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EFFECT OF CALCIUM CARBONATE AND DIFFERENTIATED NITROGEN FERTILIZATION UPON THE YIELD AND CHEMICAL COMPOSITION OF SPINACH BEET

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Abstract. Fertilizing cultivable plants is an effective way of improving yield quantity and quality. The studies conducted in the years 2008–2009 were aimed at determining the relationship between the kind of nitrogen fertilizer, manner of its application, as well as the dose of calcium carbonate and the plant unit weight, as well as chemical composition of spinach beet, grown in glasshouse in the spring period. Nitrogen was applied in the form of ammonium sulphate and urea in a localized form (N-deposit) and in the form of solution. Calcium was administered in the form of calcium carbonate in the doses of 5 and 15 g · dm^{-3} of substratum. The length of leaves, plant unit weight and selected parameters of beet leaf utility value were assessed. The substratum was also analyzed after plant harvest. The highest unit weight of plants was obtained with the application of ammonium sulfate in the form of a solution with a lower calcium carbonate dose, compared to the remaining combinations. The examined spinach beet plants were distinguished by high contents of dry matter, protein, total nitrogen, potassium, calcium and magnesium The chemical composition of leaves was significantly differentiated, depending on the examined factors. The contents of nitrates in the leaf dry matter ranged from 0.26 to 0.45%, depending on the kind of nitrogen fertilizer and manner of its application. The applied nitrogen fertilization to a small extent influenced the concentration of nitrates in beet leaves. More nitrates were contained in plants fed by a higher dose of calcium carbonate, compared to the plants which were given a lower dose of $CaCO_3$. The highest content of vitamin C and the lowest share of nitrates in leaf dry matter were obtained with the application of urea in the form of deposit with a lower dose of calcium carbonate.

Key words: spinach beet, localized fertilization, nitrates, chemical composition of leaves

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INTRODUCTION

Spinach beet is a valuable vegetable plant, containing relatively big amounts of protein, mineral salts (mainly iron and calcium, as well as provitamin A and vitamins C, B1 and B2. Leaf beet is a vegetable, which is easily assimilated by humans and is recommended for child nutrition. Large, fleshy leaves and juicy petioles are its edible parts [Wierzbicka 2002]. This plant, at present grown mainly by amateurs, is also valued due to the fact that it is easy to cultivate, has a short vegetation period, as well as modest climatic and soil requirements [Czerniak and Kołota 2007]. Spinach beet is a vegetable exposed to accumulation of nitrates in its above – ground parts. Thus, it is easy to over-fertilize with nitrogen, mainly with the application of fertilizers containing nitrogen in the form of nitrates. Sommer [2005] gives an interesting model of applying nitrogen into the soil, in a reduced form, placed point-wise, as N-deposit. Administering fertilizers in such a way is aimed at limiting the accumulation of nitrates (V) in the usable parts of vegetables.

Applying calcium fertilizers into the soil is related to the decrease of acidification, improvement of physicochemical properties, as well as supplying calcium as a nutrient. After liming procedure, the assimilability of nutrients for plants changes significantly. Besides, the accessibility of calcium for leafy plants is important, because of the occurrence of a physiological disease of leaf edge dieback – „tip burn" [Hartz et al. 2007].

The aim of the studies was to determine the relationship between nitrogen fertilizer type, administered in the form of a deposit, as well as in the form of a solution, different calcium carbonate doses, and spinach beet yield and chemical composition.

MATERIAL AND METHODS

The experiment with spinach beet of ´Lukullus` cultivars was conducted in a glasshouse in 2008 (16.04. – 30.05.) and 2009 (15.04. – 28.05.) in two-liter pots, filled with soil and sand substrates, mixed in volumetric proportion of 3:1. The experiment was established with the use of complete randomization method in six repetitions. A repetition was a pot with one plant. Nutrients were applied in the following amounts: ($g \cdot dm^{-3}$ substratum) N – 0.75; P – 0.5; K – 1.2; Mg – 0.6 and ($mg \cdot dm^{-3}$ substratum) Fe – 8.0; Cu – 13.3; Mn – 5.1; B – 1.6; Mo – 3.7; Zn – 0.74. The following fertilizers were applied: ammonium sulfate and urea in the form of a solution or deposit (the whole fertilizer dose was placed in the middle of height and width of the pot), superphosphate 20% P, potassium chloride, one-water magnesium sulfate, Fe – chelate, sulfates of Cu, Mn, Zn, boric acid, ammonium molybdate. As the experimental factors the following were examined: the dose of calcium fertilizer (5 and 15 $g \cdot dm^{-3}$), kind of nitrogen fertilizer (ammonium sulfate, urea), as well as the manner of nitrogen fertilizer application (a localized form, a solution).

At plant harvest their weight was assessed ($g \cdot plant^{-1}$), as well as the length of their leaves (blades together with petioles). Leaves were sampled for analysis at experiment liquidation. The youngest, fully grown leaf was designed for analysis, together with its petiole. In the leaves total nitrogen was determined (by means of Kjeldahl's method), and after mineralization with the use of "dry" method (temp. 550°C), as well as phosphorus (using colorimetric method with ammonium vanadio-molybdate), as well as potassium, calcium and magnesium, using ASA method (Perkin-Elmer, Analyst 300).

In the fresh material dry matter was determined with the use of dryer method, the L-ascorbic acid contents – using Tillmans's method (PN-A-04019 1998). The substratum for analyses was also sampled during experiment liquidation. The chemical analyses of substratum were performed in 0.03 M extract of acetic acid, using the universal method, according to Nowosielski [1988].

The statistical elaboration of results was conducted by means of variance analysis method, on mean values, applying Tukey's test for difference evaluation, at the significance level of $\alpha = 0{,}05$. In the tables mean values of the years 2008 and 2009 were presented.

RESULTS AND DISCUSSION

The amount of uptaken nitrogen mostly determines the yield quabtity of the cultivated plants. As Wojcieska [1994 a and b] reports, even applying very slow nitrogen doses causes increased yield, while Elia et al. [1998] and Nádasy [2002] state that high nitrogen doses affect both the growth of plants and accumulation of nitrates. According to Sommer [2005] the decrease of nitrate contents in plants is also affected by localized fertilization, involving placing a nitrogen fertilizer, containing nitrogen in the form of ammonium, about 10 cm from the main rhizosphere. The forms of nitrogen apllied in plant nutrition (ammonium, nitrate and amide) definitely have different effects upon vegetable yield and quality [Wojcieska 1994a, Michałojć 2000, Nurzyński 2008].

The obtained results indicate the statistically significant effect of the applied kind of nitrogen and calcium fertilizer upon the basic utility features of spinach beet leaf yield. The differentiated calcium carbonate doses did not significantly affect yielding, however, this effect was found with reference to nitrogen fertilization, obtaining the lowest unit plant weight after applying urea in the localized form. After the experiments have been finished in these objects, the contents of mineral nitrogen in the substratum was 328 mg · dm^{-3} ($N\text{-}NH_4$ + $N\text{-}NO_3$) on average. The concentrations of nitrates in beet leaves were interesting: they ranged from 0.26 to 0.45% d.m. No significant differences were reported in nitrate contents in the examined plant under the influence of the manner of applying the used nitrogen fertilizers. Blanke and Bacher [2001], in their studies on kohlrabi, obtained 45% less nitrates in kohlrabi bulbs, applying localized fertilization with ammonium fertilizer, as compared to conventional fertilizer. Sady et al. [2008] obtained the increased yield of white headed cabbage with the application of localized fertilization in the dose of 90 N kg·ha^{-1}, as compared to projective plant nutrition with nitrogen in the full dose (120 N kg·ha^{-1}). Szura et al. [2009] report that nitrogen fertilization with the use of ammonium deposit method did not affect the NO_3^- contents in the leaves and granary roots of red beet. Sady et al. [1995] and Kozik [2006] in their studies on lettuce, point to the more advantageous, reduced form of nitrogen fertilizer. The nitrate concentrations in the above-ground parts of plants depend not only on the form of applied fertilizer. Czerniak and Kołota [2007, 2008] report that the quality of spinach

Table 1. Plant unit weight, leaf length, L-ascorbic acid, dry matter and protein contents in spinach beet leaves, depending on nitrogen and calcium fertilization

Tabela 1. Masa jednostkowa roślin, długość liści, zawartość suchej masy, kwasu L-askorbinowego i białka w liściach buraka liściowego w zależności od nawożenia azotem i wapniem

Dose Dawka $CaCO_3$ ($g \cdot dm^{-3}$) (A)	Nitrogen fertilizer Nawóz azotowy (B)	Application method Metoda aplikacji (C)	Plant unit weight Masa jednostkowa roślin (g)	Leaf length Długość liści (cm)	Dry matter Sucha masa (%)	L-ascorbic acid $mg \cdot 100 g^{-1}$ f. w. Kwas L-askor. $mg \cdot 100 g^{-1}$ św.m.	Protein Białko (%)
5	$(NH_4)_2SO_4$	Cultan deposit	79.33	42.67	10.63	44.60	35.70
5	$(NH_4)_2SO_4$	Solution r-r	91.33	38.33	12.70	42.17	38.37
5	$CO(NH_2)_2$	Cultan deposit	54.67	25.00	11.40	47.57	35.30
5	$CO(NH_2)_2$	Solution r-r	76.00	35.33	13.77	37.63	36.70
15	$(NH_4)_2SO_4$	Cultan deposit	80.33	37.67	11.23	36.43	40.67
15	$(NH_4)_2SO_4$	Solution r-r	85.33	38.67	11.20	35.13	37.73
15	$CO(NH_2)_2$	Cultan deposit	62.33	31.66	11.70	46.50	34.60
15	$CO(NH_2)_2$	Solution r-r	75.67	35.33	11.53	43.30	35.50
Mean for $CaCO_3$ dose		5	75.33	35.33	12.13	42.99	36.52
Średnia dla dawki $CaCO_3$		15	75.92	35.83	11.42	40.34	37.13
Mean for		$(NH_4)_2SO_4$	84.08	39.33	11.44	39.58	38.12
Średnia dla		$CO(NH_2)_2$	67.17	31.83	12.10	43.75	35.53
Mean for		Cultan	69.17	34.25	11.24	43.78	36.57
Średnia dla		Solution r-r	82.08	36.92	12.30	39.56	37.08
$NIR_{\alpha = 0.05}$							
A			i.d. – r.n.	i.d. – r.n.	0.47	1.93	i.d. – r.n.
B			1.92	1.54	0.47	1.93	1.86
C			1.92	1.54	0.47	1.93	i.d. – r.n.
ABC			i.d. – r.n.	5.03	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.

i.d. – insignificant differences, r.n. – różnice nieistotne

Table 2. Chemical composition of Spinach beet leaves depending on nitrogen and calcium fertilizing (% d.m.)
Tabela 2. Skład chemiczny liści buraka liściowego w zależności od nawożenia azotem i wapniem (% s.m.)

Dose Dawka $CaCO_3$ ($g \cdot dm^{-3}$) (A)	Nitrogen fertilizer Nawóz azotowy (B)	Application method Metoda aplikacji (C)	N-Total N-og.	$N-NH_4$	$N-NO_3$	P	K	Ca	Mg
5	$(NH_4)_2SO_4$	Cultan	6.14	0.09	0.35	0.53	5.66	0.46	1.04
5	$(NH_4)_2SO_4$	Solution r-r	6.08	0.16	0.26	0.64	6.28	0.33	1.24
5	$CO(NH_2)_2$	Cultan	5.72	0.11	0.26	0.25	5.76	0.57	1.20
5	$CO(NH_2)_2$	Solution r-r	5.97	0.12	0.36	0.39	5.77	0.63	1.32
15	$(NH_4)_2SO_4$	Cultan	7.01	0.17	0.45	0.30	5.83	0.63	1.79
15	$(NH_4)_2SO_4$	Solution r-r	6.05	0.08	0.41	0.44	5.87	0.76	1.97
15	$CO(NH_2)_2$	Cultan	5.53	0.11	0.32	0.25	5.27	0.83	1.37
15	$CO(NH_2)_2$	Solution r-r	5.69	0.05	0.37	0.34	5.57	1.02	1.16
Mean for $CaCO_3$ dose		5	5.98	0.12	0.31	0.45	5.87	0.50	1.20
Średnia dla dawki $CaCO_3$		15	6.07	0.10	0.39	0.33	5.63	0.81	1.57
Mean for		$(NH_4)_2SO_4$	6.32	0.12	0.37	0.48	5.91	0.55	1.51
Średnia dla		$CO(NH_2)_2$	5.73	0.10	0.33	0.31	5.59	0.77	1.26
Mean for		Cultan	6.10	0.12	0.35	0.33	5.63	0.63	1.35
Średnia dla		Solution r-r	5.95	0.10	0.35	0.45	5.87	0.69	1.42
$NIR_{\alpha = 0.05}$									
A			i.d. – r.n.	i.d. – r.n.	0.05	0.11	i.d. – r.n.	0.15	0.11
B			0,19	0.02	i.d. – r.n.	0.11	i.d. – r.n.	0.15	0.11
C			i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	0.11	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.
ABC			0,63	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.

i.d. – insignificant differences, r.n. – różnice nieistotne

Table 3. N, P, K, Ca, Mg concentrations ($mg \cdot dm^{-3}$) and pH, EC values ($mS \cdot cm^{-1}$) in substratum after experiment completion
Tabela 3. Zawartość N, P, K, Ca, Mg ($mg \cdot dm^{-3}$) oraz wartości pH i EC ($mS \cdot cm^{-1}$) w podłożu po zakończeniu doświadczenia

Dose Dawka $CaCO_3$ ($g \cdot dm^{-3}$) (A)	Nitrogen fertilizer Nawóz azotowy (B)	Application method Metoda aplikacji (C)	$N\text{-}NH_4$	$N\text{-}NO_3$	$P\text{-}PO_4$	K	Ca	Mg	EC	pH_{H2O}
5	$(NH_4)_2SO_4$	Cultan	476.3	228.0	237.0	780.7	2601	320	3.11	6.75
5	$(NH_4)_2SO_4$	Solution r-r	309.3	143.0	204.0	799.3	2741	316	3.35	6.48
5	$CO(NH_2)_2$	Cultan	425.3	230.7	268.0	927.0	2484	385	3.32	7.08
5	$CO(NH_2)_2$	Solution r-r	152.0	266.3	242.0	839.3	2767	311	3.07	6.81
15	$(NH_4)_2SO_4$	Cultan	320.7	300.3	159.7	749.7	5543	313	3.16	6.85
15	$(NH_4)_2SO_4$	Solution r-r	223.0	253.3	176.7	808.7	5976	405	3.24	6.58
15	$CO(NH_2)_2$	Cultan	330.7	230.3	171.7	907.6	5356	351	2.70	6.91
15	$CO(NH_2)_2$	Solution r-r	119.7	330.7	193.6	824.3	5767	414	2.89	6.93
Mean for $CaCO_3$ dose		5	340.8	217.0	237.8	836.6	2648	333	3.21	
Średnia dla dawki $CaCO_3$		15	248.5	278.7	175.4	822.6	5660	371	3.00	
Mean for		$(NH_4)_2SO_4$	332.3	231.2	194.4	784.6	4215	338	3.21	
Średnia dla		$CO(NH_2)_2$	256.9	264.5	218.8	874.6	4093	365	2.99	
Mean for		Cultan	388.3	247.3	209.1	841.3	3996	342	3.07	
Średnia dla		Solution r-r	201.0	248.3	204.2	817.9	4313	362	3.14	
$NIR_{\alpha = 0.05}$										
A			48.7	53.4	11.7	i.d. – r.n.	538	i.d. – r.n.	i.d. – r.n.	
B			48.7	i.d. – r.n.	11.7	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	
C			48.7	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	
ABC			i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	i.d. – r.n.	

i.d. – insignificant differences, r.n. – różnice nieistotne

beet is also determined by the cultivar and plant harvest term. Wojciechowska [2005] also reports that fertilizing with reduced forms of nitrogen is very effective in decreasing nitrogen contents in leaf vegetable yield, with special indication of the alternative method, as compared to conventional fertilization, which is the system of localized fertilization with reduced forms of nitrogen (CULTAN, i.e. nitrogen deposit). The dose of the applied nitrogen fertilizer has a very significant effect upon the contents of nitrates in plants. Nurzyński et al. [2009], in studies on lettuce, report that together with the increase of ammonium saltpeter dose in the substratum the concentration of nitrates in the plant increased (from 0.48% d.m. to 1.45% d.m.).

The dry matter leaf contents was significantly differentiated, depending on the applied nitrogen fertilizer, manner of its application and the dose of calcium carbonate. The highest dry matter percentage was found in the leaves of plants fed with urea in the form of solution with a lower calcium carbonate dose (13.77%). The above – ground parts of spinach beet was characterized with high contents of nutrients (tab. 1). The spinach beet plants fed with urea in localized form, with a smaller $CaCO_3$ dose contained more vitamin C (47.57 mg·100 g^{-1} f.w.) than the plants from the objects fed with the same fertilizer in the conventional way (37.63 mg·100 g^{-1} f. w.). Similar vitamin C contents were obtained by Czerniak and Kołota [2008], analyzing the above-ground parts of spinach beet. As Smirnoff [1996] reports, one of the most important active substances, indispensable for the functioning of plants and humans is L-ascorbic acid. Nurzyńska-Wierdak [2005] reports that the contents of vitamin C depends on the form of the applied nitrogen fertilizer. In the studies on kohlrabi the author obtained larger contents of this component in the leaves of kohlrabi, ded with ammonium sulfate, as compared to calcium saltpeter.

The total protein and nitrogen contents in the leaves of the examined plant, was differentiated to a small extent, depending on the applied calcium carbonate dose. However, a significant effect of nitrogen fertilization was reported. More protein was contained in the plants fertilized with ammonium sulfate, as compared to urea.

The obtained results of macrocomponents in the plant depended upon nitrogen and calcium fertilization. Higher concentrations of mineral components (phosphorus, potassium, magnesium) in spinach beet were reported in the objects fed conventionally, as compared to localized fertilization, irrespectively of the applied nitrogen fertilizer (tab. 2). The mineral component contents in the leaves of of examined plants are close to these found by Czerniak and Kołota [2007, 2008]. What is also worth noticing, is the significant effect of examined factors upon the calcium contents in leaves, the deficiency of which may cause physiological disorders in leaf vegetables. The deficiency of this component may be manifested by browning and drying of leaf edges. Goto and Takakura [2003], as well as Barta and Tibbitts [2000] emphasize that at small amounts of calcium the lettuce leaf edges die away.

The conducted studies revealed a significant relationship between the differentiated nitrogen-calcium fertilization and the chemical composition of substratum (tab. 3). In the substrate fertilized with ammonium sulfate in localized manner after spinach beet harvest more ammonium and nitrate nitrogen remained, as compared to the objects fertilized with ammonium sulfate in the conventional way. The opposite relationship was reported with the application of urea in the case of substratum nitrate nitrogen concentration. Michałojć [2000] found quite a high concentration of nitrate nitrogen in the substratum after lettuce, radish and spinach harvest after application of reduced nitrogen forms.

The most potassium and phosphorus remained in the substrate fertilized with urea in the localized manner. The most magnesium was reported in the objects with $(NH_4)_2SO_4$ applied in the form of a solution. Differentiated calcium fertilization had a significant effect upon the contents of mineral nitrogen, phosphorus and calcium in the rhisosphere of examined plants.

The growth of plants and their intake of water and dissolved nutrients to a large extent are determined by general salt concentration (EC) in the substratum. The EC value is affected by all cations and anions contained in the substratum, but to the greatest extent – by nitrates, potassium and magnesium [Nurzyński 2008]. The concentration of nutrients in the substratum from under spinach beet cultivation ranged from 2.70 to 3.35 $mS \cdot cm^{-1}$. Calcium, despite its high concentration in the substratum, affected the EC value to a slight extent.

Many factors influence the growth and yields of cultivated plants, among which the acidity of rhizosphere is mentioned as one of the most important. The optimum pH range for most of the cultivated garden plants is included in the range from 5.5 to 6.5 [Nurzyński 2008]. In the presented studies the reaction of the substratum after spinach beet harvest was close to the optimum.

On the basis of the assessment of vitamin C, protein, mineral components contents and the lower nitrate contents as compared, in. e. to lettuce, spinach beet should be perceived as a very valuable vegetable.

CONCLUSIONS

1. Kind of nitrogen fertilizer and manner of nitrogen application did not affect the accumulation of NO_3^- in the above-ground parts of spinach beet.

2. The applied calcium carbonate in a higher dose caused the increased calcium and magnesium contents in the plant, and decrease of phosphorus and potassium contents.

3. The most L-ascorbic acid and the least nitrates was contained in plants fed with urea in a localized form.

4. Higher EC value in substratum was reported in the combinations with higher magnesium and potassium contents in these objects.

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ODDZIAŁYWANIE WĘGLANU WAPNIA I ZRÓŻNICOWANEGO NAWOŻENIA AZOTOWEGO NA PLON I SKŁAD CHEMICZNY BURAKA LIŚCIOWEGO

Streszczenie. Badania przeprowadzone w latach 2008–2009 miały na celu określenie zależności pomiędzy rodzajem nawozu azotowego, sposobem jego aplikacji oraz dawką węglanu wapnia a masą jednostkową roślin i składem chemicznym buraka liściowego uprawianego w szklarni w okresie wiosennym. Azot zastosowano w postaci siarczanu amonu i mocznika w formie zlokalizowanej (N-depozyt) oraz w postaci roztworu. Wapń podano w postaci węglanu wapnia w dawkach 5 i 15 g · dm^{-3} podłoża. Oceniono długość liści, masę jednostkową roślin oraz wybrane parametry wartości użytkowej liści buraka, jak również dokonano analizy podłoża po zbiorze roślin. Największą masę jednostkową roślin otrzymano, stosując siarczan amonu w postaci roztworu z mniejszą dawką węglanu wapnia, w porównaniu z pozostałymi kombinacjami. Badane rośliny buraka liściowego odznaczały się dużą zawartością suchej masy, białka, azotu ogółem, potasu, wapnia i magnezu. Skład chemiczny liści był istotnie zróżnicowany w zależności od badanych czynników. Zawartość azotanów w suchej masie liści mieściła się z zakresie od 0,26 do 0,45% w zależności od rodzaju nawozu azotowego oraz sposobu jego zastosowania. Zastosowane nawożenie azotowe w niewielkim stopniu wpływało na koncentrację azotanów w liściach buraka. Więcej azotanów zawierały rośliny żywione wyższą dawką węglanu wapnia w porównaniu z roślinami, którym podano niższą dawkę $CaCO_3$. Największą zawartość witaminy C oraz najmniejszy udział azotanów w suchej masie liści otrzymano przy stosowaniu mocznika w postaci depozytu z niższą dawką węglanu wapnia.

Słowa kluczowe: burak liściowy, nawożenie zlokalizowane, azotany, skład chemiczny liści

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