in an experiment completed by Wawrzyniak et al [24], they had four-fold less of these compounds versus potatoes grown conventionally. Higher amounts of nitrates in potatoes from conventional plantations compared with organic farms are attributed to the fact that natural and organic fertilizers applied in organic farming add to soil organic substance, which becomes a substrate for edaphon, the main link in the organic matter metabolism that transforms organic compounds into plant available forms. Presence of edaphon is a condition for decomposition of organic compounds. It also accelerates release of mineral components. Under such conditions, the nitrogen taken up by plants is completely used up for the formation of protein. In contrast, mineral fertilizers and pesticides, applied in conventional agriculture, either damage or destroy living organisms, which may lead to excessive or uncontrollable uptake of nutrients, including nitrogen, by plants [9, 21, 23, 24].

The authors' own research is supported by reports written by other researchers on the effect of the type of soil on accumulation of nitrates in plants [17, 25]. Growing potatoes on more compact soil leads to weaker accumulation of $NO_3^-$ in potato tubers compared with lighter soil, which may be explained by more intensive leaching of these compounds from lighter than from more compact soil [18, 22]. Jarych-Szyszka [7] as well as Poberezny [26] demonstrated that small amounts of rainfall and higher temperatures stimulated more intensive accumulation of nitrates in potato tubers. The

growing season during which this study was performed was characterized by alternate periods of droughts and heavy rainfall. Under such conditions, nitrification process can be activated, which may improve the availability of a nitrate nitrogen pool and, as a result, may lead to a higher concentration of nitrates in plants. Another external factor which may have affected the level of nitrates in potato tubers could have been the ambient temperature [27]. Higher temperatures occurring in 2009 during the growth of potatoes may have favoured the uptake of nitrates by plants.

## Conclusions

1. Under the influence of fertilization, an increase in the total and protein nitrogen in potato tubers appeared, reaching on average 0.29 % and 0.13 % in the series without soil liming and 0.22 % and 0.03 % in the soil limed series versus the control. The share of protein nitrogen in the total nitrogen content ranged from 51.1 % to 65.7 % and was the highest in tubers of potato plants fertilized with rate I of liquid manure.

2. Each fertilization system caused an increase in the content of nitrates(V) in potato tubers above the permissible level. Among the treatments where the same amount of nitrogen was introduced with fertilizers, in both experimental series (with and without liming), smaller excess of the permissible concentration of nitrates(V) was determined in potato tubers fertilized with farmyard manure, whereas a higher one appeared in tubers of potatoes fertilized with mineral fertilizers and rate I of liquid manure.

3. The highest content of nitrates(V) exceeding from 2.1–fold (limed soil) to 2.3–fold (unlimed soil) their allowable amount, was found in tubers of potatoes fertilized with liquid manure rate II, balanced with FYM in respect of organic carbon introduced to soil. By adding PK fertilizers to liquid manure, a further increase in the content of nitrates was observed. In the case of FYM, the effect of PK fertilizers was opposite.

### References

[1] Bélanger G., Walsh J.R., Richards J.E., Milburn P.H. and Ziadi N.: Amer. J. of Potato Res. 2002, **79**, 269–279.
[2] Boligłowa E. and Gleń K.: EJPAU, ser. Agronomy 2003, **6**(1), [online] http://www.ejpau.media.pl/volume6/issue1/agronomy/art-03.html
[3] Dzienia S., Szarek P. and Pużyński S.: Zesz. Probl. Post. Nauk Roln. 2004, **500**, 235–242.
[4] Kołodziejczyk M., Szmigiel A. and Kiełbasa S. Fragm. Agron. 2007, **2**(94), 142–150.
[5] Zarzecka K. and Gugała M.: Zesz. Probl. Post. Nauk Roln. 2006, **513**, 575–582.
[6] Wojciechowska R.: Zesz. Nauk. AR Kraków, Ser. 48, Rozprawy 2004, **297**, p. 1–102.
[7] Jarych-Szyszka M.: Żywność, Nauka, Technologia, Jakość 2006, **2**(47) supl., 76–84.
[8] Leszczyński W.: Zesz. Probl. Post. Nauk Roln. 2002, **489**, 47–64.
[9] Makaraviciute A.: Agron. Res. 2003, **1**(2), 197–209.
[10] Mauromicale G., Signorelli P., Lerna A. and Foti S.: Amer. J. Potato Res. 2003, **80**, 281–288.
[11] Płaza A., Ceglarek F. and Buraczyńska D.: EJPAU, ser. Agronomy 2004, **7**(1) [online] http://www.ejpau.media.pl/articles/volume7/issue1/agronomy/art-05.pdf
[12] Murawa D., Banaszkiewicz T., Majewska E., Błaszczuk B. and Sulima J.: Bromat. Chem. Toksykol. 2008, **41**(1), 67–71.
[13] Methods Manual 93 series electrodes. A Thermo Business Electron. Formerly Orion Research Inc., Orion 2001, p. 22–24.

[14] STATISTICA (*data analysis software system*), version 9.0. STATSOFT, INC. 2009 [online] www.statsoft.com.
[15] Bárta J., Diviš J. and Čurn V.: Zesz. Nauk. AR we Wrocławiu, 396, Rolnictwo 2000, **77**, 209–216.
[16] Janowiak J., Spychaj-Fabisiak E., Wszelaczyńska E., Pińska M. and Murawska B.: J. Cent. Eur. Agric. 2009, **10**(1), 109–114.
[17] Marks N., Sobol Z. and Kołodziejczyk M.: Zesz. Probl. Post. Nauk Roln. 2004, **500,** 341–350.
[18] Sądej W., Żołnowski A.C. and Przekwas K.: Polish J. Natur. Sci. 2007, **22**(1), 15–22.
[19] Rozporządzenie Ministra Zdrowia z dnia 13 stycznia 2003 r. w sprawie maksymalnych poziomów zanieczyszczeń chemicznych i biologicznych, które mogą znajdować się w żywności, dozwolonych substancjach dodatkowych, substancjach pomagających w przetwarzaniu się na powierzchni żywności. DzU 2003, nr 37, poz. 326.
[20] Rogozińska I., Pawelzik E., Pobereżny J. and Delgado E.: Potato Res. 2005, **48**(3–4), 167–180.
[21] Rutkowska B.: Roczn. PZH 2001, **52**(3), 231–236.
[22] Sądej W., Przekwas K. and Bartoszewicz J.: Ann. UMCS, sec. E 2004, **59**(1), 83–92.
[23] Zarzyńska K. and Wroniak J.: Zesz. Probl. Post. Nauk Roln. 2008, **530**, 249–257.
[24] Wawrzyniak A., Kwiatkowski S. and Gronowska-Senger A.: Roczn. PZH 1997, **48**(2), 181–186.
[25] Cieślik E.: Post. Nauk Roln. 1995, **6**, 67–73.
[26] Pobereżny J.: Polish J. Natur. Sci. 2008, **23**(2), 336–346.
[27] Hasegowa H.: Japan. J. Crop Sci. 1990, **59**(3), 498–502.

## ZAWARTOŚĆ AZOTANÓW(V) W BULWACH ZIEMNIAKA UPRAWIANEGO W RÓŻNYCH SYSTEMACH NAWOŻENIA

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**Abstrakt:** W statycznym doświadczeniu polowym założonym w 1973 r. na glebie brunatnej stosowano dwa rodzaje nawozów naturalnych – obornik i gnojowicę, nawozy mineralne (NPK) oraz łączne nawożenie organiczno-mineralne. Gnojowicę stosowano w dwóch dawkach: I zrównoważonej z obornikiem i nawozami mineralnymi ilością azotu oraz II zrównoważonej z obornikiem ilością węgla organicznego. Doświadczenie przeprowadzono w dwóch seriach – bez wapnowania i z wapnowaniem. W okresie badawczym stosowano 7-letnie zmianowanie roślin.

Stwierdzono, że każdy rodzaj nawożenia przyczynił się do wzrostu zawartości azotu azotanowego(V) w bulwach ziemniaka. Największą zawartość azotanów(V), przekraczającą od 2,1 (seria z wapnowaniem) do 2,3 razy (seria bez wapnowania) dopuszczalną ich ilość, zawierały bulwy ziemniaka nawożonego gnojowicą w dawce II oraz dawce II + PK. Spośród nawozów, z którymi wprowadzono do gleby jednakową ilość azotu, większe przekroczenie dopuszczalnej zawartości azotanów(V) w bulwach ziemniaka nastąpiło w wyniku stosowania nawozów mineralnych i gnojowicy w I dawce niż obornika. Uzupełnienie gnojowicy o mineralne nawozy PK powodowało dalszy wzrost zawartości azotanów, natomiast w przypadku obornika ich działanie było odwrotne. Przeprowadzony w doświadczeniu zabieg wapnowania gleby różnicował zawartość azotanów(V) w bulwach ziemniaków, jednak jego działanie nie było jednoznaczne.

**Słowa kluczowe:** nawożenie, bulwy ziemniaka, zawartość azotanów(V)