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ECOLOGICAL CHEMISTRY AND ENGINEERING A

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Elżbieta Jolanta BIELIŃSKA[1] and Sławomir LIGĘZA[2]

BIOCHEMICAL PROPERTIES OF SELECTED SOILS IN THE AREA OF PUŁAWY FOREST DISTRICT

BIOCHEMICZNE WŁAŚCIWOŚCI WYBRANYCH GLEB NA TERENIE NADLEŚNICTWA PUŁAWY

Abstract: Activities of dehydrogenases, urease, protease, and concentrations of various forms of nitrogen ($N_{tot.}$, NH_4^+-N, NO_3^--N) in soils were investigated in order to assess a degree to which forest ecosystems in the area of Pulawy Forest District are able to introduce to biological circulation or to bind in soil nitrogen compounds emitted by Zaklady Azotowe "Pulawy" SA. In this study, soils from degraded forest habitats situated along the migration line of polluted air in forest hazard zones III and II were analyzed. Strong positive correlations between activities of investigated enzymes and concentrations of nitrogen mineral forms in the soils showed that the ecosystem studied are able to introduce atmospheric nitrogen to biological circulation.

Keywords: nitrogen emission, forest soils, soil enzymes

Zaklady Azotowe "Pulawy" SA (a nitrogen fertilizers factory), built in the 1960s, was the main source of degradation of forests and barren podzol soils developed from eolian sands [1–3]. Exceptionally unfavourable environmental conditions came into being in the area located to the east of the factory, on the line of polluted air migration. Self-regeneration of the pioneer forest occurred in that disturbed, synanthropic ecosystem as a result of radical reduction of emission after 1995 [4, 5]. The forest ecosystems located to the east of Zaklady Azotowe are under the constant impact of the toxic factor despite diminishing industrial emission [3, 6].

All soil nutrient transformations are stimulated by enzymes conditioning their turning into forms available for plants and microorganisms. That transformations constitute a crucial phase limiting assimilation of nutrients by biocenoses [7].

Activities of dehydrogenases, urease, protease, and concentrations of various forms of nitrogen ($N_{tot.}$, NH_4^+-N, NO_3^--N) in soil were investigated in order to assess a degree

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to which forest ecosystems in the area of Pulawy Forest District are able to introduce to biological circulation or to bind in soils nitrogen compounds emitted by Zaklady Azotowe "Pulawy" SA, and to investigate what processes were initiated, accelerated or inhibited in the ecosystem studied.

Material and methods

The study was conducted in the area adjacent to Zaklady Azotowe "Pulawy" SA. The plant is situated on the right bank of the middle Vistula, in the northern part of Pulawy (51°25′ N; 21°57′ E). The research was carried out in the distance of 0.5 km from the factory on the post-forest soils overgrown with Wood Small-reed (*Calamagrostis epigejos* (L.) Roth) and in the distance of 1.2–3.0 km from the emission source on the forest soils of Pulawy Forest District (forest risk zone III) covered with silver birch (*Betula pendula* Roth) and Scots pine (*Pinus sylvestris* L.). In the area studied, there are the following soils developed from eolian sands of different thickness laying on fluvioglacial sands: rusty (plots P1 and P2), rusty-podzol (plot P3) and podzol soils (plots P4, P5, and P6).

Soil samples for laboratory analyses were collected every year in spring, at the depth of 5–20 cm, from 3 representative soil profiles. The samples were taken under similar weather conditions, when the soil was in dynamic equilibrium keeping biochemical processes in the range of moderate intensity. The individual soil samples from the separate plots were averaged and afterwards analyses in 3 replications were made. Data from the period 2006–2008 were analyzed in this paper.

Activities of dehydrogenazes [8], ureaze [9], and protease [10]; pH in H_2O and in 1 mol · dm^{-3} KCl [11]; organic carbon [12]; total nitrogen [13]; ammonium and nitrates nitrogen [14] were determined in the soil samples.

Linear correlation coefficients between concentrations of mineral forms of nitrogen (NH_4^+-N and NO_3^--N) and activities of the enzymes were calculated. The significance of differences between means was evaluated by Tukey's test.

Results and discussion

The soils investigated had very acid reaction with pH in water ranging from 3.1 to 5.0 and in 1 mol · KCl dm^{-3} from 2.7 to 4.4. Strong acidification of the soils (developed from the parent material poor in basic elements) was caused by long-term, intensive imission of nitric oxides and ammonia as wet and dry deposition. The highest values of pH were noticed in the soil from the plot situated closest to the source of emission (P1), which was connected with the inflow of alkali dust emitted by Zaklady Azotowe into the soil environment [6]. A clear tendency to acidity increase was observed during the study (Table 1) despite substantial reduction of nitric emission after 1995. It could be due to an after-effect of acid rains on the soil environment [3].

Table 1

Content of organic carbon, total nitrogen, ratio C:N and pH

Site	Years	pH		C	N	C:N
		H_2O	KCl	[$g \cdot kg^{-1}$]		
P1	2006	5.0	4.4	8.22	0.50	16.4
	2007	4.7	4.2	8.34	0.53	15.7
	2008	4.5	3.9	8.52	0.56	15.2
P2	2006	4.1	3.5	9.59	0.54	17.7
	2007	4.1	3.4	9.70	0.56	17.3
	2008	4.0	3.2	10.11	0.59	17.1
P3	2006	3.4	2.9	9.68	0.56	17.2
	2007	3.3	2.8	9.92	0.58	17.1
	2008	3.1	2.7	10.23	0.60	17.0
P4	2006	3.8	3.2	10.26	0.63	16.2
	2007	3.7	3.2	10.30	0.64	16.1
	2008	3.5	3.0	10.49	0.66	15.9
P5	2006	4.2	3.7	10.43	0.65	16.0
	2007	4.1	3.5	10.57	0.68	15.5
	2008	4.0	3.3	10.82	0.71	15.2
P6	2006	4.3	3.6	10.60	0.68	15.5
	2007	4.1	3.5	10.75	0.70	15.3
	2008	3.9	3.4	10.89	0.72	15.1
$LSD_{0.05}$: plots				0.22	0.02	0.4
years				0.22	0.02	0.4

Explanation: plot – distance from source of emission: P1 – 0.5 km; P2 – 0.8 km; P3 – 1.2 km; P4 – 1.5 km; P5 – 2.0 km; P6 – 3.0 km.

Amounts of organic carbon and total nitrogen in the soils increased significantly with the distance from the source of emission and were in the range from 8.22 $g\ C \cdot kg^{-1}$ in plot P1 in 2006 to 10.89 $g\ C \cdot kg^{-1}$ in plot P6 in 2008, and from 0.50 $g\ N \cdot kg^{-1}$ (plot P1, 2006) to 0.72 $g\ N \cdot kg^{-1}$ (plot P6, 2008) (Table 1). Increases in organic carbon and total nitrogen contents in the soils were found over the years although significant differences between the means were noticed for 2008 (Table 1). One of the reasons of increases of organic carbon contents in those soils was the microbiological and chemical decomposition of rootstocks in the destroyed pine forest area. That shows that the soils have retained their capacity of self-regulation and resistance to environmental stresses. New active humus originating from decomposited pine rootstocks is a regulator of quantity and quality of nutrients within barren soils [6].

The ratios of C:N in the soils were ranged from 15.1 to 17.7 (Table 1). The C:N ratio decreases were observed in the course of the study period, which indicates faster mineralization and humification of organic matter. First of all, significant differences were noted in 2008. There were no clear relations between C:N values and the location of the plots. It could be connected with an impact of a variety of abiotic and biotic environmental factors on organic mater transformations.

There were rises in concentration of NH_4^+-N in the soils with increasing distance from Zaklady Azotowe (Table 2) and in plots P4-P6 the statistical differences were significantly stronger than in plots P1-P3. Low concentration of ammonium nitrogen in soils from plots P1 and P2 could be affected by nitrogen uptake by runner roots of compact sod of Wood Small-reed and leaching by acid precipitation in autumn, winter, and spring. Many plant species prefer uptaking nitrogen as NO_3^--N but some organisms living in the places where nitrification is slow or stopped, very often show a higher growth at availability of NH_4^+ ions [15].

Table 2

Ammonium nitrogen (NH_4^+-N) and nitrate nitrogen (NO_3^--N) contents in soils [mg · kg^{-1}]

Site	Years	N-NH_4^+	N-NO_3^-	N-NH_4^+:N-NO_3^-
P1	2006	42.6	19.3	2.2
	2007	32.5	20.4	1.6
	2008	27.6	18.5	1.5
P2	2006	42.8	17.6	2.4
	2007	31.3	18.2	1.7
	2008	28.2	16.9	1.6
P3	2006	43.3	17.9	2.4
	2007	32.2	18.7	1.7
	2008	28.9	17.2	1.6
P4	2006	47.3	21.4	2.2
	2007	36.2	22.5	1.6
	2008	32.5	20.0	1.6
P5	2006	49.2	22.3	2.2
	2007	37.3	23.3	1.6
	2008	32.8	21.4	1.5
P6	2006	58.8	26.1	2.2
	2007	40.1	24.3	1.6
	2008	34.9	23.1	1.5
	$LSD_{0.05}$			
	plots	3.5	1.2	0.65
	years	2.2	1.1	0.47

Legend as in Table 1.

Similarly to ammonium nitrogen, the soils located in the furthest distance from Zaklady Azotowe also showed the highest concentration of nitrates (Table 2). In the soil of plot P1, situated in the closest distance from the emission source (0.5 km), the content of NO_3^--N was significantly higher than in the soils within plots P2-P3. It was connected with ecological conditions of the soil environment (eg a degree of anthropogenic pollution) determining activity of organisms and levels of biological sorption, which is confirmed by significant values of linear correlation coefficients between NH_4^+-N and NO_3^--N in the soils and enzyme activities (Table 4). Other studies [16] also revealed that a quantity of nitrogen mineral forms in soil is strongly dependent on biochemical reactions controlled by enzymes. Nitrogen transformations may also be attributed to abiotic processes which occur in soils, physical phenomena and plant cover. These diverse processes complement and induce each other [16]. It was stated that concentrations of NH_4^+-N and NO_3^--N decreased with the passage of time, particularly clearly in the case of the ammonium form (Table 2).

The concentration of the ammonium form was higher than the concentration of the nitrate form, which was reflected in the values of ratio NH_4^+-N:NO_3^--N (Table 2). The reaction was an important factor deciding about relations of both mineral forms of nitrogen in the soils. The strong soil acidification (Table 1) could contribute to a slowdown of microbiological oxidation of ammonium ions. Moreover, nitrates are more susceptible to losses than ammonium compounds due to greater diversity of processes leading to these loses. Besides gaseous losses (NO, N_2O, N_2), leaching out from soils by precipitation waters and diffuse migration also play a significant role. Mobility of nitrates, in comparison with ammonium ions, is not limited by soil sorption, which increases their availability and facilitates their uptake by plants [15]. Decreases of NH_4^+-N:NO_3^--N ratio through the period of the study (Table 2) suggest the acceleration of nitrification in spite of increasing soil acidification (Table 1). Until recently, it was commonly believed that mainly heterogenic organisms were responsible for nitrification within acid forest soils. However, numerous studies [17–19] reported that in acid soils, acid-tolerant autotrophic nitrifiers are subject to selection (93 % at pH 3.9–4.3), and the share of heterotrophs is minimal. The minimum value of pH for active nitrifiers was lower in the culture medium than that in the soil from which they were isolated [20]. According to Kurek [21], this fact proves that laboratory model testing does not reflect the regulation function of soil. The ratio of NH_4^+-N to NO_3^--N was significantly higher in the first year of the study (2006) than in 2007–2008, confirming the existence of a defence mechanism in natural soils, protecting microorganisms and enzymes against environmental stress.

Activities of the enzymes investigated were significantly different both in the plots and the years of the study. Direction and intensity of changes were dependant on individual properties of each enzyme (Table 3).

Activities of dehydrogenases and protease increased in the investigated soils along with the distance from the source of emission. However, there was no similar pattern in the case of urease activity. High activity of urease in the soils located in the vicinity of the factory was also observed in other studies [22, 23]. Urease is resistant to external factors, and the increase in its activity is observed under stress conditions. Availability of the substrate – urea is the sole factor limiting the enzyme activity, since urease, as an extracellular enzyme, is synthesized only in the presence of urea [24, 25]. The study by Bielińska [23] showed that a relatively high level of urease activity in the post-forest soil in the vicinity of Zaklady Azotowe "Pulawy" SA was connected with emission of nitrogen fertilizers (urea and ammonium nitrate). Emission of fertilizer dust including urea has been reduced since 1985 till present by 85 %, it still exceeds 600 Mg yr^{-1}, though [23].

Table 3

The enzymatic activity of the soil (dehydrogenases [cm^3 H_2 · kg^{-1} · d^{-1}], urease [mg NH_4^+-N · kg^{-1} · h^{-1}], and protease [mg tyrosine · kg^{-1} · h^{-1}]

Site	Years	Dehydrogenases	Urease	Protease
P1	2006	0.38	3.69	5.28
	2007	0.42	3.55	5.93
	2008	0.68	3.16	6.43
P2	2006	1.09	2.49	6.11
	2007	1.15	2.16	6.35
	2008	1.39	1.98	7.22
P3	2006	1.22	1.71	7.41
	2007	1.29	1.23	7.60
	2008	1.60	1.04	8.23
P4	2006	1.62	0.95	8.19
	2007	1.70	0.97	8.76
	2008	1.84	1.12	9.05
P5	2006	1.67	1.77	8.96
	2007	1.73	1.84	9.28
	2008	1.98	2.08	10.20
P6	2006	2.12	2.76	9.67
	2007	2.14	2.80	10.39
	2008	2.47	2.93	11.19
	$LSD_{0.05}$			
	plots	0.08	0.12	0.74
	years	0.08	0.09	0.62

Legend as in Table 1.

Activities of dehydrogenases and protease from the soils of all the plots increased in time, and in the case of urease only within plots P5–P6. Statistically significant differences were found in 2008 (Table 3). The noticed increase of enzymatic activities in the soils is an indicator of their growing self-regulation ability, which is confirmed by positives changes of forest ecosystems components, such as natural renovation of forest stands and ground cover [3]. On the basis of perennial studies carried out in the impact zone of Zaklady Azotowe "Pulawy" SA [3, 4, 6], it can be stated that concentrations of organic carbon and total nitrogen in the soils, which increased in time (1982–2008), and concentration of mineral nitrogen, which decreased owing to constant reduction of industrial dust emission ($CO(NH_2)_2$, NH_4NO_3 and particularly, since 1994, NH_3) are the stimulators of desirable tendencies.

Activities of dehydrogenases in the soils from plot P1, located closest to the emission source (0.5 km) were at low levels (Table 3), which proves reduced general microbial activity of the soil environment. Other studies also confirm high inactivation of dehydrogenases in soils at long-term industrial emission [3, 22, 23].

Table 4

Correlation coefficients between enzymatic activity of soil and ammonium nitrogen and nitrate nitrogen (*significant at p = 0.05)

	Dehydrogenases	Urease	Protease
NH_4^+-N	0.67*	0.56*	0.62*
NO_3^--N	0.64*	0.53*	0.60*

Statistical analyses of the results obtained showed strong positive correlations between activities of the enzymes and concentrations of mineral nitrogen forms (NH_4^+-N and NO_3^--N) in the soils. Thus, the investigated ecosystem is able to introduce nitrogen compounds from atmosphere into biological circulation.

Conclusions

1. Activities of dehydrogenases and protease fluctuated in a wide range, but clearly depended on human impact intensity. That pattern was not found in the case of urease activity which confirms that the enzyme is resistant to external factors, and availability of substrate – urea is the only agent limiting its activity.
2. Dehydrogenases demonstrated the highest sensitivity to human impact among the enzymes studied.
3. Statistical analyses showed strong positive correlations between biological activity parameters and concentrations of mineral nitrogen in the investigated soils.
4. Since total elimination of nitrogen emission to the forest areas surrounding Zaklady Azotowe is not possible, and the soil is an open system exposed to a constant influence of environmental factors, studies on this subject should be continued. Their results will be helpful in selecting actions connected with protection and renaturisation of the forest ecosystems affected by Zaklady Azotowe "Pulawy" SA.

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BIOCHEMICZNE WŁAŚCIWOŚCI WYBRANYCH GLEB NA TERENIE NADLEŚNICTWA PUŁAWY

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Abstrakt: W celu oceny stopnia w jakim ekosystemy leśne na terenie Nadleśnictwa Puławy są w stanie włączyć do obiegu biologicznego lub zatrzymać w glebie związki azotu emitowane przez Zakłady Azotowe „Puławy" SA zbadano aktywność ureazy i proteazy oraz zawartość różnych form azotu (N ogółem, N-NH_4^+ i N-NO_3^-) w glebach. Obiektem badań były gleby zdegradowanych siedlisk leśnych usytuowane na linii migracji skażonego przez emisje powietrza w III i II strefie zagrożenia lasu. Ścisłe dodatnie korelacje pomiędzy aktywnością badanych enzymów a zawartością mineralnych form azotu w glebach wskazują, że badane ekosystemy leśne są w stanie włączyć do obiegu biologicznego związki azotu docierające z atmosfery.

Słowa kluczowe: emisja azotowa, gleby leśne, enzymy glebowe

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IMPACT OF VARIED ORGANIC MANURING ON NITROGEN CONTENT AND UPTAKE BY CROP PLANTS

ODDZIAŁYWANIE ZRÓŻNICOWANEGO NAWOŻENIA ORGANICZNEGO NA ZAWARTOŚĆ I POBRANIE AZOTU PRZEZ ROŚLINY

Abstract: An experiment was conducted in the years 2001–2005 to determine the direct and secondary effect of barley straw (treatment with and without straw) and summer intercrop biomass (control without organic manuring, farmyard manure, summer intercrop: red clover, Westerwold ryegrass, red clover + Westerwold ryegrass) on total nitrogen content and uptake by sugar beet and spring wheat. Additionally, the farmyard manure effect was compared with the effect of summer intercrop biomass on nitrogen content and uptake by the crop plants. A field experiment was set up as a split-block design with three replicates. It was found that an application of barley straw, farmyard manure and summer intercrop biomass significantly increased total nitrogen content in sugar beet roots and leaves as well as spring wheat grain and straw. It also increased total nitrogen uptake by the crop plants. When farmyard manure had been replaced with the biomass of either red clover or red clover + Westerwold ryegrass, there were observed no significant differences in the total nitrogen content in sugar beet roots as well as spring wheat grain and straw. The highest total nitrogen content was found in the leaves of sugar beet plants harvested from the red clover-amended treatment. The quantity of nitrogen taken up by sugar beet grown in the treatment amended with red clover + Westerwold ryegrass as well as red clover was greater compared with the farmyard manure-amended treatment. The secondary effect of red clover + Westerwold ryegrass biomass on total nitrogen uptake by spring wheat did not differ significantly from farmyard manure effect whereas the effects of red clover and Westerwold ryegrass were significantly smaller.

Keywords: sugar beet, spring wheat, straw, farmyard manure, summer intercrop, total nitrogen content and uptake

Of the cultural operations, fertilisation and manuring are the factors that most strongly affect plant chemical composition and quality [1–5]. As production of farmyard manure, being the most valuable manure in sugar beet cultivation, is on the decline, numerous attempts are made to search for alternative forms of organic manures. In recent years intercrop green manures and straw have acquired more and more importance on crop production-oriented farms as a source of organic matter in the soil

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[6–8]. As a result, many try to answer the question of how does farming without farmyard manure application influence crop plant yields and quality.

The objective of the study was to evaluate the direct and secondary effect of barley straw and summer intercrop biomass on total nitrogen content and uptake by sugar beet and spring triticale. Moreover, the effect of farmyard manure application was compared to intercrop biomass incorporation on changes in total nitrogen content and uptake by the crop plants.

Materials and methods

Field studies were conducted in the years 2001–2005 at the Experimental Farm in Zawady on neutral soil (pH in KCl 6.71–6.93) classified as Mollic Gleysol characterized by average available phosphorus, potassium and magnesium (49.3–55.1 mg P $\cdot$ kg^{-1}, 112.4–120.2 mg K $\cdot$ kg^{-1} and 55.7–57.3 mg Mg $\cdot$ kg^{-1}) contents. The total nitrogen content in the soil prior to the experiment set-up was 0.93–1.05 g $\cdot$ kg^{-1}, the soil hydrolytic acidity was 14.2–15.1 mmol(+) $\cdot$ kg^{-1}, the sum of exchangeable bases was 92.3–106.5 mmol(+) $\cdot$ kg^{-1}, total exchangeable capacity was 107.4–120.7 mmol(+) $\cdot$ kg^{-1} and saturation with base cations was 85.9–88.2 %. The soil belongs to the cereal-fodder strong complex, quality class IIIb. A split-plot design with three replicates was used in this study and it comprised two factors: I. Barley straw application (treatment with and without straw); II. Summer intercrop biomass application (control – without organic matter, cattle farmyard manure, intercrop: red clover, Westerwold ryegrass, red clover + Westerwold ryegrass). The overall plot area was 37.8 m^2 but the harvested area was 21.6 m^2.

Summer intercrops were sown into spring barley cultivated for grain whose straw was incorporated in selected plots. When averaged across all the three years, straw dry matter yield amounted to 4.05 Mg $\cdot$ ha^{-1}. A supplementary nitrogen rate of 7 kg per 1 Mg straw was applied in the barley straw-manured plots, excluding plots under red clover. In the third decade of October, prior to intercrop cutting, their cut dry matter was determined in addition to the dry matter of post-harvest residues sampled from the 30-cm soil layer. Dry matter yield of summer intercrops (cut matter + post-harvest residues) averaged 6.76, 10.49 and 9.11 Mg $\cdot$ ha^{-1} for, respectively, red clover, Westerwold ryegrass and red clover + Westerwold ryegrass mixture. Cattle farmyard manure was applied at a rate of 30 Mg $\cdot$ ha^{-1} and ploughed under in the third decade of October, similarly to barley straw and summer intercrop biomass.

Sugar beet cv Korab was cultivated in the first year (2002–2004) and spring wheat cv Helia was grown in the second year (2003–2005) following an application of barley straw, farmyard manure and intercrop biomass. Mineral fertilizer rates per 1 ha in the cultivation of sugar beet were: 110.0 kg N, 32.7 kg P and 116.2 kg K. Phosphorus and potassium fertilizers and two-thirds of the nitrogen fertilizer were applied in the spring prior to soil tillage performed using a cultivation unit. The remaining amount of nitrogen fertilizer was spread following thinning of sugar beet plants. Spot seeding of sugar beet was conducted in the third decade of April. The in-row spacing was 12 cm and between-row spacing was 45 cm. Weed control was achieved by means of Betanal

Elite 274 EC (phenmedipham, desmedipham, ethofumesate) and Fusilade Forte 150 EC (fluazifop-P-butyl) whereas pests were combated using Decis 2.5 EC (deltamethrine). Sugar beet was harvested in the second decade of October. The crop that followed sugar beet was spring wheat. In the spring phosphorus, potassium and nitrogen fertilizers were applied pre-plant at the respective amounts of 24.0 kg P · ha^{-1}, 70.6 kg K · ha^{-1} and 50.0 kg N · ha^{-1} (the first rate). The second rate of nitrogen (30.0 kg N · ha^{-1}) was applied at the boot stage of spring wheat. Wheat grain was treated with Raxil Gel 206 (tiuram, tebuconazole) and sown in the first decade of April at the density of 500 grains per 1 m^2. The following preparations were applied to protect wheat plants during their growth: the herbicide Chwastox Trio 540 SL (mecoprop, MCPA, dicamba), the fungicide Amistar 250 SC (azoxystrobin) and the insecticide Fastac 100 EC (alpha-cypermethrin). Spring wheat was harvested at the full maturity stage in the first or second decade of August. During harvest there were determined sugar beet root and leaf yields as well as spring wheat grain and straw yields. Additionally, average samples of sugar beet roots and leaves as well as spring wheat grain and straw were taken and used to perform laboratory analyses. The plant material was fragmented and dried. Dry matter content in sugar beet roots and leaves as well as spring wheat grain and straw were determined by the oven-drying gravimetric method. Ground plant samples were wet-mineralized using sulphuric acid and with a catalyst. Total nitrogen content in sugar beet roots and leaves as well as spring wheat grain and straw were determined by the Kjeldahl method [9].

Table 1

Average air temperature and total rainfall according to the Zawady Meteorological Station

Month	Temperature [°C]						Rainfall [mm]					
	2001	2002	2003	2004	2005	1951–1990	2001	2002	2003	2004	2005	1951–1990
I	–1.0	–0.4	–3.7	–5.6	0.4	–3.1	19.9	8.7	7.7	11.5	13.2	24.5
II	–1.9	3.2	–5.6	–1.0	–4.0	–3.2	9.4	37.5	4.7	21.0	13.2	23.3
III	1.5	4.0	1.4	2.7	–0.7	1.0	3.6	15.8	7.0	19.6	11.7	27.0
IV	8.7	9.0	7.1	8.0	8.7	7.2	69.8	12.9	13.6	35.9	12.3	29.4
V	15.5	17.0	15.6	11.6	13.0	13.2	28.0	51.3	37.2	97.0	64.7	54.3
VI	17.1	17.2	18.4	15.4	15.9	16.2	36.0	61.1	26.6	52.8	44.1	69.3
VII	23.8	21.0	20.0	17.5	20.2	17.6	55.4	99.6	26.1	49.0	86.5	70.6
VIII	20.6	20.2	18.5	18.9	17.5	16.9	24.0	66.5	4.7	66.7	45.4	59.8
IX	12.1	12.9	13.5	13.0	15.0	12.7	108.0	18.7	24.3	19.5	15.8	48.2
X	10.6	6.9	5.4	9.4	8.5	8.0	28.0	48.9	38.0	29.5	0.0	32.0
XI	2.3	3.8	4.7	3.2	2.7	2.6	28.0	16.1	14.7	20.4	13.8	39.2
XII	–6.6	–7.7	0.5	1.3	–0.9	0.4	13.4	0.7	17.0	7.6	32.9	37.3
Average/ Sum	8.6	8.9	8.0	7.9	8.0	7.5	423.5	437.8	221.6	430.5	353.6	514.9

Total nitrogen uptake was calculated on the basis of nitrogen content of the dry matter and yield of both crop plants. The experimental data were subjected to analysis of variance and treatment means were compared by Tukey's test at the significance level of 0.05.

Air temperature and precipitation amount and distribution over the study period varied (Table 1), which influenced the growth conditions of intercrops, sugar beet and spring wheat. Compared with long-term mean temperature (7.5 ^{o}C) and precipitation sum (514.9 mm), the average air temperature in the study years was higher (by 1.1 ^{o}C in 2001, 1.4 ^{o}C in 2002, 0.5 ^{o}C in 2003 and 2005 and by 0.4 ^{o}C in 2004) whereas the total rainfall was smaller (by 91.4, 77.1, 293.3, 84.4, and 161.3 mm in 2001, 2002, 2003, 2004 and in 2005, respectively). The rainfall was higher than the long-term mean in April and September of 2001, February, July, August and October of 2002, October of 2003, April, May and August of 2004 and May and July of 2005.

Results and discussion

The studies conducted under the conditions of the Siedlecka Upland showed that there was a significant influence of barley straw and intercrop biomass application on total nitrogen content in the roots and leaves of sugar beet (Table 2).

Table 2

Total nitrogen content [g · kg^{-1} d.m.] in sugar beet roots and leaves, average for 2002–2004

Application of summer intercrop biomass	Roots			Leaves		
	Application of barley straw*					
	a	b	average	a	b	average
Control	7.27	8.09	7.68	25.13	26.67	25.90
Farmyard manure	8.80	8.72	8.76	27.70	28.84	28.27
Red clover	8.88	9.17	9.03	30.40	31.66	31.03
Westerwold ryegrass	8.23	8.44	8.34	27.06	28.01	27.54
Red clover + Westerwold ryegrass	8.61	8.92	8.77	28.22	29.64	28.93
Average	8.36	8.67	—	27.70	28.96	—
$LSD_{0.05}$ for:						
straw incorporation			0.04			0.19
application of summer intercrop biomass			0.29			0.92
interaction: straw incorporation × application of summer intercrop biomass			0.41			1.37

* a – treatment with straw; b – treatment without straw.

An application of barley straw prior to sugar beet cultivation increased total nitrogen content by an average of 0.31 and 1.26 g · kg^{-1} d.m. in roots and leaves, respectively, as compared with the control. Sugar beet roots and leaves harvested from farmyard manure-amended treatments and summer intercrop biomass-manured treatments were characterized by a significantly higher total nitrogen content compared with the control (respectively, by 1.08 and 0.66–1.35 g · kg^{-1} d.m. for roots, and by 2.37 and 1.64–5.13

$g \cdot kg^{-1}$ d.m. for leaves). Also experimental results of studies by other authors demonstrated an increase in total nitrogen content in leaves and roots of sugar beet as a result of an application of farmyard manure [3, 6] and stubble intercrops [2]. Natural and organic manures are a source of macro- and microelements which are gradually released and made available to the following plants during the process of organic matter mineralization [4, 6, 10]. Nitrogen availability for plants depends on the C/N ratio of the mineralized organic matter. A narrow C/N ratio is associated with intense mineralization of nitrogen utilized by plants [11]. In this experiment an influence of Westerwold ryegrass biomass on total nitrogen content in sugar beet roots was significantly smaller compared with farmyard manure in the treatments without straw. The highest total nitrogen content was determined in roots harvested from plots manured with both barley straw combined with red clover and a mixture of red clover and Westerwold ryegrass. When farmyard manure was replaced with red clover biomass in treatments with and without barley straw, there was observed a significant increase in total nitrogen content in sugar beet leaves. The differentiated influence of farmyard manure and intercrop green manures, either with or without straw, on total nitrogen content in sugar beet roots and leaves, which was also reported by Wesolowski et al [7] and Słowinski et al [12], results from the speed of the organic matter mineralization. Sugar beet leaves, being an assimilative and photosynthesis organ, were characterized by a higher total nitrogen content than roots [10, 12].

The amount of total nitrogen taken up was calculated as an outcome of dry matter yield and nitrogen content in the yield [10, 13]. There was found a significant influence of an application of barley straw and intercrop biomass on total nitrogen uptake by sugar beet roots and leaves (Table 3).

Table 3

Total nitrogen uptake [$kg \cdot ha^{-1}$] by sugar beet roots and leaves, average for 2002–2004

Application of summer intercrop biomass	Roots			Leaves			In total (roots + leaves)		
	Application of barley straw*								
	a	b	average	a	b	average	a	b	average
Control	101.2	119.2	110.2	118.6	144.8	131.7	219.8	264.0	241.9
Farmyard manure	135.1	138.7	136.9	160.9	173.4	167.2	296.0	312.1	304.1
Red clover	133.1	148.8	141.0	168.5	210.2	189.3	301.6	359.0	330.3
Westerwold ryegrass	119.9	123.9	121.9	135.8	146.9	141.4	255.7	270.8	263.3
Red clover + Westerwold ryegrass	141.5	151.8	146.7	166.4	195.4	180.9	307.9	347.2	327.6
Average	126.2	136.5	—	150.0	174.1	—	276.2	310.6	—
$LSD_{0.05}$ for:									
straw incorporation			1.4			1.8			3.7
application of summer intercrop biomass			6.8			8.9			16.8
interaction: straw incorporation × application of summer intercrop biomass			8.9			11.6			22.1

* a – treatment with straw; b – treatment without straw.

Total nitrogen uptake by sugar beet roots and leaves in the barley straw-amended treatment was significantly higher (respectively by 10.3 and 24.1 kg · ha^{-1}, on average) compared with the treatment without straw. Farmyard manure and biomass of summer intercrops significantly increased total nitrogen uptake by roots (by 26.7 and 11.7–36.5 kg · ha^{-1}, respectively) and leaves (by 35.5 and 9.7–57.6 kg · ha^{-1}, respectively) of sugar beet, compared with the control. The greatest total nitrogen amount was taken up by sugar beet roots and leaves in the treatment manured with the red clover + Westerwold ryegrass biomass as well as red clover. An impact of intercrop biomass on nitrogen uptake by sugar beet roots and leaves was modified by barley straw manuring. The overall uptake of total nitrogen by sugar beet (roots + leaves) ranged between 219.8 kg · ha^{-1} in the control without straw to 359.0 kg · ha^{-1} in the barley straw + red clover-amended treatment. The amount of nitrogen taken up by sugar beet roots and leaves detected in this experiment was within the limits mentioned by Wisniewski [10].

Total nitrogen content in spring wheat grain and straw fluctuated significantly under an influence of barley straw and intercrop biomass in the second year following their application (Table 4).

Table 4

Total nitrogen content in spring wheat grain and straw, average for 2003–2005 [g · kg^{-1} d.m.]

Application of summer intercrop biomass	Grain			Straw		
	Application of barley straw*					
	a	b	average	a	b	average
Control	23.89	24.33	24.11	7.00	7.23	7.12
Farmyard manure	25.10	25.96	25.53	7.90	8.18	8.04
Red clover	24.81	25.73	25.27	7.63	8.00	7.82
Westerwold ryegrass	24.42	25.08	24.75	7.37	7.79	7.58
Red clover + Westerwold ryegrass	25.71	26.23	25.97	7.87	8.26	8.07
Average	24.79	25.47	—	7.55	7.89	—
$LSD_{0.05}$ for:						
straw incorporation			0.13			0.06
application of summer intercrop biomass			0.58			0.27
interaction: straw incorporation × application of summer intercrop biomass			0.72			0.40

* a – treatment with straw; b – treatment without straw.

Barley straw ploughed under prior to the previous crop cultivation significantly increased total nitrogen content in grain (on average by 0.68 g · kg^{-1} d.m.) and straw (on average by 0.34 g · kg^{-1} d.m.) of spring wheat, compared with the control. Total nitrogen content in spring wheat grain and straw harvested from farmyard manure--amended treatment was significantly higher (by 1.42 and 0.92 g · kg^{-1} d.m., respectively) compared with the control grain and straw. Manuring with summer intercrop biomass increased total nitrogen content in spring wheat grain and straw (by 0.64–1.86 and 0.46–0.95 g · kg^{-1} d.m., respectively) in the second year following biomass application, as compared with the control. A beneficial secondary effect of farmyard manure on nitrogen content in cereal grain was found by Mazur and Koc [1] as well as Wiater and Debicki [4]. Stopes et al [13] reported that wheat grain from rotations including green manures is characterized by an increased nitrogen content. It is due to improved nitrogen release as a result of mineralization of fertilizers applied. An interaction of the experimental factors indicated that total nitrogen content was significantly reduced in spring wheat grain in the treatment where barley straw had been applied in combination with Westerwold ryegrass, and in spring wheat straw in the treatment without barley straw incorporation, compared with farmyard manure. In the remaining treatments, the secondary effect of summer intercrop biomass on total nitrogen content in spring wheat grain and straw was similar to the effect produced by an application of farmyard manure.

Total nitrogen uptake by spring wheat grain and straw was modified by an application of barley straw and summer intercrop biomass (Table 5).

Table 5

Total nitrogen uptake by spring wheat grain and straw, average for 2003–2005 [kg · ha^{-1}]

Application of summer intercrop biomass	Grain			Straw			In total (grain + straw)		
	Application of barley straw*								
	a	b	average	a	b	average	a	b	average
Control	84.6	93.3	88.9	27.3	28.2	27.8	111.9	121.5	116.7
Farmyard manure	112.8	120.2	116.5	32.8	36.5	34.6	145.6	156.7	151.1
Red clover	99.9	115.8	107.9	31.0	34.9	32.9	130.9	150.6	140.8
Westerwold ryegrass	97.2	109.9	103.6	29.4	32.8	31.1	126.6	142.7	134.7
Red clover + Westerwold ryegrass	115.2	122.6	118.9	33.8	36.4	35.1	149.0	159.0	154.0
Average	101.9	112.4	—	30.9	33.7	—	132.8	146.1	—
$LSD_{0.05}$ for:									
straw incorporation			1.1			0.4			1.7
application of summer intercrop biomass			5.9			1.9			7.6
interaction: straw incorporation × application of summer intercrop biomass			7.2			2.5			8.9

* a – treatment with straw; b – treatment without straw.

Barley straw preceding the previous crop significantly increased total nitrogen uptake by the cereal grain (on average by 10.5 kg · ha^{-1}) and straw (on average by 2.8 kg · ha^{-1}) compared with the control without straw. Farmyard manure and summer intercrop biomass significantly increased total nitrogen uptake by spring wheat grain (by 27.6 and 14.7–30.0 kg · ha^{-1}, respectively) and straw (6.8 and 3.3–7.3 kg · ha^{-1}, respectively) compared with the control. The overall uptake of total nitrogen by spring triticale harvested from treatments where the red clover + Westerwold ryegrass mixture had been used as a manure was at the level similar to that recorded for farmyard manure-amended treatment. In contrast, farmyard manure replaced by the biomass of red clover and Westerwold ryegrass significantly reduced the overall uptake of total nitrogen by spring wheat. The secondary effect of summer intercrop biomass on total nitrogen uptake by spring wheat grain and yield fluctuated depending on barley straw application. Amounts of nitrogen taken up by spring wheat ranged between 111.9 and 159.0 kg · ha^{-1} according to the treatment and supported the results reported by Goos et al [5].

Conclusions

1. Manuring with barley straw, farmyard manure and summer intercrop biomass increased total nitrogen content in sugar beet roots and leaves as well as spring wheat grain and straw. It also increased total nitrogen uptake by both the crop plants.
2. The effect of farmyard manure was similar to the impact of red clover and a red clover + Westerwold ryegrass on total nitrogen content in sugar beet roots and spring wheat grain and yield.
3. The quantity of nitrogen taken up by sugar beet in the treatment amended with red clover + Westerwold ryegrass as well as red clover was greater compared with the farmyard manure-amended treatment. The secondary effect of a red clover + Westerwold ryegrass mixture on total nitrogen uptake by spring wheat was similar to farmyard manure whereas the effect of red clover and Westerwold ryegrass was significantly smaller than farmyard manure.

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ODDZIAŁYWANIE ZRÓŻNICOWANEGO NAWOŻENIA ORGANICZNEGO NA ZAWARTOŚĆ I POBRANIE AZOTU PRZEZ ROŚLINY

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Abstrakt: W doświadczeniu przeprowadzonym w latach 2001–2005 określono bezpośrednie i następcze oddziaływanie słomy jęczmiennej (obiekt bez słomy, obiekt ze słomą) oraz biomasy wsiewki międzyplonowej (obiekt kontrolny bez nawożenia organicznego, obornik, wsiewka międzyplonowa: koniczyna czerwona, życica westrwoldzka, koniczyna czerwona + życica westerwoldzka) na zawartość i pobranie azotu ogółem przez burak cukrowy i pszenicę jarą. Porównano również wpływ obornika z działaniem biomasy wsiewek międzyplonowych na zawartość i pobranie azotu ogółem z plonem roślin. Eksperyment polowy założono w układzie split-blok, w trzech powtórzeniach. Stwierdzono, że nawożenie słomą jęczmienną, obornikiem i biomasą wsiewek międzyplonowych powoduje istotny wzrost zawartości azotu ogółem w korzeniach i liściach buraka cukrowego oraz w ziarnie i słomie pszenicy jarej. Zwiększa również pobranie azotu ogółem z plonem roślin. Zastąpienie obornika biomasą koniczyny czerwonej i mieszanki koniczyny czerwonej z życicą westerwoldzką nie różnicuje istotnie zawartości azotu ogółem w korzeniach buraka cukrowego oraz w ziarnie i słomie pszenicy jarej. Największą zawartością azotu ogółem cechowały się liście buraka cukrowego z obiektu nawożonego biomasą koniczyny czerwonej. Ilość azotu pobranego z plonem buraka cukrowego na obiekcie nawożonym biomasą mieszanki koniczyny czerwonej z życicą westerwoldzką oraz koniczyny czerwonej kształtowała się na wyższym poziomie niż z plonem w wariancie z obornikiem. Następcze działanie biomasy mieszanki koniczyny czerwonej z życicą westerwoldzką na pobranie azotu ogółem przez pszenicę jarą nie różniło się istotnie od wpływu obornika, a biomasy koniczyny czerwonej i życicy westerwoldzikiej było istotnie mniejsze.

Słowa kluczowe: burak cukrowy, pszenica jara, słoma, obornik, wsiewka międzyplonowa, zawartość i pobranie azotu ogółem

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NITROGEN AND ITS FRACTIONS IN COMPOSTS FROM WOOD WASTE

AZOT I JEGO FRAKCJE W KOMPOSTACH Z ODPADÓW DRZEWNYCH

Abstract: Composts produced on the basis of different wood-based industrial waste were analysed for total nitrogen (NT) and its fraction contents. The following nitrogen fractions were separated: water soluble (NWS), hydrolisable (NH) in sulphuric(VI) acid – 2.5 mol dm^{-3} and at the temperature 105 ^{o}C during 12 hours and non-hydrolisable (NNH). Results revealed that tested composts were differentiated by total nitrogen content not only, but also by its content in aqueous and acid extracts. Non-hydrolisable nitrogen represented from 36.22 % to 53.75 % of composts NT. Next, the percentage share of N_{H_2O} in NT varied from ca 7.95 % to 11.81 %.

Keywords: wood waste, composts, nitrogen fractions

Wood is a widespread raw material utilized in all economic fields. Its acquisition, processing and the production of new tools generate different waste whose mass is estimated for 7.4 million m^3/year [1]. According to Janowicz [2], the amount of industrial biomass from the wood industry is estimated to 6.79 m^3 million m^3/year. Such estimations do not generally involve post-used wood (1.44 do 1.68 million m^3/year) becoming a serious problem. This was the argument formulated for the utilization of wood waste. More and more wood waste are being used for the production of energy, but investigations have also been undertaken towards the recycling of wood-based waste through composting [3–5].

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Wood waste is characterized by the presence of not only wood, but also of several additives. These are among others paints, varnish, resins, glues, foils or biocides. The composting process should create suitable conditions for neutralizing these substances and breaking down lignins, maximally.

These wastes have been frequently discharged at waste landfill. In this context an important problem for composts seems to be not only the assessment of total content of nitrogen and its fractions. As it was reported recently [6, 7], the type of additives to wood waste used for composting significantly influences plant growth.

The paper reports data of investigations dealing with total nitrogen content and its chemical fractions in composts produced from wood waste.

Materials and methods

Investigations were undertaken on three composts produced from different wood waste consisted of interior plywood waste – IPW, exterior plywood waste – EPW, and fibreboard waste – FW, which were ground to the size < 10 mm before composting. The composting process was performed under field conditions on open heaps of 4–6 m^3 volume. Each heap was trapezoidal and prepared of woven polyethylene mats arranged at the field ground, with the following mixtures:

– Heap 1 – formed of fibreboard waste (FW), representing 65 % of the heap mass (weight basis) of pinewood waste (28 %), highmoor (7 %) and urea (20 kg),

– Heap 2 – formed of interior plywood waste (IPW), representing 85 % of the heap mass and highmoor for 15 % of the whole mass (weight basis),

– Heap 3 – formed of exterior plywood waste (EPW), representing 85 % of the heap mass (weight basis) and 15 % of highmoor and urea (20 kg).

Wood waste used in the current study differed in their carbon and nitrogen contents (Table 1). Each heap was supplied additionally with a biological vaccine (Activit Las) and a proper amount of water. All heaps were mixed up and covered with a black horticultural fibrous mat for reducing water loss.

During the composting process, which lasted 83 months (FW) and 66 months for both IPW and EPW, temperature and moisture and pH were monitored. Water was supplemented to ca 60 % accordingly to moisture levels and aerated by mechanical throwing. The pH of compost varied significantly throughout the whole period of composting and its values were as follows: heap 1: pH from 3.6 to 8.4; heap 2: pH from 4.1 to 7.5; and heap 3: pH from 4.5 to 9.5. Detailed characteristics of composts preparation were reported earlier [8, 9].

The sequential analysis of nitrogen in compost was made on the basis of deionized water extraction and acid hydrolysis. For this purpose, 2 g of compost (d.m.) were transferred into 100 cm^3 centrifuge tubes. Deionized water was added (50 cm^3), and the tubes were shaken for 2 hours at room temperature. The mixture was further centrifuged and extracts were next transferred to flasks (100 cm^3). The remains were hydrolyzed for 12 hours in 50 cm^3 2.5 M H_2SO_4 at 105 ^oC.

Tubes were centrifuged and filtered to 200 cm^3 flask and the remains were rinsed twice with deionized water, centrifuged with extracts and transferred to acid ones.

Total nitrogen (TN) of the composts was determined as the sum of N-Kjeldahl (NK) and nitrate nitrogen(V). In aqueous extract, N-Kjeldahl was determined (NKW) and the content of ammonium and nitrate nitrogen(V) expressed as mineral nitrogen (N_{min}). The sum of these forms was considered as aqueous extract total nitrogen (AETN). In the acid extracts (AE) total hydrolisable nitrogen was determined (NTH) as well as the ammonium nitrogen form in extracts ($N-NH_4$). The content of non-hydrolisable organic nitrogen (NNH.) was calculated as the difference between total nitrogen content and the sum of water soluble and hydrolisable nitrogen. One factorial analysis of variance (STAT), along with the application of the Duncan test were used for the statistical estimation of data at the significance level $p \le 0.05$.

Results and discussion

Waste considered for composting contain generally differentiated amounts of nitrogen. In order to obtain a proper C:N ratio of the composted material, it is frequently required to make some correction relying on the addition of nitrogen rich or poor components components. Materials used for the current composting process were dominated by wood waste, which differed mainly in nitrogen content, but less in carbon (Table 1).

Table 1

Content of total nitrogen and carbon and C : N in wastes selected

Component	Total Nitrogen (NT)	Total Carbon (CT)	C : N
	[g · kg^{-1} d.m.]		
Fibreboard waste (FW)	1.90	479.40	252.31
Interior plywood waste (IPW)	84.10	456.20	5.42
Exterior plywood waste (EPW)	6.20	497.20	80.19
Peat	9.40	528.70	56.20

Special attention should be given mainly to waste classified as interior plywood waste (IPW), which were ca 14 times richer in nitrogen as compared with exterior plywood waste (EPW) and even 44 times as referred to fibreboard waste (FW). These differences are basically attributed to the industrial processing of wood material. In the production of the IPW, urea-formaldehyde resins are used and these are derived from the condensation of urea and formaldehyde under alkaline conditions. This results in a high concentration of nitrogen in the wood products, where this substance is used. On the other hand, phenol-formaldehyde or urea-melamine-formaldehyde resins are used in the production of EPW, which explains their low nitrogen content. Therefore wood--based industrial waste used for the production of composts under study differentiated the chemical composition of these composts. From data reported by Wróblewska et al [7] it appeared, that the chemical composition of the composts differed after 7 or 8 years of composting, with total nitrogen content (NT) in the order: FW – 15.80, IPW – 77.30, and EPW – 27.70 g · kg^{-1} d.m. Result reported in Table 2 confirm the differences between composts in the case of nitrogen content, which varied accordingly: 17.64, 72.31 and 26.25 g · kg^{-1} d.m. Total nitrogen contents do not allow establishing a detailed assessment of composts, since nitrogen occurs in different forms and chemical bonds [10] undergoing changes during composting [11, 12].

Table 2

Content of total, hydrolysable and non-hydrolysable of nitrogen in compost from wood wastes [g · kg^{-1} d.m.]

Compost	Nitrogen								
	Extract						Hydro-lysable	Non-hydro-lysable	Total of composts
	Water				Acidic				
	Total	$N\text{-}NO_3$	Kjeldahl	with: $N\text{-}NH_4$	Total	with: $N\text{-}NH_4$			
FW	1.604a	1.222a	0.364a	0.070a	6.566a	1.855a	8.170a	9.470a	17.640a
IPW	8.542c	0.250c	8.192c	8.025c	37.577c	10.257c	46.119c	26.188c	72.307c
EPW	2.086b	1.582c	0.504b	0.175b	11.002b	2.842b	13.162b	13.088b	26.250b

Composts produced from wood-based industrial waste contained not only different amounts of total nitrogen, but also water soluble (NWS), hydrolisable (NH) and non-hydrolisable (NNH) nitrogen forms. These differences are statistically significant and ranged similarly for investigated N forms accordingly to homogenous groups, except for the content of nitrate(V) nitrogen (Table 2). This nitrogen form quantitatively prevailed in aqueous extracts from the FW and EPW. This could be attributed probably to the addition of urea at heap formation. The magnitude of $N\text{-}NO_3$ content relies on the fact, that on average, it represents 77.0 % of N_{tot} of aqueous extract of the FW compost, and 73.6 % in the case of the EPW compost (Fig. 2), contrarily to 4.2 % found for the IPW compost. Such high contents of the mentioned nitrogen form may create potential threat of their losses. The causes of this phenomenon remain an open matter of debates. This state may result among others from the addition of urea to the FW and EPW heaps at their formation or possibly from increased mineralization of organic matter, whose

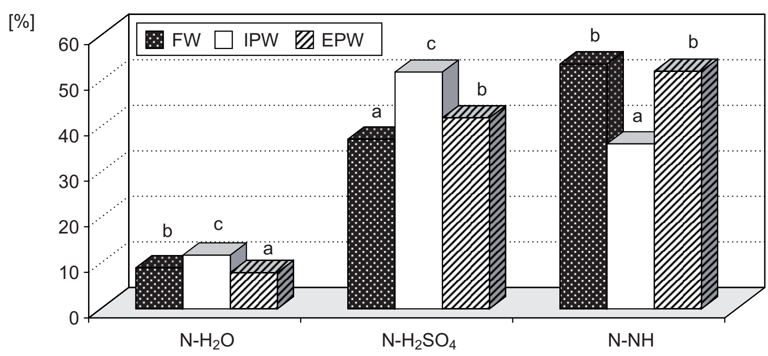

Fig. 1. Percentage share of nitrogen forms in composts

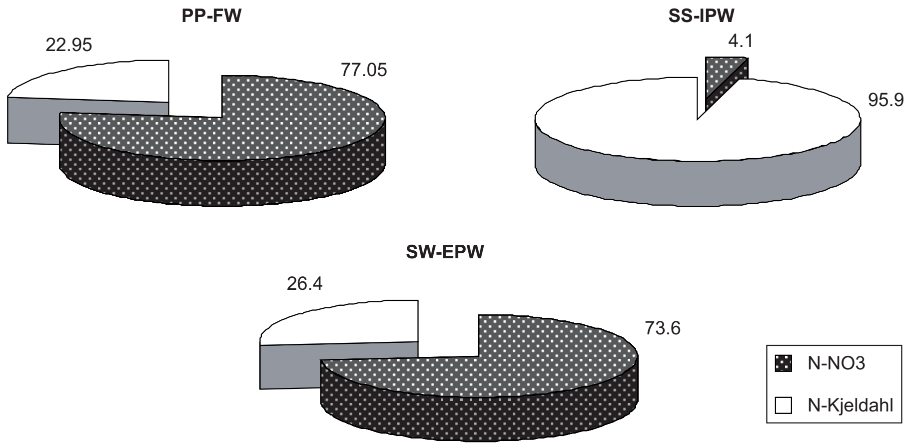

Fig. 2. Percentage share of $N\text{-}NO_3$ N-Kjeldahl in water extracts of composts

effect led to the release of appreciable amounts of nitrogen. Our data reveals that under conditions of the current study, nitrogen was partly built in more resistant organic bonds and at different degrees, accordingly to composts composition. This is supported by the pool of non-hydrolisable nitrogen (NNH) of the IPW compost as referred to the total N content. The percentage share of this N form was on average 36.2 % (Fig. 1) as compared with 53.7 % for the FW compost and next 52.1 % in the case of the EPW. Furthermore, the intermediary proof of the relatively low stability of nitrogen bonds in the IPW compost, it also their susceptibility for hydrolysis (Table 2).

Under conditions of acid hydrolysis, ca 52 % of nitrogen underwent this process extraction in IPW (Fig. 1); where 37.2 % in the FW and 41.9 % for EPW composts. At a simultaneously high content of total nitrogen (72.3 g $\cdot$ kg^{-1} d.m.), the easiness of its hydrolysis may exhibit also a toxic effect on plants. Results reported by Wróblewska et al [7] with willow (*Salix alba* L.) grown on a medium consisted of mineral soil mixture and composts of wood-based industrial waste, informed about the occurrence of such possibility. Authors have concluded that under conditions of the addition of the IPW compost, plant growth was significantly reduced. In fact the amounts of $N\text{-}NO_3$ in this compost were significantly lower as referred to those reported for the remaining composts (Table 2). But, despite this, the mineral soil medium with IPW added before starting the trial, contained 315 mg $\cdot$ dm^{-3} for each $N\text{-}NH_4$ and $N\text{-}NO_3$ forms. In the medium containing the EPW compost, these amounts were 7 and 42 mg $\cdot$ dm^{-3} $N\text{-}NH_4$ and $N\text{-}NO_3$, respectively. This proves undoubtedly about the possible effect of hydrolizated N from the IPW compost. Results listed in Table 2 indicate that the amount of hydrolisable nitrogen in this compost represented on average 52 % of investigated nitrogen forms, of which 27.3 % were classified as $N\text{-}NH_4$. Under soil conditions, this form can be relatively quickly nitrified, but it is not possible to exclude the toxic effect of $N\text{-}NH_4$ over young willow plants, or even the impact of strong salinity of the growth medium.

The negative effect of the interior plywood waste (IPW) compost on the development of willow may result also from the impact of other not investigated compounds, which could have been released during the breakdown of wood or additives used for interior plywood production. All the more so because substances classified as mineral and organic microcontaminants are generally released during wood breakdown and these originate from chemicals used for wood protection [13].

Data of the current investigation have proved that the type and origin of wood-based industrial waste were the main issue during the composting process. This is related to the technology of wood material production as well as the way of their utilization. Under conditions of using resins along with urea, it should be taken into consideration the pool of nitrogen in the waste. Admittedly, interior plywood waste were characterized by very narrow ratio of C:N (5.4 : 1), (Table 1), but the breakdown dynamics of such compost remains a matter of debates. Results of the Table 2, show that the degradation of nitrogen bonds in the compost proceeded quicker as compared with the composts characterised by a lower initial nitrogen content, but with the addition of mineral nitrogen as urea. Based on the fact that high $N\text{-}NO_3$ levels occur in composts with urea addition, future investigations should either reduce its rate or correct it during composting. On the other hand, when using interior plywood waste as a component for composts, one should take in consideration their limited share in the mixture, and on the second hand, the choice of other components, which ensure a higher transformation of nitrogen into organic bonds, hardly soluble.

Conclusions

1. Under conditions of long-standing of wood-based industrial waste composting, it was found that they differed significantly in terms of total nitrogen as well as other related forms.

2. When using the interior plywood waste for composting, one may take into consideration its naturally high nitrogen content and the properties favourable for the easy hydrolysis of its forms.

3. Urea added to composted mixtures before forming the heaps consisting of fibreboard and exterior plywood waste led to the accumulation of greater amounts of nitrate nitrogen representing in the aqueous extract from 73.7 to 78.7 % of total nitrogen content of this extract.

4. Composting of wood waste rich in nitrogen or with the addition of mineral nitrogen requires organic additives favouring a greater transformation of nitrogen into organic forms hardly hydrolisable.

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AZOT I JEGO FRAKCJE W KOMPOSTACH Z ODPADÓW DRZEWNYCH

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Abstrakt: Komposty wytworzone z różnych odpadów produkcyjnych tworzyw drzewnych, poddano analizie na zawartość azotu ogólnego i jego frakcji. Wydzielono następujące frakcje azotu: wodnorozpuszczalną (NWR), hydrolizującą (NH) w roztworze kwasu siarkowego(VI) – 2,5 M i temperaturze 105 °C przez 12 godzin – i niehydrolizującą (NNH). Stwierdzono, że komposty różniły się nie tylko zawartością całkowitą azotu, ale również jego zawartością w ekstrakcie wodnym oraz kwaśnym. Azot niehydrolizujący stanowił od 36,22 % do 53,75 % azotu ogólnego kompostów. Z kolei udział azotu wodnorozpuszczalnego w zawartości całkowitej wynosił średnio od 7,95 % do 11,81 %.

Slowa kluczowe: odpady drzewne, komposty, frakcje azotu

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EFFECT OF FOLIAR NITROGEN AND MAGNESIUM FERTILIZATION ON THE TOTAL, PROTEIN NITROGEN AND NITRATES(V) CONTENT IN POTATO TUBERS

ODDZIAŁYWANIE DOLISTNEGO NAWOŻENIA AZOTEM I MAGNEZEM NA ZAWARTOŚĆ AZOTU OGÓLNEGO, BIAŁKOWEGO ORAZ AZOTANÓW(V) W BULWACH ZIEMNIAKA

Abstract: The paper's aim has been to clarify the effect of foliar fertilization with nitrogen and magnesium on the content of total and protein nitrogen in tubers of medium-early potato cv. Zebra. The experiment was conducted in three series; in the first series, in which potatoes were fertilized only with nitrogen in the total dose of 80 kg N $\cdot$ ha^{-1}, the contribution of foliar treatment steadily increased (0, 10, 20, 30, 40 and 50 %) at the expense of soil fertilization (80, 72, 64, 48 and 40 kg N $\cdot$ ha^{-1}); in the other two series included additional magnesium fertilization. In the second series, magnesium at a rate of 7.5 kg Mg $\cdot$ ha^{-1} was sprayed over potato leaves; in the third series, 15 kg Mg $\cdot$ ha^{-1} was introduced to soil. The highest average content of total and protein nitrogen was determined in potato tubers which had received exclusive nitrogen fertilization, both as foliar sprays and to soil, whereas in the variants including addition of magnesium, a slight decrease in amounts of both nitrogen forms occurred. The highest increase in the total and protein nitrogen content in potato tubers was obtained at the 10 % contribution of foliar nitrogen application. Magnesium nutrition, either as foliar or soil treatments, did not have any significant influence on the content of total and protein nitrogen in tubers. Increasing share of foliar nitrogen fertilization led to a decreased content of nitrates(V) in potato tubers tested after harvest. A similar effect appeared under the influence of additional foliar application of magnesium, whereas the same nutrient added to soil produced a reverse effect. Magnesium sprayed over leaves tended to lower the concentration of nitrates in potato tubers. When introduced to soil, it raised the content of nitrates(V) in potato tubers.

Keywords: total N, protein N, nitrates(V), potato tubers, foliar fertilization, magnesium

The size of fertilization rates as well as treatment dates and techniques play a dominant role in shaping the volume and quality of crop yields. Nitrogen is the element which largely determines the course of growth and development processes in

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plants, therefore crops which receive proper nitrogen nutrition produce high quality yields, which are safe to consumers' health. Mineral fertilization of potatoes can improve the nutritional quality of potato yields. However, inadequate nitrogen fertilization can prolong the vegetative growth of potatoes, deteriorate storability of potato tubers and cause accumulation of harmful nitrogen compounds in tubers. The literature contains many reports on beneficial effects of nitrogen applied in foliar treatments on quality characteristics of potato tubers [1, 2]. Nitrogen sprayed over leaves is assimilated by plants 50–100 % more efficiently than nitrogen introduced to soil, and other fertilizers, including magnesium, used in conjunction with nitrogen improve the efficiency of fertilization treatments. Considering the above aspects, it seems useful to design such a growing technology that would take into account not only yield volumes but also yield quality, including concentrations of particular forms of nitrogen.

The aim of this study has been to determine the effect of foliar fertilization with nitrogen and magnesium introduced to soil or sprayed over leaves on accumulation of total nitrogen, protein nitrogen and nitrates(V) in tubers of cv. Zebra potato.

Material and methods

In a three-year field trial, conducted at the Experimental Station in Tomaszkowo near Olsztyn, the effect of foliar nitrogen fertilization in combination with foliar or soil magnesium nutrition was examined on the content of total nitrogen, protein nitrogen and nitrates(V) in tubers of the medium-early potato cultivar Zebra (the Crop Breeding Station in Szyldak).

The testes involved a two-factor experiment in a random block design with four replications, including different variants of nitrogen and magnesium fertilization, applied as foliar or soil treatments. The experiment consisted of three series; in the first one potatoes received only nitrogen fertilization, in total 80 kg N $\cdot$ ha^{-1}, with foliar treatments on the increase (0, 10, 20, 30, 40 and 50 %) at the expense of soil application (80, 72, 64, 48 and 40 kg N $\cdot$ ha^{-1}); the other two series involved additional magnesium nutrition. In the second series, magnesium was applied in a dose of 7.5 kg Mg $\cdot$ ha^{-1} as a foliar treatment and in the third series it was introduced to soil in the amount of 15 kg Mg $\cdot$ ha^{-1}. Phosphorus and potassium fertilization was identical in all the treatments and equaled 35 kg P and 100 kg K $\cdot$ ha^{-1}. Nitrogen was used as urea (46 % N) and magnesium was applied in the form of magnesium sulphate (9.5 % Mg). Fertilizers introduced to soil were applied in whole rates before planting potatoes and the foliar application consisted of 5 sprays during the vegetative growth of plants. The first spraying was performed after the rows became compact and potato plants formed first floral buds, and the following treatments took place at seven-day intervals. Once the potatoes had completed their vegetative growth, tubers were collected and samples were fragmented, dried at 60 ^{o}C and stored in sealed containers. In the material thus prepared, total and protein nitrogen content was determined with Kjeldhal's method [3], and a 24 % solution of trichloroacetic acid was used for titration of proteins while determining protein nitrogen.

Content of nitrates(V) was determined in fresh material, according to the standard analytical method recommended by the company Orion [4], with an aid of an Ionanalyzer® Orion model 407 potentiometer and ionoselective nitrate electrode, Thermo Orion model 9307™. For determinations, reference solutions of NO_3^- supplied by Orion were used. The content of nitrates(V) in potato tubers was also determined during the storage time at monthly intervals. Ten kilos of healthy tubers, 3.5–6.0 cm in diameter, from each fertilization treatment were stored. Tubers were stored in a storage chamber 12 m^3 in capacity (PPUCH Tarczyn) at 6 ^oC (±0.5 ^oC) and relative air humidity (RH) at the level of 90–95 %. Potatoes were stored for six months (from September to March).

Discussion of the results

The tests on the effect of foliar application of nitrogen together with magnesium in foliar or soil treatments on the content of total and protein nitrogen have demonstrated that the level of these components in potato tubers was modified primarily by nitrogen fertilization and to a lesser extent – by application of magnesium (Fig. 1). The effect produced by the fertilizers was also dependent on the application technique. Swiniarski et al [5] reported that high nitrogen fertilization of potatoes had an evident influence on the content of total and protein nitrogen, which sometimes even doubled compared with their concentrations in tubers from control treatments (without nitrogen fertilization). Ciecko et al [6] did not demonstrate such a strong effect of nitrogen fertilizers. Under the maximum rate of nitrogen, which was 200 kg N · ha^{-1}, total nitrogen in tubers rose by just 0.39–0.48 % versus the control. Such results were confirmed in a study completed by Wyszkowski [7], who noticed that the content of total nitrogen rose clearly under the effect of increasing rates of nitrogen fertilizer. Wyszkowski examined four potato cultivars fertilized with 200 kg N · ha^{-1} and noticed that the total nitrogen content in tubers increased from 3.4 to 6.1 g N · kg^{-1}, depending on a cultivar. Distinct correlation between nitrogen fertilization and the content of total and protein nitrogen in

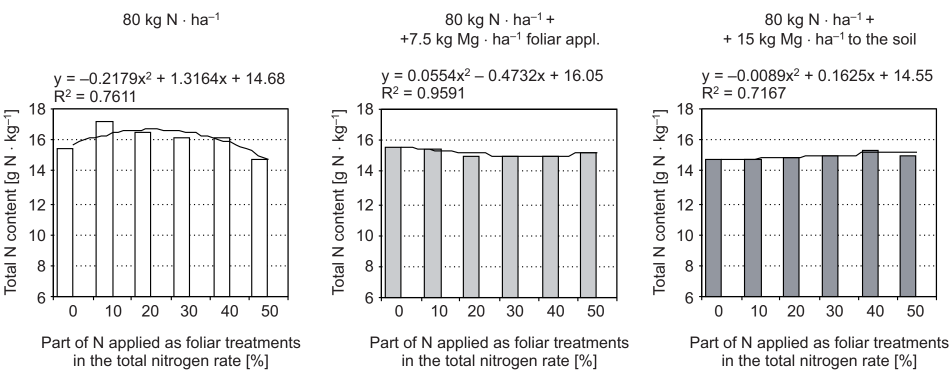

Fig. 1. Effect of foliar nitrogen fertilization and two technologies of magnesium fertilization on total nitrogen content in potato tubers of cv. Zebra

potato tubers has also been indicated by Roztropowicz [8]. In her study, as the rates of nitrogen rose from 40 to 200 kg N · ha^{-1}, the content of total and protein nitrogen rose steadily, too.

In the present study, there was only one rate of nitrogen, in which the amount of N applied in a foliar treatment increased. Foliar application of nitrogen had a varied effect on the total nitrogen content in potato tubers, which reached 15.5 g · kg^{-1} when nitrogen was introduced to soil. By substituting 10 % of nitrogen from the total rate with fertilizer sprayed over leaves, the content of total N in tubers was raised by 1.6 g, up to 17.1 g · kg^{-1}. Further increase in the contribution of foliar application of nitrogen to the total rate of nitrogen fertilizer led to a gradual decrease in the content of total nitrogen in tubers.

In her experiment, Boliglowa [9] found out that the content of total nitrogen in tubers was positively affected by foliar application of 6 % urea solution. The author discovered a higher increase in the total nitrogen concentration in tubers when urea was sprayed over leaves of potato plants rather than introduced to soil.

In our tests, it has been demonstrated that an increase in total N in potato tubers can be achieved by substituting nitrogen soil fertilization up to 40 % of the total nitrogen rate with foliar treatments. Further increase in the proportion of foliar application contributed to depressed N-total content in tubers.

Similar relationships were shown by Jablonski [10]. In his experiment, the total nitrogen content in tubers fell as the contribution of foliar nitrogen fertilization increased.

Foliar magnesium treatments included in the second series of our experiment blurred the determined effect of foliar application of nitrogen. Foliar application of 7.5 kg Mg · ha^{-1} led to a decrease in the total nitrogen content but when the percentage of nitrogen rate supplied as foliar treatments exceeded 30 %, the same magnesium treatment resulted in a small increase in the content of this element in tubers. Tubers collected from the series fertilized with magnesium introduced to soil were characterized by ca 6 % lower average content of total N than tubers from plots not fertilized with magnesium. Although the content of total N in tubers from that series was somewhat lower, its content increased as the foliar application of nitrogen reached higher percentage relative to the total fertilization rate.

With respect to protein nitrogen, foliar application of nitrogen equaled 20 % of the total N rate raised the content of protein N by about 1.1 g · kg^{-1} versus tubers from the treatment, where this nutrient was not sprayed over leaves. Further increase in foliar N fertilization did not produce any effect on the content of protein nitrogen (Fig. 2). Likewise, magnesium fertilization treatments were not found to produce any influence on protein nitrogen in tubers.

Such a relatively weak effect of magnesium fertilization on protein N may be due to the moderate abundance of soil in this element, but can also be attributed to organic fertilization (identical on all plots) with farmyard manure.

Slightly different from ours are the results reported by Rogozinska and Wojdyla [11], who discovered that besides nitrogen fertilization, application of larger quantities of

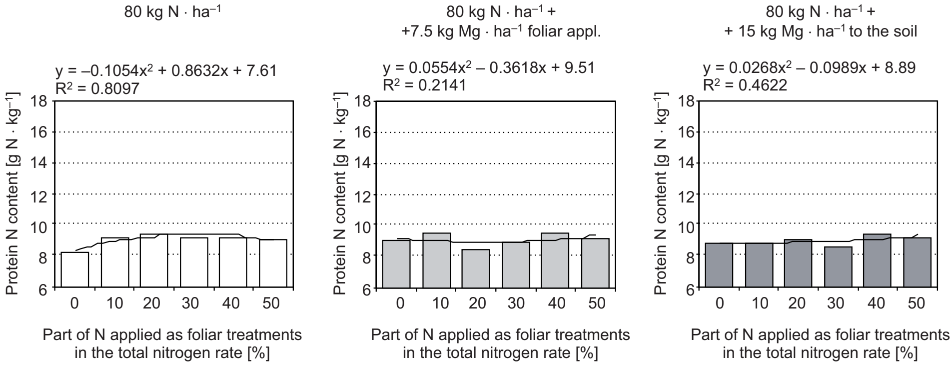

Fig. 2. Effect of foliar nitrogen fertilization and two technologies of magnesium fertilization on protein nitrogen content in potato tubers of cv. Zebra

magnesium also led to elevated total nitrogen content in potato tubers. In this study, no such effect has been obtained.

While analyzing the chemical composition of tubers for the content of total and protein nitrogen, one must not neglect another form of this element, ie nitrates(V), which affects human health. Although nitrates are relatively non-toxic to people, they can be easily reduced to nitrates(III) in a human body, and these may produce a series of unwanted changes, such as anaemia, methemoglobinemia or decomposition of vitamin A and carotenes. Moreover, nitrates are precursors of toxic N-nitroso compounds occurring in food products, for example 1,2-dimethylnitrosamine, which is responsible for liver damage and can induce cancer [12]. According to Mohler [13] and Karlowski [14], potato belongs to plants which do not readily accumulate nitrates. However, both in field experiments and in chemical analyses of commercially available potatoes, a highly diverse content of these compounds can be determined, ranging from tens to several thousands of milligrams [15–18].

In the present study, the determined amounts of nitrates(V) were re-calculated to sodium nitrate (Fig. 3). According to the currently binding regulations [19], the content of nitrates(V) in edible potato should not exceed 200 mg $NO_3^- \cdot kg^{-1}$ fresh matter of tubers. This amount corresponds to 275 mg $NaNO_3$ per 1 kg of tubers. The mineral fertilization tested in this experiment, ie 80 kg N $\cdot$ ha^{-1}, caused excessive accumulation of nitrate nitrogen(V) in all treatments. Foliar application of magnesium in general contributed to depressing the level of nitrates in tubers at harvest time, which however rose again after 2 and 3 months' storage (November and December) irrespective of the experimental fertilization variant. Tubers from treatments fertilized with nitrogen introduced to soil had a higher content of nitrates(V) than tubers from plots not fertilized with this nutrient. In later months of storage, the content of nitrates(V) in tubers continued to rise. This increase was due to relatively large water transpiration from surface of tubers and the enzymatic activity of tubers, which increased at the end of the storage period. Transpiration caused some kind of 'concentration' of nitrates(V) in tubers. In March (at the termination of storage) it was found out that the lowest quantities of this form of nitrogen appeared in tubers collected from the fertilization

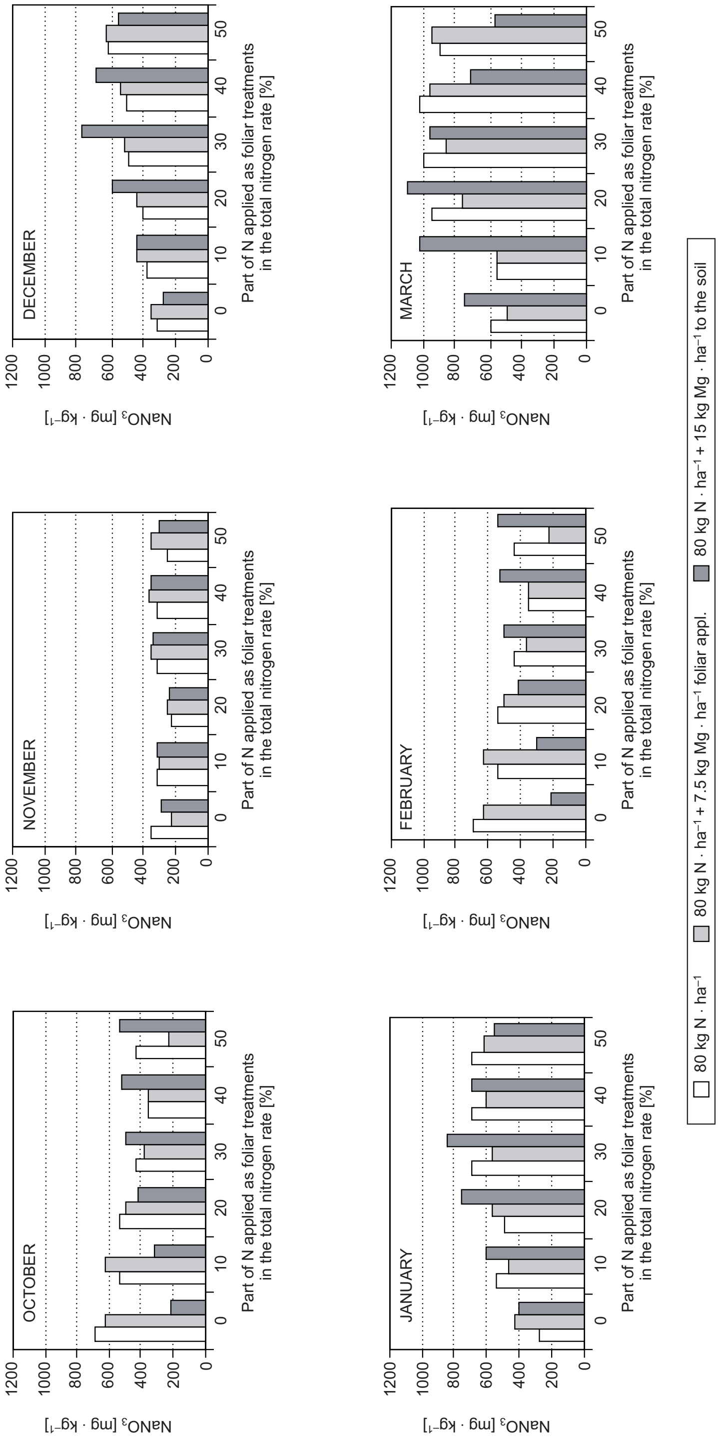

Fig. 3. Content of nitrates(V) in potato tubers of cv. Zebra, in consecutive months of storage

treatments which did not receive foliar nitrogen fertilization. Magnesium applied in a dose of 7.5 kg Mg · ha^{-1} as a foliar treatment in combination with a small percentage of foliar nitrogen application to total nitrogen rate had a beneficial effect on decreasing nitrates in tubers. In treatments receiving higher percentages of total nitrogen sprayed over leaves, superior effect was produced by magnesium applied in a dose of 15 kg Mg · ha^{-1} to soil.

Conclusions

1. The highest total and protein nitrogen content occurred in tubers from the series without magnesium addition, in contrast to the ones receiving additional magnesium nutrition, in which there was a slight increase in the concentration of both nitrogen forms.
2. The application of 10 % of supplied nitrogen as a foliar treatment caused the highest increase in the content of total nitrogen; by increasing the contribution of foliar nitrogen fertilization, the total nitrogen level in potato tubers was depressed.
3. Foliar and soil magnesium nutrition eliminated the effect produced by foliar nitrogen fertilization with respect to total nitrogen in tubers. The content of protein nitrogen in the analyzed tubers was not modified under the influence of the applied magnesium fertilization.
4. The increasing contribution of foliar nitrogen application versus the total rate of this nutrient resulted in a lower concentration of nitrates(V) in potato tubers after harvest. A similar effect was obtained when additional foliar application of magnesium was introduced. However, soil fertilization with magnesium had a reverse effect, raising this form of nitrogen in tubers.
5. The content of nitrates(V) in tubers considerably increased during storage. Magnesium applied in foliar treatments depressed the content of nitrates(V) in tubers, but when introduced to soil, it lowered the level of these compounds.

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ODDZIAŁYWANIE DOLISTNEGO NAWOŻENIA AZOTEM I MAGNEZEM NA ZAWARTOŚĆ AZOTU OGÓLNEGO, BIAŁKOWEGO ORAZ AZOTANÓW(V) W BULWACH ZIEMNIAKA

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Abstrakt: Pracę poświęcono wyjaśnieniu oddziaływania dolistnego nawożenia azotem i magnezem na zawartość azotu ogólnego i białkowego w bulwach ziemniaka średnio-wczesnego odmiany Zebra. Doświadczenie przeprowadzono z uwzględnieniem 3 serii: w pierwszej stosowano tylko nawożenie azotem – 80 kg N · ha^{-1}, gdzie systematycznie zwiększał się udział nawożenia dolistnego (0, 10 %, 20 %, 30 %, 40 %, 50 %) kosztem doglebowego (80, 72, 64, 56, 48 i 40 kg N · ha^{-1}), a w dwóch następnych seriach uwzględniono dodatkowo nawożenie magnezem. W drugiej serii magnez stosowano dolistnie w ilości 7,5 kg Mg · ha^{-1}, a w trzeciej doglebowo w dawce 15 kg Mg · ha^{-1}. Największą średnią zawartość azotu ogólnego i białkowego stwierdzono w bulwach nawożonych samym azotem – dolistnie i doglebowo, a w wariantach z dodatkiem magnezu nastąpił nieznaczny spadek koncentracji obu tych form azotu. Większy wzrost zawartości N-ogólnego i N-białkowego w bulwach ziemniaka uzyskano przy 10 % udziale nawożenia dolistnego azotem. Nawożenie magnezem zastosowane dolistnie jak i doglebowo, nie miało znaczącego wpływu na zawartość N-ogólnego i N-białkowego w bulwach ziemniaka. Zwiększający się udział dolistnego nawożenia azotem spowodował zmniejszenie zawartości azotanów(V) w bulwach ziemniaka po zbiorze bulw. Podobny efekt uzyskano podczas dodatkowej dolistnej aplikacji magnezu, natomiast składnik ten zastosowany doglebowo działał odwrotnie. Zawartość azotanów(V) w bulwach uległa znacznemu wzrostowi w okresie przechowywania. Magnez stosowany dolistnie przeważnie zmniejszał, a wprowadzany doglebowo zwiększał zawartość azotanów(V) w bulwach.

Słowa kluczowe: N-ogólny, N-białkowy, azotany(V), bulwy ziemniaka, nawożenie dolistne, magnez

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TECHNOLOGICAL VALUE OF SPRING WHEAT GRAIN IN DEPEDENCE ON NITROGEN FERTILIZATION

WARTOŚĆ TECHNOLOGICZNA ZIARNA PSZENICY JAREJ W ZALEŻNOŚCI OD NAWOŻENIA AZOTEM

Abstract: Field experiment was carried out in 2002–2004 at the Experimental Station in Zawady, belonging to the University of Podlasie. Two factorial experiments were intended in method of random blocks in three variants. The size of field to collect was 18 m^2. Two factors were taken into consideration: I factor – fertilization rate of nitrogen: a) 0 – control object, without nitrogen fertilization, b) 40 kg N · ha^{-1} (20 kg N · ha^{-1} before sowing, 20 kg N · ha^{-1} in the phase of shooting), c) 80 kg N · ha^{-1} (40 kg N · ha^{-1} before sowing, 40 kg N · ha^{-1} in the phase of shooting), d) 120 kg N · ha^{-1} (60 kg N · ha^{-1} before sowing, 60 kg N · ha^{-1} in the phase of shooting), e) 160 kg N · ha^{-1} (80 kg N · ha^{-1} before sowing , 80 kg N · ha^{-1} in the phase of shooting), II factor – spring wheat cultivars: Henika, Banti, Jasna. The harvest of spring wheat was made in the stage of full maturity of grain. The results pointed that the rates of technological value of spring wheat grain changed in dependence on nitrogen fertilization doses. The increase of dose to 160 kg N · ha^{-1} caused important increase in gluten number and falling number but it caused the drop of gluten density. Gluten deliquescence was the highest after using the dose of 120 kg N · ha^{-1}. Cultivars which were taken into consideration in this experiment had significant influence on increase of contents which determined technological value of spring wheat grain.

Keywords: spring wheat, nitrogen fertilization, cultivars, quality of grain

The main directions of spring wheat use are its consumable purposes, for example the processing of spring wheat into flour, which is later used for production of bread, pasta, culinary and cake products. The grain which is used to those purposes must characterize with high technological value. The main factor which decides about baking value are genetic properties of cultivars [1]. All the same natural environment diversifies technological value of consumer cereals. It could be also modified by conditions of cultivation, for example nitrogen fertilization. It plays a fundamental role in shaping the quality of obtained yield of spring wheat grain [2]. It is important not only to quantify of total nitrogen, but also the manner and date of its application [3]. Current researches show that increase of nitrogen dose has favourable influence on

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physical properties and chemical composition of grain, so it influences on its quality [4,5]. Determination of optimal level of nitrogen fertilization for new cultivars of spring wheat has big meaning from the point of view of important influence of this nutrient, not only on yield height but also on its quality [6]. In assessing the quality of spring wheat grain a lot of attention is paid to the enzymatic properties, especially on the amylolytic activity, on which opinion is divided. Some authors have shown that with increasing of nitrogen fertilization occurs the decrease in activity of alpha-amylase, while others are of the opinion that high doses of nitrogen can cause an increase in amylolytic activity [7, 8]. A negative consequence of the marginal increase in nitrogen fertilization in the spring wheat crop is lower gluten content. By contrast, application of nitrogen transfer to a later date increases the protein content in grain, and thereby worsening its nutritional value [9, 10].

The purpose of this study was to determine the effects of various doses of nitrogen applied before sowing in the shooting phase and the beginning of heading on the amount and quality of the grain yield of three varieties of spring wheat.

Materials and methods

This paper presents researches from years 2002–2004 which were carried out at the Experimental Station in Zawady, belonging to the University of Podlasie. The experiment was a three-replicate split blocks design and the size of field to collect was $18m^2$. Two factors were taken into consideration: I factor – fertilization rate of nitrogen: a) 0 – control object, without nitrogen fertilization, b) 40 kg N · ha^{-1} (20 kg N · ha^{-1} before sowing, 20 kg N · ha^{-1} in the phase of shooting), c) 80 kg N · ha^{-1} (40 kg N · ha^{-1} before sowing, 40 kg N · ha^{-1} in the phase of shooting), d) 120 kg N · ha^{-1} (60 kg N · ha^{-1} before sowing, 60 kg N · ha^{-1} in the phase of shooting), e) 160 kg N · ha^{-1} (80 kg N · ha^{-1} before sowing , 80 kg N · ha^{-1} in the phase of shooting), II factor – spring wheat cultivars: Henika, Banti, Jasna. Selecting fields in different years of experience has been made taking into account the possible slight differences in terms of soil physico-chemical properties. A field experiment was conducted to the soil which was classified to chapter – autogenic soil, row – brown earth soil, type – sandy soil. Terrain was flat, there was no water erosion. Topsoil granulometric composition was as follows [%]: sand (1.0–0.1) – 53, dust (0.1–0.02) – 27, fine particles (< 0.02) – 20. Selected topsoil properties were considered: organic matter content – 1.57 %, the content of available forms of mg on 100 g of soil: P_2O_5 – 4.6; K_2O – 13.3; Mg – 3.5; pH in 1 M KCl – 6.5. Sorption capacity of soil was T – 89 mmol(+) · kg^{-1}, amount of alkaline cations S – 69 mmol(+) · kg^{-1} analytical acidity Hh – 20 mmol(+) · kg^{-1}, and the degree of saturation of the soil was V – 77.5 %. In terms of the suitability of the farming land is classified to a very good cereal complex soil, belonging to the quality class IVa with a slightly neutral pH, high abundance of zinc, average abundance of potassium, magnesium, copper, iron, low abundance of boron, very low in phosphorus and decay. Spring wheat was cultivated on the position after potatoes, after its collection winter ploughing was made, prefaced with harrowing. Early spring, in the term of fortnight before sowing of spring wheat P, K fertilizers were spread, which amount was: P – 100 kg · ha^{-1} in the form of triple superphosphate 46 % and K – 120 kg · ha^{-1} in the form of potassium salt 60 %. Potassium fertilization was applied in the form of: before sowing – nitro-chalk 26 %, in the phase of shooting – ammonium sulphate 34 %. Sowing of spring wheat was made in the first decade of April in the quantity of 250 kg · ha^{-1}, with rows spaced 12 cm and depth of cover seeds 3 cm. Before sowing the seed grain was resined by mortar Raxil Gel 206 (500 cm^3/100 kg of grain). In chemical protection Aminopielik D 450 SL (3 $dm^3 \cdot ha^{-1}$) herbicide was used in fully promoting and insecticide Decis 2.5 EC (0.25 $dm^3 \cdot ha^{-1}$) in the initial period of leaf beetles larvae. In years 2002 and 2003 wheat harvest was made in the first decade of August, and in 2004 a collection was held in the third decade of July. Immediately after harvesting the average grain samples were collected in order to comply with the determinations in the laboratory. Technological value of spring wheat seeds was identified by determining gluten deliquescence, falling number, the gluten number and density of grains. For the determination of gluten deliquescence 5 g of wet gluten was weighed and formed into a ball, which was placed in a Petri dish and placed for 60 minutes in a drier at 300 ^oC.

The size of ball was measured on the graph paper. The difference in the size of gluten balls before putting to the dryer and after removing it meant gluten deliquescence [11]. The falling number was determined by Hagberg method, which involves the use of alpha-amylase, as more resistant to the effects of increased temperature. The fall time of mixer in seconds, expresses directly the falling number [12]. The gluten number was determined by the formula: $LG = X \cdot (2 - R \cdot 0.065)$, where X is the amount of wet gluten in %, R – deliquescence of wet gluten in mm, and 0.065 is the constant conversion coefficient. The density of grain in volume weight was determined in accordance with the standard [13]. Received results of researches were drawn up statistically by carrying out for all of researched features the analysis of variations for two-factorial experiments in split blocks design. For comparison of average the Least Significant Difference (LSD) were calculated by using the Tukey test by the level of significance $\alpha = 0.05$ [14]. The years of conducting researches characterize with considerable diversity of weather conditions (Table 1).

Table 1

Mean air temperature and rainfalls according to the Zawady Meteorological Station

Year	Month						Average
	III	IV	V	VI	VII	VIII	
Temperature [^oC]							
2002	3.9	9.0	17.0	17.2	21.0	20.2	14.7
2003	1.3	7.0	15.5	18.3	20.0	18.4	13.4
2004	8.0	11.7	15.4	17.5	18.9	13.0	14.0
Average 1951–1990	7.2	13.2	16.2	17.6	16.9	12.7	14.0
Rainfalls [mm]							
2002	15.8	12.9	51.3	61.1	99.6	66.5	307.2
2003	7.0	13.6	37.2	26.6	26.1	4.7	115.2
2004	35.9	97.0	52.8	49.0	66.7	19.5	320.9
Sum from 1951–1990	29.4	54.3	69.3	70.6	59.8	48.2	331.6

The growing season in 2002 should be defined as wet and very warm year, it is indicated by value of hydrotermic index K = 1.1. When the course of weather condition was analysed in year 2003 it was claimed that this year was not in favour to correct development of plants, and in the same time it was not in favour to achieve high grain yield of spring wheat. It was the year of drought with the value of hydrotermic index K = 0.6. Vegetation period of 2004 characterized with favourable conditions for growth and development of spring wheat. The value of hydrotermic index K = 1.2.

Results and discussion

Protein, which content vary in dependence of fertilization level, is important component of wheat grain [15]. The content of this compound, as well as gluten contents and its quality have significant influence on wheat grain technological value. Gluten deliquescence is one of more important parameters which determine gluten quality. Variation analysis showed important influence of nitrogen fertilization on gluten deliquescence of spring wheat grain (Table 2).

Table 2

Gluten deliquescence in spring wheat grain, mean from years 2002–2004

Cultivars	Nitrogen fertilization [kg · ha^{-1}]					Average
	0	40	80	120	160	
Banti	10.0	14.0	15.0	15.0	13.0	13.4
Henika	13.0	14.0	14.0	14.0	14.0	13.8
Jasna	14.0	14.0	14.0	15.0	13.0	14.0
Average	12.3	14.0	14.3	14.7	13.3	13.7
$LSD_{0.05}$ between:	rates of nitrogen fertilization = 1.6 cultivars = not exist in comparison: rates of nitrogen fertilization × cultivars = 2.8					

Table 3

Falling number of gluten in spring wheat grain, mean from years 2002–2004, [s]

Cultivars	Nitrogen fertilization [kg · ha^{-1}]					Average
	0	40	80	120	160	
Banti	322.0	321.0	327.0	302.0	319.0	318.2
Henika	427.0	414.0	405.0	444.0	428.0	423.6
Jasna	421.0	409.0	415.0	435.0	405.0	417.0
Average	390.0	381.3	382.3	393.7	384.0	386.3
$LSD_{0.05}$ between:	rates of nitrogen fertilization = not exist cultivars = 15.6 in comparison: rates of nitrogen fertilization × cultivars = 34.7					

Not important was the influence of cultivars on researched feature, but there was a cooperation of nitrogen fertilization with cultivars. The highest rate of gluten deliquescence was noted on 120 kg N · ha^{-1} nitrogen level. The lowest gluten deliquescence was noted on control object, which differed importantly from values which were achieved on objects fertilized with the following rates 40, 80, 120. The influence of nitrogen fertilization on gluten deliquescence depended on researched cultivars, which showed the interaction of cultivars with rates of nitrogen fertilization. Banti cultivar reacted with important increase of gluten deliquescence after using the nitrogen rate of 40 kg N · ha^{-1}. Henika and Jasna cultivars did not react significantly on changing rates of nitrogen fertilization. The interaction of cultivars with rates of nitrogen fertilization was proved. Henika cultivar had significant increase of researched feature in combination fertilized with rate of 120 kg N · ha^{-1}. Banti and Jasna cultivar did not react on increasing nitrogen fertilization. The significant effect of nitrogen fertilization and variety on the value of the number of gluten was proved in the investigation of spring wheat grain (Table 4).

Table 4

Gluten number of spring wheat, mean from years 2002–2004

Cultivars	Nitrogen fertilization [kg · ha^{-1}]					Average
	0	40	80	120	160	
Banti	38.09	43.32	46.05	44.41	49.68	44.31
Henika	39.22	38.04	40.25	39.55	44.75	40.36
Jasna	46.65	46.62	45.89	44.07	45.60	45.76
Average	41.32	42.66	44.06	42.67	46.67	43.48

$LSD_{0.05}$ between: rates of nitrogen fertilization = 3.60
cultivars = 3.82
in comparison: rates of nitrogen fertilization × cultivars = 6.76

The largest number of gluten have been reported on object fertilized with dose of 160 kg N · ha^{-1}, and it was significantly higher compared with the control object, and fertilized with dose of 40 and 120 kg N · ha^{-1}. The lowest value of the characteristic was noted on the control object. The difference between the extreme values was 6.35. The greatest value of the number of gluten was found in Jasna cultivar (45.76), while the smallest in Henika cultivar (40.36). The influence of nitrogen fertilization on the number of gluten varied depending on the cultivar, as evidenced by the interaction of nitrogen doses with the cultivar. In Banti cultivar gluten number was significantly lower on control object in comparison with combinations 80 160 kg N · ha^{-1} Henika and Jasna cultivars did not react significantly on increasing rates of nitrogen fertilization. The density of grain when it was built depended on grain lushness, its structure and fillness, the thickness of fruit-seed cover and amount and qualities of pollutant. Variation analysis showed the interaction between cultivars and nitrogen fertilization (Table 5). The highest grain density was achieved in Henika cultivar, on control object. The grain from object fertilized with rate of 160 kg N · ha^{-1} characterized with significantly the lowest grain density in comparison with control object. Banti cultivar was characterized with the lowest grain density. In comparison with Henika and Jasna it was significantly different. The results of analysis of variance showed the interaction of nitrogen fertilization and cultivars on tested features which shows that the density of grain of tested cultivars depending on the applied doses of nitrogen.

Table 5

Density of spring wheat grain mean from years 2002–2004, [kg · hl^{-1}]*

Cultivars	Nitrogen fertilization [kg · ha^{-1}]					Average
	0	40	80	120	160	
Banti	76.7	74.0	74.2	74.5	74.9	74.8
Henika	80.2	77.7	78.1	78.2	76.1	78.0
Jasna	77.7	77.3	76.6	76.3	77.2	77.0
Average	78.2	76.3	76.3	76.3	76.0	76.6
$LSD_{0.05}$ between: rates of nitrogen fertilization = 1.6; cultivars = 1.2; in comparison: rates of nitrogen fertilization × cultivars = 2.8						

* hl = 100 dm^3.

Gluten deliquescence is one of parameters which determine gluten quality. Gluten which characterised with good quality should have little deliquescence. The results of Sulek and others [16] did not confirm the influence of nitrogen fertilization on gluten deliquescence. In Knapowski and others researches [17] the 80 kg N · ha^{-1} dose cause significant increase of gluten deliquescence in comparison with control object without nitrogen fertilization but continuing increase of nitrogen doses did not have significant influence on gluten quality. In own researches this feature was different in dependence on nitrogen doses which were used. Gluten with the lowest deliquescence was achieved on control object, but the highest deliquescence had the gluten from grain fertilized with 120 kg N · ha^{-1} rate. The falling number is one of rate which let to claim if we deal with product which came from grain with higher enzymatic activity. From Budzynski and others researches [18] we can see that high rates of nitrogen can cause the increase of alfa-amylasis activity, but Mazurek and Biskupski [5] declared the fall of amylolitical activity with the increase of nitrogen rates. In own researches, similar to Haber and others researches [19] significant relations between rates of nitrogen fertilization and falling number did not appear. In Knapowski and Ralcewicz [17] researches the increase of nitrogen doses from 80 to 120 kg N · ha^{-1} caused significant increase of falling number, and continuing increase of fertilization to the level of 160 kg N · ha^{-1} did not have significant influence on its value. The index which characterize the percentage content of gluten and its deliquescence is the gluten number. In own researches the highest value of researched feature was noted in grain which was cultivated from control object fertilized with the highest dose of nitrogen 160 kg N · ha^{-1}. Stankowski and others [20] researches show similar dependence. The grain density decides about its grinding value. Big value of this feature forecasts high yield of flour, but little provides about shrivelled of grain and bad creation of endosperm. In own researches the density of grain depended on rates of nitrogen fertilization. Similar results noted Achramowicz and others [21].

Conclusion

1. The results pointer that the technological value of spring wheat grain changed according to nitrogen fertilization doses.

2. The increase of dose to 160 kg N · ha^{-1} caused important increase of gluten number and falling number but it caused the drop density of grain. Gluten deliquescence was the highest after applying the dose of 120 kg N · ha^{-1}.

3. Cultivars which were taken into consideration in this experiment had significant influence on increase of indicators which determined technological value of spring wheat grain such as falling number, gluten number and grain density. The amount of this changed in the following cultivars in dependence on nitrogen fertilization level.

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WARTOŚĆ TECHNOLOGICZNA ZIARNA PSZENICY JAREJ W ZALEŻNOŚCI OD NAWOŻENIA AZOTEM

Katedra Szczegółowej Uprawy Roślin
Akademia Podlaska

Abstrakt: Doświadczenie polowe przeprowadzono w latach 2002–2004 w Rolniczej Stacji Doświadczalnej w Zawadach, należącej do Akademii Podlaskiej. Doświadczenie dwuczynnikowe założono metodą losowanych bloków w trzech powtórzeniach. Powierzchnia poletka do zbioru wynosiła 18 m^2. W doświadczeniu badano dwa czynniki: I czynnik – dawki nawożenia azotem: 0 – obiekt kontrolny bez nawożenia azotem, 40 N kg · ha^{-1} (20 kg N · ha^{-1} przed siewem, 20 kg N · ha^{-1} w fazie strzelania w źdźbło), 80 kg N · ha^{-1} (40 kg

N · ha^{-1} przed siewem, 40 kg N · ha^{-1} w fazie strzelania w źdźbło), 120 kg N · ha^{-1} (60 kg N · ha^{-1} przed siewem, 60 kg N · ha^{-1}w fazie strzelania w źdźbło), 160 kg N · ha^{-1} (80 kg N · ha^{-1} przed siewem, 80 kg N · ha^{-1} fazie strzelania w źdźbło), II czynnik – odmiany pszenicy jarej: Henika, Banti, Jasna. Zbiór pszenicy jarej przeprowadzono w fazie pełnej dojrzałości ziarna. Z przeprowadzonych badań wynika, że wskaźniki wartości technologicznej ziarna pszenicy jarej zmieniały się w zależności od dawki nawożenia azotem. Wzrost dawki do 160 kg N · ha^{-1} spowodował znaczne zwiększenie wartości liczby glutenowej i liczby opadania, a obniżenie gęstości ziarna. Rozpływalność glutenu była największa po zastosowaniu dawki 120 kg N · ha^{-1}. Uwzględnione w doświadczeniu odmiany miały znaczny wpływ na wartości wskaźników określających wartość technologiczną ziarna pszenicy jarej.

Słowa kluczowe: pszenica jara, nawożenie azotem, odmiany, jakość ziarna

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DYNAMICS OF NITROGEN DURING DECOMPOSITION PROCESSES OF ECTOHUMUS FROM DEGRADED FOREST ECOSYSTEMS IN THE SNIEZNIK MASSIF, EASTERN SUDETY MOUNTAINS

DYNAMIKA AZOTU W PROCESACH ROZKŁADU PRÓCHNIC NADKŁADOWYCH DEGRADOWANYCH EKOSYSTEMÓW LEŚNYCH W MASYWIE ŚNIEŻNIKA W SUDETACH WSCHODNICH

Abstract: Results of mineral forms of nitrogen (N-NO_3 and N-NH_4) changes in ectohumus layers and needles during decomposition processes are presented. The experiment was conducted in controlled conditions in a chamber with stable temperature and humidity. Plant samples and soil samples from ectohumus were taken in ecosystems in various stages (object without damages signs, in the process of degradation and degraded). In the fresh material, directly after sampling, content of mineral forms of nitrogen was analyzed. Controlling of the content changes were done after 30, 60 and 90 days of incubation. In the fresh material high differences of the content of N-NO_3 between degraded ecosystems were found. The lowest content were found in needles of degraded spruce forest and this situation was permanent during the incubation. In the Oh layer content of N-NO_3 was initially the lowest, but during incubation was increasing and after 30 days of decomposition was the highest. The highest content of ammonia nitrogen was found in needles from degraded ecosystems and despite of decreasing the amount during decomposition this was stable until 90th day of incubation. In Oh layers content of N-NH_4 was decreasing with the time of incubation and the most clear was observed in ecosystems in degradation process and degraded as well.

Keywords: nitrogen forms, mountain soils, forest degradation

In the last decades an increase of nitrogen participation in terrestrial ecosystems is being observed in Europe. This can be affected by enhance of nitrogen oxides and ammonia emissions from industry and developing agriculture [1, 2]. Ecosystems enriched in excessive amount of nitrogen, defend themselves and the effect is leaching nitrogen compounds to the ground and underground waters what can favor disturbances in proper ecosystems' functioning [3–5].

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The Snieznik Massif forest ecosystems have been transformed for last decades under the influence of anthropogenic conditions. Forests in the range of Ladek Zdroj and Miedzylesie were classified to III degree of industrial damages [6]. The symptoms of the negative processes are mainly damages of needles development – yellowing and drying up.

The question is: whether in mountain spruce ecosystems we should be aware of uncontrolled nitrogen increase?

The aim of the work was to analyse changes of mineral forms of nitrogen ($N\text{-}NO_3$ and $N\text{-}NH_4$) in ectohumus layers (Olf i Oh) and spruce needles from the mountain forest ecosystems in various degrees of degradation during their decomposition process.

Material and methods

The experiment was carried out in closed chamber with controlled conditions: stable temperature 16 ^{o}C and humidity of 16 %. Samples – from needles and from ectohumus layers were taken in two replications (in tables results are given as a mean value) from the spruce forest ecosystems in the range of Snieznik Klodzki Massif, East Sudety Mountains. Samples were taken from differently degraded forest sites: object without negative changes – A, in the process of degradation – about 50 % of needles with symptoms of damages – B, and degraded – C. The objects were within approximately 200 m of each other and have the same elevation and are derived from the same parent rock. Soils in the analyzed ecosystems were podzols derived from gneiss with humus type mor. Type of forest sites was mountain coniferous forest, ass. *Calamagrostio villosae-Piceetum* [7].

In the fresh material, directly after sampling content of mineral forms of nitrogen was analyzed and after 30, 60 and 90 days of incubation. Analysis were done in the Chemical-Agricultural Station in Wroclaw using continuous flow colorimetry and analyzer SFA, type SAN++, Skalar Analitycal B.V. Holand. after the extraction in 1 % K_2SO_4.

Additionally soil samples were taken from mineral horizons, depth 0–44 cm, to characterize soil environment exposed to degradation processes.

Basic properties of the soils under degrading spruce forest (object B) are presented in the paper by Jamroz and Kocowicz [8]. In the present paper soil properties from spruce forest without degradation signs (A) and degraded (C) are reported. In the soil samples the following properties were determined: granulometric composition by areometric method Casagrande in modification of Proszynski, pH – potentiometrical in 1 M KCl, total content of organic carbon and total content of sulphur ussing CS-mat 5500 analyzer by Strohlein and total content of nitrogen using Kjeldahl method and Buchi analyzer.

Results and discussion

The analyzed soils from the region of Snieznik Massif represent podzols derived from gneiss with loamy sands and light loam (Table 1), with high content of skeleton 26 to 50 %. Ectohumus layers are divided to Olf – containing weakly decomposed organic matter, with rests of needles and parts of plants and Oh – containing well decomposed organic matter in the amount of 50–70 % less than in Olf horizon (Table 1), with black color. Reaction of the soils in degraded ecosystem, according to Polish forest soils classification [9] is very strongly acid in the whole profile except horizon of parent rock – C (Table 1). In the ecosystem without degradation signs – A, horizon Bhfe and horizon C were characterized by strongly acid reaction. This is the effect of parent rock influence, which is naturally poor in alkaline compounds mainly in calcium as well as falling spruce needles which are strongly acidic. Content of nitrogen in soil profile is low, what is connected with spruce needles naturally poor in this element. This is reflected in wide C/N ratio (Table 1), over 20 in upper layers of soil profile, as well as in B horizon from the forest without negative changes.

Table 1

Some properties of podzols in the region of Snieznik Klodzki Range in forest ecosystems of various stages of degradation

Object/Horizon	Olf	Oh	Ees	Bhfe	C
	Content of fraction ∅ < 0.02 mm [%]				
Object A	n.d.	n.d.	22	16	18
Object B*	n.d.	n.d.	33	13	32
Object C	n.d.	n.d.	16	14	17
	pH in 1 M KCl				
Object A	2.6	2.7	3.3	4.0	4.2
Object B*	2.4	2.7	3.3	3.5	4.2
Object C	3.1	2.7	2.7	3.2	3.6
	$C_{org.}$ [$g \cdot kg^{-1}$]				
Object A	453.0	231.2	9.7	64.6	62.7
Object B*	434.9	324.7	4.7	64.6	15.2
Object C	435.2	345.4	n.d.	44.6	25.8
	N_t [$g \cdot kg^{-1}$]				
Object A	16.4	11.3	n.d.	2.1	n.d.
Object B*	20.1	13.7	n.d.	6.1	0.8
Object C	22.1	19.3	n.d.	2.2	0.9
	C/N				
Object A	28	21	n.d.	31	n.d.
Object B*	22	24	n.d.	11	19
Object C	20	18	n.d.	20	29

* reported in the paper Jamroz, Kocowicz [4]; n.d. – not determined.

Mineral forms of nitrogen in all investigated objects were characterized by predominance of ammonia (Table 2). Similar results received Brozek [10], in Beskid Zachodni and others in forest ecosystems [11,12]. Acid environment favor ammonification processes, what can be confirmed by study of Sapek and Kalinska [13]. On the base of results a dependence between degree of forest degradation and $N\text{-}NO_3$ and $N\text{-}NH_4$ content, especially in the fresh material (Table 1) is worth to note. During the incubation differences between forest sites were not so clear. In the fresh material high differences of the content of $N\text{-}NO_3$ between degraded ecosystems were found. The lowest content were found in needles of degraded spruce forest – C and this situation was permanent during the incubation. In the Oh layer content of $N\text{-}NO_3$ in C object was initially the lowest, but during incubation was increasing and after 30 days of decomposition was the highest. Similar results can be found in researches by Maciaszek et al [12] during analysis of changes mineral forms of nitrogen in ectohumus layers in the controlled conditions. The highest content of ammonia form was found in needles from degraded ecosystems – C and despite of decreasing the amount during decomposition this was stable until 90^{th} day of incubation. In Oh layers content of $N\text{-}NH_4$ was decreasing with the time of incubation and the most clear was observed in ecosystems in degradation process and degraded as well (Table 2). Such distribution of mineral forms of nitrogen during mineralization reflects transformation processes of the organic matter in degraded forest ecosystems.

Table 2

Changes of mineral forms of nitrogen in ectohumus layers and spruce needles from the ecosystems in various stages of degradation

Object	Horizon	After sampling		30 days of incubaction		60 days of incubation		90 days of incubation	
		[mg · kg^{-1} d.m.]							
		$N\text{-}NO_3$	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4$	$N\text{-}NO_3$	$N\text{-}NH_4$
A	needles	1.01	2.90	0.94	5.46	0.50	4.39	0.39	3.43
A	Olf	0.58	128.59	1.59	30.26	1.28	23.76	0.86	20.39
A	Oh	1.25	8.89	1.60	7.92	1.10	6.24	0.88	5.32
B	needles	1.52	10.29	0.86	4.55	0.60	3.95	0.51	3.19
B	Olf	1.38	149.56	1.29	34.37	0.81	24.21	0.63	18.90
B	Oh	1.41	19.55	0.71	4.87	0.57	3.87	0.37	3.14
C	needles	0.10	24.61	0.75	9.13	0.41	8.10	0.36	6.97
C	Olf	23.45	183.87	4.53	23.13	2.92	18.54	2.44	14.97
C	Oh	4.87	22.63	1.06	5.38	0.71	4.26	0.50	3.42

Lower content of mineral nitrogen together with natural low level of the element in coniferous trees, especially spruce, can favor to developing of damages as yellowing and premature falling needles [14].

In the forest ecosystems without negative effects the participation of mineral forms of nitrogen should reach 2–3 % of the total N [12]. Forest sites from the Snieznik Massif are characterized by rather small participation of $N\text{-}NH_4 + N\text{-}NO_3$ forms in total nitrogen – below 1 %.

Conclusions

In mountain coniferous forests in the region of Snieznik Range during decomposition of organic matter ammonia is mainly produced and acid reaction of the soil favor this process. In spruce needles which are natural poor in nitrogen, its biological blockade can lead to chlorosis of needles. Degradation processes in the Snieznik Massif reflect changes in mineral forms of nitrogen. Higher content of $N\text{-}NO_3$ and $N\text{-}NH_4$ in more degraded forest ecosystems can point to lower biological activity in the ecosystems in degradation process.

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DYNAMIKA AZOTU W PROCESACH ROZKŁADU PRÓCHNIC NADKŁADOWYCH DEGRADOWANYCH EKOSYSTEMÓW LEŚNYCH W MASYWIE ŚNIEŻNIKA W SUDETACH WSCHODNICH

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Abstrakt: W pracy przedstawiono wyniki analiz zmian zawartości mineralnych form azotu ($N\text{-}NO_3$ oraz $N\text{-}NH_4$) w poziomach próchnic nadkładowych (Olf i Oh) oraz w igłach świerków podczas procesów ich dekompozycji. Doświadczenie prowadzono w warunkach zamkniętych w komorze inkubacyjnej, przy stałej temperaturze oraz wilgotności. Próbki materiału roślinnego – igły oraz próbki z poziomów próchnicy nakładowej pobrano z ekosystemów świerkowych w różnym stadium degradacji (obiekt bez objawów degradacji, zamierający oraz obumarły). W materiale świeżym, bezpośrednio po pobraniu w terenie wykonano oznaczenia zawartości form $N\text{-}NO_3$ oraz $N\text{-}NH_4$. Kontrolę zawartości mineralnych form azotu przeprowadzono po upływie 30, 60 i 90 dni inkubacji. W materiale wyjściowym wystąpiły znaczne różnice w zawartości form azotu azotanowego. Najmniejszą jego ilość stwierdzono w igłach świerków obumarłych i taka zawartość utrzymywała się przez cały okres inkubacji. W poziomie epihumusowym (Oh) zawartość $N\text{-}NO_3$ była początkowo najmniejsza, spośród badanych obiektów, ale z upływem czasu inkubacji zwiększała się i od 30 dnia procesu dekompozycji utrzymywała się na najwyższym poziomie. Największą zawartość azotu amonowego odnotowano w igłach świerków obumarłych i mimo tendencji spadkowych we wszystkich obiektach, taki stan utrzymał się do 90 dnia inkubacji. W poziomach epihumusowych, niezależnie od stopnia degradacji siedliska, zawartość azotu amonowego zmniejszała się wraz z upływem czasu inkubacji, a najwyraźniej zmiany te zachodziły w siedliskach zamierających i obumarłych.

Słowa kluczowe: formy azotu, gleby górskie, degradacja drzewostanów

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EFFECT OF SULPHUR AND POTASSIUM FERTILIZATION ON YIELD AND CONTENT OF VARIOUS FORMS OF NITROGEN IN SPRING RAPE

WPŁYW NAWOŻENIA SIARKĄ I POTASEM NA PLONOWANIE I ZAWARTOŚĆ RÓŻNYCH FORM AZOTU W RZEPAKU JARYM

Abstract: This study analyzed the effect of sulphur and potassium fertilization on yield and on total N, protein N, N-NO_3^- and N-NH_4^+ content in spring rape harvested during the bloom period and at full maturity. The study was based on plant material obtained from a pot experiment. The results obtained indicate that fertilization with sulphur and potassium significantly increased the yield of rape harvested during the bloom period and at full maturity. Only the effect of potassium on seed yield was not found to be significant. The highest yields were noted in the objects fertilized with the higher doses of sulphur and potassium. The effectiveness of potassium fertilization depended on the plants' supply of sulphur. Potassium influenced the effectiveness of sulphur fertilization, but to a lesser degree. Supplying the test plant with sulphur and potassium had a beneficial effect on nitrogen metabolism. This was manifested as an increased proportion of protein nitrogen in the total nitrogen and a decrease in mineral forms of this nutrient in the plants fertilized with sulphur and potassium.

Keywords: rape yield, content of various forms of nitrogen, sulphur and potassium fertilization

One of the essential conditions for obtaining optimal plant yield, in terms of both quantity and quality, is a suitable soil environment with proper proportions of nutrients [1–3]. One of the factors limiting agricultural production in Poland in the last 10–15 years has been insufficient amounts of assimilable forms of potassium and sulphur in soils. The reduction in assimilable forms of these nutrients in soils is mainly due to decreased use of mineral, natural and organic fertilizers. An additional cause of sulphur deficiency has been the significant reduction in SO_2 emissions into the atmosphere, and thus into the soil [4–7].

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Potassium and sulphur have many important functions in plants, including a strong influence on nitrogen metabolism [8–10]. Studies thus far conducted in this area have mainly concerned the effect of nitrogen or nitrogen and sulphur [11–13], while there is a lack of research on the combined effect of potassium and sulphur on the metabolism of nitrogen compounds in plants. Hence the aim of this study was to determine the scope of the influence of sulphur and potassium fertilization on yield and content of various forms of nitrogen in spring rape.

Materials and methods

The study was based on results obtained from a two-year pot experiment conducted on soil material taken from the arable layer of brown soil with a loamy silt granulometric composition. Before the study, the soil had neutral pH and was low in available phosphorus, potassium and magnesium, as well as in sulphate sulphur. The experiment was set up with a completely randomized design. It had two variables (the dose of sulphur and dose of potassium) on three levels in eight repetitions. Fertilization with elemental sulphur and potassium in the form of KCl was applied each year before sowing, as follows:

1. S_0K_0	4. S_1K_0	7. S_2K_0
2. S_0K_1	5. S_1K_1	8. S_2K_1
3. S_0K_2	6. S_1K_2	9. S_2K_2

where:

S_0 – no sulphur fertilization;

S_1 – fertilization with elemental sulphur in the amount of 0.012 g S $\cdot$ kg^{-1} of soil for spring barley and 0.024 g S $\cdot$ kg^{-1} of soil for spring rape;

S_2 – fertilization with elemental sulphur in the amount of 0.024 g S $\cdot$ kg^{-1} of soil for spring barley and 0.048 g S $\cdot$ kg^{-1} of soil for spring rape;

K_0 – no potassium fertilization;

K_1 – potassium fertilization in the form of KCl in the amount of 0.05 g K $\cdot$ kg^{-1} of soil for spring barley and 0.1 g K $\cdot$ kg^{-1} of soil for spring rape;

K_2 – potassium fertilization in the form of KCl in the amount of 0.1 g K $\cdot$ kg^{-1} of soil for spring barley and 0.2 g K $\cdot$ kg^{-1} of soil for spring rape.

The test plant in the first year of the study was the Atol variety of spring barley, and in the second year it was the Sponsor variety of spring rape. These plants were chosen for the experiment because of their differing requirements for sulphur and potassium. The plants were cultivated in pots with capacity 3 dm^3, each filled with 3 kg of soil. In all of the experimental objects the same level of fertilization with nitrogen, phosphorus and magnesium, as well as microelements, was applied each year in amounts appropriate to the requirements of these plants. Sulphur and potassium was applied in solid form and the other nutrients – in the liquid form. The plants were harvested during the bloom period and at full maturity. Plants from four repetitions were harvested each time.

This paper presents a part of the study and concerns the effect of the experimental factors on yield and on content of various forms of nitrogen in spring rape. After the rape was harvested during the bloom period and at full maturity (seeds and straw), the following forms of nitrogen were determined in the plant material: total nitrogen by the Kjeldahl method, after mineralization of the plant material in concentrated H_2SO_4 with H_2O_2; protein nitrogen by distillation after hot extraction with trichloroacetic acid; ammonia nitrogen colorimetrically by the Nessler method in trichloroacetic acid extract; and nitrate(V) nitrogen colorimetrically using sodium salicylate [14]. Mineral forms of nitrogen were determined only in the rape harvested during the bloom period. The plant material was analyzed in two repetitions in average object samples. Average values can be found in the tables. The effect of the experimental factors on rape yield was calculated by means of variance analysis for factorial experiments using Tukey confidence half-intervals.

Discussion of results

Sulphur fertilization significantly differentiated spring rape yield during the developmental stages investigated (Table 1).

Table 1

The effect of sulphur and potassium fertilization on the yelding of spring rape

Object	Phase of flowering	Full maturity	
		Seeds	Straw
	[g d.m. · pot^{-1}]		
S_0K_0	6.65	×	3.87
S_0K_1	6.67	×	4.21
S_0K_2	6.69	×	4.44
S_1K_0	12.64	8.00	25.54
S_1K_1	13.45	6.29	35.66
S_1K_2	14.89	5.59	41.27
S_2K_0	15.59	11.87	27.39
S_2K_1	20.56	13.78	38.69
S_2K_2	22.32	14.93	43.74
LSD (p = 0.01)			
S	0.64	0.37	0.73
K	0.64	n.s.	0.73
S × K	1.45	0.85	1.64

× – the plants did not develop seeds.

In the case of potassium, significant differentiation of yield occurred only in the plants harvested during the bloom period and in the straw. The interaction between sulphur and potassium was also found to be significant in all cases. It is clear from the data obtained that in both development stages the lowest yields were in the series without sulphur fertilization (S_0). Due to the lack of sulphur in the environment the rape did not enter the generative stage and thus did not produce seeds. The results obtained confirm the fact [2, 6, 13] that rape is a plant with very high sulphur requirements. In this experiment the effectiveness of sulphur fertilization depended on the degree of potassium supply to the plants, and the effectiveness of potassium fertilization depended on the amount of sulphur applied. This dependency was more marked in the case of potassium. When sulphur was lacking in the soil (S_0), the rape harvested during the bloom period did not respond to potassium fertilization with increased yield. In the case of the seeds, lack of response to potassium fertilization was noted in the series with the lower dose of sulphur (S_1).

The highest yields for the test plant were obtained in the objects fertilized with the higher doses of sulphur and potassium (S_2K_2). This confirms that the effectiveness of sulphur fertilization is highest in conditions where high doses of nitrogen, phosphorus and potassium are applied [15].

The experimental factors also had a marked influence on the content in the spring rape of the forms of nitrogen determined in the study (Table 2). Depending on the experimental object, the total nitrogen content in the plants cut during the bloom period was between 26.21 and 59.41 $g\ N \cdot kg^{-1}$. The range of values for total N in the seeds was from 32.68 to 45.77 $g\ N \cdot kg^{-1}$, while in the straw it was 4.01 to 47.37 $g\ N \cdot kg^{-1}$. Fertilization with sulphur and potassium caused a noticeable decrease in total nitrogen content in the plants. This is probably due to the increase in yield produced by these elements and to the phenomenon of nitrogen dilution [1, 16].

The highest protein nitrogen content was noted in the rape seeds, and the lowest in straw. In most cases the experimental factors caused a decrease in protein nitrogen in the spring rape. The beneficial effect of sulphur and potassium on nitrogen metabolism in the plants is demonstrated by the fact that as the amount of these nutrients applied to the rape was increased, the amount of nitrogen incorporated into protein increased. This was particularly clear in the case of the plants harvested during the bloom period and in the straw. In the seeds, the highest degree of conversion of nitrogen into protein was noted in the plants fertilized with the lower dose of sulphur (S_1). The results obtained confirm the essential role of sulphur in the process by which plants convert nitrogen compounds into protein [1, 9, 10, 17]. They also indicate that in plants insufficiently supplied with potassium the ratio of protein nitrogen to non-protein nitrogen undergoes a shift in favour of non-protein nitrogen.

Nitrate nitrogen ($N\text{-}NO_3^-$) and ammonium nitrogen ($N\text{-}NH_4^+$) content in the plants harvested during the bloom period confirm that fertilizing rape with sulphur and potassium has a beneficial effect on nitrogen metabolism (Table 2). In general it can be concluded that the lowest amounts of the mineral forms of nitrogen determined were noted in the rape that was fertilized with the higher dose of sulphur and potassium (S_2K_2), while the highest content of these forms of nitrogen occurred in the plants that were not fertilized with sulphur (S_0). Studies by other authors [17, 18] have also demonstrated that sulphur deficiency in the environment contributes to accumulation of non-protein forms of nitrogen in plants. The effect of potassium is similar, but as the data obtained indicate, it is more effective when plants are well-supplied with sulphur.

Tabela 2

The effect of sulphur and potassium fertilization on the content of various forms of nitrogen in spring rape

Object	Flowering					Seeds			Straw		
	Tot. N	Prot. N	Prot. N / Tot. N	$N-NO_3$	$N-NH_4$	Tot. N	Prot. N	Prot. N / Tot. N	Tot. N	Prot. N	Prot. N / Tot. N
	$[g N \cdot kg^{-1}]$		[%]	$[mg N \cdot kg^{-1}]$		$[g N \cdot kg^{-1}]$		[%]	$[g N \cdot kg^{-1}]$		[%]
S_0K_0	59.41	12.34	20.77	2645.71	413.58	×	×	×	46.66	10.61	22.74
S_0K_1	56.27	11.12	19.76	2911.04	456.29	×	×	×	47.37	11.37	24.00
S_0K_2	56.95	11.59	20.35	2404.63	437.64	×	×	×	41.69	11.24	26.96
S_1K_0	39.41	10.95	27.78	1854.93	377.87	45.25	34.09	75.34	9.43	5.25	55.67
S_1K_1	34.74	10.33	29.73	1170.17	344.79	45.77	34.63	75.66	6.50	3.71	57.08
S_1K_2	33.91	8.79	25.92	1322.01	328.14	44.06	32.44	73.63	6.80	4.02	59.12
S_2K_0	36.12	10.95	30.31	866.70	365.39	35.12	25.30	72.04	6.78	4.31	63.57
S_2K_1	28.25	9.31	32.95	285.88	314.39	33.43	23.48	70.24	4.62	2.77	59.96
S_2K_2	26.21	10.48	39.98	270.46	309.56	32.68	23.47	71.82	4.01	3.08	76.81

× – no determination (calculation) due to the lack of material.

Conclusions

1. Sulphur fertilization significantly increased the yield of spring rape harvested during the bloom period and at full maturity. Significant increase in rape yield as a result of potassium fertilization only occurred in plants harvested during the bloom period and in straw.

2. The effectiveness of fertilizing rape with potassium was strongly dependent on the plants' supply of sulphur. Potassium also enhanced the effectiveness of sulphur fertilization, but to a lesser extent.

3. Increasing the supply of sulphur and potassium in spring rape had a beneficial effect on nitrogen metabolism. This was manifested as increased utilization of this nutrient for protein synthesis and a reduction in mineral nitrogen content ($N\text{-}NO_3^-$, $N\text{-}NH_4^+$).

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WPŁYW NAWOŻENIA SIARKĄ I POTASEM NA PLONOWANIE I ZAWARTOŚĆ RÓŻNYCH FORM AZOTU W RZEPAKU JARYM

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Abstrakt: W pracy przeanalizowano wpływ nawożenia siarką i potasem na plonowanie i zawartość N og., N białk., N-NO_3^- i N-NH_4^+ w rzepaku jarym zbieranym w okresie kwitnienia i pełnej dojrzałości. Podstawę badań stanowił materiał roślinny uzyskany z doświadczenia wazonowego. Uzyskane wyniki wskazują, że nawożenie siarką i potasem istotnie zwiększyło plony rzepaku zbieranego w okresie kwitnienia i pełnej dojrzałości. Brak istotności wystąpił tylko w oddziaływaniu potasu na plon nasion. Najwyższe plony roślin odnotowano w obiektach nawożonych większymi dawkami siarki i potasu. Efektywność nawożenia potasem zależała od zaopatrzenia roślin w siarkę. Potas na efektywność nawożenia siarką wpływał, ale w mniejszym stopniu.

Zaopatrzenie rośliny testowej w siarkę i potas korzystnie wpłynęło na przemiany metaboliczne azotu. Ten korzystny wpływ wyraził się zwiększeniem udziału azotu białkowego w azocie ogólnym i zmniejszeniem mineralnych form tego składnika w roślinach nawożonych siarką i potasem.

Słowa kluczowe: plonowanie rzepaku, zawartość różnych form azotu, nawożenie siarką i potasem

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INFLUENCE OF FERTILIZATION ON YIELD AND QUALITY OF SPINACH (*Spinacia oleracea* L.) DURING STORAGE UNDER CONTROLLED ATMOSPHERE

WPŁYW NAWOŻENIA AZOTEM NA PLON I JAKOŚĆ SZPINAKU (*Spinacia oleracea* L.) PODCZAS PRZECHOWYWANIA W KONTROLOWANEJ ATMOSFERZE

Abstract: The aim of the study was to examine the influence of nitrogen fertilization, mainly in the form of ammonium, containing the inhibitor of nitrification Dicyandiamide that delays the release of nitrogen into the soil, on optimal growth, yield production, and yield quality development of spinach as well as the suitability of spinach for storage compared with conventionally applied fertilizer. In addition to the influence of the applied kind of fertilizers, the dependency from the concentration of the fertilizer was studied. The experimental results revealed that the application of nitrogen in the form of Basammon-nitrogen resulted in a better color development of leaves, a higher content of chlorophyll and an in tendency higher crop yield compared with calcium-ammonium nitrate. Independent from the kind of fertilizer, the standard dose of 220 kg $\cdot$ ha^{-1} N proved to be optimal. Excessive fertilization with 330 kg $\cdot$ ha^{-1} N resulted in a decrease of sugar contents, enlarged concentrations of nitrate, and the decrease in taste values. At the same time it increased the costs for fertilization and the environmental risk due to rinsing of nitrates into the groundwater. A positive aspect was the more intensive color of leaves. The kind of fertilizer did not affect the suitability for storage of spinach. However excessive nitrogen caused greater losses of soluble carbohydrates during storage.

Keywords: *Spinacia oleracea*, calcium-ammonium nitrate, Basammon-nitrogen, quality, storage in controlled atmosphere

Spinach belongs to plants with large demands of nitrogen (220 kg $\cdot$ ha^{-1}), which are necessary for the development of leaf mass as the consumed part of the plant and of the deep green color preferred by consumers. At the same time the weak assimilation capacity for nitrogen by spinach may cause leaching of nitric compounds. It may also create the risk of nitrate accumulation in leaves and a general decrease in spinach quality [1]. Because nitrogen plays a very important role for yield production and quality characteristics in spinach, it is frequently applied in excessive doses, which may lead to a reduced suitability for storage and impair quality parameters [2]. By applying

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the suitable cultivation treatment, risks of losses due to excessive accumulation of nitrates(V), disturbances in the development of plants and their metabolism, especially carbohydrate metabolism, modifications of tissues, flabbiness of plants, and enlarged susceptibility to diseases and insect attacks can be reduced [3]. One possibility represents the application of nitrification inhibitors, which limit the contamination of groundwater with nitrogen, diminish the degree of nitrate(V) accumulation in leaves, and also decrease the content of oxalates [4, 5]. Moreover, the application of nitrification inhibitors can positively affect (increase) the contents of carbohydrates and ascorbic acid [6] and result in a more attractive leaf color [4]. Sometimes, however, they can reduce yield.

In the experiments presented here, it was investigated, whether higher fertilizer concentrations applied as Basammon-nitrogen (BAS) in combination with Dicyandiamide, an inhibitor of nitrification processes, result in a better growth and improve quality parameters of spinach plants, when compared with the conventional fertilizer calcium-ammonium nitrate (KAS) under field conditions. In addition, the influence of different nitrogen concentrations per hectare for both kinds of fertilizers on the quality of spinach and its suitability for storage was investigated. This study contributed to the improvement of quality and storage suitability of spinach by resulting in recommendations for fertilization and storage systems.

Material and methods

Spinach plants (*Spinacia oleracea* L. cv. San Felix F1) were grown in experimental fields at the Marhof Research Station, Wesseling, of the University Bonn, Germany, under conditions in line with agricultural practice in a randomized block design with four replicates of each block (split-plot), where the area of single parcel was 11.25 m^2. The first factor was the applied form of fertilizer with 27 % nitrogen (calcium--ammonium nitrate (KAS) consisting of 13.5 % nitrate and 13.5 % ammonium and Basammon-nitrogen (BAS) consisting of 6.8 % nitrate(V), 18.2 % ammonium and 2 % nitrification blocker Dicyandiamide (DCD)). The second factor was the amount of applied nitrogen per hectare (standard supply of 220 kg and excessive supply of 330 kg). As control KAS with 220 kg $N \cdot ha^{-1}$ was used. Plants were cultivated on a brown soil (70–78 soil points) with a thickness of 0.75 to 1.20 m situated on top of sand and gravel, of middle water permeability and of middle to high water storage capacity with the groundwater level at 13 m depth. The soil (0–30 cm) was characterized by an pH_{KCl}-value of 6.6, P_2O_5 0.43 $g \cdot kg^{-1}$ soil, K_2O 0.24 $g \cdot kg^{-1}$ soil, and MgO 18 $g \cdot kg^{-1}$ soil. Contents of nitrate(V) and ammonia before fertilization were 39.36 ± 12.87 and 17.4 ± 9.0 kg $N \cdot ha^{-1}$, respectively. Spinach was sown in rows with a distance of 25 cm (500 seeds/m^2) at three dates: 29.04., 7.05., and 12.05. Two $kg \cdot ha^{-1}$ of Venzar 80 WP (lenacil 80 %), a pre-emergency herbicide, were used to control weeds. Other pesticides were not used during the cultivation. After 6 weeks of growing the mature plants were harvested as a rosette (so called root-spinach) and stored for 16 days at a temperature of 2–4 ^{o}C and a relative humidity between 95–100 % under a controlled atmosphere consisting of 3 % CO_2 and either 4 % or 18 % O_2, respectively (4 replicates with 20 plants each). Analyses were carried out at the beginning and at the end of the storage period to investigate quality changes. Investigated parameters were: the contents of dry matter, nitrates(V) [7], chlorophyll [8], soluble carbohydrates [9], and selected mineral substances [9]. Furthermore, changes of leaves color and chlorophyll fluorescence of PS II as indicators of freshness were measured [9]. The obtained data were analyzed with the SPSS 9.01 statistical program (SPSS Inc, 1989–1999). All data sets were tested for normal distribution and variance homogeneity ($p \leq 0.05$). Means were compared by Duncan test for homogenous variances ($p \leq 0.05$).

Results and discussion

At the end of the vegetative growth period, differences between the applied cultivation practices with respect to the development of fresh mass, dry mass and leaf area of spinach were not detected. The results did not confirm the observations of Ko et al [10] of a diminished reduction of fresh mass during storage under an atmosphere with a lowered oxygen content. During storage of spinach under controlled atmosphere slight losses of fresh mass were observed, which did not exceed the critical value of 3 % and were independent from the kind of fertilizer, the amount of nitrogen supplied and the concentration of oxygen in the storage atmosphere. Losses of dry mass could not be ascertained. The results indicated an even, well balanced supply of plants with mineral nutrients and did not confirm Lazo [11] or Kolbe and Zhang [12], who showed that fertilization with excessive nitrogen concentrations, particularly in the form of ammonium resulted in enlarged mass losses during storage. The reduction of storage temperature to 3–4 ^{o}C, the elevated relative humidity of up to 100 %, and the increased CO_2 concentration assured optimal conditions for the storage of spinach, resulting in decreased losses of fresh mass, which were smaller than 3 %.

High doses of nitrogen applied as KAS or BAS during the experiment indeed enlarged the concentration of nitrate(V) in leaves of spinach (Table 1). However nitrate content did not exceed the allowed limit of 2500 mg $\cdot$ kg^{-1} fresh mass [13]. The effect of excessive nitrogen was still visible during storage, which resulted in a further increase in leaf nitrate content as a result of transpiration processes. Neither cold storage nor the reduction of oxygen content in the storage atmosphere below 4 % did result in a reduction of nitrate content. The highest content of nitrates(V) was found in leaves of spinach fertilized with BAS (Table 1).

In plants fertilized with KAS, Ca contents were elevated before and after storage compared with plants fertilized with BAS (Table 1). This was the result of the additionally supplied calcium in form of calcium-ammonium nitrate fertilizer containing 7 % CaO. The excessive fertilization with nitrogen did not influence the accumulation of Ca ions in spinach leaves.

Independent of the kind and amount of fertilizer an increase of leaf Ca content in spinach leaves was observed during storage (Table 1), which was caused by the translocation of Ca from leaf petioles and apical shoots to leaves [14]. At the same time the concentration of K decreased, especially in plants fertilized with BAS. These changes resulted from the opposite translocation of Ca and K, the latter being transported to leaf petioles and meristematic cells of the growth cone [14]. In spinach plants fertilized with KAS the translocation of K to the growth cone and to leaf petioles was higher (data not showed). However, K contents of spinach leaves after harvest were not significantly affected by the fertilization.

Table 1

Content of nitrate(V), calcium and soluble carbohydrates in spinach leaves as affected by the kind of fertilizer and nitrogen supply as well as oxygen content in the atmosphere during storage, calculated in $g \cdot kg^{-1}$ d.m. (mean values of three experiments, n = 36)

Storage [days]	KAS 220 kg N · ha^{-1}	KAS 330 kg N · ha^{-1}	BAS 220 kg N · ha^{-1}	BAS 330 kg N · ha^{-1}
		Nitrate(V)		
0	0.43 ± 0.12 e	0.71 ± 0.29 abc	0.50 ± 0.16 de	0.73 ± 0.19 ab
16 (18 % O_2)	0.52 ± 0.23 cde	0.81 ± 0.21 a	0.53 ± 0.30 cde	0.80 ± 0.16 a
16 (4 % O_2)	0.60 ± 0.28 bcde	0.81 ± 0.17 a	0.66 ± 0.35 abcd	0.82 ± 0.11 a
		Ca		
0	14.5 ± 1.8 def	15.2 ± 2.2 ef	13.5 ± 1.0 ef	11.7 ± 1.0 f
16 (18 % O_2)	19.2 ± 2.4 bcd	19.7 ± 2.6 bc	13.7 ± 1.7 ef	16.1 ± 2.7 cde
16 (4 % O_2)	20.7 ± 2.6 ab	24.1 ± 2.5 a	16.5 ± 3.5 bcde	16.5 ± 3.3 bcde
		Total soluble carbohydrates		
0	97.4 ± 25.2 a	77.1 ± 20.8 b	105.1 ± 28.4 a	77.0 ± 18.5 b
16 (18 % O_2)	54.4 ± 16.8 cd	51.2 ± 17.5 cd	59.0 ± 14.1 c	56.0 ± 13.2 cd
16 (4 % O_2)	44.9 ± 21.6 de	33.6 ± 9.9 e	45.3 ± 12.5 cde	34.3 ± 9.7 e
		Sucrose		
0	57.2 ± 19.9 ab	46.5 ± 18.6 b	61.0 ± 24.5 a	55.0 ± 12.5 ab
16 (18 % O_2)	23.6 ± 19.3 c	23.1 ± 18.6 c	21.8 ± 17.4 c	21.8 ± 17.5 c
16 (4 % O_2)	16.5 ± 16.7 c	10.9 ± 3.5 c	15.9 ± 7.2 c	12.0 ± 2.5 c
		Glucose		
0	26.5 ± 7.2 ab	20.6 ± 8.2 bcd	29.1 ± 8.4 a	14.4 ± 10.8 def
16 (18 % O_2)	18.6 ± 4.4 cd	18.9 ± 5.7 cd	23.6 ± 7.0 abc	22.7 ± 3.7 bc
16 (4 % O_2)	12.6 ± 7.6 ef	8.7 ± 6.5 f	15.2 ± 7.7 de	11.5 ± 6.3 ef
		Fructose		
0	13.7 ± 6.2 abc	10.0 ± 7.0 bcd	15.0 ± 8.3 ab	7.6 ± 6.3 d
16 (18 % O_2)	12.4 ± 5.5 abcd	9.2 ± 5.8 cd	13.6 ± 7.5 abc	11.6 ± 6.4 abcd
16 (4 % O_2)	15.8 ± 5.1 a	14.0 ± 3.8 ab	14.2 ± 4.1 ab	10.9 ± 2.2 bc

Excessive fertilization with nitrogen resulted, independent of the kind of fertilizer, in a significant reduction of soluble carbohydrate contents in spinach leaves, particularly in reducing sugars such as glucose and fructose (Table 1). This effect persisted until the end of the shelf-life period. During this period a significant decrease of the sum of carbohydrates, caused by the decay of sucrose and the consumption of glucose in metabolic processes, was observed. Decreasing the concentration of oxygen to the 4 % level led to a quicker decrease of their concentrations (Table 1). In addition, plants fertilized with KAS were characterized by a slower reduction of the concentrations of soluble carbohydrates, except of fructose. According to Takebe et al [6] excessive fertilization with nitrogen negatively influenced carbohydrate metabolism, in particular it increased the degree of sugar degradation. These observations were confirmed by the present study. The excessive supply of nitrogen, irrespective of the applied fertilizer, resulted in a significant decrease of soluble carbohydrate contents.

The decrease of the oxygen concentration in the storage atmosphere resulted in the decrease of sugar content, particularly of sucrose and glucose. The concentration of oxygen in the atmosphere of about 4 % favored fermentative processes, probably as the result of a disadvantageous gas exchange among stored spinach plants and/or diffusion barriers within the tissue [10, 14]. In case of fermentation, carbohydrates were not completely oxidized to water and CO_2, but were degraded to ethanol. Hence, 19 times more sugar was needed for the synthesis of the same amount of ATP compared to the oxidative dissimilation. Oxygen deficiency in tissues of numerous vegetables and fruits has frequently been recorded at atmospheric oxygen concentration of ca 3 % and lower [15]. For spinach the so-called 'Extinction Point', at which fermentation processes occur, is known to correspond to 0.8 % O_2 at 0.5 % CO_2 [16]. The appearance of fermentative processes already at a concentration of 4 % O_2 was probably related to a rise in the CO_2 concentration in the storage atmosphere to the 3 % level.

At harvest, irrespective of the applied fertilizer treatment, optimum quantum yield (Fv/Fm) of photosystem II (PSII) recorded after dark adaptation reached levels of 0.82, which is typical of healthy, unimpaired plants (Table 2). Generally, storage, particularly under an atmosphere containing 4 % O_2, resulted in a significant decrease of optimum quantum yield and maximum fluorescence, while basal fluorescence rose simultaneously. The decrease of maximum fluorescence frequently indicates the occurrence of a reversible kind of stress, however an increase of basal fluorescence is interpreted as a damage of photosystem II (PSII) reaction centers at the acceptor side [17]. Changes in chlorophyll fluorescence generally reflect disturbances of chloroplast functions, a decrease of spinach quality and the loss of its freshness as a result of the 16-day storage period.

Content of total chlorophyll, Chl a and Chl b at time of crop harvest was related to nitrogen supply (Table 2). The excessive supply of nitrogen resulted in an increase of leaf chlorophyll content in spinach, independent of the kind of fertilizer. During storage of plants grown with BAS, total chlorophyll content and content of Chl *b* rose significantly (Table 2) independent of the amount of nitrogen fertilizer applied. In all cases the decrease of the oxygen concentration to the 4 % level improved the preservation of total chlorophyll content during storage (Table 2). These changes however, were not reflected in a better color appearance of leaves, expressed as a decreasing Chroma C* value (Table 2).

The present research demonstrated the essential influence of the applied fertilizer treatment on the intensity of leave color, expressed as the Chroma C* value (Table 2). The excessive fertilizations with nitrogen as BAS resulted in a more intensive color of spinach leaves. Storage under controlled atmosphere did not influence the intensity of leaf color. The experiments could not prove an impairment of leaf color during storage

(Table 2). This may be explained by adequate storage conditions, particularly the high relative humidity of up to 100 %, the low air temperature of about 2–4 °C, and the elevated CO_2 concentration in the storage atmosphere.

Table 2

Optimum quantum yield, contents of total chlorophyll, Chl *a*, Chl *b*, the Chl *a/b* ratio and color values of spinach leaves as affected by the kind of fertilizer, amount of nitrogen supply and oxygen content in the atmosphere during storage (mean values of three experiments, n = 36)

Storage [days]	KAS 220 kg N · ha^{-1}	KAS 330 kg N · ha^{-1}	BAS 220 kg N · ha^{-1}	BAS 330 kg N · ha^{-1}
Fv/Fm [rel. units]				
0	0.82 ± 0.08 a	0.83 ± 0.11 a	0.82 ± 0.09 a	0.82 ± 0.10 a
16 (18 % O_2)	0.58 ± 0.13 b	0.60 ± 0.11 b	0.64 ± 0.13 b	0.62 ± 0.12 b
16 (4 % O_2)	0.51 ± 0.09 c	0.50 ± 1.04 c	0.45 ± 0.14 c	0.49 ± 0.20 c
Total chlorophyll [mg · kg^{-1} d.m.]				
0	9.61 ± 0.76 bc	9.77 ± 0.66 abc	9.27 ± 0.64 c	10.16 ± 0.63 abc
16 (18 % O_2)	9.24 ± 1.16 c	9.45 ± 0.82 c	9.90 ± 0.67 abc	9.75 ± 1.59 abc
16 (4 % O_2)	9.71 ± 0.55 abc	10.04 ± 1.04 abc	10.58 ± 1.02 ab	10.70 ± 0.99 a
Chl *a* [mg · kg^{-1} d.m.]				
0	7.01 ± 0.48 ab	7.16 ± 0.45 ab	6.91 ± 0.49 ab	7.47 ± 0.49 a
16 (18 % O_2)	6.72 ± 0.88 b	6.84 ± 0.62 ab	7.18 ± 0.54 ab	7.04 ± 1.08 ab
16 (4 % O_2)	7.05 ± 0.42 ab	7.20 ± 0.75 ab	7.38 ± 0.68 ab	7.52 ± 0.71 a
Chl *b* [mg · kg^{-1} d.m.]				
0	2.59 ± 0.29 bc	2.62 ± 0.29 bc	2.36 ± 0.22 c	2.70 ± 0.17bc
16 (18 % O_2)	2.52 ± 0.29 bc	2.61 ± 0.22 bc	2.73 ± 0.15 b	2.71 ± 0.53b
16 (4 % O_2)	2.66 ± 0.18 bc	2.85 ± 0.31 b	3.20 ± 0.51 a	3.18 ± 0.38a
Chl *a/b* ratio [rel. units]				
0	2.71 ± 0.14 bc	2.76 ± 0.24 b	2.94 ± 0.23 a	2.77 ± 0.10 b
16 (18 % O_2)	2.66 ± 0.09 bc	2.62 ± 0.11 bc	2.63 ± 0.10 bc	2.61 ± 0.16 bc
16 (4 % O_2)	2.66 ± 0.15 bc	2.53 ± 0.13 cd	2.34 ± 0.29 e	2.38 ± 0.22 de
Chroma C* [rel. units]				
0	20.06 ± 2.01 a	18.19 ± 0.94 ab	19.71 ± 1.33 a	15.69 ± 2.10 c
16 (18 % O_2)	19.92 ± 1.49 a	18.53 ± 1.71 a	19.59 ± 2.15 a	16.17 ± 3.17 bc
16 (4 % O_2)	20.14 ± 0.85 a	18.77 ± 2.13 a	19.94 ± 2.02 a	16.07 ± 2.96 bc

The choice of the suitable kind of fertilization in case of only small differences in growth and postharvest behavior should be based first of all on the profitability of the applied cultivation practice. Excessive fertilization, independent of the kind of applied fertilizer, resulted in additional costs and in the decrease of the yield per hectare (Table 3). In comparison with the standard supply, the excessive fertilization resulted in measurable losses and lowered profits in the case of KAS by about 6400 EUR and in the case of BAS by about 5540 EUR per hectare. In case of the standard nitrogen supply, fertilization in the form of BAS resulted in the greatest profit.

Table 3

Summarized calculation of costs, losses and profit by the application of KAS and BAS in spinach cultivation based on spinach yield harvested from 1 ha and stored for 16-days under controlled atmosphere

Combination	Yield [Mg · ha^{-1}, EUR · ha^{-1}]	Storage losses [%, EUR · ha^{-1}]		Fertilizer [EUR · ha^{-1}]	Profit [EUR · ha^{-1}]	
		18 % O_2	4 % O_2		18 % O_2	4 % O_2
KAS 220 kg · N/ha	30.30 60600	1.97 1194	1.25 758	1062.5	58343.5	58779.5
KAS 330 kg · N/ha	27.42 54840	2.52 1382	1.87 1026	1527.7	51930.3	52286.3
BAS 220 kg · N/ha	30.84 61680	1.55 956	1.83 1129	366.6	60357.4	60184.4
BAS 330 kg · N/ha	28.14 56280	1.62 912	2.27 1278	550.1	54817.9	54451.9

Assumption: mean prize for (2008): a) 1 Mg of spinach: 2000 EUR, b) 1 Mg KAS: 1250 EUR, c) 1 Mg BAS: 450 EUR.

Conclusions

1. During storage under controlled atmosphere both of the tested fertilizers, KAS and BAS, showed similar influences on spinach quality, especially on losses of fresh mass, which did not reached the allowed limit of losses of 3 %.
2. The positive influence of fertilization with BAS resulted in a more intensive leaf color and higher contents of chlorophyll.
3. Fertilization in the form of KAS resulted in a greater leaf mass and a higher concentration of Ca in the plant.
4. Excessive nitrogen fertilization improved leaves color, lowered the content of sugars, and enhanced the accumulation of nitrates(V), especially during storage. Worthy of note, excessive nitrogen fertilization resulted in higher costs and caused leaching of nitrogen into the groundwater.
5. The reduction of oxygen content in the storage atmosphere from 18 % to 4 % at a CO_2 concentration of 3 % was unfavorable for spinach plants due to the enhanced consumption of sugars and production of ethanol, which resulted in a quicker loss of spinach quality.
6. Based on the results of the present experiment it can be concluded that spinach should be stored at a low temperature of 0–5 ^{o}C, high humidity of more than 98 % and in an atmosphere consisting of 3–5 % CO_2 with a partially reduced oxygen concentration not lower than 7–10 %.

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Abstrakt: Celem pracy było przebadanie wpływu nawozów azotowych z przewagą związków amonowych zawierających inhibitor nitryfikacji (DCD) opóźniający uwalnianie azotu do gleby na rozwój, plonowanie i jakość plonu oraz zdolność przechowalniczą szpinaku w porównaniu z konwencjonalnym nawozem stosowanym w jego uprawie. Ponadto wpływ zastosowanych nawozów przebadano w zależności od ilości ich dawki. Badania wykazały, że zastosowanie azotu w postaci Basammonu spowodowało lepsze wybarwienie liści, większą zawartość chlorofilu i tendencyjnie wyższy plon w porównaniu do saletry wapniowo-amonowej. Niezależnie od rodzaju nawozu optymalną okazała się dawka standardowa w ilości N 220 kg $\cdot$ ha^{-1}. Luksusowe nawożenie azotem w ilości N 330 kg $\cdot$ ha^{-1} spowodowało obniżenie zawartości cukrów, zwiększoną koncentrację azotanów i obniżenie walorów smakowych, przy jednoczesnym, niepożądanym wzroście kosztów zabiegów i zanieczyszczenia środowiska na skutek wypłukiwania azotanów do wód gruntowych. Pozytywnym aspektem okazało się zwiększenie intensywności wybarwienia liści. Rodzaj nawozu nie wpłynął na zdolność przechowalniczą szpinaku, natomiast nadmiar azotu spowodował większe straty węglowodanów rozpuszczalnych w czasie przechowywania.

Słowa kluczowe: *Spinacia oleracea*, saletra wapniowo-amonowa, Basammon, jakość, przechowywanie w kontrolowanej atmosferze

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INFLUENCE OF THE ACTIVE SUBSTANCE OF PRP®FIX ON THE CONVERSION OF NITROGEN IN COMPOSTS FROM THE MUNICIPAL SEWAGE SLUDGE

WPŁYW SUBSTANCJI CZYNNEJ PRP®FIX NA PRZEMIANY AZOTU W KOMPOSTACH Z KOMUNALNEGO OSADU ŚCIEKOWEGO

Abstract: Aim of the conducted research was to estimate influence of mineral granulate PRP®FIX on conversions of total, ammonium and nitrate nitrogen in composts prepared from municipal sewage sludge with addition of straw and urban green waste. Composts were prepared in three repetitions in November of 2007 and were composted in 70 dm^3 plastic containers kept in building of Hall of Vegetation of the former University of Agriculture.

The first compost consisted of municipal sewage sludge (70 %) and wheaten straw (30 %), the second consisted of sewage sludge (70 %) and urban green waste (30 %). In the first series of experiment decomposition was conducted without addition of PRP®FIX substance and in the second series PRP®FIX substance was added in amount of 3 kg per 1 m^3 of composted mass. Decomposition of composts was conducted through 180 days and total content of nitrogen as well as its ammonium and nitrate forms were determined each 30 days.

Conducted research show that during the time of decomposition of composts prepared from sewage sludge with 30-percentage addition of structure-making materials content of total nitrogen decreased in their mass. Course of changes of ammonium and nitrate nitrogen content in composts was different. In both of the composts content of $N\text{-}NH_4$ was increasing until 90th day of composting and after that period was decreasing. However, considerable increase of content of nitrate nitrogen was found after 120 days and lasted till 180th day of composting.

Addition of PRP®FIX substance caused increase of content of ammonium nitrogen on average by 17.2 % and had no distinct influence on shaping on total content of nitrogen and its nitrate form.

Keywords: municipal sewage sludge, composts from sewage sludge, chemical composition, fertilizing value, active substance PRP®FIX

Civilization development is causing more and more waste including among others municipal sewage sludge. Methods of utilization are being searched limiting their harmful influence on environment.

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One of the cheapest method of recycling is process of composting with addition of different organic waste. As a result of that process pathogenic threat is being eliminated and the fertilizing value is being preserved or increased in received product [1].

In order to accelerate the decomposition process and increase the availability of macro- and micronutrients to composting mass are added different preparations. One of them can be active substance PRP®FIX containing complex of mineral ingredients which regulate the development of microorganisms in waste mass.

With this end in view in 2007 researches were conducted which aim was estimation of influence of active substance PRP®FIX on conversions of total, ammonium and nitrate nitrogen in composts prepared from sewage sludge.

Material and methods

In November of 2007 in hall of vegetation of the former University of Agriculture in Szczecin composts were prepared, which in 70 % (in conversion on dry matter) consisted of municipal sewage sludge and in 30 % of wheaten straw or urban green waste. In the first series of experiment decomposition of composts were conducted without PRP®FIX and in the second series with addition of 3 kg of PRP®FIX in conversion on 1 m^3 of composts.

Experiment was set up in three repetitions. Decomposition of composts was conducted through 180 days and total content of nitrogen and its mineral forms ($N-NH_4$ and $N-NO_3$) were determined each 30 days.

Content of the first row elements (N, P, K) and of the second (Ca, Mg, S) decides on the fertilizing value of composts. In sewage sludge, used for preparation of composts, content of nitrogen was one and a half higher than in manure (30.2 $g \cdot kg^{-1}$ d.m.). Content of phosphorus (13.02 $g \cdot kg^{-1}$ d.m.) was also higher than mean content in manure, while content of potassium and magnesium was lower (Table 1). Data in Table 2 showed that wheaten straw, in comparison with urban green waste (two structure-making materials), contained more nitrogen, potassium, calcium and sulphur.

Table 1

Physical and chemical properties of sewage sludge

pH in H_2O	Dry matter [$g \cdot kg^{-1}$]	Organic carbon	$N-NH_4$	$N-NO_3$	Total content					C:N (N=1)
					N	P	K	Mg	S	
		[$g \cdot kg^{-1}$ d.m.]								
10.1	225.0	251.0	1.24	0.030	30.2	13.02	3.98	3.05	4.98	8.31

Table 2

Total content of macronutrients in components of composts [$g \cdot kg^{-1}$ d.m.]

Components	N	P	K	Mg	Ca	S
Wheaten straw	10.1	1.26	14.1	0.90	2.31	2.1
Urban green waste	8.25	2.19	2.94	0.98	2.04	1.07

Content of heavy metals in sewage sludge did not exceed norms given in Decree of Minister of Environment [2].

Chemical analyzes of composts were conducted in accordance with the current norms: ammonium nitrogen – PN 75/C-04576-15, nitrate nitrogen in the presence of phenyldisulphide acid, total nitrogen was determined on Coestech CNS elemental analyzer. Significance of differences between individual determined values was assessed with Tukey's test on significance level $p < 0.05$.

Results and discussion

In the day of setting up the experiment total content of nitrogen in compost prepared from sewage sludge and wheaten straw with and without PRP®FIX was almost equal (37.8 and 37.9 g · kg^{-1} d.m.) – Table 3. However, in compost with 30-percent addition of urban green waste – with and without PRP®FIX total content of nitrogen was lower 31.2 and 32.1 g · kg^{-1} d.m.), but somewhat higher content of that element was noted in compost with PRP®FIX. During the time of decomposition of both composts with and without PRP®FIX total content of nitrogen was decreasing. Significant decrease of total content of nitrogen, in comparison with the day the experiment was set up, was found after 180 days of decomposition of composts. Mean loss of total content of nitrogen in that time amounted to 38.3 %. There was no significant difference noted in total content of nitrogen in composts prepared from sewage sludge with straw or urban green waste with and without addition of PRP®FIX. But similar as after preparation of composts more nitrogen was contained in composts prepared from sewage sludge and straw than in composts with addition of urban green waste.

Table 3

Changes of total content of nitrogen in composts prepared from municipal sewage sludge with and without participation of PRP®FIX during the time of their decomposition [g · kg^{-1} d.m.]

Type of compost*	Time of research								$LSD_{0.05}$
	on the day of setting up the experiment	after 30 days	after 60 days	after 90 days	after 120 days	after 150 days	after 180 days	$\bar{x}$	
Compost I	37.8	34.8	32.4	26.4	24.4	23.8	22.9	28.9	n.s.
Compost I + PRP®FIX	37.9	35.0	32.5	27.0	25.5	23.6	22.4	29.1	
Compost II	31.2	30.2	28.5	25.5	21.8	21.8	20.1	25.6	
Compost II + PRP®FIX	32.1	30.4	28.1	25.6	21.8	21.8	20.3	25.7	
Mean	34.7	32.6	30.4	26.1	23.4	22.7	21.4	27.3	
$LSD_{0.05}$	12.30								

* Explanations of composition of composts in conversion to dry matter: Compost I – municipal sewage sludge (70 %) + wheaten straw (30 %), Compost I + PRP®FIX – municipal sewage sludge (70 %) + wheaten straw (30 %) + PRP®FIX, Compost II – municipal sewage sludge (70 %) + urban green waste (30 %), Compost II + PRP®FIX – municipal sewage sludge (70 %) + urban green waste (30 %) + PRP®FIX.

Decomposition of organic compounds had influence on changes of total content of nitrogen. Under the influence of their decomposition nitrogen converts to form of ammonium. In the research of Krzywy et al [3] there was the decrease of total nitrogen content in composts prepared from sewage sludge. Ciećko et al [4] also proved that during the composting of sewage sludge with and without addition of organic materials losses of nitrogen followed. Huge influence on their tempo had properties and origin of sewage sludge as well as type of added structure components.

After the preparation of composts higher content of ammonium nitrogen was in compost prepared from sewage sludge and urban green waste. Addition of PRP®FIX did not become significantly diverse of that form of nitrogen in both composts (Table 4). On 90th day of decomposition of composts significant increase of $N\text{-}NH_4$ content was found, in relation to content determined in the day of setting up the experiment. Mean content of $N\text{-}NH_4$ in composts increased almost six times and was always higher in composts with addition of PRP®FIX. After 90 days of decomposition content of ammonium nitrogen in composts decreased reaching after 180 days in compost prepared from sewage sludge+straw content of 4.87 $g \cdot kg^{-1}$ d.m. and in compost prepared from sewage sludge+urban green waste – 4.92 $g \cdot kg^{-1}$ d.m. However, in composts with addition of PRP®FIX there was 13 % above of that form of nitrogen.

Table 4

Changes of content of ammonium nitrogen in composts prepared from municipal sewage sludge with and without participation of PRP®FIX during the time of their decomposition [$g \cdot kg^{-1}$ d.m.]

Type of compost*	Time of research								$LSD_{0.05}$
	on the day of setting up the experiment	after 30 days	after 60 days	after 90 days	after 120 days	after 150 days	after 180 days	$\bar{x}$	
Compost I	1.00	1.44	3.15	6.37	5.33	5.03	4.87	3.88	n.s.
Compost I + PRP®FIX	1.05	1.66	4.23	7.21	6.81	6.24	5.52	4.67	
Compost II	1.21	1.41	3.45	6.86	6.03	5.35	4.92	4.17	
Compost II + PRP®FIX	1.22	1.47	4.37	7.45	6.95	6.29	5.58	4.76	
Mean	1.12	1.49	3.80	6.97	6.28	5.72	5.22	4.37	
$LSD_{0.05}$	5.281								

* Explanations of composition of composts are given in Table 3.

On the day of the setting up the experiment mean content of nitrate(V) nitrogen in composts amounted to 0.056 $g \cdot kg^{-1}$ d.m. which presented merely 0.16 percentage participation in total content of nitrogen. Till 90th day of decomposition changes of content of $N\text{-}NO_3$ in composts were not large. After that period significant increase of content of $N\text{-}NO_3$ in composts, which on 180th day of research, in relation to initial value, amounted on average 69.9 %. Differences in content of $N\text{-}NO_3$ in individual composts were not statistically proved, but somewhat higher content of that form was in composts with addition of PRP®FIX.

Table 5

Changes of content of nitrate(V) nitrogen in composts prepared from municipal sewage sludge with and without participation of PRP®FIX during the time of their decomposition [g · kg^{-1} d.m.]

Type of compost*	Time of research								$LSD_{0.05}$
	on the day of setting up the experiment	after 30 days	after 60 days	after 90 days	after 120 days	after 150 days	after 180 days	$\bar{x}$	
Compost I	0.052	0.052	0.055	0.057	0.074	0.083	0.097	0.067	n.s.
Compost I + PRP®FIX	0.063	0.063	0.063	0.048	0.075	0.084	0.103	0.071	
Compost II	0.054	0.043	0.054	0.049	0.065	0.073	0.084	0.060	
Compost II + PRP®FIX	0.053	0.044	0.055	0.054	0.076	0.082	0.097	0.066	
Mean	0.056	0.050	0.057	0.052	0.072	0.080	0.095	0.066	
$LSD_{0.05}$	0.037								

* Explanations of composition of composts are given in Table 3.

In opinion of Struczyński [5] appearance of nitrate nitrogen in compost mass shows its maturity.

Conclusions

1. During the decomposition of composts prepared from municipal sewage sludge with 30 % addition of structure-making materiale total content of nitrogen in their mass decreased.

2. Course of changes of ammonium and nitrate(V) nitrogen content in composts was different. In both of the composts content of $N\text{-}NH_4$ was increasing until 90^{th} day of composting and after that period was decreasing. However, considerable increase of content of nitrate nitrogen was determined after 120 days and lasted till 180^{th} day of composting.

3. Addition of PRP®FIX substance caused increase of content of ammonium nitrogen on average by 17.2 % and had no larger influence on shaping on total content of nitrogen and its nitrate form.

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WPŁYW SUBSTANCJI CZYNNEJ PRP®FIX NA PRZEMIANY AZOTU W KOMPOSTACH Z KOMUNALNEGO OSADU ŚCIEKOWEGO

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Abstrakt: Przeprowadzone badania miały na celu określenie wpływu granulatu mineralnego PRP®FIX na przemiany azotu ogólnego, amonowego i azotanowego(V) w kompostach z komunalnego osadu ściekowego z dodatkiem słomy i odpadów zieleni miejskiej. Komposty sporządzono w trzech powtórzeniach w listopadzie 2007 roku i kompostowano w 70-litrowych pojemnikach plastikowych, przechowywanych w budynku Hali Wegetacyjnej byłej Akademii Rolniczej w Szczecinie.

Pierwszy kompost składał się (w przeliczeniu na suchą masę) z komunalnego osadu ściekowego (70 %) oraz słomy pszennej (30 %), a drugi z osadu ściekowego (70 %) i odpadów zieleni miejskiej (30 %). W I serii doświadczenia rozkład prowadzono bez dodatku, a w serii II do masy kompostowej dodano substancję PRP®FIX w ilości 3 kg na 1 m^3 masy kompostowej. Rozkład kompostów prowadzono przez 180 dni, oznaczając co 30 dni ogólną zawartość azotu oraz jego formy amonową i azotanową(V).

Przeprowadzone badania wskazują, że w czasie rozkładu kompostów z komunalnego osadu ściekowego z 30-procentowym dodatkiem materiałów strukturotwórczych nastąpiło zmniejszenie w ich masie ogólnej zawartości azotu. Przebieg zmian zawartości azotu amonowego i azotanowego(V) w kompostach był różny. W obu kompostach zawartość $N\text{-}NH_4$ zwiększała się do 90. dnia kompostowania, a po tym okresie zmniejszała się. Natomiast znaczniejsze zwiększenie zawartości azotu azotanowego(V) stwierdzono po 120 dniach i trwało ono do 180 dnia kompostowania. Natomiast dodatek substancji PRP®FIX spowodował wzrost zawartości azotu amonowego średnio o 17,2 %, i nie miał większego wpływu na kształtowanie ogólnej zawartości azotu i jego formy azotanowej(V).

Słowa kluczowe: komunalny osad ściekowy, komposty z osadów ściekowych, skład chemiczny, wartość nawozowa, substancja czynna PRP®FIX

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INFLUENCE OF DIVERSIFIED FERTILIZATION ON NITRATES CONTENTS IN SOIL AND IN WILD STRAWBERRY FRUITS

WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA NA ZAWARTOŚĆ AZOTANÓW W GLEBIE I W OWOCACH POZIOMKI

Abstract: The objective of an experiment conducted in 2005–2007 was to determine the effect of the application of composted bark (20 Mg · ha^{-1} d.m.) and manure (20 Mg · ha^{-1} d.m.) on the nitrate content of soil and wild strawberry fruits. Both compost and manure caused an increase in the content of readily hydrolyzable nitrogen (by 66 % and 79 % respectively) and N-NO_3 (by 165 % and 188 % respectively) in soil, compared with the control treatment. Elevated levels of readily mineralizable nitrogen and N-NO_3 in soil contributed to an increase in the total nitrogen content of wild strawberry fruits, by 20.4 % and 29.7 % respectively. Organic fertilization had no significant effect on N-NO_3 accumulation in wild strawberry fruits.

Keywords: wild strawberry fruits, soil, nitrates, organic fertilization, bark compost, manure

The wild strawberry cultivation on a productive scale is not as widespread as the cultivation of other fruits [1]. Currently, there is a significant growth in the interest in this plant because of its dietetic values. The national and international literature includes only a few works on the cultivation of this type of plant. The accurate growth of this plant is determined by the composition of the nutritive components in the soil [2]. The aim of this work was to compare the effect of the organic fertilizers (manure and bark compost) on the content of nitrates in the soil and in the fruits of the wild strawberries.

Materials and methods

A field trial was carried out in 2005–2007. Wild strawberries cv. Baron Solemacher were grown in light soil containing 20 % silt and clay, as well as available nutrients in

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the following amounts: P – 18 mg · kg^{-1}, K – 80 mg · kg^{-1}, Mg – 17 mg · kg^{-1}, Ca – 106 mg · kg^{-1} soil, pH 5.8 in 1M KCl. Wild strawberries were planted in strips and rows, with two rows 50 cm apart within the strip and planting distance of 40 cm within the row. The entire wild strawberry plantation was mulched with straw during the growing season.

The experiment, performed in three replications, involved three treatments: 1 – control without fertilization, 2 – fertilization with composted bark in the amount of 20 Mg · ha^{-1} d.m., 3 – fertilization with manure in the amount of 20 Mg · ha^{-1} d.m. The fertilizers were ploughed in to a depth of 20 cm. The macronutrient content of fertilizers is given in Table 1.

Table 1

Macronutrient content of fertilizers

Fertilizer	N	P	K	Mg	Ca
	[g · kg^{-1} d.m.]				
Bark compost	12.0	13.2	37.1	1.8	4.7
Manure	25.3	14.0	47.0	2.9	4.3

Total nitrogen content was determined by the Kjeldahl method, N-NO_3 content was measured spectrophotometrically (PN-R04028), and readily hydrolyzable nitrogen content was estimated by the Cornfield method. Soil samples for chemical analyses were collected during flowering and fruiting, and at the end of the growing period. The levels of total nitrogen (Kjeldahl method) and N-NO_3 (colorimetric method with the use of phenyl disulfonic acid) were determined in wild strawberry fruits immediately after harvest.

Fruits were harvested from June 4 to October 15 each year, at 10–15 day intervals.

Results

Since the yield and quality of wild strawberry fruits depend not only on fertilization but also on weather conditions, average air temperatures and precipitation totals during the growing season (from March to October) are presented below:

Year	Temperature [^{o}C]	Rainfall [mm]
2005	10.25	360.16
2006	17.73	483.60
2007	12.56	563.36

The content of total nitrogen, readily hydrolyzable nitrogen and nitrate nitrogen in soil affects plant nutrition (Table 2). Total nitrogen levels did not change significantly throughout the experimental period or as a result of fertilization. Readily hydrolyzable nitrogen is unstable, it undergoes rapid mineralization and may be taken up by plants [3]. The content of this nitrogen fraction was significantly affected by fertilization – it increased 1.66-fold and 1.79-fold, compared with the control treatment, following the application of compost and manure respectively. This is consistent with the findings of Mazur [4]. An analysis of quantitative changes in the above nitrogen fraction in particular years of the study showed that the year 2006 provided favorable conditions for its accumulation in the soil environment. Fertilization had a profound effect on the $N\text{-}NO_3$ content of soil, which increased 2.66-fold and 2.88-fold following the application of compost and manure, respectively. The increase in the levels of both nitrogen fractions was accompanied by an increase in their percentage share of total nitrogen. A similar dependency was noted by Mazur [5].

Table 2

The content of various nitrogen fractions in soil
(mean values of three sample collections)

Object	Years	Total N [$mg \cdot kg^{-1}$]	Hydrolyzable nitrogen		$N\text{-}NO_3$	
			[$mg \cdot kg^{-1}$]	content in total N [%]	[$mg \cdot kg^{-1}$]	content in total N [%]
Control	2005	107.0	10.8	10.1	6.8	6.4
	2006	108.0	23.3	12.3	7.2	6.7
	2007	108.1	10.2	9.4	5.4	5.0
	mean	107.7	14.8	13.7	6.5	6.0
Bark compost	2005	108.0	24.2	22.4	16.9	15.6
	2006	109.5	26.4	24.1	18.4	16.8
	2007	107.9	23.8	22.0	16.6	15.4
	mean	108.5	24.8	22.8	17.2	15.9
Manure	2005	113.3	26.4	23.3	17.0	15.0
	2006	101.9	28.8	28.3	19.8	19.4
	2007	110.6	24.4	22.1	19.2	17.4
	mean	108.6	26.5	24.4	18.7	17.2
$LSD_{0.05}$		n.s.	9.05		2.31	

The content of total nitrogen and nitrate nitrogen in wild strawberry fruits is presented in Table 3. In the compost-fertilized treatment, total nitrogen content increased 1.20-fold. Manure was found to have a more beneficial effect on total nitrogen content which increased 1.3-fold in the treatment fertilized with manure, in comparison with the control treatment (Fig. 1), which agrees with the findings of Feadi and Baruzzi [2]. Fertilization caused no significant changes in $N\text{-}NO_3$ content, while the proportion of $N\text{-}NO_3$ in total nitrogen decreased along with an increase in total nitrogen concentrations. Similar results were reported by Caruso et al [6]. In fertilized treatments, total nitrogen content decreased in the third year, and in the treatment with manure application also in the second year of the study. The same trend was observed with respect to $N\text{-}NO_3$ content, including in the control treatment. According to Tagliavini et al [7] and Tworkowski et al [8], the nitrate content of fruits may vary depending on weather conditions, the age of plants and nitrogen accumulation in roots.

Table 3

The total nitrogen content and nitrate(V) in the fruits of the wild strawberries

Object	Years	Total N [mg · kg^{-1} f.m.]	N-NO_3 [mg · kg^{-1} f.m.]	N-NO_3 content in total N [%]
Control	2005	120.3	45.5	37.4
	2006	123.6	42.8	34.6
	2007	122.5	30.6	25.0
	mean	122.1	39.6	32.4
Bark compost	2005	155.5	40.5	26.0
	2006	142.8	45.2	31.6
	2007	142.6	37.4	26.2
	mean	147.0	41.0	27.9
Manure	2005	165.0	49.6	30.1
	2006	160.2	42.0	26.2
	2007	150.0	34.6	23.1
	mean	158.4	42.1	26.6
$LSD_{0.05}$		12.4	n.s.	

Figure 1 illustrates the effect of fertilization on both nitrogen fractions. Relative data support the findings of other authors [1, 9], pointing to a more beneficial impact of manure than compost.

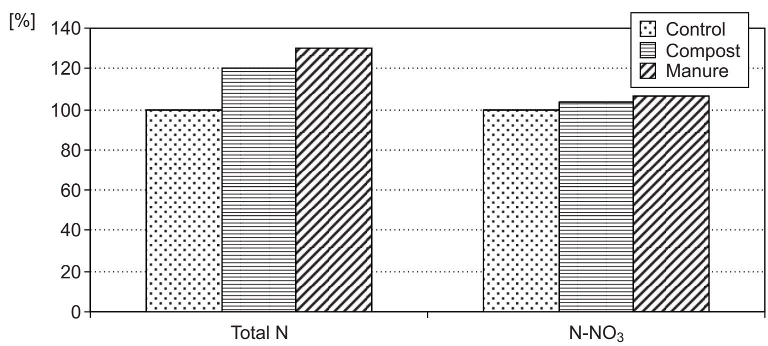

Fig. 1. The influence of fertilization on total nitrogen and nitrate(V) content in wild strawberry fruits (relative, mean values in three years)

Conclusions

1. The application of compost and manure to wild strawberries contributed to an increase in the content of readily hydrolyzable nitrogen (by 66 % and 79 %, respectively) and N-NO_3 (by 165 % and 188 %, respectively) in soil, compared with the control treatment.

2. The application of compost and manure caused an increase in the total nitrogen content of wild strawberry fruits, by 20.4 % and 29.7 %, respectively, in comparison with the control treatment.

3. Fertilization had no significant effect on N-NO_3 accumulation in wild strawberry fruits.

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WPŁYW ZRÓŻNICOWANEGO NAWOŻENIA NA ZAWARTOŚĆ AZOTANÓW W GLEBIE I W OWOCACH POZIOMKI

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Abstrakt: W latach 2005–2007 przeprowadzono doświadczenie, w którym badano wpływ nawożenia kompostem z kory w dawce 20 Mg · ha^{-1} s.m. i obornika 20 Mg · ha^{-1} s.m. na zawartość azotanów w glebie i owocach poziomki. Stosowanie kompostu i obornika spowodowało wzrost zawartości w glebie N-łatwo hydrolizującego o 66 % i 79 %, a N-NO_3 o 165 % i o 188 % w stosunku do kontroli. Wzrost zawartości w glebie azotu łatwo ulegającego mineralizacji i N-NO_3 wpłynęło na kumulację w owocach poziomki N-ogółem o 20,4 % i o 29,7 %. Zastosowane nawożenie organiczne nie miało statystycznie istotnego wpływu na kumulację N-NO_3 w owocach poziomki.

Słowa kluczowe: owoce poziomki, gleba, azotany, nawożenie organiczne, kompost z kory, obornik

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IMPACT OF LAND USE METHOD IN A CATCHMENTS AREA ON THE DYNAMICS OF THE NITROGEN COMPOUNDS IN THE OUTFLOWING WATER

WPŁYW SPOSOBU UŻYTKOWANIA ZLEWNI NA DYNAMIKĘ ZWIĄZKÓW AZOTU W WODACH ODPŁYWAJĄCYCH

Abstract: Research on the impact of catchments land management on the concentration of the nitrogen compounds (N-NO_3, N-NO_2 and N-NH_4) in the runoff water was conducted in the years 2005–2007. An investigation was made into the water being discharged from the catchments areas located in the foothill terrains of the Malopolska region, which were utilised as forest, agricultural land and rural settlement. An analysis of the concentrations of investigated indicators proves that differences exist both among the studied sites as well as differences which occur within the sites between the winter and summer periods.

In the outflowing water from the catchment area used as forest, N-NO_3 concentration varied in the range of 0.124 to 9.024 mg · dm^{-3}. In the water discharged from the catchment area utilised as typical agricultural land, the concentrations of nitrates(V) were in the range of 0.145–10.397 mg · dm^{-3} and in the case of water flowing from the catchment area used as rural settlement, the concentrations were in the range of 0.934–11.487 mg · dm^{-3}. The concentrations of nitrates(III) in the outflowing water from the catchment area utilized as forest varied in the range of 0.003 to 0.146 mg · dm^{-3}, while in the water discharged from the typical agricultural area the concentrations were in the range of 0.020–0.404 mg · dm^{-3} However, in the case of the water flowing from the area of rural settlement nitrate(III) concentrations were in the range of 0.050–0.811 mg · dm^{-3}. The concentrations of N-NH_4 in water flowing from the catchment area used as forest, varied from 0.008 to 0.189 mg · dm^{-3}, and similarly ammonia concentrations in the water originating from agricultural land were at the level of 0.113–9.169 mg · dm^{-3} respectively. But in the case of water coming from the area of rural settlement they were in the range of 0.310–5.698 mg · dm^{-3}.

Keywords: catchments land use, nitrate compounds, water quality

Under natural conditions, the chemical composition of water is determined by substances of natural origin. Changes in water quality are caused by its contact with the atmosphere, land surface and underground layer. Apart from the leaching process of the rock and the soil, the significant impact on the ion concentrations in the surface water of

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agricultural catchments play anthropogenic impact eg the quantity of the compounds supplied on their surface, together with dry and wet precipitation as well as the transformations caused by anthropogenic activity, including land use method. It has been increasingly established that agricultural activity is also a source of water pollution [1]. The biogenic substances discharged into the water from agricultural areas, which determine the quality of these resources, can originate from spatial agriculture production as well as from the farm buildings [2, 3]. The objective of this work was to assess the impact of the method of using land in a catchments area on the concentrations of nitrogen compounds ($N\text{-}NO_3$, $N\text{-}NO_2$ and $N\text{-}NH_4$) in the water which drains these catchments.

Material and methods

The field studies were conducted from November 2005 to October 2007 within two meso-regions, eg the Bochenski and Wisnicki Foothills [4], in the Malopolska region, the district of Bochnia (Bochnia and Nowy Wisnicz commune) and the district of Brzesko (Brzesko commune). Based on results by the direct method the quality of the water was assessed and classified according to the regulations established by the Minister for the Environment [Official Journal No. 32 posit. 284 from March 1st 2004]. For this purpose three streams were chosen which drain the area eg agricultural land, rural settlements and forested areas, and from which water samples were subjected to physical-chemical analyses, determined nitrates(V), nitrates(III) and ammonia by the flow method of colorimetric analysis.

Catchment area with typical forest character (Site Zl)

The catchment area of 247.07 ha is located in the terrain of the Bochnia commune. The length of the principal stream is about 2.7 km. Its source is situated at an elevation of 330 m a.s.l. and the sampling point is at an altitude 260 m a.s.l. The principal part of the area (47.40 %) is characterized by slopes in the range of 5–10 %. The slopes above 15 % are represented in the small area of the catchment, and this area is mainly forestland. 75 % of the catchment area is used as a forest with pine trees being the dominant species. Agricultural land occupies 23 % of the basin and majority lies in upper part of the catchment area. In these forestlands brown leached, brown acid, podsols and gley soils can be found.

Catchment area with typical rural settlement character (Site Zz)

The catchment area covers s 598.21 ha. The length of the main stream is about 4.5 km. In the terrain of the basin, land slopes within the range of 5 to 10 % are prevalent (37.58 %), however, the land with slopes (10–15 %) occupies 25.53 %. 71 % of the catchment area is used for agriculture, mainly for grain crops. 19 % of the catchment area is covered by forestlands which have pine and beech trees as a dominant species and these are located in the southern part of the basin. A large number of built-up areas belonging to the town of Jadowniki are located in the lower part of the catchment area.

In the agricultural areas brown leached soils, brown acid proper and podsols soils can be found.

Catchment area with typical agricultural character (Site Zr)

The catchment area is 130.25 ha. The length of the main stream, whose source is situated at an elevation of 320 m a.s.l., amounts to about 2.7 km. The water sampling point is located at an altitude of 220 m a.s.l. The prevailing part of the basin area (81.56 %) consists of the terrain with slopes in the range of 0–10 %. 93 % of the catchment area is used for agriculture. The major part, which constitutes 81 % of the catchment area, is occupied by arable lands. The catchment area is covered mostly by brown proper soils. The remaining part is made up of brown acid soils and podsols.

Results and discussion

Nitrates(V)

The distribution analyses of nitrate(V) concentrations in the water of the studied sites, confirm that differences exist among the sites in relation to each other, as well as the fact that differences exist within each site over particular months of the period in which this study took place. During the time of research, nitrate(V) concentrations registered in outflowing water from the catchment area used for agriculture (Zr), were at the level 0.145–10.397 mg · dm^{-3}. In the case of water flowing from the catchment area used as rural settlement (Zz), N-NO_3 concentration levels in the whole research period, were in the range of 0.934–11.487 mg · dm^{-3}. Whereas, the average concentrations of N-NO_3 in the outflowing water from the catchment area used as forest (Zl) amounted to 2.63 mg · dm^{-3} and varied in the range of 0.124 to 9.024 mg · dm^{-3}. The highest values were recorded in February and March, however, it was during the summer period that the lowest concentrations of N-NO_3 were predominant. Over the whole investigation period, this water was seen to contain lower levels of N-NO_3 concentration than the water being discharged from the area with a typical agricultural character (Tables 1, 2).

Nitrates(III)

Nitrate(III) concentrations, which in this period of research were recorded in outflowing water from the area with a typical agricultural character (Zr), vary in the range of 0.020–0.404 mg · dm^{-3}. The highest levels of N-NO_2 concentrations were observed over the period from May to September, with the lowest levels being recorded in the winter months. In the case of water coming from the terrain where a typical rural settlement (Zz) is located the levels of concentration over the whole research period were in the range of 0.050–0.811 mg · dm^{-3}. The distribution of the concentrations in particular months was similar to that for the water draining the agricultural terrain. The water flowing from the rural settlement area was characterised by a significantly higher concentration of N-NO_2. And in the water discharged from the catchment area used for forest (Zl), N-NO_2 concentration varied in the range of 0.003 to 0.146 mg · dm^{-3}. In the whole research period, water flowing off the catchment area used for forest was characterized by low levels of N-NO_2 concentrations, lower than in the water discharged from typical agricultural land and rural settlements (Tables 1, 2).

Ammonia

In this period of research, the concentrations of ammonia (N-NH_4) recorded in the catchment area used as typical agricultural land, (Zr) were at the level of 0.113–9.169

Table 1

The statistical significance of the average concentrations of biogenic chemical indicators in water flowing from the areas: typical agricultural (site Zr), rural settlement (site Zz) and forest (site Zl)

Treatment	Mean	*SD*	Remainder	Student *t*-test	*p*
Nitrates(V)					
Zr Zz	4.21 6.77	2.85 3.02	2.56**	–3.019	0.004
Zr Zl	4.21 2.63	2.85 2.80	1.58	1.942	0.058
Zz Zl	6.77 2.63	3.02 2.80	4.14**	4.929	0.000
Nitrates(III)					
Zr Zz	0.14 0.27	0.11 0.23	0.13*	–2.515	0.015
Zr Zl	0.14 0.04	0.11 0.04	0.10**	4.202	0.000
Zz Zl	0.27 0.04	0.23 0.04	0.23**	4.824	0.000
Ammonia					
Zr Zz	3.00 1.86	2.94 1.31	1.14	1.741	0.088
Zr Zl	3.00 0.07	2.94 0.05	2.93**	4.888	0.000
Zz Zl	1.86 0.07	1.31 0.05	1.79**	6.707	0.000

Explanations: Zr – catchment area used as typical agricultural land, Zz – catchment area used as a rural settlement and agricultural land, Zl – catchment area used as forest, *SD* – standard deviation, *p* – probability level, * – statistically significant at $p < 0.05$, ** – statistically significant at $p < 0.01$.

Table 2

The average seasonal levels of factors indicating the quality of water discharged from catchment areas of various usages

Parameters	Treatment	Period					
		XII–II	III–V	VI–VIII	IX–XI	XI–IV	V–X
Nitrates(V) [$mg \cdot dm^{-3}$]	Zr	6.10	4.57	3.43	2.76	5.10	3.22
	Zz	6.98	7.10	6.89	6.11	7.00	6.54
	Zl	4.40	3.35	1.68	1.07	4.04	1.22
Nitrates(III) [$mg \cdot dm^{-3}$]	Zr	0.079	0.115	0.215	0.138	0.071	0.203
	Zz	0.085	0.225	0.531	0.229	0.093	0.441
	Zl	0.060	0.046	0.032	0.015	0.043	0.033
Ammonia [$mg \cdot dm^{-3}$]	Zr	0.270	4.850	5.490	0.235	0.364	2.256
	Zz	1.076	2.651	1.650	1.773	0.810	1.452
	Zl	0.027	0.025	0.041	0.142	0.08	0.052

Explanations as in Table 1.

$mg \cdot dm^{-3}$. The lowest levels were observed during the winter months, and the highest in the summer periods. In the case of water flowing off an area of rural settlement (Zz), the concentration levels varied in the range of 0.310–5.698 $mg \cdot dm^{-3}$ over the whole investigation period. But in the catchment area which is used as forest (Zl), $N\text{-}NH_4$ concentrations in the water varied in the range of 0.008 to 0.189 $mg \cdot dm^{-3}$. And over the whole research period this water was characterized by manifold lower concentration levels of $N\text{-}NH_4$ than in the water being discharged from the terrain used as typical agricultural land (Tables 1, 2).

Visibly higher concentration levels of nitrates(V), nitrates(III) and ammonia in water flowing from the typical agricultural area can be recognized as being the result of agricultural activity, however, we should also link the higher concentration levels in the water coming from rural settlement areas with inappropriate wastewater management. The distinct increase in chemical compound concentrations in water flowing off the terrain where a compact built-up area is located, when compared with water from typical agricultural and forested areas is confirmed by research conducted by Pijanowski and Kanownik [5–7]. Also Koc et al [8, 9] when analysing the concentrations of selected chemical compounds in water coming from rural settlement and forest areas found that rural settlement played a dominant role in providing chemical compounds to the water. This finding supports the results obtained in this work. Rajda and Natkaniec [10] when comparing selected compounds in the water flowing from a catchment area characterised by typical agricultural and rural settlements confirmed that rural settlements increased their concentrations particularly in the case of $N\text{-}NO_2$, $N\text{-}NH_4$ and $P\text{-}PO_4$. Quality analysis by the direct method proved that the factors which lowered the water quality the most were biogenic compounds. In the case of water draining typical agricultural land its quality was decreased the most by ammonium and nitrate(III) – to

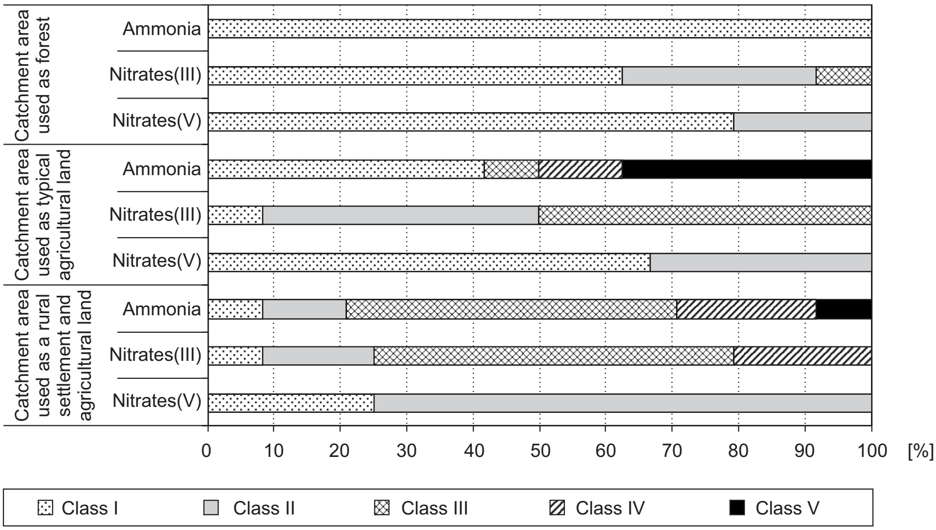

Fig. 1. Distribution of the frequency [%] of biogenic indicators of the quality of water flowing from the studied areas, characteristic for each class

the 4th class of water cleanness. The quality of water in streams flowing from the wooded areas was determined by biogenic compounds (maximum level of the 2nd class). And on the basis of a direct quality assessment of single water samples, it was found that only water flowing from forestland can be qualified as being of the 1st class of cleanness (Fig. 1).

Conclusions

1. The land use method has a significant impact on the concentration of nitrogen compounds in the surface water. Decisively, the lowest contents of investigated indicators in runoff water from a forest confirm the fact that wooded land establishes a biological barrier which limits the migration of nitrogen compounds to the surface water.

2. The principal source responsible for increasing the nitrogen compound concentration in the surface water of rural areas are pollutants originating from settlement areas. This is caused mainly by inefficient wastewater management.

3. This research has also shown the occurrence of seasonal changes in the investigated indicators over particular months, seasons as well as over a half-year period. The reduction in the concentration levels of respective compounds, together with the beginning of the growing season can be explained by the increased absorption of chemical elements by the vegetation cover.

4. On the basis of water classification, it can be assumed that increasingly its quality is being lowered by the proximity of rural settlement areas, subsequently by typical agricultural land and is most definitely least affected by forest. The significant impact

on the decrease in water quality in typical agricultural areas, particularly in rural settlements, is shown by biogenic indicators.

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WPŁYW SPOSOBU UŻYTKOWANIA ZLEWNI NA DYNAMIKĘ ZWIĄZKÓW AZOTU W WODACH ODPŁYWAJĄCYCH

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Abstrakt: Badania wpływu sposobu zagospodarowania zlewni na stężenia związków azotu ($N\text{-}NO_3$, $N\text{-}NO_2$ i $N\text{-}NH_4$) w wodach odpływających prowadzono w latach 2005–2007. Analizie poddano jakość wód odpływających z położonych w terenach podgórskich woj. małopolskiego zlewni o użytkowaniu: leśnym, rolniczym i osadniczo-rolniczym.

Analiza stężeń badanych wskaźników pozwala stwierdzić ich zróżnicowanie zarówno pomiędzy badanymi obiektami, jak również w czasie, głównie między okresem zimowym a letnim. W wodach odpływających z terenu zlewni o użytkowaniu leśnym stężenia $N\text{-}NO_3$ wahały się w przedziale od 0,124 do 9,024 mg · dm^{-3}. W wodach odpływających z terenu zlewni o użytkowaniu typowo rolniczym stężenia azotanów(V) mieściły się w granicach 0,145–10,397 mg · dm^{-3}, a w przypadku wód odpływających ze zlewni o użytkowaniu osadniczo-rolniczym w przedziale 0,934–11,487 mg · dm^{-3}. Stężenia azotanów(III) w wodach odpływających ze zlewni o użytkowaniu leśnym wahały się w przedziale od 0,003 do 0,146 mg · dm^{-3}, w wodach odpływających ze zlewni o użytkowaniu typowo rolniczym w granicach 0,020–0,404 mg · dm^{-3}, natomiast w przypadku wód odpływających z terenu o użytkowaniu osadniczo-rolniczym w przedziale 0,050–0,811 mg · dm^{-3}. Stężenia $N\text{-}NH_4$ w wodach odpływających z terenu zlewni o użytkowaniu leśnym wahały się od 0,008 do 0,189 mg · dm^{-3}, w wodach odpływających z terenu zlewni użytkowanej rolniczo kształtowały się na poziomie 0,113–9,169 mg · dm^{-3}, a w przypadku wód odpływających z terenu o użytkowaniu osadniczo-rolniczym w przedziale 0,310–5,698 mg · dm^{-3}.

Słowa kluczowe: użytkowanie zlewni, związki azotu, jakość wód

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INFLUENCE OF MUNICIPAL SEWAGE SLUDGE ON CONCENTRATION OF NITRATES(V) IN SOIL

WPŁYW KOMUNALNEGO OSADU ŚCIEKOWEGO NA ZAWARTOŚĆ AZOTANÓW(V) W GLEBIE

Abstract: In a four-year, microplot experiment (1 m^2) carried out on anthropogenic soil, the influence of sewage application on concentration of nitrates in soil was investigated. Municipal sewage sludge at the doses of 0, 70, 140, 210 and 280 Mg · ha^{-1} of fresh weight was introduced to soil in autumn 2004, after which grass mix was sown. The waste used in the research originated from the wastewater treatment plant in Olsztyn. In 2005–2008, soil for chemical analysis was sampled four times during each growing season (April, July, September and November). The content of nitrates in fresh soil matter was determined by colorimetric method with phenoldisulphonic acid.

Each year, nitrates in soil increased proportionally to a sewage sludge dose. Thus, the application of the highest dose, ie 280 Mg · ha^{-1}, raised the average N-NO_3 content in soil nearly two-fold higher than determined in the control soil. The highest accumulation of the mineral form of nitrogen was found in soil sampled in July, which could have been connected with a more intensive transformation of N compounds introduced to soil with sewage sludge. The determined values of N-NO_3 in soil fluctuated throughout the experiment, with the highest content of nitrates found in 2005, while in 2006 and 2007 the mean N-NO_3 concentrations were similar. In 2008, an insignificant increase of this nutrient in soil was determined.

Keywords: sewage sludge, nitrate in soil

Municipal sewage sludge is a waste fertilizer, which is rich in nutrients, including nitrogen compounds. Nitrogen is an elementary component essential for all organisms. Nitrate, as a one of the nitrogen mineral forms in soil, represents a small percentage of its total content. In contrast to NH_4^+, NO_3^- is poorly absorbed in soil and nitrates are easily leached into deeper horizons of soil. This process may endanger the quality of groundwater and surface waters [1]. When using sewage sludge for soil fertilization, nitrogen content, both in soil and in the applied dose of sludge, should be considered. The date of sludge application should also be taken into consideration so as to prevent potential adverse effects of nitrates(V) on the environment [2].

The purpose of the study has been to determine the impact of municipal sewage sludge doses on changes in the concentration of N-NO_3 in soil within four years.

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Material and methods

A four-year, microplot experiment (1 m^2) was established in 2004 on anthropogenic soil originating from clay. Sewage sludge was applied in autumn at the doses of 0, 70, 140, 210 and 280 Mg · ha^{-1} of fresh weight. Afterwards, grass mix was sown. In 2005–2008, soil for chemical analysis was sampled four times during each growing season (April, July, September and November). The waste fertilizer used in the research, which came from the wastewater treatment plant in Olsztyn, contained 27.61 % of dry matter, 33.30 g · kg^{-1} of total N, and its value of pH in water suspension was 8.39. Before the experiment, the soil contained 2.6 g · kg^{-1} of total nitrogen and its pH in 1 M KCl was 7.36. The content of N-NO_3 in soil was determined by colorimetric method with phenoldisulphonic acid.

Results and discussion

The study showed high variation of nitrate in soil depending on a dose of sewage sludge in the subsequent years (Table 1). The results are confirmed by the findings of Baran et al [3], who demonstrated considerable variation over time of N-NO_3 concentration in soil after application of sewage sludge.

Table 1

The content of N-NO_3 in soil [mg · kg^{-1}] in the subsequent years of the research depending on a dose of sludge

Sewage sludge dose [Mg · ha^{-1}]	Years				Mean
	2005	2006	2007	2008	
0	10.98	2.23	1.73	6.53	5.37
70	23.98	2.55	2.40	7.96	9.22
140	41.98	3.50	2.82	8.89	14.29
210	53.39	5.04	3.34	10.17	17.99
280	61.71	5.44	4.15	11.22	20.63
Mean	38.41	3.75	2.89	8.95	

$LSD_{0.05}$ years 0.29
$LSD_{0.05}$ doses 0.37
$LSD_{0.05}$ interaction 0.72

Increased amounts of waste introduced into soil resulted in a significant increase of concentration of N-NO_3 in soil (from 5.3 mg · kg^{-1} in the control object to about 20.5 mg · kg^{-1} after application of the highest dose). Slightly different results were obtained by Bożym and Pulikowski [4] in a lysimetric experiment. These authors reported that an increase of a sewage sludge dose resulted in a nitrate content increase in soil only in the first year of the experiment. In our study, an increase in the accumulation of this form of mineral nitrogen in soil was directly proportional to a dose of the waste. This effect was noticed each year during the study (Table 1). However, the content of N-NO_3 in soil in the first year of the study was several-fold higher than in the subsequent years. Baran et al [3] showed an evident reduction in the amount of nitrate nitrogen(V) in soil in the second year of the experiment. In our study, the concentrations of nitrate in the soil collected in 2006 and 2007 were on an approximately identical level, which was a result of a considerable uptake of mineral forms of nitrogen by grass, as verified by Delibacak et al [2]. It is estimated that between 20 % to 55 % of organic nitrogen in soil undergoes mineralization in the first year after the application of sewage sludge [5, 6]. It was only in the final year of the experiment that an increasing accumulation of the analyzed nutrient in the soil occurred, but not to such a high level as in 2005 (Table 1). The concentration of N-NO_3 changed over time under the influence of sewage sludge doses (Table 1). In the first and in the last year of the research, the concentration of N-NO_3 grew most proportionally to the quantity of waste introduced to soil. Such dependence, albeit on a minimum level, remained in soil in the third year after sludge application.

The content of nitrate nitrogen(V) in soil changed significantly during the growing season, from April to November (Table 2). The highest concentration of this component was found in soil collected in July, on average around 17 mg · kg^{-1}. Such high accumulation of N-NO_3 in soil at that time can be explained by the increasing nitrification and mineralization processes of the nitrogen introduced to soil with sludge. In soil collected in April and September, the N-NO_3 content was on a lower level (about 13 mg · kg^{-1}), while in November it was the lowest.

Table 2

Seasonal changes of N-NO_3 content in soil [mg · kg^{-1}] depending on a dose of sludge

Sewage sludge dose [Mg · ha^{-1}]	Month				Mean
	April	July	September	November	
0	4.44	5.94	6.29	4.80	5.37
70	8.68	12.83	9.46	5.92	9.22
140	12.52	18.17	14.94	11.55	14.29
210	16.47	23.06	17.76	14.66	17.99
280	19.55	25.87	20.38	16.71	20.63
Mean	12.33	17.17	13.77	10.73	

$LSD_{.05}$ doses 0.37
$LSD_{0.05}$ month 0.21
$LSD_{0.05}$ interaction 0.44

Fluctuations of N-NO_3 content in soil depending on a sewage sludge dose and time of sampling were proved to be significant at the level of $p = 0.05$ (Table 2). In each of the four dates of soil sampling, the accumulation of N-NO_3 increased proportionally to a dose of the introduced waste. In the literature, no results confirming seasonal changes of nitrate concentrations in soil were found [4]. On the other hand, Sienkiewicz et al [7] attributed seasonal changes in the N-NO_3 content in soil to the changing conditions which determine N transformations in soil and to the changeable uptake of N by plants.

The concentration of N-NO_3 in soil fluctuated seasonally in the following years of the experiment (Table 3). A characteristic feature was the high content of nitrate in soil collected in all periods in the first year of study, especially in soil samples collected in July 2005. On all sampling dates in 2006 and 2007, the accumulation of nitrate nitrogen(V) in soil was similar. There was an increase in the concentration of $N\text{-}NO_3$ in soil collected in July and September 2008 (Table 3).

Table 3

Seasonal changes of $N\text{-}NO_3$ in the soil [$mg \cdot kg^{-1}$] in successive years

Year	Month				Mean
	April	July	September	November	
2005	33.19	51.35	40.64	28.44	38.41
2006	6.53	2.75	2.61	3.11	3.75
2007	2.67	2.08	1.41	5.40	2.89
2008	6.95	12.50	10.41	5.96	8.95
Mean	12.33	17.17	13.77	10.73	

$LSD_{0.05}$ years 0.29
$LSD_{0.05}$ month 0.21
$LSD_{0.05}$ interaction 0.51

When examining the seasonal changes of nitrate in soil in the subsequent years of the research, depending on a dose of sewage sludge, a significant difference in the quantity

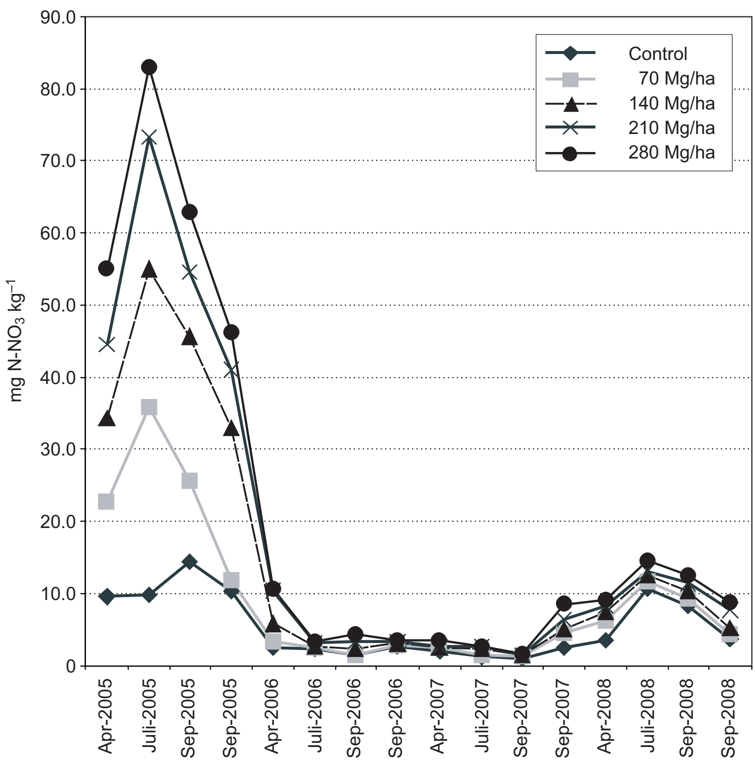

Fig. 1. Seasonal changes of $N\text{-}NO_3$ in soil in the subsequent years of the research depending on a dose of sewage sludge

of the component in the soil collected in 2005 compared with the remaining years of research can be observed (Fig. 1). In the first year of the experiment, an increase in the N-NO_3 concentration in soil with a dose of sewage sludge was the highest. In 2006 and 2007, irrespective of the dose of the fertilizer or the date of soil sampling, the content of nitrate nitrogen(V) in soil remained on a similar level. Another characteristic event was the increase in the quantity of N-NO_3 in soil in the last year of the experiment, although the changes associated with the doses of sludge were no longer as big as observed in the soil collected in 2005. In July of the first and the last year of the research, the greatest increase was observed in the analyzed form €of mineral nitrogen in soil, compared with the remaining dates of soil sampling soil in all the years of the experiment.

Conclusions

1. The content of nitrate in soil increased every year proportionally to a dose of sludge. The dose of 280 Mg · ha^{-1} of sewage sludge raised the average N-NO_3 content over two-fold higher than determined in the control soil.
2. The highest concentration of nitrate nitrogen(V) occurred in soil collected in July.
3. Accumulation of N-NO_3 in soil changed in the subsequent years, being the in the first year after sludge application, whereas in the years 2006 and 2007, the average N-NO_3 content was similar. In 2008, a slight increase in the concentration of N-NO_3 in the soil was found.

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WPŁYW KOMUNALNEGO OSADU ŚCIEKOWEGO NA ZAWARTOŚĆ AZOTANÓW(V) W GLEBIE

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Abstrakt: W czteroletnim doświadczeniu mikropoletkowym (1 m^2) prowadzonym na glebie antropogennej badano wpływ dawki osadu ściekowego na zmiany koncentracji azotu azotanowego(V) w glebie. Komunalny osad ściekowy zastosowano jednorazowo jesienią 2004 r. w dawkach: 0, 70, 140, 210 i 280 Mg · ha^{-1} świeżej masy. Następnie wysiano mieszankę traw gazonowych. Osad ściekowy wykorzystany w badaniach pochodził z miejskiej oczyszczalni ścieków w Olsztynie. W latach 2005–2008 glebę do analiz chemicznych pobierano czterokrotnie w każdym okresie wegetacyjnym (IV, VII, IX i XI). Zawartość azotanów(V) w świeżej masie gleby oznaczono metodą kolorymetryczną z wykorzystaniem kwasu fenolodisulfonowego.

Zawartość azotanów(V) w glebie zwiększała się w każdym roku proporcjonalnie wraz z dawką osadu. W wyniku zastosowania 280 Mg · ha^{-1} odpadu średnia zawartość N-NO_3 była ponad dwukrotnie większa niż w glebie obiektu kontrolnego. Największa koncentracja tej formy azotu mineralnego występowała w glebie pobieranej w lipcu, co mogło być spowodowane intensywnymi przemianami związków N dostarczonych w osadzie (mineralizacja i nitryfikacja). Nagromadzenie N-NO_3 w glebie zmieniało się w kolejnych latach – najwięcej było w 2005 r., natomiast w latach 2006 i 2007 średnie zawartości N-NO_3 kształtowały się na zbliżonym poziomie. W 2008 r. stwierdzono nieznaczny wzrost koncentracji tego składnika w doświadczalnej glebie.

Słowa kluczowe: osad ściekowy, azotany(V) w glebie

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EFFECT OF THE SOURCE OF VEGETABLE DIETARY PROTEIN ON NITROGEN EXCRETION TO THE ENVIRONMENT IN GROWING-FINISHING PIGS

WPŁYW ŹRÓDŁA BIAŁKA ROŚLINNEGO NA WYDALANIE AZOTU DO ŚRODOWISKA W TUCZU ŚWIŃ

Abstract: The aim of this study was to determine the effect of different sources of vegetable protein in diets for growing-finishing pigs on total protein digestibility, and on the levels of nitrogen retention, utilization and excretion to the environment. Digestibility and balance trials were conducted twice, on 24 growing-finishing pigs weighing 40 kg (fed grower diets) and 75 kg (fed finisher diets). The animals were placed in individual metabolism cages and were divided into three groups, as follows: SBM (control) group fed a diet in which the only protein source was genetically modified soybean meal, and two experimental groups fed diets containing alternative sources of vegetable protein: RSM+FB group (00-rapeseed meal + faba bean seeds) and RSM+FP group (00-rapeseed meal + field pea seeds).

It was found that 00-rapeseed meal and faba bean seeds (RSM+FB) used as a substitute for soybean meal (SBM) in diets for growing-finishing pigs significantly decreased total protein digestibility, increased fecal nitrogen excretion, and reduced nitrogen retention and utilization. The combination of 00-rapeseed meal and field pea seeds (RSM+FP) improved nitrogen balance parameters in pigs, compared with the RSM+FB group, and the obtained values were similar to those noted in the SBM group. The use of alternative dietary vegetable protein sources in pig production reduced urinary nitrogen excretion. It was estimated that an average pig fed grower and finisher diets with 00-rapeseed meal and faba bean seeds excreted in feces and urine 7.0/3.1 % and 3.6/2.6 % N more, in comparison with an average pig fed control diets with soybean meal and diets with 00-rapeseed meal and field pea seeds, respectively.

Keywords: sources of vegetable protein, protein digestibility, nitrogen balance, nitrogen excretion to the environment, growing-finishing pigs

High production levels and high population density on commercial pig farms constitute a potential threat to the environment, mostly due to high emissions of NH_3, methane and phosphorus. In view of the above, this study investigated the implementa-

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tion of environment-friendly pig production technologies aimed to reduce the load put on the environment by the unused excess and indigestible nutrients.

From the perspective of pig nutrient requirements, protein contained in rapeseed meal is characterized by a highly desirable amino acid composition. This protein contains less lysine and more methionine, cystine, threonine and tryptophan, compared with protein derived from soybean meal and legume seeds [1, 2]. The ileal and fecal digestibility of protein and lysine derived from rapeseed meal is lower, in comparison with other high-protein feeds [3]. However, rapeseed protein has a high biological value due to good proportions of amino acids [4]. Protein contained in faba bean and field pea seeds has a high lysine content and low concentrations of methionine and tryptophan [5]. The lysine to methionine and cystine ratio in this protein is 1:03 [6], while the proportion between these amino acids in diets for growing pigs should be in the 1:0.65–0.70 range [7]. Therefore, the above feed components cannot be the only source of supplemental protein in pig diets – they should be offered together with high-protein feeds with an increased methionine content or supplemented with crystalline methionine. 00-rapeseed meal may be a good supplement to protein derived from legume seeds in diets for growing-finishing pigs. The combination of rapeseed meal and faba bean or field pea in pig nutrition can be beneficial due to their complementary protein amino acid composition. All of these feed components are also easily available on the domestic market. However, they contain numerous anti-nutritional factors whose presence may exert a negative effect.

The aim of this study was to determine the effect of different sources of vegetable protein in diets for growing-finishing pigs on total protein digestibility, and on the levels of nitrogen retention, utilization and excretion to the environment.

Materials and methods

Two digestibility and balance trials were conducted to determine total protein digestibility (by the simple balance method) and nitrogen balance in pigs fed complete grower and finisher diets. A six-day experimental period proper was preceded by an eight-day adaptation period. The experiment was performed on 24 young hybrid (Polish Large White x Polish Landrace) x Duroc) boars with average body weight of approximately 40 kg at the beginning of experiment I, and approximately 75 kg at the beginning of experiment II, divided into three experimental groups. The animals were placed in individual metabolism cages, with free access to water, and were fed a restricted ration of complete grower and finisher diets whose composition is presented in Table 1.

During the experimental period proper, the entire amounts of feces and urine were collected. 5 % samples of the total amount of feces excreted daily were collected, preserved with sulfuric acid and assayed for total nitrogen content. Urine collected into containers was preserved with sulfuric acid, to ensure pH below 2, and 5 % samples were assayed for total nitrogen content [8]. Nitrogen losses to the environment were estimated based on nitrogen intake and fecal and urinary nitrogen excretion.

Table 1

Chemical composition and nutritive value of complete diets grower and finisher [%]

Specification	Diets for growing pigs			Diets for finishing pigs		
	SBM*	RSM +FB	RSM +FP	SBM*	RSM +FB	RSM +FP
Source of vegetable protein						
Soyabean meal	19.50	6.00	6.00	13.50	—	—
Rapeseed meal “00”	—	15.00	15.00	—	15.00	15.00
Field bean var. “Nadwiślański”	—	10.00	—	—	10.00	—
Field pea var. Albatros	—	—	15.00	—	—	15.00
Other raw materials mixtures						
Barley	57.20	45.79	45.69	63.93	52.45	52.45
Wheat	20.00	20.00	20.00	20.00	20.00	20.00
Vitamin and mineral supplement**	3.15	3.15	3.15	2.45	2.45	2.45
L-lysine [HCl, 78 %]	0.15	0.06	0.06	0.12	0.10	0.10
Nutritive value [g/kg]						
Crude protein	171.00	170.80	172.70	153.10	153.70	153.10
Digestible crude protein	141.00	128.00	131.00	129.00	122.00	123.00
Lysine	9.46	9.52	9.44	7.97	8.22	7.97
Methionine + cystine	5.96	6.62	6.65	5.00	6.10	6.16
Threonine	6.25	6.74	6.73	5.43	5.94	5.93
Tryptophan	2.09	2.11	2.09	1.62	1.84	1.44
Metabolizable energy [MJ/kg]	13.05	12.47	12.82	13.26	12.77	12.75
Lysine/metabolizable energy [g/1 MJ ME]	0.72	0.76	0.74	0.60	0.64	0.63

* SBM – postextractive soybean meal – control; RSM+FB – postextractive 00-rapeseed meal + field bean; RSM+FP – postextractive 00-rapeseed meal + field pea.
** Limestone – 1.30/0.90, dicalcium phosphate – 0.60/0.60, salt – 0.25/0.25, mineral-vitamin premix grower/finisher – 1.00/0.70 %.

The digestible protein content of experimental diets was determined based on the digestibility coefficients calculated during digestibility trials. The levels of lysine, methionine, cystine, threonine and tryptophan in diets were calculated based on the concentrations of the above amino acids in feed raw materials used for diet formulation. The amount of metabolizable energy was determined based on the chemical composition of diets, the findings of Sobotka [9], and an equation developed by Hoffman and Schieman and modified by Muller and Kirchgessner [6].

The results regarding protein digestibility and nitrogen balance were verified statistically by a one-factor analysis of variance (ANOVA) and Duncan’s multiple range test, using STATISTICA 8.1 software [10].

Results and discussion

As shown in Table 2, the source of dietary vegetable protein affected total protein digestibility and nitrogen balance parameters in pigs.

Table 2

Digestibility of protein and utilization of nitrogen from grower and finisher concentrates differing in dietary protein source

Specification	Source of vegetable dietary protein					
	Concentrates for growing pigs			Concentrates for finishing pigs		
	SBM* 0+0	RSM+FB 15+10	RSM+FP 15+15	SBM* 0+0	RSM+FB 15+10	RSM+FP 15+15
Digestibility of coefficient [%]						
Crude protein [N × 6.25]	82.4^{Aa}	75.2^{Ba}	79.1^{ABb}	84.1^{A}	79.6^{B}	80.2^{B}
Daily nitrogen balance [g/day]						
N intake	60.2	60.1	60.8	68.6	68.7	68.6
Fecal N excretion	10.6^{B}	14.9^{Aa}	12.7^{Ab}	10.8^{B}	14.2^{A}	13.6^{A}
Fecal N excretion / N intake [%]	17.6	23.7	20.5	15.7	20.6	20.3
N digested	49.6^{a}	45.3^{b}	48.1^{b}	57.8^{b}	54.5^{a}	55.0^{a}
Urinary N excretion	25.3	23.5	24.3	33.2	31.4	30.8
Urinary N excretion /N intake [%]	42.0^{b}	39.1^{a}	39.9^{ab}	48.4^{b}	45.6^{a}	44.9^{a}
Retention	24.3^{b}	21.8^{a}	23.8^{b}	24.4	23.1	24.3
Nitrogen utilization [%]						
Digested / intake	82.4^{Aa}	75.2^{Ba}	79.1^{ABb}	84.2^{A}	79.5^{B}	80.2^{B}
Retention / intake	40.4^{a}	36.2^{b}	39.1^{ab}	35.5^{a}	33.7^{b}	35.4^{ab}
Retention / digested [PVB]**	49.0	48.1	49.5	42.2	42.4	44.2

* See Table 1; ** apparent biological value of protein; a, b – $p \le 0.05$; A, B – $p \le 0.01$.

The substitution of 00-rapeseed meal and faba bean seeds for genetically modified soybean meal in RSM+FB grower and finisher diets (in 78 % and 100 % respectively) caused a highly significant decrease in total protein digestibility. The combination of 00-rapeseed meal and field pea seeds (RSM+FP) improved protein digestibility, compared with diets containing 00-rapeseed meal and faba bean seeds, while the values of protein digestibility obtained for diets with soybean meal (SBM) were slightly higher. The above was most probably due to the presence of anti-nutritional factors in the analyzed sources of vegetable protein.

At comparable nitrogen intake, pigs fed grower and finisher diets with 00-rapeseed meal and faba bean seeds (RSM+FB) or with 00-rapeseed meal and field pea seeds (RSM+FP) excreted highly significantly more nitrogen in feces (14.9/14.2 g and 12.7/13.6 g respectively) than pigs fed control SBM diets with genetically modified soybean meal (10.6/10.8 g). It should be stressed, however, that 00-rapeseed meal and field pea seeds proved to be better substitutes for soybean meal protein than 00-rapeseed meal and faba bean seeds. This resulted from differences in total protein digestibility in these feed components. Lower urinary nitrogen excretion (statistically non-significant differences) was noted in pigs fed grower and finisher RSM+FB and RSM+FP diets, compared with animals receiving SBM diets. This suggests that protein derived from rapeseed meal and legume seeds had more desirable proportions of essential amino acids. Also Gatel and Grosjean [11] and Shriver et al [12] reported that supplementing protein with lysine and methionine in diets for pigs reduced urinary nitrogen excretion.

The results of table Table 3 shows that the source of dietary vegetable protein had little affected on the elimination nitrogen to the environment.

Table 3

Nitrogen excretion levels as dependent on the source of vegetable dietary protein in the growing-finishing pigs [g]*

Specification	SBM** 0+0	RSM+FB 15+10	RSM+FG 15+15
Diets for growing pigs [40 kg BW]			
N intake	842.8	841.7	851.1
Fecal N excretion	148.4	208.6	177.8
Urinary N excretion	354.2	329.0	340.2
Total N excretion	502.6	537.6	518.0
Nitrogen excretion levels as dependent on the source protein			
[g]	*0.0*	*+35*	*+15.4*
[%]	*100*	*107.0*	*103.1*
[g]	—	*0.0*	*–19.6*
[%]	—	*100*	*96.4*
Diets for finishing pigs [75 kg BW]			
N intake	960.2	964.0	960.2
Fecal N excretion	151.2	198.8	190.4
Urinary N excretion	464.8	439.6	431.2
Total N excretion	616.0	638.4	621.6
Nitrogen excretion levels as dependent on the source protein			
[g]	*0.0*	*+22.4*	*+4.4*
[%]	*100*	*103.6*	*101.0*
[g]	—	*0.0*	*–16.8*
[%]	—	*100*	*97.4*

* Analysis performed during digestibility and balance trials; ** see Table 1.

Increased fecal nitrogen utilization in pigs receiving vegetable protein sources alternative to soybean meal resulted in slightly lower nitrogen retention and worse nitrogen utilization in relation to nitrogen intake. It was estimated that an average pig fed grower and finisher diets with 00-rapeseed meal and faba bean seeds excreted in feces and urine 7.0/3.1 % and 3.6/2.6 % N more, in comparison with an average pig fed control diets with soybean meal and diets with 00-rapeseed meal and field pea seeds respectively.

Conclusions

1. 00-rapeseed meal and faba bean seeds used as a substitute for genetically modified soybean meal in diets for growing-finishing pigs negatively affected total portein digestibility, fecal nitrogen excretion, nitrogen retention and utilization.

2. The combination of 00-rapeseed meal and field pea seeds improved nitrogen balance parameters in pigs, compared with diets containing 00-rapeseed meal and faba bean seeds.

3. The use of alternative dietary vegetable protein sources in pig production reduced urinary nitrogen excretion.

4. It was estimated that an average pig fed grower and finisher diets with 00-rapeseed meal and faba bean seeds excreted in feces and urine 7.0/3.1 % and 3.6/2.6 % N more, in comparison with an average pig fed control diets with soybean meal and diets with 00-rapeseed meal and field pea seeds respectively.

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WPŁYW ŹRÓDŁA BIAŁKA ROŚLINNEGO NA WYDALANIE AZOTU DO ŚRODOWISKA W TUCZU ŚWIŃ

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Abstrakt: Celem badań było określenie wpływu różnych źródeł białka roślinnego w mieszankach paszowych dla tuczników na strawność białka ogólnego, retencję azotu i jego wykorzystanie oraz na ilość azotu wydalonego do środowiska. Badania strawnościowo-bilansowe przeprowadzono dwukrotnie, na 24 tucznikach utrzymywanych indywidualnie w klatkach metabolicznych, przy masie ciała 40 kg (mieszanki grower) i 75 kg (mieszanki finiszer), przydzielonych do trzech grup doświadczalnych: SBM (kontrolna) – żywiona mieszanką wyłącznie z białka pochodzącego z genetycznie modyfikowanej poekstrakcyjnej śruty sojowej i doświadczalnych żywionych mieszankami zawierającymi alternatywne źródła białka roślinnego: RSM+FB (poekstrakcyjna śruta rzepakową "00" + nasiona bobiku), oraz RSM+FP (poekstrakcyjna śruta rzepakowa "00" + nasiona grochu).

Stwierdzono, że użycie w mieszankach paszowych dla tuczników poekstrakcyjnej śruty rzepakowej "00" i nasion bobiku (RSM+FB) jako alternatywnego źródła białka roślinnego w odniesieniu do poekstrakcyjnej śruty sojowej (SBM), statystycznie istotnie obniżyło strawność białka ogólnego, zwiększyło wydalanie N w kale, zmniejszyło retencję N i jego wykorzystanie. Połączenie poekstrakcyjnej śruty rzepakowej z nasionami grochu (RSM+FP) poprawiło analizowane parametry gospodarki azotowej w organizmie świń w porównaniu do grupy RSM+FB i były to także wartości zbliżone do wyników bilansu azotu uzyskanych w grupie SBM. Stosowanie alternatywnych źródeł białka w tuczu świń zmniejszyło wydalanie azotu w moczu. Oszacowano, że tucznik żywiony mieszanką grower/finiszer z udziałem poekstrakcyjnej śruty rzepakowej "00" i bobiku wydalał w kale i moczu o 7,0/3,1 % więcej N do środowiska niż tucznik z grupy z poekstrakcyjną śrutą sojową i o 3,6/2,6 % w porównaniu do tucznika otrzymującego w dawce poekstrakcyjną śrutę rzepakową łącznie z grochem.

Słowa kluczowe: źródła białka roślinnego, strawność białka, bilans azotu, wydalanie azotu do środowiska, tuczniki

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EFFECT OF THE NITROGEN AND MICROELEMENTS APPLICATION METHOD ON THE CHANGES IN THE CONTENT OF TOTAL NITROGEN AND ITS MINERAL FORMS IN LIGHT SOIL

ODDZIAŁYWANIE SPOSOBU APLIKACJI AZOTU I MIKROELEMENTÓW NA ZMIANY ZAWARTOŚCI AZOTU OGÓŁEM I JEGO MINERALNYCH FORM W GLEBIE LEKKIEJ

Abstract: The present research, carried out over 2004–2007, aimed at evaluating the effect of the nitrogen application method and foliar application of microelements on the quantitative changes in nitrogen compounds in soil under monoculture of two corn cultivars. Nitrogen fertilisation was applied at a single dose (soil application) and at a split dose (soil and foliar application). Fertilisation with microelements was applied at the 5-leaf phase. After three research years it was observed that the corn cultivars researched as well as the nitrogen application method significantly determined the content of total N in soil. Significantly higher contents of this parameter were recorded in soil under 'L.G 22.44' corn and after the use of a single nitrogen dose, as compared with the split dose. The nitrogen application method showed a significant effect on the contents of available nitrogen forms. Significantly higher contents of both ammonium nitrogen and nitrate nitrogen(V) were recorded after the application of a single nitrogen dose, as compared with the split dose and irrespective of the cultivar and nitrogen application method, after the use of the microelements investigated.

Keywords: nitrogen application method, microelement fertilisation, total nitrogen, mineral nitrogen

The basic agrotechnical treatment which aims at maintaining the soil fertility and ensuring the plants with an adequate amount of nutrients, including available nitrogen forms, is fertilisation. On average in Poland about 88 kg N per 1 ha of agricultural acreage is introduced to soil with fertilisers, and crops use from 50 to 70 % of this nutrient [1, 2]. In contemporary agriculture there is a principle of balanced fertilisation to ensure maximum crop yields of good quality and maintaining soil in the state of

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adequate fertility. The optimization of fertilisation is of special importance when nitrogen is applied as it can pose a potential threat for ecosystems [3].

With that in mind, over 2004–2007 research was launched which aimed at determining the effect of the nitrogen application method and foliar microelement application on the quantitative changes in nitrogen compounds in soil under corn in monoculture.

Material and methods

The research was carried out (2004–2007) as the field experiment set up on the soil of IVa quality class, representing the good rye complex, located on the farm at Wieldzadz (the Kujawy-Pomerania province). The soil reaction was slightly acidic. The soil showed an average content of available forms of phosphorus and potassium and an average content of total nitrogen.

The field experiment was set up as a randomized split-plot design as a three-factor experiment in four replications. The experimental plot size was 20 m^2. The experimental factors were as follows:

– factor I – corn cultivar of FAO 240 (n = 2, 'LG 22.44', 'Nysa');

– factor II – nitrogen application (n=2, into soil, into soil + foliar application):

  – 150 kg N · ha^{-1} pre-sowing in a form of $CO(NH_2)_2$,

  – 150 kg N · ha^{-1} (2/3 +1/3), 2/3 of the dose into soil (100 kg N · ha^{-1}), + 1/3 of the dose (50 kg N · ha^{-1} was applied as follows: 20 kg N · ha^{-1} into soil + 30 kg N · ha^{-1} foliar application: every 10 days in three sprayings (1/3 + 1/3 + 1/3), at the 5-leaf phase in a form of 10 % urea solution);

– factor III – microelement fertilisers were applied together with nitrogen at the 5-leaf phase, (n = 4, B_0 – control, B_1 – ADOB Zn, B_2 – ADOB Cu, B_3 – Basfoliar 36 Extra).

The corn seed dressing applied was VITAVAX 200 FS and seed-sowing took place on 25.04.2007. All the cultivation treatments, sowing and the harvest performed at full grain ripeness were compliant with the adequate agrotechnical guidelines for that crop. Phosphorus and potassium fertilisers were applied at the following doses: 43 kg P · ha^{-1} – in a form of triple superphosphate, 124 kg K · ha^{-1} – in a form of high-percentage potassium salt. Throughout the vegetation period in 2007 the average temperature and total rainfall were higher than the multiyear means (1996–2007).

In 2007 of corn from the arable layer representative soil samples were taken for which the following were determined:

– total nitrogen content (N_t) – with the Kjeldahl method, after mineralization process in H_2SO_4,

– content of nitrate(V) nitrogen ($N\text{-}NO_3^-$) extracted with potassium sulphate(VI) – using the colorimetric method with diphenylsulphonic acid,

– the content of ammonium nitrogen ($N\text{-}NH_4^+$) – extracted with 1 % aluminium-potassium sulphate(VI) and determined with the Kjeldahl method.

The present research results were statistically verified with the analysis of variance following the model compliant with the experimental design. The significance of differences was verified with the Tukey test.

Results and discussion

In soil the nitrogen forms in soil most available to plants are nitrate(V) and ammonium ions. The content of these nitrogen forms is inconsiderable and it can range from a few dozen or so milligram per 1 kg of soil, which undergo considerable changes throughout the year depending on the weather conditions, intensity of plant uptake and the fertilisation dose and fertiliser application date.

The contents of total nitrogen and nitrate(V) nitrogen in soil under corn in monoculture were significantly determined by the genotype of the cultivars researched (Table 1). The average contents ranged, respectively, from 0.61 to 0.87 $g \cdot kg^{-1}$ and from 3.06 to 5.70 $mg \cdot kg^{-1}$. Following the application of nitrogen, both at the single dose and split dose (2/3 + 1/3), there was noted on average significantly higher contents of total nitrogen in soil under 'LG 22.44' corn, as compared with 'NYSA'. It is common knowledge that the yield-forming nature of nitrogen increases the amount of plant post-harvest residue [4, 5], and the relationship is closely connected with crop species and even their cultivars [6–8].

Table 1

Content of different nitrogen forms in soil

Nitrogen fertilization	Cultivar							
	'LG 22.44'				'NYSA'			
	Microelements fertilization							
	B_0	B_1	B_2	B_3	B_0	B_1	B_2	B_3
Total Nitrogen [$g \cdot kg^{-1}$ soil]								
150	0.87*	0.96*	0.87*	0.86*	0.73	0.75	0.71	0.61
100 + 50	0.76*	0.76*	0.88*	0.82*	0.67	0.63	0.57	0.61
Average	0.81^x	0.86^x	0.87	0.84^x	0.70^x	0.69^x	0.64^x	0.61
Ammonium $N\text{-}NH_4^+$ [$mg \cdot kg^{-1}$ soil]								
150	18.95b	27.38a	11.50d	16.18c	15.88b	21.75a	16.50b	22.10a
100 + 50	14.93b	16.45a	11.80c	13.38c	15.88b	19.30a	11.50c	16.45b
Average	16.94^x	21.91^x	11.65	14.78^x	15.88	20.53^x	14.00^x	19.28^x
Nitrate V $N\text{-}NO_3^-$ [$mg \cdot kg^{-1}$ soil]								
150	4.46*c	6.37* a	5.54*b	2.93d	3.31b	3.25b	3.56b	4.63*a
100 + 50	2.87c	4.19b	5.86a	3.18c	3.97a	4.05a	3.31c	3.23c
Average	3.66^x	5.28^x	5.70	3.06	3.64^x	3.65^x	3.43	3.93^x

a, b… – average value marked with different letters in the row differ significantly depending on the microelements applied ($p < 0.05$); * – higher average values which differ significantly depending on the corn cultivars researched ($p < 0.05$); x – average values which differ significantly depending on the nitrogen application method ($p < 0.05$).

The contents of nitrate(V) nitrogen were, in general, also significantly higher in soil under 'LG 22.44' corn only after the application of single dose nitrogen (150 kg $N \cdot ha^{-1}$). The average contents ranged, from 2.93 to 6.37 $mg \cdot kg^{-1}$. Fertilisation shows a high impact on the fertility of soils, affecting the content of nitrogen forms [9–11]. The research showed that both the content of total nitrogen and its mineral forms ($N\text{-}NH_4^+$, $N\text{-}NO_3^-$) were significantly modified by the nitrogen application method, while the contents of $N\text{-}NH_4^+$ and $N\text{-}NO_3^-$ also depended on the microelements applied. It was observed that the contents were, in general, significantly higher following the nitrogen application at the single dose against microelements, especially the content of ammonium nitrogen (Table 1).

The significantly highest contents of the available nitrogen forms researched, in general, were noted after the application of zinc (B_2), which enhances the corn yield size, and thus the amount of plant post-harvest residue. Zinc plays an essential role in metabolism as well as participates in different enzymatic processes (synthesis of protein and auxins) [12].

Optimization of fertilisation, namely adjusting the fertiliser doses to real fertilisation needs, as well as fertiliser applications at optimal dates can have a significant effect on a more effective use of nitrogen from the fertilisers applied and thus – on the corn yielding [13].

Nutrients uptake by corn in the initial period of development accounts for only 3 % [14]. The mineral nitrogen forms, introduced together with nitrogen fertilisers, unused by the plant, undergo processes of retrogradation and immobilization and can make their effective use by crops difficult.

The present results showed that the percentage of $N\text{-}NH_4^+$ in total nitrogen was higher than $N\text{-}NO_3^-$, both after the application of the single dose and the split dose (Fig. 1).

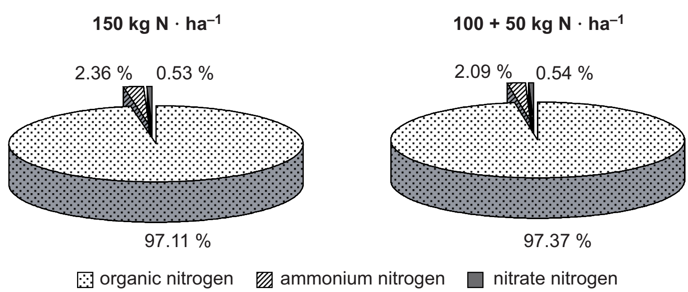

Fig. 1. Percentage of the mineral nitrogen forms researched in the total nitrogen

One can therefore assume that the soil conditions were favourable to the hydrolysis of urea and to mineralization processes of eg post-harvest residue.

There were also noted higher contents of ammonium nitrate following the application of a single dose (Table 1, Fig. 1), which could have been due to the fact that splitting the nitrogen dose increases the effectiveness of the use of this element by corn and thus prevents its retrogradation by incorporating this element into the plant biomass [15, 16].

Conclusions

1. After three research years, it was observed that the corn cultivars researched as well as the nitrogen application method significantly determined by the content of total nitrogen in soil. Significantly higher contents of this parameter were found in soil under 'L.G 22.44' corn and after the application of a single nitrogen dose, as compared with the split dose.

2. The nitrogen application method demonstrated a significant effect on the contents of available nitrogen forms in soil. Significantly higher contents of both ammonium nitrogen and nitrate(V) nitrogen were recorded following the application of a single nitrogen dose, as compared with the split dose.

3. On average higher contents of ammonium nitrogen and nitrate(V) nitrogen were found following the application of the microelements researched, irrespective of the cultivar and the nitrogen application method.

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ODDZIAŁYWANIE SPOSOBU APLIKACJI AZOTU I MIKROELEMENTÓW NA ZMIANY ZAWARTOŚCI AZOTU OGÓŁEM I JEGO MINERALNYCH FORM W GLEBIE LEKKIEJ

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Abstrakt: Badania prowadzono w latach 2004–2007, których celem było określenie wpływu sposobu aplikacji azotu oraz nalistnego stosowania mikroelementów na zmiany ilościowe związków azotu w glebie pod uprawą w monokulturze dwóch odmian kukurydzy. Nawożenie azotem stosowano w dawce jednorazowej (doglebowo) oraz w dawce dzielonej (doglebowo i nalistnie) Nawożenie mikroelementami natomiast zastosowano w fazie 5 liścia. Po trzech latach badań stwierdzono, że badane odmiany kukurydzy, jak również sposób aplikacji azotu istotnie decydowały o zawartości N ogółem w glebie. Istotnie wyższe zawartości tego parametru stwierdzono w glebie spod uprawy kukurydzy odmiany “L.G 22.44” oraz po zastosowaniu jednorazowej dawki azotu w stosunku do dawki dzielonej. Sposób aplikacji azotu istotnie wpływał na zawartości przyswajalnych form azotu. Istotnie wyższe zawartości zarówno azotu amonowego, jak i azotu azotanowego(V) stwierdzono po zastosowaniu jednorazowej dawki azotu w porównaniu do dawki dzielonej oraz niezależnie od odmiany i sposobu aplikacji azotu, po zastosowaniu badanych mikroelementów.

Słowa kluczowe: sposób aplikacji azotu, nawożenie mikroelementami, azot ogółem, azot mineralny

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NUTRIENT DIGESTIBILITY AND NITROGEN BALANCE IN GROWING-FINISHING PIGS FED DIETS CONTAINING BLUE LUPINE (*Lupinus angustifolius*) SEEDS

WPŁYW ŁUBINU WĄSKOLISTNEGO W MIESZANKACH DLA TUCZNIKÓW NA STRAWNOŚĆ SKŁADNIKÓW POKARMOWYCH I BILANS AZOTU

Abstract: The objective of this study was to determine the effect of total substitution of blue lupine seeds (cv. Wersal, Baron and Zeus) for soybean meal in diets for growing-finishing pigs on nutrient digestibility, nitrogen retention and nitrogen utilization. Balance and digestibility trials were conducted on 24 pigs with body weight of approximately 60 kg, divided into four groups. In the control, diet the main source of protein was soybean meal (15 %), which was replaced with blue lupine seeds cv. Wersal (29 %), Baron (26 %) or Zeus (30 %) in experimental diets. The cereal component was barley grain, and the diets were supplemented with synthetic amino acids, minerals and vitamins, so as to meet the nutrient requirements of animals.

Total protein digestibility was high and comparable in all groups (75.7–77.5 %). Significant differences were noted with respect to the digestibility of crude fat and crude fiber, which was found to be lower in pigs fed a diet containing blue lupine seeds cv. Baron.

Nitrogen intake was at a similar level in all groups (65.8–67.4 g), while the highest nitrogen retention was observed in the control group (24.6 g). In experimental groups nitrogen retention ranged from 20.3 to 21.7 g, due to higher fecal and urinary nitrogen excretion. Nitrogen utilization (retention/intake, retention/digestion) was slightly higher in the control group, at 36.6 and 47.7 %, compared with 30.2–32.3 % and 41.1–44.3 % respectively in experimental groups. The results of the study indicate that blue lupine seeds used as the main source of protein in diets for growing-finishing pigs may affect nutrient digestibility and fecal and urinary nitrogen retention.

Keywords: blue lupine, digestibility, nitrogen balance, growing-finishing pigs

Nitrogen excretion is dependent on ration balancing for energy and protein, to meet the animal's requirements. Nutrient utilization can be improved by selecting appropriate feed components which increase the digestibility of energy and protein, and their

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utilization for production purposes. In pig fattening, the efforts to minimize nitrogen excretion may be hindered by diet formulation with an excess of protein, and by an insufficient supply of essential amino acids [1]. Typical diets for pigs often contain only lysine or sulfur amino acids, whereas other limiting amino acids are disregarded [2, 3].

The effect of blue lupine seeds as the main source of protein and a substitute for soybean meal in diets for growing-finishing pigs, supplemented with synthetic amino acids, was determined based on nutrient digestibility. Nitrogen balance, including the retention and utilization of this nutrient, was also analyzed.

Materials and methods

The experimental materials comprised seeds of three blue lupine cultivars, Wersal, Baron and Zeus, used as the main source of protein in diets for growing-finishing pigs (Table 1). In the control group (I) the major protein component was soybean meal (15 %), which was replaced with blue lupine seeds in experimental diets, as follows: group II – cv. Wersal (29 %), group III – cv. Baron (26 %), group IV – cv. Zeus (30 %). The cereal component was barley grain. All diets were supplemented with synthetic amino acids (lysine, methionine, threonine and tryptophan), minerals and vitamins, so as to meet the nutrient requirements of animals.

Table 1

Composition [%] and nutritional value of diets

Components	Group			
	Control I	Wersal II	Baron III	Zeus IV
Barley	82.05	67.88	70.87	66.90
Soybean meal	15	—	—	—
Blue lupine	—	29	26	30
Feed additives*	2.5	2.5	2.5	2.5
L-lysine	0.32	0.4	0.4	0.35
DL-methionine	0.08	0.15	0.15	0.17
L-threonine	0.05	0.06	0.06	0.05
L-tryptophan	—	0.02	0.02	0.03
1 kg mixed feed				
ME [MJ]	13.04	13.03	12.40	12.79
Crude protein [g]	161.3	162.5	161.8	162.1
Crude fiber [g]	38.0	74.8	69.9	75.9
Oligosaccharides [g]	—	21.3	18.1	20.0
Alkaloids [g]	—	0.16	0.09	0.12

* Limestone, dicalcium phosphate, NaCl, mineral-vitamin premix.

The diets were fed to 24 growing-finishing pigs with body weight of approximately 60 kg. The animals were kept and fed individually. Nutrient digestibility and nitrogen balance were determined by standard methods.

The results were verified statistically by a one-factor analysis of variance (ANOVA) and Duncan's multiple range test, using STATISTICA 7.0 software.

Results and discussion

The blue lupine cultivars used in the experiment differed with regard to their chemical composition (Table 2). The protein content of seeds was as follows: cv. Wersal – 316.7 g/kg, cv. Zeus – 319.0 g/kg, cv. Baron – 333.2 g/kg. Blue lupine seeds contained small amounts of crude fat (48.7–54.6 g), slightly different levels of N-free extractives (409.3–428.3 g), and comparable concentrations of crude fiber.

Table 2

Chemical composition of blue lupine seeds [g/kg d.m.]

Specification	Blue lupine cultivars		
	Wersal	Baron	Zeus
Total protein	316.7	333.2	319.0
Crude fat	49.8	48.7	54.6
N-free extractives	428.3	409.3	419.2
Crude fiber	164.8	167.5	167.0
NDF	265.4	271.6	249.7
ADF	224.5	221.0	223.0
ADL	12.2	11.5	13.5
Hemicelluloses	40.9	50.6	26.7
Cellulose	212.3	209.5	209.5
Alkaloids	0.56	0.36	0.41
Oligosaccharides	73.6	69.7	63.2

Significant differences were noted with respect to the content of neutral detergent fiber and hemicelluloses which were most abundant in cv. Baron. The control diet with soybean meal and experimental diets containing blue lupine seeds were formulated as iso-protein diets, with protein concentrations ranging from 161.3 to 162.5 g (Table 1). Experimental diets with lupine seeds contained slightly different amounts of oligosaccharides (18.1–23.0 g/kg). The alkaloid content of experimental diets II, II and IV (0.09, 0.12 and 0.16 g/kg, respectively) depended on alkaloid concentrations in the seeds of particular lupine cultivars.

Table 3 presents the digestibility of nutrients from the control and experimental diets. The replacement of soybean meal with seeds of three blue lupine cultivars resulted in high total protein digestibility (75.7–77.5 %), which was comparable in all groups. These values are consistent with those reported by Fernandez and Batterham [4], and somewhat lower than those obtained by Salgado et al [5] for diets with a high content of lupine seeds. The findings of Froidmont et al [6] also confirm the need to supplement diets for pigs with all essential amino acids.

The use of blue lupine seeds as a substitute for soybean meal in diets for pigs allowed to achieve high total protein digestibility, but it decreased the digestibility of other nutrients. Among the three tested lupine cultivars, the lowest nutrient digestibility coefficients were noted for cv. Baron whose seeds had higher concentrations of hemicelluloses and NDF, compared with the seeds of the other two cultivars.

Table 3

Nutrient digestibility and nitrogen balance

Specification	Group				SEM
	Control I	Wersal II	Baron III	Zeus IV	
Digestibility coefficient [%]					
Total protein	77.5	76.8	75.7	76.5	0.377
Crude fat	46.0^{AC}	41.9^{A}	29.6^{Bb}	37.3^{ADa}	1.624
Crude fiber	45.1^{A}	45.0^{A}	35.4^{Bb}	43.5^{a}	1.304
N-free extractives	90.3^{A}	89.7^{a}	88.3^{Bb}	88.8^{B}	0.224
Daily nitrogen balance					
N intake [g]	67.1	65.8	67.4	67.4	0.522
N excreted in feces [g]	15.6	16.4	18.3	18.2	0.470
N excreted in urine [g]	26.9	29.1	27.3	28.9	0.728
N digestion [g]	51.5	49.4	49.0	49.2	0.580
N retention [g]	24.6	20.3	21.7	20.4	0.876
Retention/digestion [%]	47.7	41.1	44.3	41.4	1.667
Retention/intake [%]	36.6	30.8	32.3	30.2	1.233

a, b, c, d – $p < 0.05$; A, B, C, D – $p < 0.01$

Nitrogen balance parameters (Table 3) were negatively affected by the addition of lupine seeds to diets, despite their supplementation with amino acids. Nitrogen intake was at a similar level in all groups (65.8–67.4 g), while the highest nitrogen retention was observed in the control group (24.6 g). In experimental groups II, III and IV nitrogen retention was 20.3, 21.7 g and 20.4 g respectively, due to higher fecal and urinary nitrogen excretion Rahman et al [7] and Froidmont et al [6] also pointed to the possibility of increased urinary nitrogen excretion in pigs fed diets containing lupine seeds. Nitrogen utilization in relation to nitrogen intake and digestion was higher in the control group, at 36.6 and 47.7 %, compared with 30.2–32.3 % and 41.1–44.3 % respectively in experimental groups. In the groups receiving diets with lupine seeds, the best nitrogen utilization was noted for cv. Baron, which could result from the lowest concentrations of oligosaccharides in the seeds of this cultivar (oligosaccharides are known to limit nitrogen utilization). The nitrogen balance parameters obtained in this study for growing-finishing pigs fed diets with blue lupine seeds are similar to those reported by Chachulowa et al [8] and slightly worse than those presented by Salgado et al [5].

Conclusions

The use of blue lupine seeds (cv. Wersal – 29 %, cv. Baron – 26 %, cv. Zeus – 30 %) as a substitute for soybean meal in diets for pigs allowed to achieve high total protein digestibility, but it decreased the digestibility of other nutrients. Among the three tested lupine cultivars, the lowest nutrient digestibility coefficients were noted for cv. Baron whose seeds had higher concentrations of hemicelluloses and NDF, compared with the seeds of the other two cultivars.

The supplementation of lupine-containing diets with amino acids did not enable to reduce nitrogen excretion to the environment. Despite the high digestibility of protein from experimental diets, comparable with that of protein in a cereal-soybean diet, higher amounts of nitrogen were excreted in feces and urine following the intake of lupine-based diets.

In view of a reduction in atmospheric nitrogen emissions, lupine seeds should not be substituted for soybean meal in diets for growing-finishing pigs, even if these diets are well balanced with respect to the proportions of essential amino acids.

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WPŁYW ŁUBINU WĄSKOLISTNEGO W MIESZANKACH DLA TUCZNIKÓW NA STRAWNOŚĆ SKŁADNIKÓW POKARMOWYCH I BILANS AZOTU

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Abstrakt: Celem badań było określenie w jakim stopniu całkowita substytucja poekstrakcyjnej śruty sojowej nasionami łubinu wąskolistnego odmiany Wersal, Baron lub Zeus różnicuje strawność składników pokarmowych i retencję azotu oraz jego wykorzystanie u tuczników. Badania bilansowo-strawnościowe przeprowadzono na 24 tucznikach o masie ciała około 60 kg podzielonych na 4 grupy. W mieszance grupy kontrolnej podstawowym komponentem białkowym była śruta poekstrakcyjna sojowa (15 %), którą w dietach doświadczalnych zastąpiono nasionami łubinu wąskolistnego Wersal (29 %), Baron (26 %) lub Zeus (30 %).

Komponentem zbożowym było ziarno jęczmienia, oprócz którego zgodnie z zapotrzebowaniem zwierząt, zastosowano aminokwasy syntetyczne i dodatki mineralno-witaminowe.

Strawność białka ogólnego była duża i zbliżona u zwierząt wszystkich grup (75.7–77.5 %). Znaczne różnice dotyczyły strawności tłuszczu surowego i włókna surowego, którą zmniejszyły zastosowane w mieszance nasiona odmiany Baron.

Przy zbliżonej ilości azotu pobranego (65.8–67.4 g) największa jego retencja wystąpiła w grupie kontrolnej (24.6g), w grupach doświadczalnych kształtowała się na poziomie 20.3–21.7 g i była wynikiem większej ilości azotu wydalanego w kale i moczu. Wykorzystanie azotu (retencja/pobrany, retencja/strawiony) nieco korzystniej kształtowało się w grupie kontrolnej i wynosiło 36.6 i 47.7 %, w grupach doświadczalnych odpowiednio 30.2–32.3 % i 41.1–44.3 %. Uzyskane wyniki wskazują, że nasiona łubinu wąskolistnego jako podstawowe źródło białka w mieszankach dla tuczników mogą różnicować strawność składników pokarmowych i wpływać na ilość azotu wydalanego przez tuczniki w kale i moczu.

Słowa kluczowe: łubin wąskolistny, strawność, bilans azotu, tuczniki

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Małgorzata SZCZEPANEK[1]

EFFECT OF RATE AND TIME OF NITROGEN FERTILIZATION ON YIELD QUALITY OF RED FESCUE GROWN FOR SEEDS

WPŁYW DAWEK I TERMINÓW NAWOŻENIA AZOTEM NA JAKOŚĆ PLONU KOSTRZEWY CZERWONEJ UPRAWIANEJ NA NASIONA

Abstract: Nitrogen rates of 20, 40 or 60 kg · ha^{-1} were applied in autumn, and 40, 60 and 80 kg · ha^{-1} in spring in production years (in a single rate or in two parts: 40 kg · ha^{-1} at the start of growth and 40 kg · ha^{-1} at the beginning of stem formation). In the first year of seed harvesting, the spring nitrogen rate did not have an effect on the proportion of normally germinating, hard, fresh and dead seeds in the preliminary or final assessments in germination test. In the second year, the application of part of nitrogen for vegetative growth, with limited formation of generative organs, contributed to lowering of seed yield quality. Division of a rate of 80 kg N · ha^{-1} applied in spring resulted in a decrease in the proportion of normal seedlings as compared with a single application at the start of growth. In conditions of the lowest rate of autumn fertilization, a reduction in seed number in spikelets and an increase in thousand seed weight were accompanied by a decrease in dead seed proportion in yield.

Keywords: red fescue, seed germination, nitrogen fertilization

Fast and even germination is an essential condition of success in establishment of grass surfaces. The quality of sowing material has a direct influence on the rate of sod formation. Minimal requirements of germination capacity for grasses are within the range from 70 to 80 %, depending on species [1]. In the study of red fescue it was indicated that not only cultivars, but even seed batches are differentiated in respect of thousand seed weight and seed germination parameters [2, 3]. The objective of grass seed production should be to obtain a high yield, but also to ensure its best possible quality. This is determined by habitat [4] and agrotechnical factors [5, 6] and their interaction. A balance between the number per area unit or per inflorescence and the conditions prevailing during their filling can be considered as the basis for good grain filling [7]. As the main nutrient, nitrogen exerts an impact on the number of autumn

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shoots which can become generative in the following year, after vernalization. Excessive rates of mineral nitrogen before winter cannot be used due to a risk of leaching [8]. Spring nitrogen fertilization should satisfy the needs for developing generative shoots and seeds. It is difficult to determine the rate based on the content of mineral nitrogen in soil, since fertilizers must be applied very early, and the relation between yielding and the amount of this component in soil is relatively low [9]. Rowarth et al [10] in their study of perennial ryegrass indicated that nitrogen used in very early stages of spikelet initiation increases the weight of seedlings and germination capacity, but its application at flowering does not have such an effect. Meijer and Vreeke [9] report that in conditions of fertilizing red fescue with higher rates of nitrogen the proportion of stalks from late tillering is increased, which results in a higher proportion of light seeds in yield and a decrease in thousand seed weight. An increase in plant density brings about a similar effect [7]. The means of nitrogen application should favour seed filling, since a larger thousand seed weight is accompanied by a higher germinating capacity and shorter germinating time [11].

The research hypothesis assumed that the amount of available nitrogen during autumn tillering before vernalization and the growth and development of generative shoots from the following spring had an effect on the size of aboveground biomass and changes in yield structure elements. Consequently, this affects the quality of the obtained yield of red fescue in the first and second production years. The aim of this study was to estimate the effect of amounts and division of mineral nitrogen fertilization rates on the yield quality of red fescue seeds in two successive years of seed harvesting.

Methods

The study was based on a strict field experiment established in Chrzastowo (53°09′ N; 17°35′ E), in two series: the first in 2004 and the second in 2005. Red fescue was used for seeds for two successive years, in 2005 and 2006 and in 2006 and 2007, respectively. The experiment was located on the podsolic soil of the very good rye complex, quality class IV with granulometric composition of silty heavy loamy sand. It was characterized by neutral reaction (pH in KCl 6.62, Hh 6.83), the high content of phosphorus, and average of potassium and magnesium (15.9 P_2O_5; 13.3 K_2O; 5.4 Mg mg 100 g of soil). Before the establishment of the experiment the amount of nitrogen determined by the distillation method [12] was 10.2 N-NO_3^- and 3.57 N-NH_4^+ mg · kg d.m. of soil. The split-block design was used in four replications. The area of plots was 15 m^2. The lawn cultivar Nimba of red fescue (*Festuca rubra* ssp. *commutata*) was sown in mid-April, in an amount of 8 kg · ha^{-1}, at a depth of 1 cm, with a row spacing of 24 cm, 2–3 days after the spring barley sowing used as a cover crop. In autumn, after harvesting of the cover crop in the establishment year and of seeds in the first production year doses of 26 kg P and 66 kg K were applied. Moreover various rates of nitrogen fertilization were applied ie 20, 40 or 60 kg N · ha^{-1} (the second factor). In the spring in production years, rates of nitrogen fertilization (the first factor) were: 40, 60 and 80 kg N · ha^{-1} sown in a single rate or divided into two parts, of which one (40 kg · ha^{-1}) was applied at the start of growth, and the other (40 kg · ha^{-1}) 30–40 days later, at the beginning of stem formation. Due to the shallow root system of grasses [13], the nitrogen which was available in spring was assumed to be the content of $N\text{-}NO_3^-$ and $N\text{-}NH_4^+$ in the soil layer 0–30 cm directly before the start of growth, and nitrogen from mineral fertilizers (ammonium nitrate(V)) applied in spring, assuming 70 % utilization of this component by plants [14]. Nitrogen uptake was determined based on its content in seed and straw yield. Nitrogen in the plant material was determined by the Kjeldahl method [15]. On the last days of June or in the first week of July the harvest was carried out by the two-phase method. In December or January, after 5–6 months from harvest, based on a sample of 100 seeds, in four replications, a germination test was carried out [16]. At the beginning of the test, blotting paper was soaked with 0.2 % KNO_3. The preliminary assessment of germination was carried out after 7 days, determining the proportion of normal seedlings (germinating energy). Final counting was performed after 21 days from sowing, the following categories being determined: normal seedlings (including those intact, with small defects and with secondary infection), abnormal seedlings, fresh seeds, hard seeds and dead seeds. The analysis of variance (at $\alpha = 0.05$) was carried out after transformation of the results. In the estimation of significant differences Tukey's test was used. No significant interaction was found between autumn and spring fertilization. Thus, only mean values for the tested factors have been presented.

Results and discussion

The weather conditions in full production years (2005–2007) of red fescue were varied. The most favorable conditions were in 2005, when the abundant rainfall in May (a total precipitation of 78.8 mm) favored the development of generative shoots. Heavy water deficiency in June 2006 (a total precipitation of 14.6 mm) resulted in growth stunting, drying of leaves, stems and seeds. In 2007 the growing season already started in the middle of March. Unfortunately, only 16.6 mm of rain fell down in April, in the course of red fescue shooting. Heavy precipitation at the end of June and at the beginning of July made it difficult to harvest the plants.

In the first production year, the nitrogen uptake by red fescue in seed and straw yield was almost equal to the amount considered as available in spring (from soil and mineral fertilizers) (Fig. 1). The lowest level of spring nitrogen fertilization (40 $kg \cdot ha^{-1}$), where the uptake was higher by 14–15 kg within all the rates of autumn fertilization, was an exception. Mineralization was likely to be the primary source of nitrogen. According to Grzebisz [14], the amount of nitrogen that is released in such a way from organic matter on medium soils is 40–50 $kg \cdot ha^{-1}$ per year. In the second year of harvesting, almost in all the treatments of spring and autumn fertilization a part of nitrogen was not used for the growth of generative organs. By contrast, vegetative shoots from spring tillering appeared, which were important beneficiaries of the available nitrogen. Weakening of vernalized autumn shoots after winter (freezing of leaves at a length of 5–9 cm and slow regrowth in spring) favoured their formation. Such a state of the plantation contributed to a fall in quality of the seed yield obtained in the second production year. According to Fairey and Lefkovitch [7], too large density of shoots, causing increasing competition

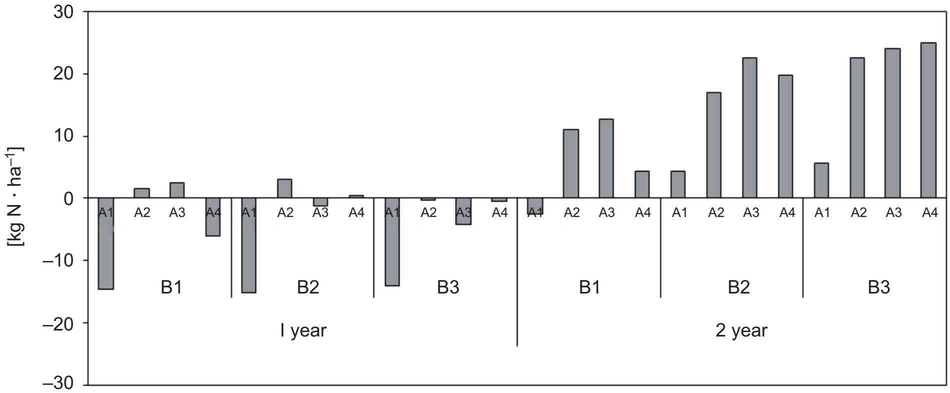

Fig. 1. Differences between amount of nitrogen available in spring (from soil and fertilizer) and taken up in seed and straw yield; A, B – nitrogen rates in autumn: 20 (B1), 40 (B2), 60 (B3) kg · ha^{-1} and in spring: 40 (A1), 60 (A2), 80 (A3), 40 + 40 (A4) kg · ha^{-1}

inside and between plants, affects a decrease in the thousand seed weight of red fescue seeds.

In the first and second year of harvesting, the proportion of normal seedlings in the preliminary assessment was similar in particular variants of spring nitrogen fertilization (Table 1). Only in the first year, in the second series (2006) a favourable effect of an autumn rate of 40 kg in relation to 60 kg N · ha^{-1} was indicated. The number of normal seedlings in that year was small, particularly in the second production year, which may have been a symptom of premature wilting of seeds in conditions of water deficit in June. The significant correlation of Sielianinow's coefficient in the period from May to June indicates a relation between hydrothermal conditions from stem formation to wax maturity and the number of normal seedlings (Table 4). Kozlowski and Kukulka [4] report that moderate temperatures and uniform precipitation during flowering and maturing positively affect the germination energy of red fescue. On average for two series of experiments the proportion of normal seedlings in the preliminary assessment in the second year was less almost by half than in the first year. Also the negative correlation coefficient indicates unfavourable influence of long utilization. Similar results were obtained in a study concerning red fescue whose seeds in the second year had a germination energy nearly 25 % less as compared with the first year [17].

The effect of nitrogen rate applied in autumn in the establishment year on the proportion of normal seedlings in the final assessment was significant only in the first year of the second series of investigation (2006) (Table 1). Similarly to the germination energy analysis, a positive effect of a rate of 40 kg in relation to 20 and 60 kg N · ha^{-1} was proved. The rate of autumn fertilization had no significant influence on this category of sowing material in the second year of seed harvesting. In the first production year, the amount and division of nitrogen rate applied in spring had no significant effect on the proportion of normally germinating seeds in the final assessment of the test. In the second year, the variant of two rates of spring nitrogen fertilization (40 kg · ha^{-1} at the start of growth and 40 kg · ha^{-1} at the beginning of stem

Table 1

Normal seedlings in preliminary and final assessment [%]

Dose of N [kg · ha^{-1}]	Preliminary assessment						Final assessment					
	Production year											
	I			II			I			II		
	2005	2006	average	2006	2007	average	2005	2006	average	2006	2007	average
Autumn												
20	83.9	44.3 ab	64.1	25.8	45.4	35.6	94.1	66.7 b	80.4	52.6	79.6	66.1
40	84.3	50.3 a	67.3	29.1	45.1	37.1	93.6	77.4 a	85.5	57.1	76.4	66.8
60	83.1	39.7 b	61.4	28.9	44.3	36.6	93.3	61.3 b	77.3	59.4	75.4	67.4
Spring												
40	84.3	47.5	65.9	25.8	48.5	37.2	93.5	68.4	80.9	54.6 ab	81.2 a	67.9 ab
60	84.6	41.3	63.0	28.3	47.2	37.7	93.8	65.8	79.8	60.6 a	78.0 ab	69.3 ab
80	81.1	47.0	64.1	31.8	43.2	37.5	93.4	72.6	83.0	63.2 a	76.6 ab	69.9 a
40 + 40	85.1	43.2	64.1	25.7	40.8	33.3	93.9	67.1	80.5	47.1 b	72.7 b	59.9 b
Average	83.8	44.8	64.3	27.9	44.9	36.4	93.7	68.5	81.1	56.4	77.1	66.7

a, b... – averages followed by the same letter constitute a homogenous group.

Table 2

Abnormal seedlings and hard seeds in final assessment [%]

Dose of N [kg · ha^{-1}]	Abnormal seedlings						Hard seeds					
	Production year											
	I			II			I			II		
	2005	2006	average	2006	2007	average	2005	2006	average	2006	2007	average
Autumn												
20	1.81	4.38	3.09	5.15	1.91	3.53	0.25	3.01	1.63	3.53	2.24	2.88
40	1.81	4.89	3.35	4.14	1.28	2.71	0.25	1.64	0.95	1.88	2.64	2.26
60	2.25	3.38	2.81	3.65	2.20	2.92	0.56	2.88	1.72	4.79	2.96	3.87
Spring												
40	1.67	4.18	2.93	3.04	1.53	2.29	0.67	3.18	1.93	3.89	2.20	3.04
60	2.00	4.67	3.33	6.18	1.88	4.03	0.25	1.83	1.04	2.17	2.82	2.50
80	2.17	3.84	3.00	3.17	1.71	2.44	0.25	2.35	1.30	2.34	3.27	2.81
40 + 40	2.00	4.17	3.08	4.86	2.08	3.47	0.25	2.67	1.46	5.19	2.16	3.67
Average	1.96	4.21	3.09	4.31	1.80	3.06	0.35	2.51	1.43	3.40	2.61	3.00

formation) proved to be significantly worse as compared with single rates of 60 and 80 kg · ha^{-1} in 2006, or only 40 kg N · ha^{-1} in 2007, applied early in spring. Synthesis of two series confirmed the negative effect of division of 80 kg · N rate on the number of normal seedlings. Nevertheless, although the differences were noticeable in relation to all the rates applied, they were significant only in relation to the largest. In 2006, a decrease in number of normally germinating seeds in the variant of divided rates was accompanied mostly by an increased (though not significantly) proportion of fresh seeds (Table 3). In 2007, in turn, an increase in proportion of dead seeds was observed, which might have been caused by heavy lodging, resulting in moisture growth after cutting at the bottom part of stand and latent germinating of a part of the seeds before threshing (the total precipitation from cutting to threshing was as large as 89.2 mm). The proportion of normal seedlings, as in the preliminary assessment, was the lowest in 2006, irrespective of the production year. Moreover, it was 14% less in the second year of seed harvesting than in the first. In a study by Fairey and Lefkovitch [7], red fescue showed the lowest germination capacity in the third year of seed harvesting.

The number of normal seedlings after 7 and 21 days of the test was higher for well filled seeds (significant correlation with thousand seed weight) (Table 4). Similar relations for red fescue were observed by Larsen and Andreasen [11]. Fairey and Lefkovitch [18], delaying nitrogen application by 3–4 weeks in relation to the early spring (end of March / beginning of April), indicated a significant increase in thousand seed weight in fescue. Nevertheless, germination capacity remained at a similar level. In the present study, an increase in the number of generative shoots and of seeds per spikelet had a negative effect on the proportion of this seed category. In the conditions which favoured productivity (at higher hydrothermal coefficient) the seeds had a high functional value (Table 4).

The proportion of abnormal seedlings was small and independent of rate, time of nitrogen fertilization, and year of production (Table 2). Such seedlings mostly did not form a radicle or coleoptile. Water shortage in May and June increased a number of such seeds in yield. There were few hard seeds too, irrespective of the level of nitrogen fertilization in autumn and spring (Table 2). In the second production year there were twice as many of them than in the first one.

The proportion of fresh seeds, which swelled but did not form any elements of seedling, had not significant relation to the level of nitrogen fertilization applied in spring in the first or second year or harvest (Table 3). Nitrogen applied in autumn at a dose of 40 kg · ha^{-1} resulted in a decrease in proportion of this category of seeds in the first production year of the second series (2006) relative to a dose of 20 kg; while the most such seeds were generated at a fertilization dose of 60 kg. In 2005, fresh seeds occurred sporadically, while in the dry 2006, they made up to 1/3 of yield. An increase in their proportion in 2006, along with the reduction in number of normally germinating seeds, may indicate a poor setting of the embryo due to premature wilting in conditions of water deficit and large proportion of vegetative shoots. Grzesiuk and Kulka [19] report that immature seeds can contain more germination inhibitors, and thus their dormancy is deeper than that of mature seeds. Fresh seeds, as hard ones, occurred in larger amounts at lower thousand seed weight and in the second production year.

Table 3

Fresh and dead seeds in final assessment [%]

Dose of N [kg · ha^{-1}]	Fresh seeds						Dead seeds					
	Production year											
	I			II			I			II		
	2005	2006	average	2006	2007	average	2005	2006	average	2006	2007	average
Autumn												
20	0.06	21.79 b	10.93	29.46	11.08	20.27	3.75	2.50	3.13	3.28	5.15	4.21 a
40	0.13	14.19 a	7.19	35.46	13.19	24.32	4.06	5.45	4.76	5.77	6.45	6.11 b
60	0.00	27.90 c	13.95	29.01	12.66	20.84	4.31	4.50	4.41	3.91	6.48	5.19 ab
Spring												
40	0.00	19.58	9.79	32.92	10.68	21.80	4.08	2.17	3.13	5.37	4.34 a	4.85
60	0.08	24.17	12.13	27.88	12.08	19.98	4.00	4.33	4.17	3.53	5.11 ab	4.32
80	0.17	19.38	9.77	28.79	12.60	20.70	4.33	1.68	3.01	3.18	5.76 ab	4.47
40 + 40	0.00	22.05	11.03	35.64	13.89	24.76	3.75	8.42	6.08	5.19	8.90 b	7.05
Average	0.06	21.29	10.68	31.31	12.31	21.81	4.04	4.15	4.10	4.32	6.03	5.17

a, b… – for explanations, see Table 1.

Table 4

Correlation coefficients

Specification	Year of production	TSW	Number of generative shoots	Number of spikelets in panicle	Number of seeds in spikelet	Seed yield	Sielianinow's coefficient V–VI
Normal seedlings in preliminary assessment	–0.63*	0.44*	–0.38*	0.16*	–0.32*	0.63*	0.25*
Normal seedlings in final assessment	–0.55*	0.29*	–0.19*	0.12	–0.15*	0.44*	0.52*
Abnormal seedlings	0.00	0.01	–0.14	0.08	–0.06	–0.22*	–0.33*
Hard seeds	0.29*	–0.25*	0.14	–0.12	0.06	–0.31*	–0.09
Fresh seeds	0.39*	–0.25*	0.13	–0.17*	0.20*	–0.56*	–0.47*
Dead seeds	0.12	–0.19*	0.14	0.01	0.21*	–0.02	0.15*

* – significant at $\alpha = 0.05$.

According to quality requirements for sowing material [1] swollen, but not germinating seeds are as germinating. Further detailed investigations are needed for this category of seeds, in order to fund physiological reasons for germination inhibition. The effectiveness of KNO_3 recommended by ISTA might be too small for breaking the dormancy of red fescue seeds. Salehi and Khosh-Khui [20] indicated that in red fescue very good results are obtained using sulphuric acid, which increased the germinating capacity from 42.5 to 84 %.

Autumn and spring nitrogen fertilization rates had a significant effect on the proportion of dead seeds (rotting and moulding) only in the second production year (Table 3). On average for two series, fewer such seeds were in the variant with the least autumn rate. Correlation coefficients indicate that an increase in the number of seeds per spikelet and reduction of thousand seed weight increase the proportion of this category of seeds in yield (Table 4). In 2007 spring nitrogen fertilization in the smallest amount of 40 kg contributed to a decrease in the proportion of dead seeds, but the difference was significant only in relation to the effect of a divided rate of 80 kg, half of which was applied at stem formation. The variant of delayed nitrogen fertilization favoured forming vegetative shoots, which enhanced lodging. In these conditions there is a higher risk of infection by pathogens, which can cause rotting and moulding of seeds.

Conclusions

1. Amount of nitrogen applied during autumn tillering of red fescue usually had no effect on the proportion of normal seedlings in seed yield in the first and second production years.
2. Nitrogen rates at the start of growth had no effect on the proportion of normal seedlings in seed yield in the first year. In the second year, the application of a half of 80 kg $N \cdot ha^{-1}$ at the beginning of stem formation resulted in a decrease in proportion of this category of seeds, as compared with a single application of full rate at the start of growth.
3. Number of hard and fresh seeds was only to a small extent determined by the method of autumn and spring nitrogen fertilization, both in the first and second production years. The proportion of these categories was higher at a smaller thousand seed weight.
4. Decrease in nitrogen fertilization rates applied after seed harvesting in the first production year from 40 to 20 kg $N \cdot ha^{-1}$ caused a reduction in the proportion of dead seeds in yield in the second year of harvesting.

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WPŁYW DAWEK I TERMINÓW NAWOŻENIA AZOTEM NA JAKOŚĆ PLONU NASION KOSTRZEWY CZERWONEJ UPRAWIANEJ NA NASIONA

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Abstrakt: Jesienią stosowano 20, 40 lub 60 kg N · ha^{-1}, natomiast wiosną w latach pełnego użytkowania 40, 60 oraz 80 kg N · ha^{-1} (jednorazowo lub w dwóch częściach: 40 kg · ha^{-1} w czasie początku wegetacji i 40 kg^{-1} na początku strzelania w źdźbło). W pierwszym roku zbioru nasion wiosenna dawka azotu nie miała wpływu na udział nasion normalnie kiełkujących, twardych, świeżych i martwych w ocenie wstępnej ani końcowej testu kiełkowania. W drugim roku wykorzystanie części azotu na wzrost wegetatywny, przy ograniczeniu tworzenia organów generatywnych przyczyniło się do pogorszenia jakości otrzymanego plonu nasion. Dzielenie dawki 80 kg · ha^{-1} azotu stosowanego wiosną w porównaniu do jednorazowej aplikacji spowodowało zmniejszenie udziału siewek normalnych z 69,9 do 59,9 %. W warunkach najmniejszej dawki nawożenia jesiennego ograniczeniu liczby nasion w kłoskach i zwiększeniu masy tysiąca nasion towarzyszyło zmniejszenie udziału nasion martwych w plonie.

Słowa kluczowe: kostrzewa czerwona, kiełkowanie nasion, nawożenie azotowe

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UTILIZATION OF NITROGEN AND OTHER MACROELEMENTS BY NON-PAPILIONACEOUS PLANTS CULTIVATED IN STUBBLE INTERCROP

ZAGOSPODAROWYWANIE AZOTU I INNYCH MAKROSKŁADNIKÓW PRZEZ ROŚLINY NIEMOTYLKOWATE UPRAWIANE W MIĘDZYPLONIE ŚCIERNISKOWYM

Abstract: Field experiments were carried out in 2002–2004 at the Research Station of the University of Technology and Life Sciences in Mochelek (17°51′E, 53°13′N), on soil of very good rye complex, in randomized split-plot design. The experimental factors were: 1) nitrogen dose: 0, 45 and 90 kg · ha^{-1}; 2) species of plant cultivated in intercrop: oilseed radish 'Adagio', common sunflower 'Wielkopolski', and tansy phacelia 'Stala'. The aim of the study was to estimate the ability to utilize nitrogen and other macroelements in the aboveground biomass and crop residue of plants cultivated in stubble intercrop. Tested non-papilionaceous plants cultivated in stubble intercrop utilized considerable amounts of nitrogen and potassium left after forecrop harvest. Radish had a significantly higher potential for accumulation of nitrogen, phosphorus, potassium and calcium than sunflower and phacelia. Tested plants accumulate nitrogen mostly in the aboveground biomass. Only 19.5 % (sunflower) to 31.7 % (radish) of this component have been accumulated in crop residue. An increase in nitrogen fertilization of oilseed radish, common sunflower, and tansy phacelia cultivated in stubble intercrop up to 90 kg · ha^{-1} significantly increased the accumulation of nitrogen and other macrocomponents in the aboveground biomass and crop residue of these plants.

Keywords: utilization of macroelements, stubble intercrop, nitrogen, oilseed radish, tansy phacelia, common sunflower

Consumption of mineral fertilizers in Poland is relatively low. In recent years, however, an upward tendency can be observed. In the economic year 2001–2002 mineral fertilizer use was only 93.2 kg · ha^{-1} NPK, and in 2005–2006 it rose to 123.3 kg · ha^{-1} NPK [1]. Statistical data indicate considerable differentiation in the amount of fertilizers applied in particular regions of our country. The least is used in Podkarpackie province (61.3 kg · ha^{-1} NPK), and the most in Kujawy-Pomerania, Opole and

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Wielkopolska provinces (182.3; 175.0 and 161.0 kg · ha^{-1} NPK, respectively). Thus, in conditions of low level of fertilizer component supply of plants, there are areas where high or very high rates of mineral fertilizers are applied. In these areas there is a risk of losses of mineral components, which are not utilized during plant growth and released into soil during mineralization of crop residue of these plants.

The mass of nitrogen leached out of soil in the autumn and winter periods depends on soil properties, the crop species, the amount of precipitation and air temperature [2, 3]. Under condition of low total rainfalls nitrogen leaching is small, whereas heavy rains in this period contribute to leaching of 50–90 kg · ha^{-1} N.

Apart from the loss of fertilizer components, which potentially could be utilized by a successive crop, certain negative environmental consequences appear [4–6]. The longer the period from harvesting of a given plant to sowing the successive plant, the higher these consequences are. The longest period when soil remains not covered with plants occurs when spring crops come in succession after the harvesting of rape or winter cereals. In these conditions, cultivation of intercrops, which take up fertilizer components from soil and accumulate them in their biomass, seems necessary.

The aim of this study was to estimate the ability to utilize nitrogen and other macroelements in the aboveground biomass and crop residue of oilseed radish, tansy phacelia and common sunflower cultivated in stubble intercrop.

Material and methods

Field experiments were carried out in 2002–2004 at the Research Station of the University of Technology and Life Sciences in Mochelek (17°51′E, 53°13′N), in Kujawy-Pomerania province, on lessive soil formed of heavy loamy sand of a very good rye complex. The soil is characterized by a very high content of available phosphorus (95.5 mg P in 1 kg) and potassium (330.0 mg K in 1 kg) and a moderate content of magnesium (59.8 mg Mg in 1 kg). The total content of nitrogen was 625 N in 1 kg of soil.

The experimental factors were as follows:

1) nitrogen fertilization rate: 0, 45 and 90 kg · ha^{-1};

2) species of the plant cultivated in stubble intercrop: oilseed radish 'Adagio', common sunflower 'Wielkopolski', and tansy phacelia 'Stala'.

Field experiments were conducted in randomized split-plot design in four replications. Seeds were sown after the harvest of spring barley within the period of 5–9 August. Plants were harvested after 71–77 days from sowing, from plots with an area of 27 m^2.

After the harvest of forecrop (spring barley), phosphorus (26 kg · ha^{-1} P) and potassium (66 kg · ha^{-1} K) fertilizers were applied. After that, the soil was disked, and next ploughed at a depth of about 12 cm. Nitrogen fertilization was applied in the form of ammonium nitrate, before seedbed preparing by means of a cultivation unit.

Seeds of plants cultivated in stubble intercrop were sown after the seedbed preparation by means of a plot drill, with a row spacing of 12.5 cm and a depth of

2–3 cm. The sowing rate was respectively: radish – 12, sunflower – 30, phacelia – 10 kg · ha^{-1}.

Plant harvest was conducted at the beginning of flowering stage of radish and phacelia and at budding stage of sunflower. After plant cutting, 1 kg of the aboveground biomass of intercrops was taken from each plot in order to estimate the content of macroelements. Crop residue was collected from soil monoliths 25 × 25 × 25 cm, which were screened and rinsed with water.

Chemical analyses of the aboveground biomass and crop residue of intercrops were performed after the mineralization of shredded plant material (wet combustion with perhydrol and sulphuric acid) applying the following methods: total N – the Kjeldahl method [7] , P – the vanadium-molybdenum method [8], K the flame photometry method [9], Ca – the flame photometry method [10], Mg – colorimetry with titan yellow [7].

Results concerning yielding, the content and accumulation of total nitrogen were presented in the study by Wilczewski et al [11].

The significance of differences was determined with Tukey's confidence half--intervals at the significance level $\alpha = 0.05$.

Results

Very favorable weather conditions during the study period were observed (Table 1). High total rainfall in whole intercrops growing period in 2002 and 2004 effected in high biomass yield [11]. In 2003 definitely low rainfall occured over that period. Nevertheless the growth and development of the crops was correct and high yields were obtained. This resulted from a high amount of rainfall in July. Moreover in the year 2003 very favorable temperature conditions occured in September and a very intensive plants growth and development was observed in that month.

Table 1

Weather conditions at the research site

Months	Years			Average for 1949–2005
	2002	2003	2004	
Total monthly rainfall [mm]				
July	77.9	106.2	53.5	71.3
August	58.0	17.7	138.7	49.3
September	70.5	16.7	40.0	41.4
October	111.8	34.0	63.8	32.5
Total VII–X	318.2	174.4	296	194.5
Average air temperature [^{o}C]				
July	18.9	19.2	16.4	17.8
August	19.9	18.4	17.9	17.4
September	12.9	13.6	12.7	13.2
October	6.2	4.7	8.8	8.3
Average VII–X	14.5	14.0	14.0	14.2

The tested plants were characterized by varied potential for element accumulation in the biomass. The most nitrogen in aboveground parts and crop residue was accumulated by radish, while significantly less by sunflower and phacelia (Table 2).

Table 2

Nitrogen accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	50.8	59.0	59.2	56.4
45	67.7	79.5	82.2	76.5
90	86.5	98.2	118.1	100.9
Average	68.3	78.9	86.5	77.9
LSD for: I –13.03; II – 4.41; II × I –7.64; I × II – 13.31				
Crop residue				
0	14.2	14.0	31.5	19.9
45	16.9	19.4	41.9	26.1
90	26.7	23.9	47.0	32.5
Average	19.3	19.1	40.1	26.2
LSD* for: I – 4.98; II – 4.55; II × I – ns; I × II – ns				

* – LSD – lowest significant difference; ns – non-significant.

With the increase in nitrogen fertilization, also the accumulation of this element in plants rose significantly, particularly in their aboveground biomass, where both introducing a rate of 45 kg · ha^{-1} N and increasing fertilization to 90 kg · ha^{-1} resulted in a significant rise in accumulation in all the tested plants. Accumulation of nitrogen in crop residue was to a lesser degree dependent on the nitrogen rate. Significant increase in the weight of nitrogen accumulated in crop residue of phacelia and sunflower was obtained only after introducing a rate of 90 kg · ha^{-1}. Accumulation of nitrogen in crop residue of radish increased significantly after introducing a nitrogen fertilization rate of 45 kg · ha^{-1}, while the increase to 90 kg · ha^{-1} did not exert a significant effect on accumulation of this element.

Oilseed radish accumulated significantly more phosphorus in the aboveground biomass and crop residue than the other plants (Table 3). Particularly big differences between the species were found in the amount of phosphorus accumulated in crop residue, in treatments fertilized with the highest nitrogen rate, in which radish accumulated 2–3 times more of this component than the other plants.

A rate of nitrogen applied before the sowing of intercrops influenced significantly the amount of phosphorus accumulated in their biomass. The extent of this effect was higher in relation to the aboveground parts, in which every increase in nitrogen rate caused a significant increase in phosphorus accumulation. In the biomass of crop residue, only in plants fertilized with a rate of 90 kg · ha^{-1} significantly higher accumulation of this element was found than in plants not fertilized with nitrogen.

Table 3

Phosphorus accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	11.0	12.3	10.7	11.3
45	15.4	15.9	16.3	15.9
90	17.0	16.8	22.0	18.6
Average	14.5	15.0	16.3	15.3
LSD for: I – 2.48; II – 1.14; II × I – 1.97; I × II – 2.76				
Crop residue				
0	4.8	3.8	11.3	6.6
45	6.0	5.4	13.3	8.2
90	7.8	5.5	14.5	9.3
Average	6.2	4.9	13.0	8.0
LSD for: I – 1.75; II – 1.62; II × I – ns; I × II – ns				

Potassium, like nitrogen and phosphorus, was accumulated mostly in the aboveground parts, where from 63.3 % (radish) to 77.3 % (sunflower) of the total weight of this component was located (Table 4).

Table 4

Potassium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	99.8	128.3	116.2	114.8
45	141.5	154.8	126.5	140.9
90	139.8	171.5	168.7	160.0
Average	127.0	151.5	137.1	138.6
LSD for: I – 35.98; II – 11.21; II × I – 19.42; I × II – 36.13				
Crop residue				
0	30.0	31.9	67.7	43.2
45	38.3	49.4	86.0	57.9
90	52.1	51.7	85.0	63.0
Average	40.1	44.4	79.6	54.7
LSD for: I –11.10; II – 9.12; II × I – ns; I × II – ns				

Sunflower accumulated significantly more potassium than the other plants in the aboveground biomass. Oilseed radish accumulated significantly more this element in crop residue than phacelia and sunflower. Potassium accumulation in the aboveground biomass of intercrops increased with nitrogen fertilization intensification. Statistical confirmation of this increase was obtained for phacelia and sunflower only after increasing a nitrogen rate from 0 to 45 kg · ha^{-1}, and for radish, only after replacing a dose of 45 with a rate of 90 kg · ha^{-1} N.

Oilseed radish accumulated significantly more Ca than phacelia in crop residue (Table 5). Sunflower accumulated significantly less this component than phacelia. An increase in calcium accumulation in the aboveground biomass of intercrops was recorded with an increase of N rate. Statistically proved differentiation of this character values was found only after increasing a nitrogen rate from 0 to 90 kg · ha^{-1} N in the biomass of phacelia and sunflower. Radish did not respond to this factor significantly.

Table 5

Calcium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	34.7	37.4	35.9	36.0
45	37.6	39.8	36.7	38.0
90	45.0	47.9	43.4	45.4
Average	39.1	41.7	38.7	39.8
LSD for: I – 9.44; II – 2.36; II × I – ns; I × II – 9.14				
Crop residue				
0	12.5	7.6	17.1	12.4
45	14.6	11.1	19.3	15.0
90	19.8	10.3	20.9	17.0
Average	15.6	9.7	19.1	14.8
LSD for: I – ns; II – 2.25; II × I – ns; I × II – ns				

Tested plants cultivated in stubble intercrop accumulated slight amounts of magnesium in their biomass (Table 6). Radish accumulated the most of this element in crop residue, while sunflower, in the aboveground parts. Phacelia accumulated significantly less magnesium than sunflower and radish, both in the aboveground biomass and in crop residue. The rate of nitrogen had a significant effect on Mg accumulated in the biomass of intercrops. Particularly strong influence was found in the aboveground biomass of intercrops, where both introducing a rate of 45 kg · ha^{-1} N and its increasing to 90 kg · ha^{-1} resulted in a statistically proved increase in the accumulation of this element. For the crop residue, a significantly higher accumulation of Mg occurred in treatments fertilized with nitrogen than in unfertilized intercrops. However, there were no differences between plants fertilized with 45 kg · ha^{-1} N and 90 kg · ha^{-1} N.

Table 6

Magnesium accumulation in the biomass of stubble intercrops [kg · ha^{-1}] – averages for 2002–2004

Nitrogen rate (I) [kg · ha^{-1}]	Intercrop (II)			Average
	Tansy phacelia	Common sunflower	Oilseed radish	
Aboveground biomass				
0	7.0	8.7	6.4	7.4
45	8.1	10.7	8.5	9.1
90	8.7	12.5	11.0	10.7
Average	7.9	10.6	8.6	9.1
LSD for: I –1.56; II – 0.52; II × I – 0.90; I × II – 1.59				
Crop residue				
0	2.1	2.2	5.2	3.2
45	2.2	3.3	6.4	4.0
90	3.0	3.9	5.8	4.2
Average	2.4	3.1	5.8	3.8
LSD for: I – 0.73; II – 0.47; II × I – 0.81; I × II – 0.93				

A positive correlation between the nitrogen rate applied before sowing intercrops and the accumulation of macroelements in their biomass was observed in the study (Table 7). Nitrogen accumulation in the biomass increased to the largest extent. Correlation coefficients concerning nitrogen accumulation both in crop residue and in the aboveground biomass were significant for all the tested plants. A positive correlation between the nitrogen rate and phosphorus accumulation in the aboveground parts and all the biomass of intercrops, particularly in phacelia and radish, was also significant. Calcium was the element whose accumulation in the biomass of intercrops was least dependent on the nitrogen dose.

Table 7

Correlation coefficients between nitrogen rate and macroelement weight accumulated in intercrop biomass

Intercrop	N	P	K	Ca	Mg
	Aboveground biomass				
Tansy phacelia	0.64*	0.57*	0.26	0.31	0.27
Common sunflower	0.70*	0.41*	0.23	0.22	0.47*
Oilseed radish	0.66*	0.66*	0.49*	0.25	0.57*
Crop residue					
Tansy phacelia	0.50*	0.42*	055*	0.39*	0.43*
Common sunflower	0.43*	0.35	0.46*	0.25	0.53*
Oilseed radish	0.58*	0.38	0.32	0.20	0.15
Total accumulation					
Tansy phacelia	0.71*	0.63*	0.41*	0.41*	0.37
Common sunflower	0.70*	0.43*	0.33	0.24	0.55*
Oilseed radish	0.73*	0.75*	0.51*	0.31	0.51*

* Significant coefficient for $p < 0.05$; number of observations $n = 27$.

Discussion

Tansy phacelia, common sunflower and oilseed radish cultivated in stubble intercrop accumulated in the biomass considerable amounts of nitrogen and potassium, moderate amounts of calcium and small amounts of phosphorus and magnesium. The ability of plants cultivated in stubble intercrop to take up nitrogen left in soil after the harvest of forecrop plants is of great value. In the present study, this ability was shown in treatments without nitrogen fertilization, where the tested plants showed a remarkable potential. Oilseed radish, which as a plant of a high nitrogen content in the biomass [12, 13] is characterized by a high nitrogen requirement, proved to be of particular value. This plant also utilized nitrogen applied with fertilizers before sowing the intercrops to a remarkably higher degree. The total weight of nitrogen accumulated in the biomass of radish fertilized with a rate of 90 kg $\cdot$ ha^{-1} N was by 74.4 kg higher than that of unfertilized radish.

The investigations carried out have confirmed the large ability of macroelement utilization by non-papilionaceous plants cultivated in stubble intercrops that are already known from the literature [13–15]. A higher macroelement accumulation in the biomass of oilseed radish than in common sunflower and tansy phacelia, mostly resulted from a higher mass of macroelements accumulated in crop residue, indicates the usefulness of this plant for utilization of fertilizer components which were not used by the forecrop. It also confirms a high forecrop value of radish for cereals, which as successive crops can produce a higher yield than after other non-papilionaceous plants cultivated in stubble intercrop [5] or the yield with a higher total protein content [16].

The basic weight of macrocomponents, accounting for from 65.7 % (phosphorus) to 74.8 % (nitrogen) of total accumulation, was located in the aboveground biomass of intercrops, and only from 25.2 to 34.3 % in crop residue. This resulted both from a higher yield of plant aboveground biomass than that of crop residue and from a higher concentration of the tested elements in the biomass, irrespective of the level of nitrogen fertilization [11, 17, 18]. The results confirm the conclusions of Batalin [19], who claimed that a sufficient water supply of plants favours the inflow of elements to aboveground parts and a decrease in crop residue proportion in yield, and consequently, results in a smaller accumulation of macroelements in crop residue.

Due to a significant increase in the biomass yield of plants cultivated in intercrops as a result of nitrogen fertilization [11], a positive effect of this factor on macroelement accumulation, expressed by positive correlation coefficients, is evident. However, it should be emphasized that the extent of this relation was different for particular elements and plant species cultivated in stubble intercrop. The accumulation of nitrogen, supplied in fertilizers, phosphorus and potassium, whose abundance in soil before establishing the experiment was very high, underwent the highest increase. Moreover, the weight of elements accumulated in the biomass of oilseed radish was more dependent on the nitrogen rate than those of the other plants. Sunflower and phacelia response to an increase in nitrogen rate was smaller, which resulted from a weaker effect of this factor on the dry matter yield of these plants [11].

Conclusions

1. Tested non-papilionaceous plants cultivated in stubble intercrop can utilize considerable amounts of nitrogen and potassium remaining after harvest of forecrop and applied preplant in the form of mineral fertilizers. Oilseed radish had a significantly higher potential of accumulating nitrogen, phosphorus, potassium and calcium than sunflower and phacelia.

2. Tested plants have accumulated nitrogen mainly in the aboveground biomass. Only 19.5 % (sunflower) to 31.7 % (radish) of this component have been accumulated in crop residue.

3. Higher rates of nitrogen fertilization in oilseed radish, common sunflower and tansy phacelia cultivated in stubble intercrop up to 90 kg · ha^{-1} have significantly increased the accumulation of nitrogen and other macroelements in the aboveground biomass and crop residue of these plants.

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ZAGOSPODAROWYWANIE AZOTU I INNYCH MAKROSKŁADNIKÓW PRZEZ ROŚLINY NIEMOTYLKOWATE UPRAWIANE W MIĘDZYPLONIE ŚCIERNISKOWYM

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Abstrakt: Badania polowe wykonano w latach 2002–2004 w Stacji Badawczej Uniwersytetu Technologiczno-Przyrodniczego w Mochełku (17°51′E, 53°13′N), na glebie kompleksu żytniego bardzo dobrego, w układzie losowanych podbloków. Czynnikami doświadczenia były: 1) dawka azotu: 0, 45 i 90 kg · ha^{-1};

2) gatunek rośliny uprawianej w międzyplonie: rzodkiew oleista ‘Adagio’, słonecznik zwyczajny ‘Wielkopolski’, facelia błękitna ‘Stala’. Celem badań było określenie możliwości zagospodarowywania azotu i innych makroskładników w biomasie nadziemnej i resztkach pozbiorowych roślin uprawianych w międzyplonie ścierniskowym. Badane rośliny niemotylkowate, uprawiane w międzyplonie ścierniskowym zagospodarowywały znaczne ilości azotu i potasu pozostających po zbiorze przedplonu. Rzodkiew oleista ma istotnie wyższy potencjał akumulacji azotu, fosforu, potasu i wapnia niż słonecznik i facelia. Badane rośliny akumulowały azot głównie w biomasie nadziemnej. Jedynie 19,5 % (słonecznik) do 31,7 % (rzodkiew) tego składnika zostało zakumulowane w resztkach pozbiorowych. Zwiększanie nawożenia azotem rzodkwi oleistej, słonecznika zwyczajnego i facelii błękitnej, uprawianych w międzyplonie ścierniskowym, w zakresie do 90 kg · ha^{-1} znacznie zwiększało akumulację azotu i innych makroskładników w biomasie nadziemnej i resztkach pozbiorowych tych roślin.

Słowa kluczowe: zagospodarowywanie makroskładników, międzyplon ścierniskowy, azot, rzodkiew oleista, facelia błękitna, słonecznik zwyczajny

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Robert WITKOWICZ[1] and Jacek ANTONKIEWICZ[2]

EFFECT OF AGRONOMIC FACTORS ON PROTEIN YIELD AND CONTENT OF NITROGEN IN GRAIN OF NAKED OAT (*Avena sativa*)

WPŁYW WYBRANYCH ZABIEGÓW AGROTECHNICZNYCH NA ZAWARTOŚĆ AZOTU I PLON BIAŁKA W ZIARNIE OWSA NAGOZIARNISTEGO (*Avena sativa*)

Abstract: Mineral fertilization, particularly with nitrogen is a factor visibly modifying the quantity and quality of oat grain yield. The range of changes in protein yield and the element contents depend not only on the level of mineral fertilization but also on the genotype and growth regulators. Because of high dependence of agronomic measures efficiency on the genotype, it is necessary to investigate this interaction.

Field experiments were conducted in Wierzbica on typical brown soil, where protein yield ranged from 75 to 88 $g \cdot m^{-2}$, whereas in the experiment conducted in Prusy on degraded chernozem, protein yield fell within the range of 540 to 740 $kg \cdot ha^{-1}$. The field experiment conducted in Wierzbica demonstrated that protein yield in naked oat was stimulated by the genotype and phosphorus-potassium fertilization and apparently limited by the application of Moddus growth regulator. Under conditions of a better site in Prusy only genotype statistically significant effect was registered, with persisting influence of the other factors. An apparent difference was noticed in the efficiency of nitrogen fertilization effect on the protein yield, because under site conditions in Prusy the increase in yield by 0.3 of standard deviation unit was demonstrated in comparison with very slight growth in its yield in Wierzbica.

Because protein yield is the resultant of grain yield and its nitrogen content, a less significant effect of the tested factor on its content was observed. The main factor which statistically significantly determined nitrogen content was the choice of oat cultivar/strain. Both in Wierzbica and Prusy both oat strains (STH 4770 and STH 7000) contained bigger nitrogen quantities than Akt cv. The other tested agronomic factors caused changes in nitrogen content but they were not statistically significant.

Keywords: naked oat, protein yield, nitrogen, mineral fertilization, plant growth regulator

Nitrogen is one of basic elements crucial for the proper growth and development of plants. Moreover, it determines the quality and level of crop yields [1, 2]. The uptake

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and utilization of nitrogen by plants depend on the localities, including soil, agronomic and climatic conditions [3, 4].

Mineral fertilization, particularly with nitrogen, is a factor apparently modifying the quantity and quality of oat grain [5, 6]. The range of changes in protein yield and component contents depends not only on the fertilization level but also on the genotype and growth regulators [7]. A serious dependence of agronomic factors on genotype makes necessary to examine this interaction. The research aimed at an assessment of the effect of mineral fertilization, kind and dose of growth regulator and genotype on total nitrogen content and protein yield in naked oat grain.

Materials and methods

The field experiments were conducted in 2003 in two localities: in Prusy near Krakow (one experiment) and in Wierzbica (two experiments). Agronomic measures applied were the same as generally used.

The field experiments in Wierzbica were set up using fractional design 2^{5-1} in two replications. Each plot area was 6 m^2, but the yield and its components were estimated basing on the test area of 1 m^2. The seeds were sown at 500 pcs · m^{-2} density. The experimental factors and their levels were shown in Table 1. The experiment was located on typical brown soil classified to IV class of soil quality, with pH = 5.9. The strains selected for the experiments revealed some specific properties, such as increase in 1000 grains weight (STH 4770) and shortened stem (STH7000).

Table 1

Agronomic factors and their levels in experiments conducted in Wierzbica

Agronomic factors	The factor levels	
	1 [low]	2 [high]
Genotype [experiment I]	STH 4770 Strain	Akt Cultivar
Genotype [experiment II]	STH 7000 Strain	Akt Cultivar
PK fertilization	0 kg · ha^{-1} PK	226 kg · ha^{-1} PK
Foliar application of urea	0 kg · ha^{-1} N	17 kg · ha^{-1} N
Moddus plant growth regulator	0 dm^3 ha^{-1} [M 1]	0.4 dm^3 ha^{-1} [M 2]
Promalin plant growth regulator	0 dm^3 · ha^{-1}	0.15 dm^3 · ha^{-1}

The field experiment conducted in Prusy was set up using fractional design 3^{4-1} in two replications. The plot for harvest area was 10 m^2 and the seeds were also sown at the density of 500 pcs · m^{-2}. The experiment was conducted on degraded chernozem counted to the first soil quality class. The experimental factors and their levels were listed in Table 2.

The amount of NPK fertilization in both localities resulted from the naked oat grain harvest assumed on the level of 4 Mg · ha^{-2} and the site abundance. Nitrogen foliar fertilization constituted 1/4 of the nitrogen fertilization used (17 kg · ha^{-1} in Wierzbica and 9 kg · ha^{-1} in Prusy). The second, higher dose of N used foliarly in Prusy resulted from the doubling of the lower dose, which approximately equalled the dose applied in

Wierzbica (18 kg · ha^{-1}). After oat grain harvesting and determining the crop yield, nitrogen content was determined using Kjeldahl distilling method.

Table 2

Agronomic factors and their levels in experiment conducted in Prusy

Agronomic factors	The factor levels		
	1 [low]	2 [medium]	3 [high]
Genotype	Strain STH 7000	Cultivar Akt	Strain STH 4770
PK fertilization	0 kg · ha^{-1} PK [PK 1]	72 kg · ha^{-1} P [PK 2]	256 kg · ha^{-1} PK [PK 3]
Foliar application of urea	0 kg · ha^{-1} N	9 kg · ha^{-1} N	18 kg · ha^{-1} N
Moddus plant growth regulator	0 dm^3 · ha^{-1}	0.4 dm^3 · ha^{-1}	0.6 dm^3 · ha^{-1}

The course of rainfall-thermal conditions was shown in Gaussen-Walter diagrams. The diagram analysis reveals that more advantageous rainfall-thermal conditions for growth and development of oat plants occurred in Wierzbica. The course of rainfall curve, lowered in relation to mean temperatures curve, points to alternate occurrence of decades fulfilling or not fulfilling oat water needs. Three such decades fulfilling oat water needs were registered in Prusy locality, including two subsequent ones (2nd and 3rd decade in May), with the remaining part of vegetation period revealing considerable rainfall deficiency (Fig. 1 and 2). The reference of the course of lowered rainfall curve to lowered curve of water needs acc. to Dziezyc points rather to their fulfillment, but only until the first decade of June.

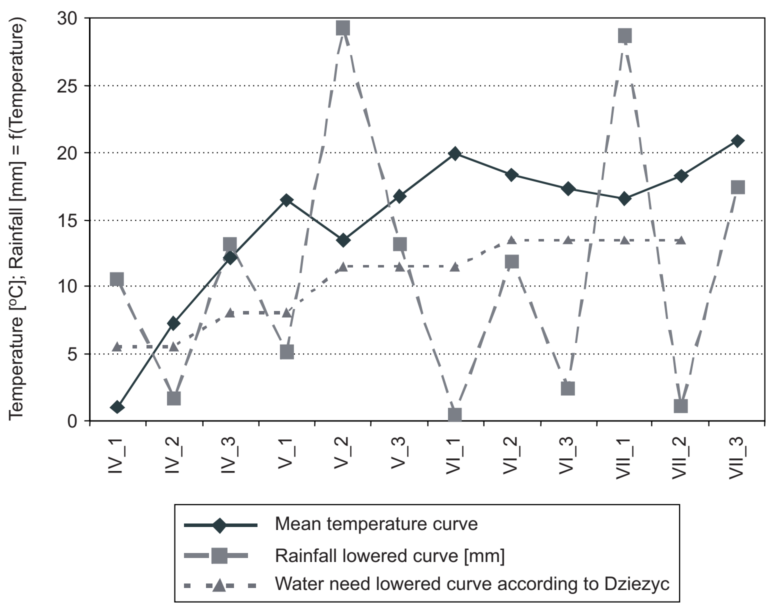

Fig. 1. Weather diagram for the vegetation period in Wierzbica

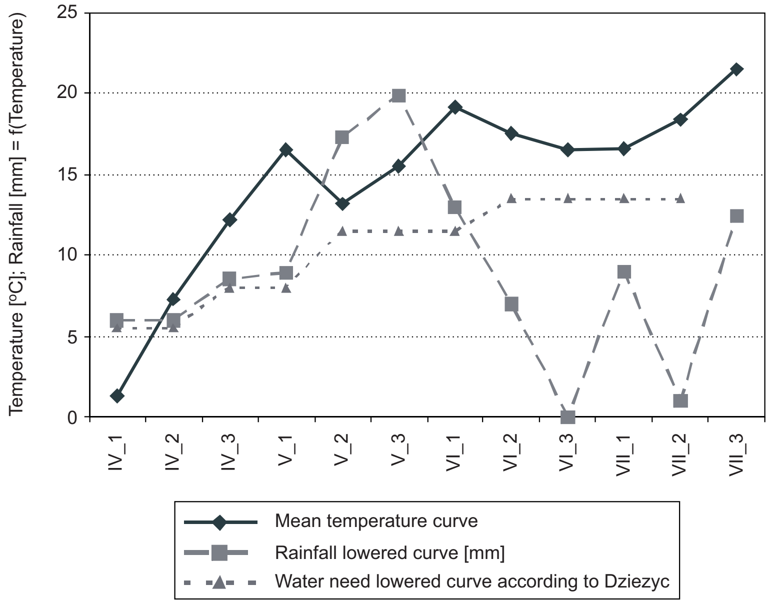

Fig. 2. Weather diagram for the vegetation period in Prusy

The obtained results were verified using ANOVA procedure. STATISTICA 7.1 packet, module planning of two and three-value experiments was used. In case of three-value experiment, variation caused by the experimental factors was divided into linear and square factor. It was determined by a suspicion that a parabola may describe the effect of investigated factors on the yield and protein content in grain better than the straight line.

Verification of the basic assumed, null working hypotheses H_0: $\sum_{i=1}^{k} k_i^2 = 0$ was conducted on the basis of F-Fisher-Snedecor test. Before conducting analyses of variance the distribution of features fit to normal distribution was checked using Kolmogorow--Smirnow test, as well as homogeneity of error variance assumption using Bartlett's test. Multiple regression analysis of variance was also conducted with the use of ANOVA models. Standardized regression coefficients were presented in the Tables in order to facilitate comparison of the effect of individual factors. Their statistical significance confirms statistically significant effect of respective variability source. Statistical significance on $\alpha = 0.05$ level was marked in bold and on $\alpha = 0.01$ level in bold and italics [8].

Results and discussion

The environment conditions in Wierzbica allowed to accumulate higher content of total nitrogen in oat grain, ranging from 24.02–26.45 $g \cdot kg^{-1}$. In Prusy nitrogen concentrations were lower and fluctuated from 17.66 to 19.05 $g \cdot kg^{-1}$. Despite the site differences, the interrelations in nitrogen content between the genotypes remained unchanged. Definitely the highest nitrogen content was characteristic for STH4770 strain and the lowest for Akt cultivar (Table 3 and 4).

In Wierzbica, the genotype used in the experiment comparing STH4770 strain with Akt cultivar as the only one from among tested factors had a statistically significant effect. Akt cv. revealed lower nitrogen content by 0.72 of standard deviation unit, which constituted 2.43 $g \cdot kg^{-1}$. Negative, but statistically insignificant results obtained in Wierzbica were also caused by the application of phosphorus-potassium fertilization and Promalin growth regulator. Foliar application of urea and the use of Moddus regulator had definitely stronger and also positive influence on nitrogen content. Standardised regression coefficients for urea fertilization for experiments I and II were respectively 0.297 and 0.303, which indicated increase in N content, respectively by 0.99 and 0.79 $g \cdot kg^{-1}$. The effect of Modus growth regulator in these experiments was respectively 0.132 and 0.265, which showed increase in N content respectively by 0.45 and 0.69 $g \cdot kg^{-1}$ (Table 3).

Table 3

The effect of tested factors on nitrogen content in oat grains and protein yield in the experiment in Wierzbica

Factor	Experiment I			Experiment II		
	STH 4770 – Akt			STH 7000 – Akt		
	The factor level and standardized regression coefficient*					
	1	2	Coefficient	2	1	Coefficient
Content N [$g \cdot kg^{-1}$]						
Cultivar/Strain	26.45	24.02	***–0.720***	24.73	24.02	–0.272
PK	25.39	25.08	–0.092	24.55	24.20	–0.133
N	24.74	25.73	0.297	23.98	24.77	0.303
Moddus	25.01	25.46	0.132	24.03	24.72	0.265
Promalin	25.28	25.19	–0.029	24.50	24.25	–0.096
Protein yield [$g \cdot m^{-2}$]						
Cultivar/Strain	83.50	85.04	0.084	76.99	85.04	**0.337**
PK	80.41	88.13	**0.424**	75.24	86.79	***0.483***
N	83.88	84.66	0.043	80.11	81.92	0.076
Moddus	83.45	85.09	0.090	85.85	76.18	**–0.405**
Promalin	84.62	83.92	–0.039	81.87	80.16	–0.072

* – see Table 1.

The only statistically significant effect in the experiment conducted in Prusy was the genotype square effect resulting from apparently lower nitrogen content in Akt cv., constituting medium level of the experimental factor (genotype). Estimating the effect of phosphorus-potassium fertilization in Prusy one should emphasize the fact of increased nitrogen content already after application of solely phosphorus fertilizer.

Introduction of additional potassium fertilization on the 3rd level of this factor did not cause any greater changes in N content. Foliar fertilization with increasing doses of urea led to elevated N content in oat grain. Application of Moddus growth regulator caused also statistically insignificant increase in oat grain N concentrations (Table 4).

Table 4

The effect of tested factors on nitrogen content in oat grains and protein yield in the experiment in Prusy

Factor	The factor level*			Standardized coefficient of regression effects		
	1	2	3	Linear	Square	Intercept
N Content [g · kg^{-1}]						
Cultivar/Strain	19.03	17.66	19.05	0.004	***0.401***	–0.200
PK	17.74	18.46	18.33	0.138	–0.079	
N	17.98	18.27	18.55	0.135	0.032	
Moddus	17.84	18.58	17.93	0.221	–0.150	
Protein yield [Mg · ha^{-2}]						
Cultivar/Strain	0.545	0.651	0.740	***0.580***	–0.073	–0.252
PK	0.656	0.639	0.659	0.010	0.020	
N	0.624	0.652	0.659	0.103	–0.076	
Moddus	0.645	0.659	0.621	–0.073	–0.128	

* – see Table 2.

In this experiment N content in oat grain was affected (within the limit of statistical significance) also by two interactions: 1 – genotype with phosphorous-potassium fertilization and 2 – phosphorus–potassium fertilization with Moddus regulator application. The first of the interactions revealed a different response of dwarf strain (STH 7000) to subsequent levels of phosphorus-potassium fertilization. On its subsequent levels the treatment caused a decline in grain N concentration. On the other hand, STH 4770 strain (the highest) revealed increase in nitrogen content in result of complex phosphorus-potassium fertilization. Behaviour of Akt cv. may be described as undirected or as a lack of reaction to this experimental factor (Fig. 3). The second of the interactions mentioned above revealed a decrease in nitrogen concentration in grain in effect of a higher dose of Moddus growth regulator at simultaneous lack of phosphorus--potassium fertilization. On the treatments where only phosphorus or complex phosphorus-potassium fertilization was applied, an increase in nitrogen content in oat grain was observed with increasing doses of Moddus regulator (Fig. 4). Therefore, it seems that the analysed fertilizer factor may alleviate the unfavourable consequence of lowering nitrogen content in grain after the application of a higher dose of Moddus growth regulator (0 dm^3 · ha^{-1}).

Protein yield as a resultant of nitrogen content and grain yield was shaped by the analysed experimental factors in a different way. In both experiments conducted in Wierzbica the protein yield was statistically significantly increased by phosphorus-

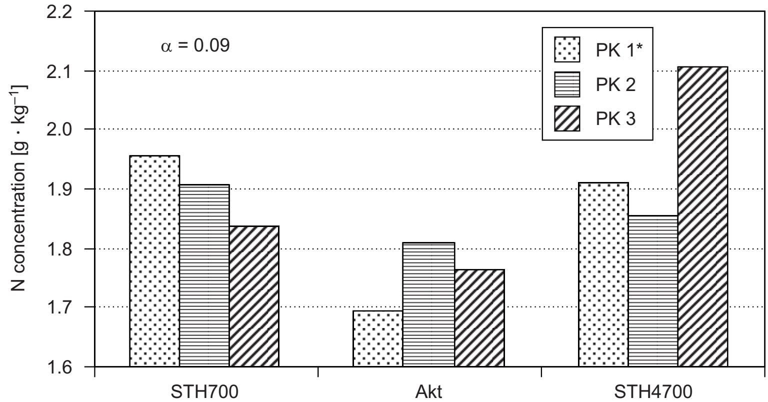

Fig. 3. N concentration under the influence of PK fertilization and genotype interaction in Prusy: * – see Table 2

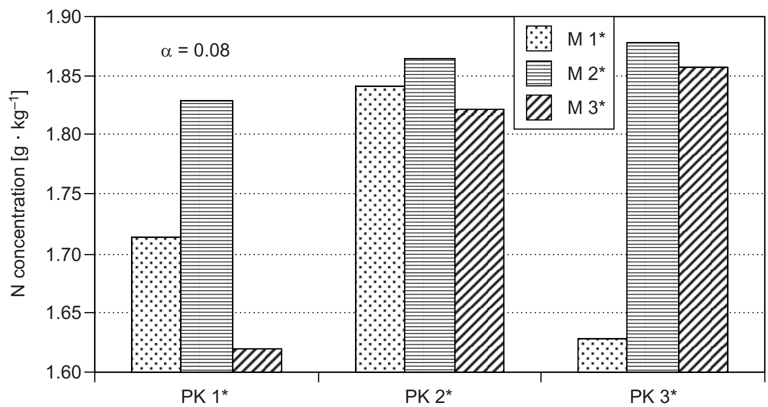

Fig. 4. N concentration under the PK fertilization and plant growth regulator Moddus interaction in Prusy. * – see Table 2

-potassium fertilization, respectively for experiments I and II by 0.424 and 0.483 of standard deviation unit. In the experiment with dwarf STH 7000 strain, Moddus growth regulator also had statistically significant effect since it considerably decreased protein yield (by 0.405 of standard deviation unit, ie by 9.67 g $\cdot$ m^{-2}). Also statistically lower protein yield was confirmed for the dwarf strain (a decline in comparison with Akt cv. by 0.337 of standard deviation unit). Protein yield in Wierzbica in the experiment I was also shaped by the cooperation of the genotype with the applied Moddus growth regulator. STH 4770 strain responded by an apparent increase in protein yield after Moddus growth regulation application, contrary to Akt cv. (Fig. 5).

In Prusy only the genotype determined statistically the protein yield. The highest yield (740 kg $\cdot$ ha^{-1}) was obtained from STH 4770 strain, whereas Akt cv. yielded by 89 kg $\cdot$ ha^{-1} lower, and the dwarf STH 7000 strain produced even 195 kg $\cdot$ ha^{-1} lower yield. In Prusy, a decline in protein yield from dwarf STH 7000 strain was registered with

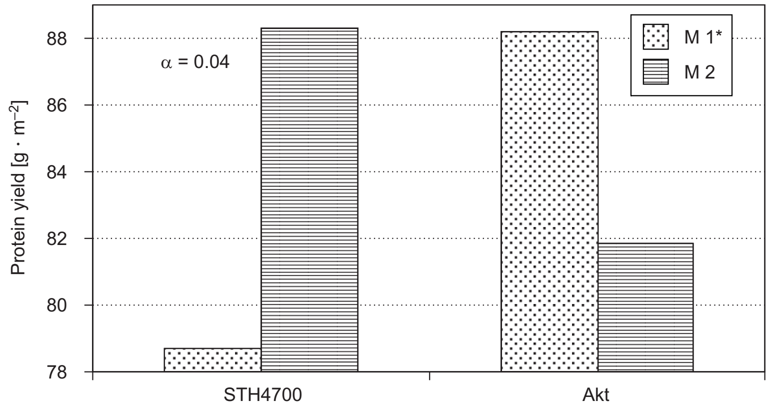

Fig. 5. Protein yield under the genotype and Moddus plant growth regulator interaction in Wierzbica: * – see Table 1

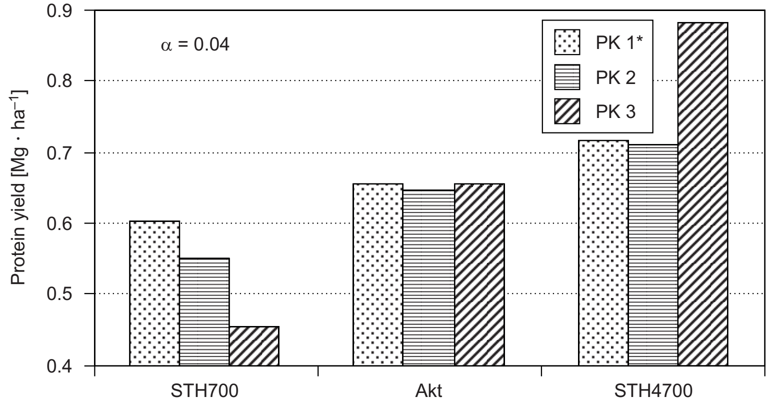

Fig. 6. Protein yield under the influence of PK fertilization and genotype interaction in Prusy: * – see Table 2

increasing level of phosphorus-potassium fertilization, whereas the opposite response of STH4770 strain was observed and no response from Akt cv. to this factor (Fig. 6).

The factor which in either of the two localities did not affect protein yield was urea foliar fertilization, while application of Promalin growth regulator had no influence in Wierzbica, and phosphorus-potassium fertilization in Prusy. The obtained results confirm that chemical composition of oat grain depends among others on the cultivar or genotype [7] but also on a number of agronomic factors [9, 10].

One of the major chemical components determining grain quality is protein. An important agent modifying biological value of protein in oat grain is introduction of new cultivar varieties and genotypes of this plant [7, 11]. Also investigations of other authors [12, 13] confirm that naked oat cultivars contain greater amounts of crude protein in comparison with the husked one.

Conclusions

1. In Wierzbica a higher nitrogen content in oat grain and higher protein yield were obtained.

2. Application of growth regulators resulted in the decline in naked oat protein yield but Moddus growth regulator caused also increased N grain concentrations.

3. Phosphorus-potassium fertilization and foliar urea application did not affect nitrogen concentrations in oat grain cultivated in Prusy, whereas phosphorus-potassium fertilization used in Wierzbica apparently increased protein yield.

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WPŁYW WYBRANYCH ZABIEGÓW AGROTECHNICZNYCH NA PLON BIAŁKA I ZAWARTOŚĆ AZOTU W ZIARNIE OWSA NAGOZIARNISTEGO (*Avena sativa*)

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Abstrakt: Nawożenie mineralne, zwłaszcza azotem jest czynnikiem modyfikującym w wyraźny sposób ilość i jakość ziarna owsa. Zakres zmian w plonie białka oraz zawartości składników uzależniony jest nie tylko od poziomu nawożenia mineralnego, ale również genotypu i regulatorów wzrostu. Z uwagi na dużą zależność skuteczności zabiegów agrotechnicznych od genotypu zachodzi konieczność badania tej interakcji.

Doświadczenia polowe przeprowadzano w Wierzbicy na glebie brunatnej typowej właściwej i uzyskany plon białka wahał się od 75 do 88 g $\cdot$ m^{-2}. Natomiast w eksperymencie przeprowadzonym w Prusach, na czarnoziemie zdegradowanym, plon białka zawierał się w zakresie od 540 do 740 kg $\cdot$ ha^{-1}. Z przeprowadzonych doświadczeń polowych w Wierzbicy wynika, że plon białka owsa nagoziarnistego był stymulowany przez genotyp oraz nawożenie fosforowo-potasowe i wyraźnie ograniczany przez zastosowanie regulatora wzrostu Moddus. W Prusach stwierdzono statystycznie istotny wpływ tylko genotypu, przy zachowaniu tendencji wpływu pozostałych badanych czynników. Zaobserwowano wyraźną różnicę w skuteczności oddziaływania nawożenia azotem na plon białka, bowiem w warunkach siedliskowych Prus wykazano zwiększenie jego plonu aż o 0,3 jednostki odchylenia standardowego przy bardzo niewielkim zwiększeniu jego plonu w Wierzbicy.

Zaobserwowano również mniej istotny wpływ badanych czynników na zawartość N w ziarnie owsa. Zasadniczo czynnikiem w sposób statystycznie znaczący warunkującym zawartość azotu był dobór odmiany/rodu owsa. Zarówno w Wierzbicy, jak i w Prusach obydwa rody (STH 4770, STH 7000) zawierały więcej azotu niż odmiana Akt. Pozostałe badane czynniki agrotechniczne powodowały zmiany w zawartości azotu, ale nie były one statystycznie istotne.

Słowa kluczowe: owies nagoziarnisty, plon białka, azot, nawożenie mineralne, regulator wzrostu

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EFFECT OF MINERAL FERTILIZERS ON MEADOW SWARD PRODUCTIVITY

WPŁYW NAWOŻENIA MINERALNEGO NA PRODUKCYJNOŚĆ RUNI ŁĄKOWEJ

Abstract: The most fundamental condition for maintaining an appropriate species condition in grass communities is systematic fertilization and proper use. Nitrogen is the most productive element, although when not used by meadow sward it can become a serious threat to the environment. This study shows how various types of fertilization and sod-seeding rates of clover/grass mixtures, influence the yield and protein and energy values of green feed. The greatest growth was observed for *Lolium perenne* L. and *Trifolium pratense* L. The analysis of the annual yield over three years of full use showed that sod-seeding at 30 kg/ha and 40 kg/ha with NPK mineral fertilization ensured the best yield. Fully fertilized meadow sward also had a higher protein content. Nitrogen increased the productivity and the share of sod-seeded grasses, and decreased the share of clovers and weeds in the botanical composition. The greatest protein values (PDIN and PDIE) and energy values (UFL and UFV) were observed in meadow sward after sod-seeding and NPK fertilization. Green feed from this meadow sward had energy and protein values that are appropriate for ruminants.

Keywords: meadow sward, mineral fertilization, sod-seeding rate, yield

Grasslands have many various environmental and social functions. They protect the soil against erosion, neutralize pollution and fulfill human needs for recreation in a natural landscape [1–3]. But the most important function is an economic one – to provide ruminants with feed rich in protein and energy [4–6].

The main condition responsible for maintaining an appropriate composition of grass communities is systematic mineral fertilization and proper usage by man [3, 7–9]. Mineral fertilization improves the nutritional value of grassland yield [2, 10, 11]. The use of clover/grass mixtures combined with the use of nitrogen (below 90 kg/ha) increases the protein content in meadow sward [12].

The aim of this study was to determine the effect of mineral fertilization on the yield of meadow sward over three consecutive years of full use. It was also determined how

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the clover/grass mixture applied in sod-seeding affects the yield of plants, protein and energy values of green feed.

Material and methods

An experiment was carried out using a split-plot method with two variable factors: (A) seeding rate (0 kg/ha – control; 20 kg/ha – low rate; 30 kg/ha – medium rate; 40 kg/ha – full rate) and (B) mineral fertilization (0; $P_{50\ kg}K_{80\ kg}$; $N_{90\ kg}P_{50\ kg}K_{80\ kg}$). Nitrogen and potassium fertilizers were used in spring, and after the 1st and 2nd yield. Phosphorus fertilization was carried out only in spring. Nitrogen and potassium fertilizers were applied 3 times during the growing season, in identical doses, over the three consecutive years of the experiment – after the spring start of vegetation, and after the 1st and 2nd cut. Phosphorus fertilization was used in one dose – in spring. The following fertilization was used in the experiment: 34 % ammonium nitrate, 46 % triple superphosphate, and 60 % potash.

Sod-seeding was performed using a mixture of *Trifolium pratense* L. (15 %), *Lolium perenne* L. (35 %), *Festuca pratensis* L. (30 %), *Phleum pretense* L. (10 %) and *Lolium multiflorum* L. (10 %). During the growing season, meadow sward was mown 3 times.

During the growing seasons at the examined site, the meadow sward mainly utilized water from the rhizospere, supplemented with rainwater and capillary motion from the surface of groundwater. The lowest precipitation occurred in 2004 (498.6 mm) and was 68 mm lower than the average precipitation in years 1970–2006. The highest precipitation was observed in 2005 (581.0 mm), the same year with the highest precipitation during the growing season. Year 2006 was the hottest during the experiment (mean temperature – 9.5 ^{o}C) and also with the hottest growing season (IV–IX) – 16.6 ^{o}C, 1.7 ^{o}C higher than the mean temperature from the period between 1970–2006.

During the three years of full use (2004–2006), each yield was subject to species composition examination based on botanical analysis and dry-weight determination. The content of basic nutrients in the examined material was determined based on laboratory chemical analyses. Protein and energy values were calculated using a relevant computer program [13].

In the consecutive years of this study (2004–2006), we carried out an examination of the species composition in each cut. The usage value of the meadow sward (Luv) was determined using detailed weight-botanical analyses.

Based on the laboratory chemical analyses of the collected vegetable material (0.5 kg d.m. from each site), the following nutritional indicators were determined:

– dry mass – spray dryer method,
– crude protein – Kjeldahl method,
– crude fiber – Henneberg and Stohman method,
– crude fat – Soxhlet method,
– crude ash – combustion of the vegetable material at 600 ^{o}C.

The nutritional value of the examined green feed was performed according to INRA 88. Protein and energy values were calculated using the computer program

INWAR 1993. Protein parameters included: crude protein mass [kg/ha], PDIN – protein digested in the small intestine coming from nitrogen conversions [kg/ha], PDIE – protein digested in the small intestine coming from energy conversions [kg/ha], and PDIF protein digested in the small intestine coming from feed [kg/ha]. The examinations of the energy value were performed using a calculation of feed units for lactation – UFL, and feed units for maintenance and meat production – UFV.

The experiment was performed on a Kentucky bluegrass meadow (oak shark beeches of forests) at the Field Research Station in Pawlowice near Wroclaw, SW Poland, growing on light alluvial soil made of light clayey sand on firm clayey sand, with a bedding of slightly clayey sand. The soil quality was assigned class 3, 2z complex. The pH of the examined soil was 6.2. The concentration of available phosphorus (P) was high (7.6 mg/100 g soil), potassium (K) concentration was low (1.4 mg/100 g soil).

Results of this study were analyzed statistically using the variance analysis for split-plot. Means were compared using a t-test and the LSD confidence intervals. A null hypotheses on the lack of differences between the examined coefficients and on the lack of interaction were verified by the F test at the significance level $\alpha = 0.05$

Results and discussion

Botanical and dry weight analyses of meadow sward over three consecutive years of full use showed the dominance of species sod-seeded into residential species (Table 1). Among the sod-seeded grasses, the greatest growth was observed for *Lolium perenne* L. (17.7 % d.m.) after sod-seeding at a full rate (40 kg/ha) and mineral fertilization (NPK). In the case of medium rate sod-seeding (30 kg/ha) and fertilization with only phosphorus and potassium, the greatest share was observed for *Trifolium pratense* L. – 18.8 % d.m. In the combination of medium sod-seeding rate and mineral fertilization (NPK), the greatest share of dry weight was observed for *Festuca pratensis* Huds. – 13.3 %. The combined phosphorus and potassium fertilization was most effective in increasing the content of sod-seeded species at a medium sod-seeding rate, and NPK fertilization at a full sod-seeding rate.

Table 1

Percentage of sod-seeded species [d.m.] in the botanical composition of the 1st cut (2004–2006)

Sod-seeding rate (A)	50 %			75 %			100 %		
Mineral fertilization (B)	0	PK	NPK	0	PK	NPK	0	PK	NPK
Festuca pratensis Huds.	12.1	10.8	13.3	11.8	15.1	13.1	8.9	10.2	13.5
Phleum pratense L.	5.4	5.3	5.2	4.3	7.2	7.7	5.1	6.4	8.2
Lolium perenne L.	12.4	11.1	16.6	13.2	16.3	17.5	14.0	16.1	17.7
Trifolium pratense L.	11.3	12.3	8.9	14.7	18.8	16.2	11.9	11.9	15.3
Total sod species (C)	48.0	46.5	55.6	54.6	69.2	66.7	48.4	55.9	64.7

With regard to a usable value number (*Nuv*), the best botanical compositions were observed in meadow sward from sites sod-seeded at a medium rate, and fertilized with

NPK (*Nuv* 9.1), and with phosphorus and potassium (*Nuv* 8.9) (Table 2). Sod-seeded grasses increased the nutritional value of meadow sward at sites that were sod-seeded at a medium rate, after full mineral fertilization (*Nuv* 5.3).

Table 2

Use value number (Lnv) of individual plant fractions in meadow sward in 2004–2006

Sod-seeding rate (A)		Control			50 %			75 %			100 %		
Mineral fertilization (B)		0	PK	NPK	0	PK	NPK	0	PK	NPK	0	PK	NPK
Plant fraction (C)	Sod grasses				3.6	3.3	4.0	3.9	4.9	5.3	3.6	4.3	5.0
	Remaining grasses	4.9	5.5	5.8	3.0	2.5	2.6	2.7	1.9	1.9	2.3	2.0	1.8
	Red clover				1.0	1.1	0.9	1.3	1.7	1.5	1.1	1.4	1.3
	Herbs & weeds	1.3	1.2	1.3	0.7	0.8	0.7	0.5	0.4	0.4	0.7	0.6	0.5
Total		6.2	6.7	7.1	8.3	7.6	8.2	8.4	8.9	9.1	7.7	8.3	8.6
$LSD_{\alpha = 0.05}$		for (A) = 0.2; (B) = 0.1; (C) = 0.2; (A × B) = 0.2; (A × C) = 0.4; (B × C) = 0.4											

The analysis of the annual yield of meadow sward over the years of full use shows that sod-seeding at higher rates and NPK fertilization was most effective in increasing meadow sward yield (Table 3). Meadow sward after renovation but without mineral fertilization also had better yield than the control site by 3.32 · 100 kg/ha, 4.16 · 100 kg/ha and 5.63 · 100 kg/ha, with regard to respective sod-seeding rates.

Table 3

Annual yield of meadow sward [100 kg d.m./ha] – mean from years 2004–2006

Specification	Sod-seeding rate (A)				
Mineral fertilization (B)	Control	50 %	75 %	100 %	Mean
0	34.98	38.30	39.14	40.61	38.26
PK	38.48	44.08	44.94	44.86	43.09
NPK	71.42	72.33	81.20	81.43	76.59
Mean	48.29	51.57	55.09	55.63	52.65
$LSD_{\alpha = 0.05}$	for (A) = 3.25; for (B) = 7.46				

Regardless of the applied sod-seeding rate higher total protein content was observed at sites where nitrogen fertilization was used. The highest percentage of total protein was recorded at the site sod-seeded at a medium rate and with NPK fertilization. An increase in sod-seeded species by 1 % resulted in an increase of total protein in dry weight by 0.13 %. This study showed that the applied pratotechnical factors influenced the content of total protein in meadow sward. The highest value of PDIE in meadow sward was observed at sites after the application of medium and full seeding rate with the mineral NPK fertilization (Table 4). The mean amount of PDIE obtained from meadow sward fertilized with nitrogen was more than 100 % greater than at sites without mineral fertilization. and 80 % greater than at sites fertilized only with phosphorus and potassium.

Table 4

PDIE. PDIN and PDIF [kg/ha] in annual meadow sward yield (2004–2006)

Sod-seeding rate (A)	Control			50 %			75 %			100 %		
Mineral fertilization (B)	0	PK	NPK	0	PK	NPK	0	PK	NPK	0	PK	NPK
PDIE	2335	2601	490	2611	3036	507	266	315	589	278	313	570
$LSD_{\alpha = 0.05}$ for (A) = 31; (B) = 29												
PDIN	181	211	436	217	269	469	2345	302	613	2456	293	568
$LSD_{\alpha = 0.05}$ for (A) = 37; for (B) = 26; for (A × B) = 56												
PDIF	65	75	156	78	96	168	84	1088	220	88	1055	204
$LSD_{\alpha = 0.05}$ for (A) = 14; for (B) = 9; (A × B) = 20												

Similar to PDIE, the highest value of PDIN was observed at the site where a medium rate of sod-seeding was applied and mineral fertilization involved phosphorus, potassium and nitrogen.

The highest UFL yield was observed at sites at medium and full sod-seeding rates, and after NPK fertilization. The amount of energy obtained from meadow sward from those sites was on average 130 % greater than from meadow swards without sod-seeding and mineral fertilization (Table 5).

Table 5

Amount of energy in green feed expressed in UFL and UFV in annual yield of meadow sward (2004–2006)

Sod-seeding rate (A)	Control			50 %			75 %			100 %		
Mineral fertilization (B)	0	PK	NPK	0	PK	NPK	0	PK	NPK	0	PK	NPK
UFL	2646	2930	5365	2896	3338	5445	2926	3356	6057	3050	3360	5992
$LSD_{\alpha = 0.05}$ for (A) = 323; for (B) = 328												
UFV	2465	2731	4991	2698	3097	5056	2760	3123	5624	2840	3111	5557
$LSD_{\alpha = 0.05}$ for (A) = 298; for (B) = 310												

Similar to UFL. the highest value of UFV was obtained from meadow sward collected from sites with higher sod-seeding norms and fully fertilized. Mean annual UFL yield from sites with nitrogen fertilization was 5715 units and was satisfactory, 100 % higher than at sites where no fertilization was applied. Sod-seeding with full mineral fertilization increased the UFV yield by more than 100 % compared with the control meadow sward.

Over the years 2004–2006. after using various sod-seeding rates and mineral fertilization. better productivity was achieved than the control meadow sward. The analysis of individual methods shows that sod-seeding at a medium rate and full mineral fertilization resulted in the most desirable changes in the species composition.

Mineral fertilization, especially using nitrogen, is a basic productivity factor for grass communities [14, 15]. Our study shows that nitrogen fertilization increased the share of grasses in meadow sward and decreased the amount of weeds and clovers. The highest shares of grasses in meadow sward were observed at sites where a full sod-seeding rate was applied together with full mineral fertilization (NPK). Similar results were obtained by Jodelka et al [16] and Stypinski [17].

A study by Wolski [18] showed that grasses best suited for sod-seeding are *Lolium perenne* L., *Lolium multiflorum* Lam., *Festuca pratensis* Huds.and *Dactylis glomerata* L. while among clovers – *Trifolium pratense* L. and *Trifolium repens* L. These species showed their high usefulness for renovation under the atmospheric and soil conditions of Lower Silesia, Poland.

Sometimes it is useful to introduce quickly growing species to achieve a radical improvement in yield and quality of feed [7]. Clover/grass mixtures used in this study increased the yield of meadow sward at sod-seeded sites and improved their nutritional value. Among the sod-seeded grasses. the greatest growth was observed for *Lolium perenne* L. Other authors also confirmed the high value of *Lolium perenne* L. for sod-seeding [3, 4].

Trifolium pratense L. also developed very well in meadow sward, especially when not fertilized with nitrogen. Other studies in Lower Silesia, Poland, showed that sod-seeding *Trifolium pratense* L. permanently supplemented meadow sward with *Fabaceae* Lindl. [19]. The presence of clovers increases the nutritional and tasteful value of feed used for grass-eating animals [20]. Thanks to these plants, feed has a better chemical composition, especially when it comes to protein and minerals, and has a higher digestibility and tastiness.

Conclusions

Over the 3 consecutive years of full use, nitrogen fertilization increased the productivity of the meadow sward usable value and the share of sod-seeded grasses. It decreased the share of clovers and weeds.

1. The application of nitrogen fertilization increased the share of species sod-seeded at a full seeding rate (40 kg/ha). Phosphorus-potassium fertilization was most effective at a medium sod-seeding rate (30 kg/ha).

2. Meadow clover in the sod-seeded mixture increased meadow sward productivity. The described manner of green feed production may thus be applied in extensive use in grasslands.

3. The highest protein values – PDIN, PDIE, PDIF and energy values – UFL and UFV, were observed in meadow sward at higher rates of sod-seeding and after full mineral fertilization.

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WPŁYW NAWOŻENIA MINERALNEGO NA PRODUKCYJNOŚĆ RUNI ŁĄKOWEJ

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Abstrakt: Podstawowym warunkiem zapewniającym utrzymanie właściwego składu gatunkowego zbiorowisk trawiastych jest systematyczne nawożenie mineralne oraz właściwe użytkowanie. Azot jest najbardziej plonotwórczym składnikiem pokarmowym. niewykorzystany przez ruń łąkową może stanowić poważne zagrożenie dla środowiska przyrodniczego. W badaniach określono, jak zróżnicowane nawożenie mineralne i normy wysiewu mieszanki koniczynowo-trawiastej zastosowane w siewie szczelinowym kształtują plonowanie, wartość białkową oraz energetyczną zielonki. Plonowanie runi łąkowej zależało od ilości podsianych nasion mieszanki koniczynowo-trawiastej i nawożenia mineralnego. Z wykorzystanych w mieszance gatunków w runi łąkowej najlepiej rozwijały się *Lolium perenne* L. i *Trifolium pratense* L. Analizując plon roczny runi łąkowej w latach pełnego użytkowania stwierdzono. że podsiew w ilości 30 kg/ha i 40 kg/ha oraz nawożenie mineralne NPK zapewniały najlepsze jej plonowanie. Większą zawartość białka ogólnego odnotowano w runi łąkowej nawożonej pełną dawką NPK. Nawożenie azotowe zwiększało produkcyjność runi łąkowej oraz udział podsianych traw, natomiast zmniejszało udział koniczyny łąkowej i chwastów w składzie botanicznym. Największe wartości białkowe – PDIN i PDIE i energetyczne – UFL i UFV. stwierdzono w runi łąkowej obiektów po podsiewie oraz po nawożeniu mineralnym azotowo-fosforowo-potasowym. Produkowana z łąki pasza charakteryzowała się odpowiednią dla przeżuwaczy wartością energetyczną oraz białkową.

Słowa kluczowe: ruń łąkowa, nawożenie mineralne, norma podsiewu, plon

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EFFECT OF TWO TECHNOLOGIES OF NITROGEN FERTILIZATION ON CONTENTS OF GLYCOALKALOIDS AND AMINO ACIDS IN POTATO TUBERS

ODDZIAŁYWANIE DWÓCH TECHNOLOGII NAWOŻENIA AZOTEM NA ZAWARTOŚĆ GLIKOALKALOIDÓW ORAZ AMINOKWASÓW W BULWACH ZIEMNIAKA

Abstract: The purpose of this study has been to assess the effect of two technologies of top-dressing nitrogen fertilization on contents of total nitrogen, glycoalkaloids (TGA) and amino acids in tubers of a medium-early potato cultivar called Mila. The study was based on a two-factor experiment in a random block design with four replications and involved four different variants of top-dressing nitrogen fertilization: soil and foliar application. In the first series, 1/2 of the total nitrogen rate was introduced as top-dressing soil fertilization and in the second series as foliar application. The rates of NPK were 107, 214, 321 and 428 kg NPK ha^{-1} at a N : P : K ratio equal to 1.00 : 0.44 : 1.25.

Increasing NPK fertilization caused a rise in the total nitrogen and glycoalkaloids in tubers of the test potato cultivar. No effect of the top-dressing nitrogen fertilization technology on the above characteristics was noticed. The content of glycoalkaloids in tubers was positively correlated with the content of total nitrogen, with the dependence being more evident in tubers from objects fertilized with nitrogen introduced to soil than over leaves. The type of top-dressing nitrogen fertilization had impact on the shape of relationships between the total nitrogen content and the content of amino acids. Regarding exogenous amino acids, significant dependences were verified for phenylalanine, methionine and the sum of these amino acids. In the pool of endogenous amino acids, such dependences occurred in the case of glycine and prolamin. The total content of glycoalkaloids (TGA), depending on the method of top-dressing nitrogen fertilization, was positively correlated with the content of asparagic acid and tyrosine and negatively correlated with the presence of alanine, glycine and lycine.

Keywords: total N, glycoalkaloids, TGA, potato tubers, foliar fertilization, nitrogen

Glycoalkaloids are specific toxic substances present in plants belonging to the nightshade family (*Solanaceae*). In potato (*Solanum tuberosum* L.), very high levels of glycoalkaloids, commonly known as solanine, appear in the organs in which metabolism

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is very intense, ie in leaves and stem apexes, as well as in places where tissues have been damaged; less solanine is accumulated in tubers. Potatoes with elevated amounts of glycoalkaloids are characterized by a bitter, burning taste and the content of glycoalkaloids above 20 mg · 100 g^{-1} can be harmful to consumers' health [1–3]. Currently grown cultivars of potatoes contain between 3 to 10 mg TGA 100 · g^{-1} [4, 5]. The quantity of TGA (total glycoalkaloids) is changeable depending on the cultivar, weather conditions during the growing season, disease incidence and occurrence of pests which damage leaves and tubers, rates and types of fertilizers [6–9] Many authors found out that TGA grew steadily under the influence of increasing rates of nitrogen [10–12]. However, in the literature references lack any update information on how the content of TGA is shaped in potato tubers depending on the nitrogen fertilization technology applied.

This paper discusses the effect of two methods of nitrogen fertilization against a background of increasing NPK rates on the content of glycoalkaloids and the content of some exo- and endogenous amino acids in potato tubers.

Material and methods

The study was based on a two-factor field experiment, set up according to the random block method with four replications. The material consisted of an edible, medium-early potato cultivar called Mila. This cultivar produces moderately high yields, contains an average amount of starch, ie 2.4 mg 100 g^{-1} of potato flesh and is very suitable for food processing, including production of crisps, chips as well as dried and frozen potato products.

In a three-year, field experiment, conducted at the Experimental Station in Tomaszkowo near Olsztyn, two top-dressing nitrogen fertilization technologies were compared against a background of increasing NPK fertilization rates. The first-order factor consisted of two series of nitrogen top-dressing: soil (conventional) and foliar (sprays) methods. Top-dressing involved 50 % of the nitrogen rate applied. The nitrogen fertilizer used in the experiment was 46 % urea. The second-order factor comprised increasing mineral fertilization, which consisted of the following rates: 107, 214, 321 and 428 kg NPK ha^{-1} at an N:P:K ratio equal 1.00 : 0.44 : 1.25. The rates of nitrogen applied as top-dressing fertilization treatments were, respectively, 20, 40, 60 and 80 kg N ha^{-1}. Foliar application of this element was performed six times during the whole growing season, using the concentrations of urea equal 2.4, 4.8, 7.2 and 9.6 %. The first spraying was performed a week after the full emergence of potato plants; the following treatments took place at seven-day intervals. The remaining mineral fertilizers, phosphorus and potassium, were introduced in the form of triple granulated superphosphate 45 % P_2O_5 and potassium salt 57 % K_2O.

During the growth of potato plants, ie in the early and after the flowering phase as well as after the vegetative growth, samples of tubers were taken for determination of glycoalkaloids with the colorimetric method according to Bergers [13], total nitrogen content with Kjeldahl's method after open sulfuric acid digestion of plant samples [14] and the amino acid content on an amino acid analyzer of Beckmann Instruments (Beckmann Automatic Amino Acid Analyser).

The results underwent statistical processing with ANOVA at the significance level of $\alpha = 0.05$, using Statistica v. 8.0 software [15].

Results and discussion

Nitrogen fertilization plays a decisive role in shaping the content of all forms of nitrogen substances found in crops. This basic element can modify the chemical composition of plants by increasing the percentage of protein and non-protein nitrogen compounds. High nitrogen fertilization may raise the content of total N up to two-fold compared with the values recorded in potato tubers from objects not fertilized with this component [16]. In a study completed by Ciecko et al [17], the total N content was 0.39 to 0.48 % higher than the control, depending on a cultivar, under the influence of a rate of nitrogen equal 200 kg N $\cdot$ ha^{-1}. These results have been confirmed by Wyszkowski [18] who found out that total N increased considerably under the effect of increasing rates of nitrogen introduced as a fertilizer. This author completed a study on four potato cultivars and reported that the content of total nitrogen under the influence of 200 kg N $\cdot$ ha^{-1} rose from 0.34 to 0.61 % versus the concentrations of nitrogen in potato tubers from objects not fertilized with nitrogen. Significant correlation between nitrogen fertilization and total nitrogen content in potato tubers has also been described by Roztropowicz [19]. By raising rates of nitrogen from 40 to 200 kg N $\cdot$ ha^{-1}, it was possible to observe a parallel increase in the total and protein nitrogen in potato tubers.

In the experiment presented in this paper, the increasing NPK fertilization caused significant increase in the content of total N determined in harvested potato tubers (Table 1). The maximum quantities of this component, about 17 % higher in the soil top-dressed objects and 23 % in the foliar top-dressed series, were observed under the influence of the highest rate of the fertilizers, ie $N_{160}P_{160}K_{240}$. However, the differences were not confirmed statistically, which means that the technology of fertilization with the main rate of nitrogen applied in the form of top-dressing treatments was not a decisive factor in shaping the content of total nitrogen. The mean amounts of total N in the analyzed tubers were similar and reached 1.47 % in the series where nitrogen was introduced to soil and 1.53 % in the series involving foliar application of nitrogen.

In the present study, NPK fertilization had a significant influence on the synthesis of glycoalkaloids in the potato. This dependence, however, occurred in forming tubers after the flowering phase. Also at that time, the content of TGA in tubers was the highest, on average 4.79 mg $\cdot$ 100g^{-1} in the series top-dressed with nitrogen introduced to soil and 4.88 mg $\cdot$ 100 g^{-1} in the series where nitrogen was sprayed over leaves. Afterwards, the content of glycoalkaloids in tubers began to decline. At harvest, it was 3.64 and 4.14 mg $\cdot$ 100 g^{-1} for the respective series. Although no significant differences were found in the content of TGA between the two series, the results suggest that more intense synthesis of glycoalkaloids took place in plants fertilized with nitrogen sprayed over leaves than introduced to soil.

Table 1

The effect of NPK fertilization at two top-dressing nitrogen fertilization technologies on the content of total N and glycoalkaloids in potato tubers

Treatments	Total-N [%] after harvest time	TGA [$mg \cdot 100\ g^{-1}$] at the early flowering phase	TGA [$mg \cdot 100\ g^{-1}$] after flowering phase	TGA [$mg \cdot 100\ g^{-1}$] after harvest time
1. Control (without fertilizers)	1.36	2.82	3.40	2.24
1/2 of nitrogen rate introduced as a top-dressing soil application				
2. $N_{40}P_{17}K_{50}$	1.36	3.83	4.10	2.59
3. $N_{80}P_{34}K_{100}$	1.40	4.62	4.89	2.92
4. $N_{120}P_{51}K_{150}$	1.50	5.05	5.15	4.50
5. $N_{160}P_{68}K_{200}$	1.60	4.77	5.03	4.56
Average	1.47	4.56	4.79	3.64
Correlation coefficient between nitrogen fertilization and TGA content r =		0.89*	0.91*	0.95**
1/2 of nitrogen rate introduced as a top-dressing foliar application				
6. $N_{40}P_{17}K_{50}$	1.36	5.19	3.49	3.50
7. $N_{80}P_{34}K_{100}$	1.43	4.52	4.65	4.43
8. $N_{120}P_{51}K_{150}$	1.65	4.36	5.51	5.31
9. $N_{160}P_{68}K_{200}$	1.68	4.46	5.89	3.32
Average	1.53	4.63	4.88	4.14
Correlation coefficient between nitrogen fertilization and TGA content r =		0.44	0.97**	0.54
LSD (p = 0.05) for: technique of nitrogen fertilization	n.s.	n.s.	n.s.	n.s.
increasing NPK fertilization	0.06	n.s.	1.34	0.97
interaction	n.s.	n.s.	n.s.	n.s.

n.s. – not significant; * – correlation coefficient significant at p = 0.05, ** – correlation coefficient significant at p = 0.01.

Results of determinations from three sampling dates were used for calculating correlation coefficients, which suggested that there was a clear positive correlation between the rate of applied nitrogen and the amount of TGA in tubers. This dependence occurred most evidently in the series with soil top-dressing nitrogen fertilization. On each of the examined dates, a high correlation coefficient in the early flowering phase (r = 0.89), after flowering (r = 0.91) and after harvest (r = 0.95) suggested significant dependence between the rate of nitrogen fertilization and the content of glycoalkaloids in tubers.

According to reported data [20] glycoalkaloids gathered in tubers can be indirectly dependent on nitrogen fertilization. Potato glycoalkaloids are a by-product (waste) occurring during metabolic transformations in potato plants, which may explain their larger accumulation in tubers from objects receiving more nitrogen with fertilizers [21].

Besides shaping the total N content in plants, nitrogen fertilization can also modify the amino acid composition of protein and therefore affect protein content and quality. In the present experiment, concentrations of some exogenous and endogenous amino acids were determined, which enabled the author to trace dependences between their quantities and the volume of an NPK rate or the content of solanine in tubers (Tables 2 and 3).

Having analyzed the composition of amino acids in potato tubers, it was demonstrated that only one endogenous amino acid, namely glycine, was highly significantly correlated (r = –0.92) with the content of total N in tubers of potatoes top-dressed with nitrogen introduced to soil, whereas in the series with nitrogen sprayed over leaves such a dependence occurred in the case of two amino acids: glycine (r = –0.85) and, positively correlated, prolamin (r = 0.95). Regarding exogenous amino acids (Table 3), the following were dependent on the content of total N in the series fertilized by soil application of nitrogen: phenylalanine (r = –0.95), methionine (r = –0.88) and sum of exogenous amino acids (r = –0.85). In the series in which nitrogen was sprayed over leaves, only methionine proved to be dependent (r = –0.87).

The content of solanine determined in potato tubers proved to be associated with certain amino acids. Glycoalkaloids are a product appearing during secondary metabolism in potato plants. Should toxic substances, a waste product in potato tubers, be produced in excessive amounts, the secondary metabolism mechanism is activated, which aids synthesis of solanine. This situation occurs when nitrogen fertilization is high. When the level of available nitrogen rises, plants take advantage of sugars and nitrogen-free compounds to synthesize nitrogen acceptors, especially asparagic and glutamic acids. In general, these amino acids are not used up for synthesis of protein but for production of glycoalkaloids during secondary metabolism. The substrates used for their synthesis are not tolerated by plants, therefore they have to be detoxicated via their conversion into less toxic solanine [21], so significant correlations between the content of solanine and the amounts of such amino acids as aspartic acid and glutamic acid are justify [20].

In the present experiment, the content of glycoalkaloids in tubers was correlated with the content of such endogenous amino acids as alanine, aspartic acid and glycine in the series with top-dressed nitrogen applied to soil (Table 2) as well as tyrosine in the series

Table 2

The effect of NPK fertilization at two top-dressing nitrogen fertilization technologies on the content of some endogenous amino acids in potato tubers, in g · 100 g^{-1} of total protein

Treatments	Ala	Asp	Cys-Cys	Glu	Gly	Pro	Ser	Tyr	Sum of endogenous amino acids
1. Control (without fertilizers)	3.84	11.32	0.76	14.06	3.17	3.39	3.46	3.08	43.08
1/2 of nitrogen rate introduced as a top-dressing soil application									
2. $N_{40}P_{17}K_{50}$	3.81	13.00	0.79	13.58	3.21	3.89	3.55	3.16	44.99
3. $N_{80}P_{34}K_{100}$	3.65	12.87	0.70	13.60	3.19	4.19	3.32	3.10	44.62
4. $N_{120}P_{51}K_{150}$	3.63	15.69	0.63	13.48	2.91	4.05	3.33	3.11	46.83
5. $N_{160}P_{68}K_{200}$	3.62	14.14	0.69	13.35	2.91	4.04	3.33	3.14	45.22
Average	3.68	13.93	0.70	13.50	3.06	4.04	3.38	3.13	45.42
correlation coefficient between amino acids content and total N content *r* =	–0.80	0.70	–0.69	–0.74	–0.92**	0.47	–0.68	0.26	0.56
correlation coefficient between amino acids content and TGA content *r* =	–0.85*	0.90*	–0.83	–0.80	–0.96**	0.58	–0.69	0.25	0.80
1/2 of nitrogen rate introduced as a top-dressing foliar application									
6. $N_{40}P_{17}K_{50}$	3.73	14.61	0.71	13.33	3.06	3.55	3.47	3.23	45.69
7. $N_{80}P_{34}K_{100}$	3.73	14.49	0.64	12.86	2.97	3.76	3.38	3.22	45.05
8. $N_{120}P_{51}K_{150}$	3.77	15.16	0.64	13.92	2.85	3.84	3.30	3.25	46.73
9. $N_{160}P_{68}K_{200}$	3.56	15.33	0.65	13.54	2.86	4.35	3.35	3.19	46.83
Average	3.70	14.90	0.66	13.41	2.94	3.88	3.38	3.22	46.08
correlation coefficient between amino acids content and total N content *r* =	–0.78	0.62	–0.65	0.13	–0.85*	0.95**	–0.77	0.28	0.76
correlation coefficient between amino acids content and TGA content *r* =	–0.06	0.71	–0.82	–0.27	–0.73	0.28	–0.76	0.86*	0.65

* – correlation coefficient significant at p = 0.05, * – correlation coefficient significant at p = 0.01; Ala – alanine, Glu – glutamic acid, Ser – serine, Asp – aspartic acid, Gly – glycine, Tyr – tyrosine, Cys-Cys – cystine + cysteine, Pro – proline.

Tabela 3

The effect of NPK fertilization at two top-dressing nitrogen fertilization technologies on the content of some exogenous amino acids in potato tubers, in g · 100 g^{-1} of total protein

Treatments	Arg	Phe	His	Ile	Leu	Lys	Met	Thr	Val	Sum of exogenous amino acids
1. Control (without fertilizers)	3.12	3.75	1.57	3.43	5.84	4.91	1.24	3.15	4.34	31.35
1/2 of nitrogen rate introduced as a top-dressing soil application										
2. $N_{40}P_{17}K_{50}$	3.44	3.71	1.60	3.59	6.02	4.75	1.35	3.24	4.31	32.01
3. $N_{80}P_{34}K_{100}$	3.29	3.67	1.56	3.33	5.73	4.73	1.20	3.02	4.20	30.73
4. $N_{120}P_{51}K_{150}$	3.36	3.65	1.50	3.29	5.83	4.58	1.20	3.02	4.30	30.73
5. $N_{160}P_{68}K_{200}$	3.30	3.70	1.61	3.30	5.45	4.59	1.06	3.03	4.50	30.54
Average	3.35	3.68	1.57	3.38	5.76	4.66	1.20	3.08	4.33	31.00
correlation coefficient between amino acids content and total N content r =	0.53	–0.95**	–0.35	–0.78	–0.72	–0.76	–0.88*	–0.75	–0.45	–0.85*
correlation coefficient between amino acids content and TGA content r =	0.32	–0.64	–0.27	–0.72	–0.62	–0.94*	–0.72	–0.70	0.49	–0.72
1/2 of nitrogen rate introduced as a top-dressing foliar application										
6. $N_{40}P_{17}K_{50}$	3.54	3.73	1.43	3.31	5.55	4.74	1.14	3.16	4.40	31.00
7. $N_{80}P_{34}K_{100}$	3.28	3.66	1.42	3.23	5.36	4.77	1.02	3.08	4.32	30.14
8. $N_{120}P_{51}K_{150}$	3.52	3.62	1.49	3.24	5.30	4.70	1.06	3.01	4.26	30.20
9. $N_{160}P_{68}K_{200}$	3.51	3.57	1.42	3.17	5.30	4.66	0.82	3.06	4.15	29.66
Average	3.46	3.65	1.44	3.24	5.38	4.72	1.01	3.08	4.28	30.25
correlation coefficient between amino acids content and total N content r =	0.15	–0.41	0.01	–0.71	–0.82	–0.83	–0.87*	–0.67	–0.43	–0.75
correlation coefficient between amino acids content and TGA content r =	0.51	–0.51	–0.40	–0.61	–0.79	–0.60	–0.30	–0.77	–0.16	–0.72

* – correlation coefficient significant at p = 0.05, ** – correlation coefficient significant at p = 0.01; Arg – arginine, Ile – isoleucine, Met – methionine, Phe –phenylalanine, Leu – leucine, Thr – threonine, His – histidine, Lys – lysine, Val – valine.

in which nitrogen was sprayed over leaves. Among the exogenous amino acids (Table 3), it was only tubers from objects receiving soil top-dressing nitrogen fertilization that the content of lysine proved to be closely correlated with the content of total N (r = –0.94). In the series with foliar application of nitrogen, no significant dependences were observed between the content of amino acids and the content of total nitrogen in tubers.

Conclusions

1. Application of increasing NPK fertilization rates caused significant increase in the content of total N in potato tubers. The technology used for top-dressing fertilization with nitrogen did not play a decisive role in shaping the content of this component in tubers.

2. Under the influence of rising NPK rates, the content of glycoalkaloids was observed to have increased in tubers of the examined potato cultivar. Correlation coefficients suggest that the level of TGA in tubers was much more dependent on the volume of NPK rates in the series with top-dressing nitrogen fertilization applied to soil than in the series with foliar application of nitrogen.

3. The content of total N, which was shaped in tubers under the effect of the applied NPK rates, in general was negatively correlated with the content of exogenous amino acids, especially phenylalanine, methionine and sum of exogenous amino acids, in the series with the top-dressing nitrogen fertilization applied as a soil treatment and methionine in the series of top-dressing nitrogen fertilization applied as sprays over leaves. Regarding endogenous amino acids, significant correlation was determined for the content of glycine and prolamin.

4. The content of TGA in the analyzed tubers was negatively correlated with the content of alanine, glycine and lysine, being positively correlated with the content of asparagine acid in the series with nitrogen introduced as a foliar treatment, and positively correlated with the content of tyrosine in the series with nitrogen introduced to soil.

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ODDZIAŁYWANIE DWÓCH TECHNOLOGII NAWOŻENIA AZOTEM NA ZAWARTOŚĆ GLIKOALKALOIDÓW ORAZ AMINOKWASÓW W BULWACH ZIEMNIAKA

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Abstrakt: Celem pracy było określenie wpływu dwóch technologii pogłównego nawożenia azotem na zawartość azotu ogólnego, glikoalkaloidów (TGA) i aminokwasów w bulwach ziemniaka średnio-wczesnego odmiany Mila. Badania oparto na doświadczeniu dwuczynnikowym prowadzonym w układzie losowanych bloków w czterech powtórzeniach, z różnymi wariantami pogłównego nawożenia azotem – doglebowo i dolistnie. W pierwszej serii 1/2 ogólnej dawki N stosowano pogłównie w formie doglebowej, a w drugiej w postaci oprysku nalistnego. Dawki NPK wynosiły kolejno 107, 214, 321 i 428 kg NPK $\cdot$ ha^{-1} przy stosunku N : P : K – 1.00 : 0.44 : 1.25.

Wzrastające nawożenie NPK spowodowało wzrost zawartości N-ogółem oraz glikoalkaloidów w bulwach uprawianej odmiany ziemniaka. Nie stwierdzono wpływu technologii stosowania azotu aplikowanego pogłównie na wymienione cechy. Zawartość glikoalkaloidów w bulwach była dodatnio skorelowana z zawartością N-ogółem, przy czym zależność ta była bardziej widoczna w przypadku bulw pochodzących z obiektów nawożonych azotem pogłównie doglebowo niż dolistnie. Sposób pogłównego nawożenia azotem wpłynął na kształtowanie się zależności pomiędzy zawartością N-ogółem a zawartością aminokwasów. W odniesieniu do aminokwasów egzogennych zależności istotne stwierdzono w przypadku fenyloalaniny, metioniny i sumy tych aminokwasów, a w puli aminokwasów endogennych w odniesieniu do glicyny i prolaminy. Zawartość glikoalkaloidów (TGA), w zależności od sposobu nawożenia pogłównego azotem była dodatnio skorelowana z zawartością kwasu asparaginowego i tyrozyny oraz ujemnie z zawartością alaniny, glicyny i lizyny.

Słowa kluczowe: N-ogólny, glikoalkaloidy, TGA, bulwy ziemniaka, nawożenie dolistne, azot

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Prof. dr hab. Maria Wacławek
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