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EFFECT OF ORGANIC AND NITROGEN FERTILIZATION ON SELECTED COMPONENTS IN POTATO TUBERS GROWN IN A SIMPLIFIED CROP ROTATION

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Abstract

Fertilization is one of the factors of agro-technical practice that determines potato yield volume and quality. This research involved the early table potato cultivar Bila grown in the first year of the tenth (2006) and the eleventh rotation cycle (2009) in a long-term, static field experiment (set up in 1979). A three-year simplified crop rotation included potato – winter rye 1 – winter rye 2. The experimental factors covered: I organic fertilization (without FYM and with FYM at the amount of 30 t ha^{-1}), II nitrogen doses 0, 60, 120, 180 kg N ha^{-1} under potato and 0, 40, 80, 120 kg N ha^{-1} under rye. The aim of the present research was to evaluate the yielding and content of selected chemical components of the tubers of cv. Bila potato grown in a simplified system depending on different organic and mineral fertilization regimes, implemented for many years. The results show a significantly positive effect of FYM and nitrogen fertilization on the tuber yield volume and on the content of total protein and magnesium, as well as a negative effect on the content of nitrates(V). However, FYM fertilization increased but nitrogen fertilization decreased the content of ascorbic acid. The highest nutritive value of tubers was achieved after the application of 60 kg N ha^{-1}. However, a dose higher than 120 kg N ha^{-1} applied with FYM increased the content of nitrates(V) above the toxicity threshold (200 mg NO_3^- kg^{-1} of the fresh product).

Key words: potato, protein, magnesium, vitamin C, nitrates(V).

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WPŁYW NAWOŻENIA ORGANICZNEGO I AZOTU NA WYBRANE SKŁADNIKI BULW ZIEMNIAKA UPRAWIANEGO W UPROSZCZONYM ZMIANOWANIU

Abstrakt

Nawożenie jest jednym z czynników agrotechniki decydujących o wielkości i jakości plonu ziemniaka. Badania nad wczesną, konsumpcyjną odmianą ziemniaka Bila, pochodzącą z pierwszego roku 10. (2006 r.) i 11. rotacji (2009 r.) wieloletniego polowego doświadczenia statycznego (od 1979 r.), prowadzono w 3-letnim uproszczonym zmianowaniu: ziemniak – żyto ozime 1 – żyto ozime 2. Czynnikami doświadczenia były: I – nawożenie organiczne (bez obornika ozime i z obornikiem w ilości 30 t ha^{-1}), II – dawki azotu 0, 60, 120, 180 kg N ha^{-1} pod uprawę ziemniaka i 0, 40, 80, 120 kg N ha^{-1} pod uprawę żyta.

Celem badań była ocena plonowania oraz zawartości wybranych składników chemicznych w bulwach ziemniaka odmiany Bila uprawianego w systemie uproszczonym, w zależności od wieloletniego zróżnicowanego nawożenia organicznego i mineralnego.

Wykazano istotnie pozytywne działanie obornika i nawożenia azotem na wielkość plonu bulw oraz zawartość białka ogólnego i magnezu, a negatywne na zawartość azotanów(V). Natomiast zawartość kwasu askorbinowego istotnie wzrastała pod wpływem nawożenia obornikiem, a malała pod wpływem azotu.

Najwyższą wartość odżywczą miały bulwy nawożone dawką 60 kg N ha^{-1}, natomiast przekroczenie dawki 120 kg N ha^{-1} na tle obornika powodowało wzrost zawartości azotanów(V) powyżej progu toksyczności (200 mg NO_3^- kg^{-1} świeżego produktu).

Słowa kluczowe: ziemniak, białko, magnez, witamina C, azotany(V).

INTRODUCTION

Potatoes grown for the food processing industry most often come from traditional plantations, where intensive mineral fertilization and intensive plant protection technologies are emplyed (Rytel 2010). In Poland, potatoes have many uses (Rogozińska et al. 2005, Jabłoński 2006, Pobereżny, Wszelaczyńska 2011). Fertilization, especially with mineral nitrogen, is one of the agro-technical factors determining potato yield volume (Blecharczyk, Małecka 2000, Ciećko et al. 2000, Rogozińska et al. 2005, Jabłoński 2006, 2009). Unsurprisingly, high nitrogen doses have an unfavourable effect on the tuber quality (Peshin, Singh 1999, Leszczyński 2000, Belanger et al. 2002, Prośba-Białczyk 2004, Rogozińska et al. 2005, Jabłoński 2006). Organic fertilisers can alleviate the effects of unbalanced mineral fertilization, especially in light soil. With the above in mind, this research was undertaken in order to define whether and to what extent varied nitrogen fertilization applied for many years with or without FYM determined the yield volume, the content of total protein and magnesium, vitamin C and nitrates(V) in the tubers of the table potato cultivar Bila grown in a simplified crop rotation.

The aim was to evaluate the yielding and selected chemical components of the tubers of cv. Bila potato grown in a simplified system, depending on different, long-term organic and mineral fertilization regimes.

MATERIAL AND METHODS

The research involved an early cultivar of table potato called Bila cultivar, grown in the first year of the tenth (2006) and the eleventh rotation (2009) of a long-term, static field experiment. The experiment was set up in 1979 at the Agricultural Experimental Station at Wierzchucinek (the Kujawy and Pomorze Province, today Experimental Station of the Faculty of Agriculture and Biotechnology, the University of Technology and Life Sciences in Bydgoszcz) on Luvisol representing the good wheat complex. The experiment was carried out in a three-year simplified crop rotation cycle: potato – winter rye (1) – winter rye (2). Once winter rye (2) was harvested, straw was left to be ploughed in. The experiment followed the design:

1. PKN_0	5. PKN_0 + FYM
2. PKN_1	6. PKN_1 + FYM
3. PKN_2	7. PKN_2 + FYM
4. PKN_3	8. PKN_3 + FYM

Plant	Fertilization levels (kg ha^{-1})					
	P	K	N_0	N_1	N_2	N_3
Potato	35	100	0	60	120	180
Winter rye (1)	35	66	0	40	80	120
Winter rye (2)	35	83	0	40	80	120

The fertilisers were applied as triple superphosphate (46%), potassium salt (50%) as well as ammonium nitrate (34%). The nitrogen doses were applied without and with FYM in the amount of 30 t ha^{-1}. The potato experiment was set up in a split-plot design with four replications, where factor I comprised FYM fertilization, and factor II included nitrogen doses. Potato tubers were planted in the third decade of April.

The total tuber yield was determined and the potato samples were analysed for the following:

– total nitrogen (with the Kiejdahl method). Tuber samples (dry weight) for N_{tot} assessment were mineralized in a mixture of H_2SO_4 and H_2O_2 in a Digest Automat K-438, auto-Sampler K371, and then analyzed in an Autokjedahl Unit K-370 apparatus (Gozdecka, Gęsiński 2009);

– magnesium (with atomic absorption spectrophotometry AAS in the dry weight), the same mineralization procedure as for the N_{tot} determination was followed. The magnesium content was measured with a VARIAN AA240FS Fast Sequential Atomic Absorption Spectrometer system USA (Ostrowska et al. 1991);

– vitamin C levels were measured spectrophotometrically (absorbance was measured at 520 nm with a Shimadzu UV-1800, UV Spectrophotometer system, Japan) by a method in which 2,6-dichlorophenolindophenol dye is reduced by ascorbic acid. The details are described elsewhere (Egoaville et al. 1988);

– nitrates(V) were determined with the use of an ion-selective Elmetron make (Kunsch et al. 1981) using a multi-purpose computer device: CX-721.

The results of the 3-year research were statistically verified, applying analysis of variance for two-factor experiments. The data were analysed using Sigma Stat software (SPSS, Chicago, USA). The main effects were tested by Anova, and pairwise multiple comparisons were made using the Tukey's Test at the 0.05 level. Coefficients of correlation (*r*) and regression (*y*) were calculated to present the relationships between the traits.

The soil analyses made prior to and after 28 years of the experiment show that the fertilization applied and the absence of liming changed the classification of the soil reaction from slightly acid (pH 5.6) to acid (pH 4.0) in the case of the treatments with FYM and very acid (pH 3.7) in respect of the treatments without FYM. These results have been presented in an earlier report (Janowiak et al. 2010).

RESULTS AND DISCUSSION

The tuber yield of the early potato cultivar Bila was on average 30.2 t ha^{-1}, ranging from 24.6 t ha^{-1} to 37.4 t ha^{-1} (Table 1). The lowest yield was recorded for the control, without fertilization, and the highest one – for the treatment with FYM and NPK with nitrogen in the dose of 120 kg N ha^{-1}. The above data are concordant with the results by Blecharczyk et al. (2008), who completed long-term research on potato grown in a simplified crop rotation system and in monoculture; in both systems, the highest tuber yield was reported after FYM fertilization combined with NPK (29.4 t ha^{-1}). In several reports (Blecharczyk, Małecka 2000, Mercik, Stępień 2006), combined orga-

Table 1

Total yield of potato tubers (t ha^{-1})

Natural fertilization	Nitrogen dose (kg ha^{-1})				Mean
	0	60	120	180	
Without manure	24.6	27.6	26.2	25.5	25.9
Manure	33.0	34.1	37.4	34.0	34.6
Mean	28.8	30.8	31.8	29.8	30.2

LSD α=0.05:
natural fertilization (I) – 2.39
nitrogen fertilization (II) – 2.43
interaction (II/I) – n.s.

nic and mineral (NPK) fertilization increased the total tuber yield by about 10%, as compared with the yield recorded for the mineral fertilization only. The literature shows that FYM fertilization enhances the physicochemical soil properties and increases the level of plant yielding (Blecharczyk, Małecka 2000, Jankowska-Huflejt 2006, Mercik, Stępień 2006, Blecharczyk et al. 2008). The statistical analysis of the current results demonstrated that FYM applied during potato growth significantly determined the tuber yield. After the FYM application, a 33.6% tuber yield increase was noted relative to the treatment without FYM. Contrary results were reported by Blecharczyk et al. 2008, where the FYM application, irrespective of the farming system (simplified crop rotation, monoculture), decreased the tuber yield by 14.6%. Significantly smaller yield was found for potatoes cultivated in the organic system (on manure) in comparison to the conventional one. The three-year average decrease was 35.9% (Hamouz et al. 2005), which corroborates the 30% decrease reported by Prośba-Białczyk (2004) .

According to Ciećko et al. (2000), Jabłoński (2006, 2009), nitrogen fertilization is the factor that best enhances the yield volume. In the present research, mineral fertilization with nitrogen, with or without FYM, significantly increased the tuber yield up to the dose of 120 kg N ha^{-1}. The application of the highest nitrogen dose (180 kg N ha^{-1}), on the other hand, decreased the above trait (Table 1). Blecharczyk et al. (2008), applying only mineral fertilization (NPK) with nitrogen at the level of 90 kg N ha^{-1}, recorded a 22.8% decrease in the yield relative to the comprehensive fertilization treatment (FYM+NPK). Jabłoński (2004), investigating varied fertilization, recorded the highest potato tuber yields for 150 kg N ha^{-1}. In another report, the same author (Jabłoński 2006) showed that the higher the level of nitrogen fertilization, the higher the potato yield, up to the dose of 135 kg N ha^{-1}. In the present research, the application of the highest nitrogen dose carried out for many years, with and without FYM, considerably decreased the soil pH value from pH=5.6 to pH=4.0 and pH=3.7, respectively, which inhibited the adequate plant growth and development. Such a result was also reported in the 29th potato rotation (Janowiak et al. 2010). Jankowska-Huflejt (2006), testing the effect of long-term potato fertilization with FYM combined with mineral fertilization in various combinations, thus verirying a clearly acidifying effect of nitrogen. A decrease in soil pH was recorded especially for the treatments with mineral fertilization containing nitrogen. The present research and the reports by the above authors demonstrate that FYM slightly alleviated those effects and, according to Jabłoński (2004), setting an optimal nitrogen dose should account for both the soil richness in nutrients and the soil reaction.

Protein is considered one of the basic nutrients of potato tuber and it shows a high biological value corresponding to animal protein. In the fresh weight of tubers, protein constitues 1.7-2.3%, of which 35-68% is the true protein, also referred to as 'pure' protein (Mitrus et al. 2003, Pęksa 2003, Zarzecka, Gugała 2006, Rytel 2010). In the present research, the content of total protein in potato tubers, on average, ranged from 85 to 117 g kg^{-1} in the dry weight (the experiment mean of 101 g kg^{-1}), being significantly determined by nitrogen fertilization as well as natural fertilization (Table 2). The significantly highest protein content (33.0% higher than the control) was determined in potato tubers from the treatment where nitrogen was applied in the dose of 180 kg N ha^{-1} with FYM. Mitrus et al. (2003) showed that the protein content in the tubers of potato cultivars (Irga and Ekra) increased

Table 2

Total protein content in potato tubers (g kg^{-1} d.m.)

Natural fertilization	Nitrogen dose (kg ha^{-1})				Mean
	0	60	120	180	
Without manure	85	103	101	108	99
Manure	88	95	111	117	103
Mean	87	99	106	112	101

LSD α=0.05:
natural fertilization (I) – 3.1
nitrogen fertilization (II) – 4.3
interaction (II/I) – n.s.

significantly under the influence of nitrogen fertilization. The increase in the total protein content after the application of the higher tested fertilizer dose (90 kg N ha) was 10.76% for cv. Irga cultivar and 11.08% for cv. Ekra , albeit to the detriment of the biological value.

Zarzecka, Gugała (2006) and Gugała et al. (2008), who investigated the effect of traditional and simplified farming systems on the content of total protein in cv. Wiking, recorded a higher protein content in the traditional farming system: 99.5 g kg^{-1} of dry weight versus 97.9 g kg^{-1} in the simplified system. On the other hand, Klikocka (2002), who performed an experiment on the traditional and simplified systems, recorded a growing tendency for the content of that nutrient in both systems, although she did not prove it to be significant. Kraska (2002), Dzienia et al. (2004), Lachman et al. 2005 as well as Gugała et al. (2008), however, showed that the cultivation method did not have a significant effect on changes in the content of total protein in potato tubers.

Potato tubers contain more than 1% of mineral compounds (Leszczyński 2000, Rytel 2010). In the present research, the magnesium content ranged from 0.77 g kg^{-1} to 0.91 g kg^{-1}, with an average of 0.84 g kg^{-1} in the dry weight (Table 3). The applied nitrogen fertilization significantly affected the magnesium content in potato tubers. The highest mean Mg content was recorded in the tubers fertilised with the dose of 60 kg N ha^{-1}. Higher nitrogen doses gradually decreased the content of that nutrient in tubers. Similar tendencies were also observed for the treatments with FYM. The results were submitted to the linear regression analysis. The relationships for which the coefficient

Table 3

Magnesium content in potato tubers (g kg^{-1} d.m.)

Natural fertilization	Nitrogen dose (kg ha^{-1})				Mean
	0	60	120	180	
Without manure	0.85	0.91	0.80	0.77	0.83
Manure	0.85	0.89	0.83	0.82	0.85
Mean	0.85	0.90	0.81	0.79	0.84

LSD α=0.05:
natural fertilization (I) – 0.019
nitrogen fertilization (II) – 0.036
interaction (II/I) – n.s.

of determination was higher than 35 are given in Figures 1-3. There was a significant negative coefficient of correlation between the nitrogen dose and the magnesium content in tubers (*r*=-0.60) – Figure 1. According to Ciećko et al. (2000), different levels of mineral fertilization (NPK) did not significantly modify the Mg content in potato tubers, although its highest concentration was reported, similarly to the present research, after the nitrogen dose of 60 kg N ha^{-1}. Rudzińska-Mękal, Mikos-Bielak (2001) claim the opposite. According to these authors, the magnesium content in potato tubers mostly depends on the duration of the plant growing season, hence the earliness of a cultivar plays a role. The cited authors, who investigated 5 potato cultivars submitted to FYM application and fertilised with the nitrogen dose of 100 kg

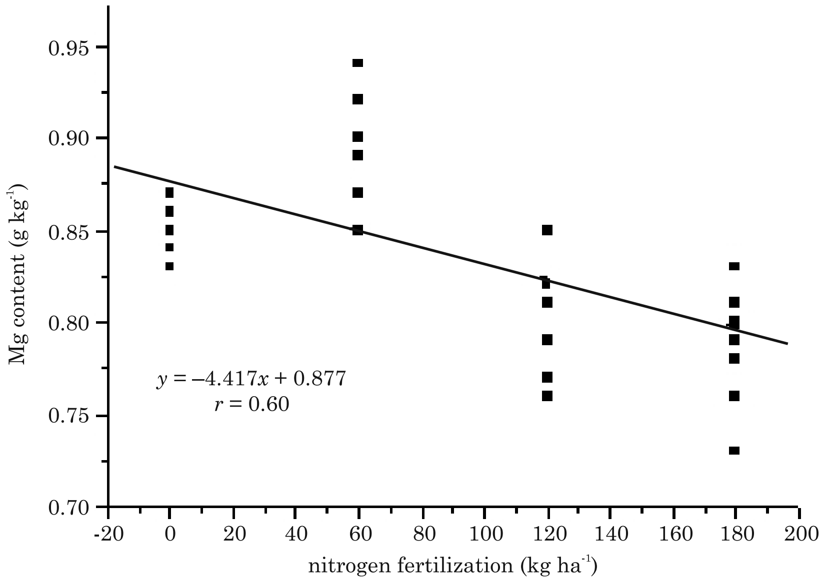

Fig. 1 Relationship between nitrogen fertilization and magnesium content in potato tubers

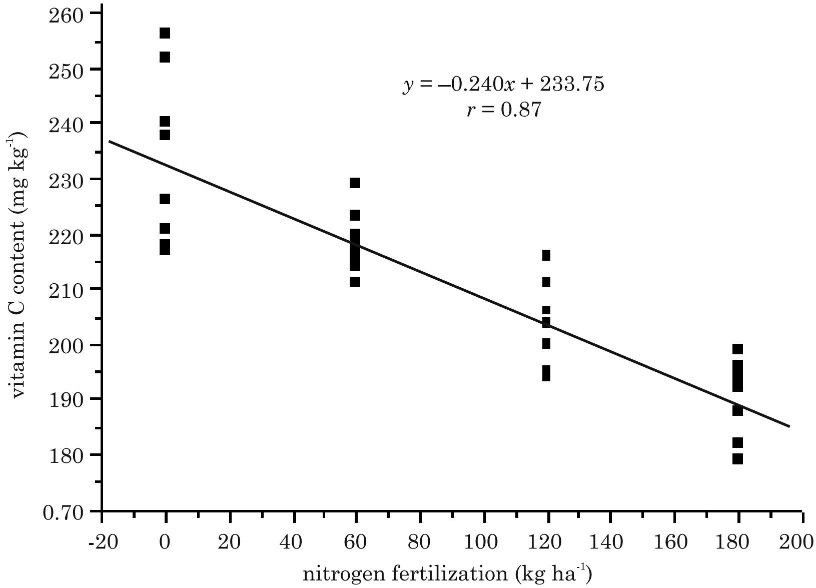

Fig. 2 Relationship between nitrogen fertilization and vitamin C in potato tubers

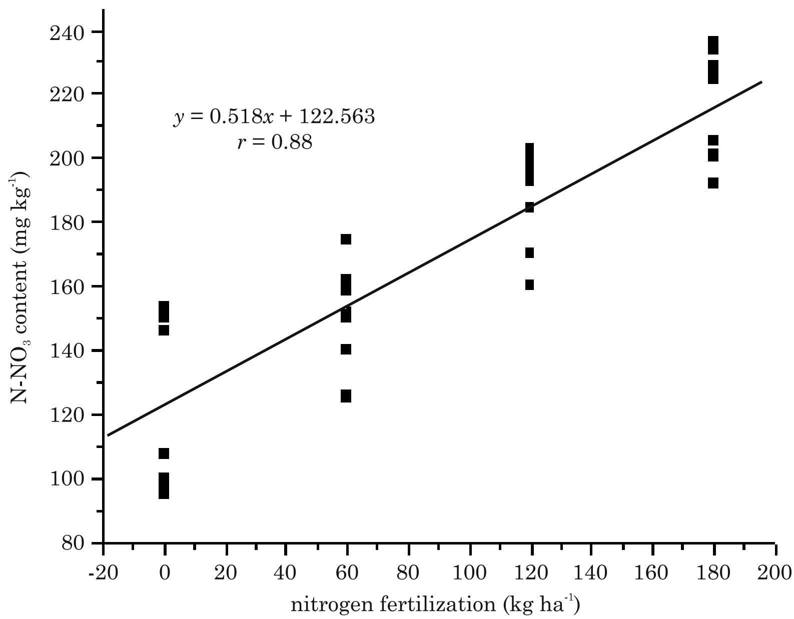

Fig. 3 Relationship between nitrogen fertilization and nitrates(V) content in potato tubers

N ha^{-1}, found the lowest content of magnesium nutrient in the early cultivars Drop and Perkoz (0.09 to 0.10%), a higher Mg content in the medium late cultivars Irga and Grot (0.11%), and the highest one in the late cultivar Elba (0.12%).

The human magnesium requirements are mostly satsfied through consumption of plant products (Leszczyński 2000, Wszelaczyńska 2001, Wszelaczyńska, Pobereżny 2011). With its high share in the diet of an average Pole, potato is perceived as an essential Mg source (Rudzińska-Mękal, Mikos-Bielak 2001, Wszelaczyńska 2001, Rytel 2010). Drawing on the results, it was calculated that the consumption of 200 g of potato with the highest magnesium content, that is after the application of 60 kg N ha^{-1}, introduces 38 mg of that nutrient into the body (180 mg day^{-1} of magnesium in the dry weight – Table 3), which covers 13% of the adult's daily requirement, the finding which coincides with the earlier results (Leszczyński 2000, Wszelaczyńska 2001).

Potato is also an essential source of vitamin C. Its content is about 200 mg kg^{-1} of fresh tuber weight, although it varies in a wide range (from 30-300 mg) depending on the cultivar and the year of cultivation (Hamouz et al. 1999, Kraska 2002, Brown 2005, Zarzyńska, Goliszewski 2005, Zarzecka et al. 2007, Hamouz et al. 2009), which was demonstrated by the present results, since the content of ascorbic acid in the fresh weight of potato tubers ranged from 1867 to 247 mg kg^{-1} (Table 4). Zarzecka et al. (2007) recorded an average content of ascorbic acid in cv. Wiking potato tubers to be 221.0 mg kg^{-1} of the fresh weight. In that research, a simplified potato growing method did not differentiate the vitamin C content significantly, which coincides with the results reported by Hamouz et al. (1999), Kraska (2002), Zarzyńska, Goliszewski (2005), Hamouz et al. (2009), who observed that the growing method did not change the content of ascorbic acid. Different results were recorded by Sawicka, Kuś (2002), who found that the growing methods (integrated, organic) differentiated the vitamin C content. In the present research, the increasing nitrogen doses steadily decreased the vitamin C content by 6.4%, 12.2% and 17.5% (Table 4) as compared to the treatment

Table 4

Ascorbic acid content in potato tubers (g kg^{-1} f. m.)

Natural fertilization	Nitrogen dose (kg ha^{-1})				Mean
	0	60	120	180	
Without manure	221	216	201	187	206
Manure	247	221	209	199	219
Mean	234	219	205	193	212

LSD α=0.05:
natural fertilization (I) – 6.1
nitrogen fertilization (II) – 13.1
interaction (II/I) – n.s.

without fertilization. This tendency coincides with the calculated negative coefficient of correlation (*r*=-0.87) between the nitrogen dose and the vitamin C content (Figure 2). Hamouz et al (2009) proved the negative effect of an increased level of nitrogen fertilization equal 180 kg N ha on the AA content. According to these authors, the AA content decreased by an average 12.4% in the experimental years in comparison with the control (100 kg N ha, 44 kg P ha, 108 kg K ha, 30 kg Mg ha). However, Lin et al. (2004) discovered that nitrogen fertilization had very small impact on the AA content; only high doses of nitrogen that lead to the yield depression significantly reduced the AA content. Reversely, the effect of organic fertilization on the content of ascorbic acid is less unambiguous. In the present research, organic fertilization significantly increased the vitamin C content – by more than 6%. Wszelaczyńska et al. (2007), investigating the effect of organic fertilization on the vitamin C content in cv. Bila potato tubers, recorded its slight and insiginificant increase. Among the cultivars they investigated, the highest vitamin C content was recorded in the early cultivars Bila and Bard. Zarzecka (2006), having reviewed the results of research carried out by many authors for over 10 years, with the focus on the effect of organic fertilization on the tuber quality, showed that there was no obvious effect of organic fertilization on the content of vitamin C in potato tubers. Those results confirm the hypothesis that FYM alleviates the effects of the long-term application of high mineral nitrogen doses, since the coefficient of correlation (*r*=-0.87) points to a significantly negative relationship between nitrogen fertilization and the content of vitamin C (Figure 2).

For the consumer's health, it is very important that potato tubers contain the lowest content of harmful compounds, including nitrates(V). In the investigated potato flesh, the content of nitrates(V) ranged from 100 to 231 mg kg^{-1} of fresh weight (Table 5). The lowest content of nitrates(V) was recorded in potato tubers from the control (with neither FYM nor nitrogen).

The fertilization applied in the present research significantly determined the content of nitrates(V) in tubers. The FYM fertilization as well as higher

Table 5

Nitrates(V) content in potato tubers (mg kg^{-1} f. m.)

Natural fertilization	Nitrogen dose (kg ha^{-1})				Mean
	0	60	120	180	
Without manure	100	135	177	200	153
Manure	150	161	199	231	185
Mean	125	148	188	215	169

LSD α=0.05:
natural fertilization (I) – 13.1
nitrogen fertilization (II) – 14.4
interaction (II/I) – n.s.

nitrogen doses significantly increased the content of nitrates(V) in potato: by 21.3, 18.6, 50.3 and 72.2%, respectively, as compared with the control. The relationship between nitrogen fertilization and the content of nitrates(V) is supported by a significant positive value of the coefficient of correlation (r=0.88) – Figure 3. According to Amr, Hadidi (2001), Dzienia et al. (2004), Hamouz et al. (2005), Lachman et al. (2005), Zarzecka, Gugała (2006) as well as Ierna (2009), the strongest effect on the content of nitrates(V) is produced by nitrogen fertilization, the cultivar and weather conditions, whereas the cultivation method does not change the content of that nutrient in tubers. The Ministry of Health, in the Regulation of January 13, 2003 (*Regulation* ...), defined the maximum level of pollution with nitrates(V) in potato tubers at 200 mg NO_3^- kg^{-1} of the fresh product (*Regulation* ... 2003). Considering the range of toxicity, and thus the toxic effect of nitrates(V), in the context of the fertilization of table potato, the nitrogen dose of 120 kg N ha should not be exceeded.

CONCLUSIONS

1. The fertilization with FYM and nitrogen of potatoes grown in a simplified crop rotation significantly affected the tuber yield volume. The highest total tuber yield was recorded after the use of nitrogen at the dose of 120 kg N ha^{-1} with FYM applied.

2. After the FYM treatment, the content of magnesium and vitamin C increased significantly, although after the application of increasing nitrogen rates (120 and 180 kg N ha^{-1}) there was a decrease in the content of those nutrients, as compared with their content determined after the nitrogen dose of 60 kg N ha^{-1}.

3. The content of total protein and nitrates(V) in potato tubers increased due to FYM within the whole range of the applid nitrogen doses. Interestingly, exceeding the dose of 120 kg N ha^{-1} applied with FYM increased the content of nitrates(V) above the threshold of toxicity.

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