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INFLUENCE OF NITROGEN DOSES ON SALT CONCENTRATION, YIELD, BIOLOGICAL VALUE, AND CHEMICAL COMPOSITION OF SOME VEGETABLE PLANT SPECIES. PART I. YIELD AND BIOLOGICAL VALUE

Karolina Pitura, Zenia Michałojć
University of Life Sciences in Lublin

Abstract. A study on the influence of doses nitrogen on salt concentration, yield, biological value, and chemical composition of butterhead lettuce, kale, and leafy celery was carried out under greenhouse conditions in 2006-2008. The experiment was set up as a completely randomized design. A single experimental unit consisted of one pot with a plant. Increasing rates of nitrogen in the form of ammonium nitrate (34% N): 0.3; 0.6; 0.9; 1.2 g N·dm^{-3} of growing medium, were applied in all investigations, while the other macronutrients were the same for all plants. The obtained results revealed that the salt concentration in the growing medium depended both on the rate of nitrogen and the plant grown. Significantly lower crop yield was recorded when the highest nitrogen rate was applied (1.2 g N·dm^{-3}), although this relationship was shown when there was high variation in EC in particular types of medium. It was found that excessive salt concentration in the growing medium due to increasing nitrogen rates significantly reduced vitamin C content in butterhead lettuce and leafy celery. An opposite relationship was observed for kale leaves. It was found that the protein levels in the tested plants increased with an increase in nitrogen rates. As compared to the lowest rate, the increase was 32.2% for butterhead lettuce, 30.6% for kale, and 41.2% for leafy celery.

Key words: *Lactuca sativa var. capitata, Apium graveolens* L. var. *dulce* Mill., *Brassica oleracea* L. var. *acephala*, salinity, nitrogen dose, yield, vitamin C

INTRODUCTION

A reduced amount of substrate for growing plants in protected cultivation requires a detailed calculation of fertilization doses. Excessive rates of nutrients lead to soil salinity, while too low rates cause physiological disturbances in plants and in conse-

Corresponding author – Adres do korespondencji: Zenia Michałojć, Department of Soil Cultivation and Horticultural Plant Fertilization, University of Life Sciences in Lublin, ul. Leszczyńskiego 58, 20-068 Lublin, e-mail: zenia.michalojc@up.lublin.pl

quence lower yields and lower biological value of crops. According to Al-Maskri et al. [2010], salinity is one of the main factors limiting plant growth and crop yield quality. All cations and anions affect excessive salt concentration in the medium, but nitrogen, potassium, and magnesium are crucial [Sonneveld and Voogt, 2009; Oliveira *et al.* 2011]. The toxic action of particular ions towards the cell is the negative effect of excessive salt concentration on plants. Protein degradation and changes in enzymatic activity were observed at high accumulation of ions. Substrate salinity induces a response in plants similar to that in the case of drought, because the accumulation of proline, ABA, phaseic acid, and hormones causing the stomata to close due to reduced water intake occurs in both situations [Tuteja 2007; Youssef 2009]. In consequence, crop yields are lower, the synthesis of photosynthetic pigments (especially chlorophyll b) in plants is inhibited, and the lipid peroxidation process is accelerated [Hawrylak 2007]. Salinity also causes disturbances in nutrient uptake. An excess of Na^+ and Cl^- can be a reason for limited uptake of K^+, Ca^+, and NO_3^- ions by plants. Sodium ions compete with potassium ions for the binding site within the root, which results in worse uptake of an element, thus its deficit in a plant [Hussain et al. 2009]. Applying excessive nitrogen rates leads not only to soil salinity, but also to the worsening of yield quality through excessive accumulation of nitrates in the aboveground parts, mainly of leafy plant species [Wojciechowska 2005]. A plant's response salt concentration in the soil depends, among others, on a species. Leafy celery is considered to be sensitive to soil salinity, butterhead lettuce is medium sensitive, and kale is slightly sensitive [Breś *et al.* 2009]. The studies conducted by Markiewicz and Kleiber [2010] found that lettuce cultivars showed relatively high tolerance to growing medium salinity ranging from 1.60 up to 5.10 $mS \cdot cm^{-1}$.

The study was aimed at evaluating the influence of different nitrogen rates on salt concentration in the growing medium, and in consequence on yield and biological value of butterhead lettuce, kale, and leafy celery.

MATERIALS AND METHODS

The experiments were carried out in the spring of 2006–2008. The study involved butterhead lettuce (*Lactuca sativa* var. *capitata*) cv. 'Alanis', leafy celery (*Apium graveolens* L. var. *dulce* Mill.) cv. 'Verde Pascal', and kale (*Brassica oleracea* L. var. *acephala*) cv. 'Lerchenzungen'. The growing period of lettuce lasted on average 60 days (sowing time in the 3rd decade of March, harvest in the 3rd decade of May), for kale it was 75 days (sowing time in the 3rd decade of March, harvest in the 1st decade of June), while for celery 86 days (sowing time in the 3rd decade of March, harvest in the 2nd decade of June). In all years of the experiment, the plants grew under similar temperature and moisture conditions.

Vegetables were grown in a greenhouse in 2 dm^3 pots filled with peat growing medium. Medium pH was 4.6, and the medium was limed to pH 6.5 using 10 g $CaCO_3$ dm^{-3}. The mineral nutrient content in peat before planting vegetables to their permanent place was as follows (in $mg \cdot dm^{-3}$): $N\text{-}NH_4$ – trace amountsl; $N\text{-}NO_3$ – 25; $P\text{-}PO_4$ – 25; K – 10; Ca – 40; and Mg - 8, while in water for watering: $N\text{-}NH_4 + N\text{-}NO_3$ – 18; $P\text{-}PO_4$ – 11;

K – 4; Ca – 110; Mg – 9; pH – 7.2; and EC – 0.6 mS·cm^{-1}. The experiment was set up as a completely randomized design in 8 replicates. A single experimental unit consisted of one pot with a plant. Increasing rates of nitrogen in the form of ammonium nitrate (34% N): 0.3; 0.6; 0.9; 1.2 g N·dm^{-3} of growing medium, were applied in all investigations. Phosphorus, potassium, and magnesium rates were the same for all plants and amounted to (in g·dm^{-3}): 0.4 P, 0.9 K, and 0.45 Mg. When calculating the rates, the nutrient content in peat and water was taken into account. Phosphorus, micronutrients (in mg·dm^{-3}: Fe – 16; Mn – 10.2; Cu – 26.6; Zn – 1.48; B – 3.2; Mo – 7.4), and ¼ of N, K, Mg rates were supplied the medium during its preparation before planting vegetables. The remaining amounts of N, K, and Mg were applied three times during plant growth every 8–12 days.

The plants were harvested after they reached commercial maturity. Fresh weight yield (g·plant^{-1}) was determined after harvest and plant material samples were subjected to chemical analysis. The weight of the above-ground parts of butterhead lettuce, kale, and leafy celery was determined by the oven-dry method, while vitamin C content in fresh material was analyzed by Tillman's method (PN-A-04019 1998). After drying the plant material at 60°C and grinding it, N-total was determined in a Kjeltec 2200 Distillation Unit using Kjeldahl's method.

Protein content was determined in dry matter and calculated on the basis of total nitrogen, multiplying it by a coefficient of 6.25.

Medium acidity was measured by means of the potentiometric technique, while salt concentration was measured with a conductometer in the growing medium suspended in distilled water (1:2 ratio). After the plants were harvested, nitrate and ammonium nitrogen in the medium was determined in 0.03 M acetic acid extract with activated charcoal addition (solution/medium ratio 1:10) by Bremner's microdistillation modified by Starck.

The obtained results on yield, plant material, and growing medium were statistically analysed by analysis of variance based on Tukey's test at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

The experiment revealed that increasing nitrogen rates (0.3; 0.6; 0.9; 1.2 g N·dm^{-3}) significantly affected the salt concentration in the medium in which the studied plants were grown (Table 1). The highest EC values in the growing medium were recorded after applying the highest nitrogen dose: for leafy celery – 4.38 mS·cm^{-1}, for butterhead lettuce – 2.60 mS·cm^{-1}, for kale – 1.66 mS·cm^{-1}, whereas the lowest one when the lowest nitrogen rate was used for the growing media: for kale – 1.06 mS·cm^{-1}, for butterhead lettuce – 1.32 mS·cm^{-1}, for leafy celery – 2.78 mS·cm^{-1}. The difference in salt concentration (EC) in particular media between the lowest (0.3 g N·dm^{-3}) and the highest nitrogen rate (1.2 g N·dm^{-3}) was as follows: for kale – 0.6 mS·cm^{-1}, for butterhead lettuce – 1.28 mS·cm^{-1}, for leafy celery – 1.6 mS·cm^{-1}. Therefore, the salt concentration in the investigated medium depended not only on the nitrogen rate, but also on the plant grown. It is also worth underlining that nitrogen was applied at the same rates for all the vegetables tested. The salt concentration in a medium is largely determined by anions rather than cations, and among anions – chlorides, nitrates, and sulfates [Breś *et al.* 2009]. Rates of nitrogen were differentiated in the present study by applying its different forms: as cations NH_4^+ and anions NO_3^- (ammonium nitrate). The growing medium analysis revealed high variation in nitrogen content, especially in the case of nitrates. The application of the highest rate of nitrogen influenced its content in the growing medium after harvest: for kale it was 50 mg N-NO_3, for butterhead lettuce – 550 mg N-NO_3, and for leafy celery – 770 mg N-$NO_3 \cdot dm^{-3}$, while mineral nitrogen (N-NH_4+N-NO_3) content was, respectively: 68 mg N-min., 663 mg N-min., 914 mg N-min (Table 1). These data confirm the significant effect of NO_3^- ions on salt concentration in the medium. The higher rates of nitrogen fertilization (0.35 g $N \cdot dm^{-3}$), unlike its lower rate (0.25 g $N \cdot dm^{-3}$), led to an increase in EC value by 1.75 $mS \cdot cm^{-1}$ [Nurzyński *et al.* 2007]. In turn, the study of Dzida [2007] on thyme as well as the study of Dzida and Pitura [2008] on leafy beetroot showed an increase in salt concentration in the medium as the content of NO_3^- in it increased.

Table 1. Concentration of N-NH_4, N-NO_3, N-min. ($mg \cdot dm^{-3}$), pH $_{(H2O)}$ and EC ($mS \cdot cm^{-1}$) in substrate of lettuce, curly kale and leaf celery. Means from 2006–2008

Tabela 1. Zawartość of N-NH_4, N-NO_3, N-min. ($mg \cdot dm^{-3}$) oraz pH $_{(H2O)}$ i EC ($mS \cdot cm^{-1}$) w podłożu sałaty, jarmużu i selera naciowego. Średnie z lat 2006–2008

Species Gatunek	Dose – Dawka g $N \cdot dm^{-3}$	N-NH_4	N-NO_3	N-min	pH	EC
Lettuce Sałata	0.3	41	87	128	6.84	1.32
	0.6	87	227	314	6.77	2.25
	0.9	89	425	514	6.81	2.46
	1.2	113	550	663	6.65	2.60
	$\bar{x}$	82	322	405	6.65–6.84	2.16
Curly kale Jarmuż	0.3	7	8	15	6.95	1.06
	0.6	22	9	31	7.25	1.20
	0.9	16	12	28	7.26	1.22
	1.2	18	50	68	7.37	1.66
	$\bar{x}$	16	20	36	6.95–7.37	1.28
Leaf celery Seler lisciowy	0.3	19	34	53	7.37	2.78
	0.6	30	338	368	7.13	3.32
	0.9	39	486	525	7.02	3.66
	1.2	144	770	914	6.90	4.38
	$\bar{x}$	58	407	465	6.90–7.37	3.53
$LSD_{0.05}$ for dose $NIR_{0,05}$ dla dawki	lettuce – sałaty	48	80	128		0.98
	curly kale – jarmużu	13	14	17		0.17
	leaf celery – selera	18	108	127		0.72

Excessive salt concentration in the medium causes a change in its pH [Sonneveld and Voogt, 2009]. The present study did not unequivocally confirm such a correlation; the experiment on the growing medium for kale showed an increase in pH from 6.95 to 7.37 with an increase in EC value, whilst the tests involving celery demonstrated an opposite trend: a decrease of pH from 7.37 to 6.90. Butterhead lettuce did not show any clear relationship (Table 1).

Nitrogen is a nutrient that largely determines crop yield. The present study revealed a significant effect of different nitrogen rates on butterhead lettuce, kale, and leafy celery yields (Table 2). It was found that fresh weight of kale increased with an increase in the rate of nitrogen from 0.3 g N to 0.6 g N·dm^{-3}, while for celery it was the case when the increase in nitrogen rate was from 0.3 g N to 0.9 g N·dm^{-3}. The experiment with butterhead lettuce indicated that the highest weight of plants was achieved after applying 0.3 g N·dm^{-3}. Thus, the tested vegetable species responded in a different way to increasing nitrogen rates. Significantly lower yields were observed for all the studied species after using the highest nitrogen rate (1.2 g N·dm^{-3}), although this correlation was shown at high variation in EC (Table 1). Lettuce yield increased due to increasing nitrogen rates [Boroujerdnia and Ansari, 2007]. Similarly, the studies by Chohura and Kołota [2011] proved that, regardless of the type of nitrogen fertilizer, an increase in nitrogen concentration in the soil from 50 mg to 100 mg N·dm^{-3} caused a significant increase in radish yield. Biesiada and Kuś [2010] reported positive effects of increasing rates of nitrogen on basil herb yields.

The applied nitrogen rates differentiated vitamin C content in butterhead lettuce, kale, and leafy celery (Table 2). The highest vitamin C concentrations were determined in lettuce and celery leaves after using the lowest nitrogen dose. The rates higher than 0.3 g N·dm^{-3} contributed to a reduction in the content of this compound, although its significantly lower levels were recorded after the highest nitrogen dose had been applied. A different response was observed for kale leaves; a significant increase in vitamin C concentration was found when the applied rate of nitrogen was higher than 0.3 g N· dm^{-3}. Nitrogen applied at the rates from 0.6 to 1.2 g N· dm^{-3} of growing medium caused a further increase in vitamin C content in the plants. This relationship was found when medium salinity was equal to or lower than 1.6 mS·cm^{-1}. The concentration of vitamin C in butterhead lettuce decreased with salinity higher than 2.25 mS·cm^{-1}, while in leafy celery – 2.78 mS·cm^{-1} (Tables 1 and 2). The obtained results indicate that excessive salt concentration in the growing medium significantly reduces ascorbic acid synthesis in plants. Kozik [1998] reported a decrease in vitamin C content resulting from an elevated nitrogen concentration in the substrate. On the other hand, Kozik and Ruprik [2000] did not observe any effect of nitrogen fertilization on vitamin C concentration in lettuce plants. In their study on pepper, Golcz and Kozik [2004] showed a decrease in this compound due to increased nitrogen content in the substrate. A reduction in vitamin C content due to increased nitrogen doses was also reported by Nurzyński [1973] in experiments with cabbage and kale. Conducting experiments with leafy beetroot, Dzida [2004] recorded an increase in the value of substrate EC and an increase in vitamin C concentration in the leaves of the studied plants after applying a higher rate of nitrogen (1.2 g · plant^{-1}), as compared to the lower rate (0.8 g · plant^{-1}), with a simultaneous increase in the rates of potassium fertilizer.

Table 2. The weight (g·plant^{-1}), Vitamin C (mg·100g^{-1} f.m), dry matter, and protein (% d.m) content in lettuce, curly kale and leaf celery. Mean from 2006–2008
Tabela 2. Masa roślin (g·roślina^{-1}), zawartość witaminy C (mg·100g^{-1} św.m), białka i suchej masy (% s.m.) w sałacie, jarmużu i selerze naciowym. Średnie z lat 2006–2008

Species Gatunek	Dose – Dawka g N·dm^{-3}	Weight Masa g	Vitamin C Witamina C mg	Dry matter Sucha masa %	Protein Białko %
Lettuce Sałata	0.3	149	37.44	5.72	23.44
	0.6	127	36.18	7.60	23.75
	0.9	118	29.19	8.32	27.38
	1.2	71	24.09	9.25	31.00
	$\bar{x}$	116	31.72	7.72	26.39
Curly kale Jarmuż	0.3	205	112.87	18.30	21.25
	0.6	327	177.37	15.05	23.75
	0.9	334	188.12	14.40	26.25
	1.2	287	204.25	13.77	27.75
	$\bar{x}$	288	170.65	15.38	24.75
Leaf celery Seler naciowy	0.3	186	79.56	19.91	20.01
	0.6	201	65.28	20.24	23.43
	0.9	188	63.24	19.09	26.12
	1.2	146	51.00	20.20	28.25
	$\bar{x}$	180	64.77	19.86	24.45
$LSD_{0.05}$ for dose $NIR_{0,05}$ dla dawki	lettuce – sałaty	54	8.35	0.13	1.89
	curly kale – jarmużu	46	25.45	0.67	1.95
	leaf celery – selera	28	10.67	0.30	1.11

The increasing nitrogen rates had also significant effects on protein content in butterhead lettuce, kale, and leafy celery. Its content was found to increase with an increase in nitrogen rate (Table 2). A comparison of protein content in the studied plants between the lowest and highest nitrogen rates showed an increase in protein concentration in butterhead lettuce by 32.2%, in kale by 30.6, and in leafy celery by 41.2%. This relationship proves that plants take up nitrogen proportionally to its concentration in the growing medium. No significant effect of the nitrogen rate on protein content in rucola leaves was reported by Nurzyńska-Wierdak [2009].

The percentage of dry matter in the studied plants varied (Table 2): it ranged from 5.72% to 9.25% in butterhead lettuce. Dry matter in plant tissues increased along with an increase in nitrogen rate. Dry matter content in kale amounted from 13.77% to 18.30% and a reverse correlation was found. Dry matter in the above-ground parts of leafy celery ranged from 19.09% to 20.24%. No significant differences in dry matter content were found (Table 2). The study by Jarosz and Dzida [2006] involving lettuce revealed an increase in dry matter percentage with an increase in nitrogen rates, which was confirmed by the present experiment. Napa cabbage was characterized by the highest content of dry matter in the treatments where the nitrogen rate was applied at 60 kg N·ha^{-1}, as compared to the rates of 20 and 100 kg N·ha^{-1} [Kalisz 2007]. The study of Adamczewska-Sowińska and Uklańska [2010] on endive showed no significant influence of nitrogen rate on dry matter concentration in plants.

CONCLUSIONS

1. The salt concentration in the growing medium depended both on the rate of nitrogen and the plant grown. The difference in salt concentration in particular media between the lowest (0.3 g N·dm^{-3}) and the highest nitrogen rate (1.2 g N·dm^{-3}) was as follows: for kale – 0.6 mS·cm^{-1}, for butterhead lettuce – 1.28 mS·cm^{-1}, for leafy celery – 1.6 mS·cm^{-1}.
2. Significantly lower crop yield was recorded when the highest nitrogen rate was applied (1.2 g N·dm^{-3}), although this relationship was shown when there was high variation in EC in particular types of medium.
3. It was found that excessive salt concentration in the growing medium due to increasing nitrogen rates significantly reduced vitamin C content in butterhead lettuce and leafy celery. An opposite relationship was observed for kale leaves.
4. The protein levels in the tested plants increased with an increase in nitrogen rates. As compared to the lowest rate, the increase was 32.2% for butterhead lettuce, 30.6% for kale, and 41.2% for leafy celery.

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WPŁYW DAWEK AZOTU NA STĘŻENIA SOLI, PLONOWANIE, WARTOŚĆ BIOLOGICZNĄ ORAZ SKŁAD CHEMICZNY WYBRANYCH GATUNKÓW ROŚLIN WARZYWNYCH. CZĘŚĆ I. PLONOWANIE I WARTOŚĆ BIOLOGICZNA

Streszczenie: Badano wpływ dawek azotu na stężenia soli, plonowanie, wartość biologiczną sałaty, jarmużu, selera naciowego. Doświadczenia przeprowadzono w warunkach szklarniowych w latach 2006–2008, założono je w układzie kompletnej randomizacji. Jednostką eksperymentalną stanowiła jedna rośliną w doniczce. We wszystkich doświadczeniach zastosowano wzrastające dawki azotu – 0,3; 0,6; 0,9; 1,2 g $N \cdot dm^{-3}$ podłoża w postaci saletry amonowej (34% N). Uzyskane wyniki wykazały, iż stężenie soli w podłożach uzależnione było zarówno od dawki azotu jak i uprawianej rośliny. Stwierdzono istotnie mniejszy plon roślin po zastosowaniu największej dawki azotu (1,2 g $N \cdot dm^{-3}$), aczkolwiek przy dużym zróżnicowaniu w EC w podłożu spod sałaty, jarmużu i selera. Wykazano, iż nadmierna koncentracja soli w podłożu spowodowana wzrastającymi dawkami azotu istotnie obniżyła zawartość witaminy C w sałacie i selerze. Odwrotną zależność odnotowano w liściach jarmużu. Wykazano wzrost zawartości białka w badanych roślinach wraz ze wzrostem dawek azotu. Jego wzrost w porównaniu do najmniejszej dawki azotu w sałacie wynosił 32,2% w jarmużu 30,6% w selerze 41,2%.

Słowa kluczowe: sałata, jarmuż, seler naciowy, zasolenie, dawki azotu, plon, witamina C

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