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THE EFFECT OF FOLIAR FEEDING OF POTASSIUM SALTS AND UREA IN SPINACH ON GAS EXCHANGE, LEAF YIELD AND QUALITY

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Abstract

In a pot experiment conducted in a phytotron, the effectiveness of foliar feeding of different potassium salts, with and without the addition of 0.5% $CO(NH_2)_2$, in spinach *(Spinacia oleracea* L.*)* was investigated. Potassium was applied 3 times in the form of 1% solutions KCl, KNO_3, K_2SO_4 and $C_6H_5K_3O_7{\cdot}H_2O$, compared to water as the control treatment. The obtained results show that foliar feeding of potassium salts in spinach is an efficient method of supplementing the level of K^+ in plants during vegetation. Plants fed with KNO_3 had the highest content of potassium in leaves, and those fertilized with K_2SO_4, $C_6H_5K_3O_7 \times H_2O$ and KCl had an only slightly lower potassium content. The application of potassium salts resulted in more intensive gas exchange in leaves (stomatal conductance, photosynthesis, transpiration) and, as a consequence of that, increased leaf yield. Potassium nitrate and citrate influenced most effectively the abovementioned processes. The treatment of spinach with potassium salts resulted in an increased content of protein, chlorophyll, carotenoids, nitrates and iron as well as a decreased content of vitamin C and calcium in leaves.

Key words: *Spinacia oleracea,* potassium salts, urea, foliar feeding, gas exchange, yield, leaf quality.

INTRODUCTION

The yielding of spinach (*Spinacia oleracea* L.) depends primarily on water and nutrient availability in soil (Orłowski and Kołota, 1999). Potassium is the main ion of osmotic solution in plants (Mengel and Arneke, 1982). Its accumulation in cells leads to osmotic water uptake and generates cell turgor necessary for growth (Mengel and Arneke, 1982; De La Guardia and Benlloch, 1980) and pore opening (Fisher and Hsiao, 1968). In whole plants, the level of K^+ affects the osmotic absorption of water by roots, controls leaf transpiration (Hsiao and Läuchli, 1986) and increases vitamin C content in fruits (Huang et al. 2000). Its relatively large concentration is a condition necessary for protein biosynthesis (Marschner, 1995).

The versatile role of potassium ions in plants arises from the fact that potassium is an activator or coenzyme of numerous plant enzymes (Bussakorn et al. 2003). The only way to quickly supplement any potassium deficiencies during cultivation is to apply foliar feeding of this element. In Poland there are no studies on the effect of foliar feeding of potassium on yield and its quality as well as on the effectiveness of different forms of potassium salts. But data available in foreign literature show that potassium, as the monovalent cation with a relatively small diameter, easily passes through the leaf epidermis (Mengel, 2002). When applying different foliar fertilisers in spinach cultivation, Alan and Padem (1994) found its highest content in leaves already after 24-48 hours after application.

The penetration of the potassium cation into plant leaves, as shown in literature, depends on the applied form of potassium salt, however, results in this respect are not unambiguous. Wittwer and Teubner (1959) showed the highest uptake of foliar-applied K ions from potassium citrate solution, whereas Abadia et al. (2002) and Reed et al. (1988) claim that the application of chelated forms of this nutrient do not increase its absorption compared to inorganic salt forms, and it only increases its mobility in the plant. Also, there is a lack of agreement between researchers with regard to the effectiveness of inorganic potassium salts. Restrepo Diaz et al. (2008), applying foliar fertilization of olive trees with KCl and K_2SO_4 solutions, did not find any differences in growth, fruiting and K content in fruits, whereas Umar et al. (1999), applying the same salts in peanut plants, showed that KCl had a more beneficial effect on yield, whereas K_2SO_4 on protein and fat content in seeds. Miley and O o s t e r h u i s (1994), applying foliar feeding of KNO_3, K_2SO_4, KCl and K_2CO_3 solutions in cotton plants, found that KNO_3 had significantly increased the yield of seed hairs and bolls compared to the control treatment and K_2CO_3. There are no studies on the effect of foliar-applied potassium salt forms on the growth and yield quality of leaf vegetables as well as on the interaction of these forms with urea. But the addition of urea during foliar application of macro- and micronutrients is used in horticultural practice, since it is generally thought that it increases the availability of other nutrients in leaves, which is also confirmed in a study by K a n n a n (1980) and W e i n b a u m (1988).

In the light of the lack of studies on the effectiveness of foliar nutrition of leaf vegetables with potassium salts and the unknown usefulness of potassium salt forms available on the market, it seemed expedient to undertake such research.

MATERIALS AND METHODS

The experiments were conducted in a phytotron of the University of Life Sciences in 2008 in the period 12 May – 24 June (replication I) and 7 July – 18 August (replication II). Spinach plants (cv. 'Matador') grew in 1.5 dm^3 pots filled with medium for sowing and pricking out of leaf vegetables. One litre of growing medium contained 130 mg $N\text{-}NO_3$, 66 mg P, 165 mg K, 915 mg Ca and 141 mg Mg, its pH in H_2O was 5.5, whereas salinity 1.02 g NaCl × dm^{-3}. The experiment was carried out with fluorescent light, with far flux density of approx. 200 µmoli × m^{-2} × s^{-1}, day length of 14 hours and temperature 18/15°C (day/night). Each experiment comprised 50 pots, with 2 plants growing in one pot. In the third week of growth, 10 experimental series were set up (5 pots in each), differentiated in terms of foliar-applied potassium salts and the addition of urea or not. The respective experimental series were sprayed with 1% water solutions of the following potassium salts: 1) H_2O – control, 2) KCl, 3) KNO_3, 4) K_2SO_4, 5) $C_6H_5K_3O_7{\cdot}H_2O$ in pure form, or a mixture of particular salts with 0.5% $CO(NH_2)_2$ (experiment design – Tab. 1). Foliar feeding of the abovementioned potassium salts in the plants was repeated in the fourth and fifth weeks of growth. The solutions were applied at air temperature of 18°C, just before nightfall, using a manual sprayer, each time until full moisturizing of the accessible leaf surface was obtained.

After 5 days from the last spraying, measurements were made of leaf stomatal conductance for water vapour as well as transpiration and photosynthesis intensity. The measurements were made in 10 replications on fully-developed middle leaves of spinach rosettes, using a leaf microclimate control system LCA-4. During recording, temperature in the measurement chamber was approx. 20°C and far flux density approx. 200 µmoli × m^{-2} × s^{-1}.

Table 1

Effect of potassium salts and addition of urea on stomatal conductance and intensity of transpiration of spinach leaves.

Potassium salts	Solution without urea	Solution with urea	Mean	Solution without urea	Solution with urea	Mean
	conductance (mol $H_2O \times m^{-2}{\cdot}s^{-1}$)			transpiration (mmol $H_2O \times m^{-2}{\cdot}s^{-1}$)		
Control (H_2O)	0.21	0.30	0.25	2.50	2.74	2,62
KCl	0.29	0.34	0.31	3.16	3.24	3,20
KNO_3	0.45	0.47	0.46	4.62	4.80	4,71
K_2SO_4	0.34	0.36	0.35	2.75	3.15	2,95
$C_6H_5K_3O_7 \times H_2O$	0.37	0.45	0.41	3.17	3.35	3,26
Mean	0.33	0.38		3.24	3.46	
$LSD_{0.05}$ for salt		0.04			0.21	
$LSD_{0.05}$ for urea		0.02			0.09	
$LSD_{0.05}$ for salt × urea		0.07			n.s.	

Table 2
Effect of potassium salts and addition of urea on intensity of photosynthesis and fresh yield of spinach leaves.

Potassium salts	Solution		Mean	Solution		Mean
	without urea	with urea		without urea	with urea	
	photosynthesis (μmol $CO_2 \times m^{-2} \times s^{-1}$)			leaf weight ($g \times plant^{-1}$)		
Control (H_2O)	6.25	6.66	6.45	10.9	13.0	11,9
KCl	6.96	7.56	7.26	13.8	15.0	14,4
KNO_3	8.86	9.28	9.07	15.4	17.3	16,3
K_2SO_4	7.35	7.93	7.64	14.2	14.5	14,3
$C_6H_5K_3O_7 \times H_2O$	7.84	9.17	8.50	14.3	16.7	15,5
Mean	7.45	8.12		13.7	15.3	
$LSD_{0.05}$ for salt		0.33			2.2	
$LSD_{0.05}$ for urea		0.15			1.0	
$LSD_{0.05}$ for salt × urea		0.54			n.s.	

Table 3
Effect of potassium salts and addition of urea on content of crude protein and nitrates in fresh weight of spinach leaves.

Potassium salts	Solution		Mean	Solution		Mean
	without urea	with urea		without urea	with urea	
	protein ($mg \times g^{-1}$f.m.)			nitrates (μg$NO_3 \times g^{-1}$f.m.)		
Control (H_2O)	25.4	32.3	28.8	132.2	148.7	140,4
KCl	29.6	35.0	32.3	152.8	221.9	187,3
KNO_3	30.7	35.9	33.3	444.2	611.5	527,8
K_2SO_4	26.6	29.5	28.0	196.2	262.4	229,3
$C_6H_5K_3O_7 \times H_2O$	30.0	36.9	33.4	256.1	376.0	316,0
Mean	28.5	33.9		236.3	324.1	
$LSD_{0.05}$ for salt		4.4			95.2	
$LSD_{0.05}$ for urea		1.9			42.0	
$LSD_{0.05}$ for salt × urea		n.s.			n.s.	

Table 4
Effect of potassium salts and addition of urea on content of chlorophyll ”a+b” and carotenoids in spinach leaves.

Potassium salts	Solution: without urea	Solution: with urea	Mean	Solution: without urea	Solution: with urea	Mean
	chlorophyll (mg × g^{-1}f.m.)			carotenoids (mg × g^{-1}f.m.)		
Control (H_2O)	2.03	2.28	2.15	0.28	0.33	0,30
KCl	2.37	2.59	2.48	0.32	0.35	0,33
KNO_3	2.82	3.00	2.91	0.37	0.41	0,39
K_2SO_4	2.47	2.77	2.62	0.34	0.37	0,35
$C_6H_5K_3O_7 \times H_2O$	2.52	2.80	2.66	0.37	0.40	0,38
Mean	2.44	2.69		0.34	0.37	
$LSD_{0.05}$ for salt		0.34			0.05	
$LSD_{0.05}$ for urea		0.15			0.02	
$LSD_{0.05}$ for salt × urea		n.s.			n.s.	

Table 5
Effect of potassium salts and addition of urea on content of vitamin C and iron in spinach leaves.

Potassium salts	Solution: without urea	Solution: with urea	Mean	Solution: without urea	Solution: with urea	Mean
	vitamin C (mg × 100g^{-1}f.m.)			iron (µg × g^{-1}d.m.)		
Control (H_2O)	90.3	103.3	96.8	90	100	95,0
KCl	89.9	89.1	89.5	105	90	97,5
KNO_3	87.8	94.5	91.2	115	110	112,5
K_2SO_4	79.1	93.3	86.2	90	100	95,0
$C_6H_5K_3O_7 \times H_2O$	89.0	88.9	88.9	115	120	117,5
Mean	87.2	93.8		103	104	
$LSD_{0.05}$ for salt		3.4			13.1	
$LSD_{0.05}$ for urea		1.5			n.s.	
$LSD_{0.05}$ for salt × urea		5.6			21.9	

Table 6
Effect of potassium salts and addition of urea on content of potassium and calcium in dry weight of spinach leaves.

Potassium salts	Solution		Mean	Solution		Mean
	without urea	with urea		without urea	with urea	
	potassium (%)			calcium (%)		
Control (H_2O)	4.22	4.71	4.46	1.78	1.56	1,67
KCl	5.03	5.45	5.24	1.66	1.40	1,53
KNO_3	5.43	5.60	5.51	1.50	1.40	1,45
K_2SO_4	5.38	5.48	5.43	1.52	1.40	1,46
$C_6H_5K_3O_7 \times H_2O$	5.09	5.64	5.36	1.58	1.28	1,43
Mean	5.03	5.38		1.61	1.41	
$LSD_{0.05}$ for salt		0.22			n.s.	
$LSD_{0.05}$ for urea		0.10			0.12	
$LSD_{0.05}$ for salt × urea		0.36			n.s.	

Concurrently, leaf samples were collected to determine the content of protein, vitamin C, nitrates, chlorophyll "a+b" and carotenoids. The content of the abovementioned compounds was determined using the following methods: protein – according to Kjeldahl; vitamin C according to Pijanowski et al. (1973); nitrates according to Cataldo et al. (1975); chlorophyll "a+b" according to Arnon (1949); carotenoids according to Britton (1985). Subsequently, average leaf fresh weight per plant was determined, and after drying, the content of potassium, calcium and iron was determined in leaf dry matter. The content of the abovementioned elements was determined using the atomic absorption method by means of an atomic absorption system (AAS). Prior to the analysis, fresh leaves were washed in distilled water. This paper presents average results obtained in two experiments. These data were subjected to statistical analysis using double cross-classification, determining the significance of differences by Tukey's test at the probability level $\alpha = 0.05$.

RESULTS AND DISCUSSION

The results presented in Tab. 1 and 2 show that foliar feeding of all the applied potassium salts had a significantly beneficial effect on the stomatal conductance of spinach leaves and, what follows, their transpiration and photosynthesis. Feeding of KNO_3, had the greatest effect on gas exchange components, $C_6H_5K_3O_7 \times H_2O$ and K_2SO_4 had a slightly smaller effect, with the smallest effect shown by KCl. Such efficiency of the used potassium salts resulted from the level of potassium accumulation in leaves. The data presented in Tab. 4 show that leaves treated with potassium nitrate contained the largest amount of potassium (5.51%), there was a smaller amount in those fed with potassium citrate and potassium sulphate (on average 5.39%), and the least amount in those treated with potassium chloride (5,24%). However, compared to the control treatment, the potassium content in foliar-fed leaves was significantly higher, which confirms the opinion expressed in a paper by Mengel (2002) as well as by Alan and Padem (1994) that K^+ easily passes through the leaf epidermis. The potassium content in spinach leaves in the conditions of citrate application does not confirm the thesis of Wittwer and Taubner (1959) that the uptake of K ions from potassium citrate solution is higher than that from other salts, and it is rather in agreement with the statement of Abadia et al. (2002) and Reed et al. (1988) that the application of chelated forms of this nutrient does not increase its absorption compared to inorganic salt forms. Hence, the larger accumulation of potassium in spinach leaves under the influence of foliar nutrition increased the degree of stomata opening, which, as indicated by the obtained results, on the one hand, significantly increased water vapour diffusion from leaves (transpiration), and on the other hand, CO_2 diffusion into the leaf interior (photosynthesis), which was also noted by Fisher and Hsiao (1968) as well as by Hsiao and Läuchli (1986) in their studies.

The obtained results also showed that the addition of urea to the solutions applied in each case increased stomatal conductance of leaves, thus, their transpiration and photosynthesis. It was probably associated with the beneficial effect of $CO(NH_2)_2$ on K ion accumulation in leaves (an increase by ca. 11%), which is also confirmed by Kannan (1980) and Weinbaum (1988).

The more efficient photosynthesis process in plants foliar-fed with potassium salts was undoubtedly a source of higher plant yields. The results contained in Tab. 2 show that all the applied potassium salts significantly increased leaf fresh weight per plant compared to the control treatment. The highest yield was produced by plants treated with potassium nitrate, which can be explained by the increased supply of potassium and nitrogen to these plants, whereas lower yields were obtained from those treated with potassium citrate, and the lowest from those fed with potassium chloride and sulphate. The addition of urea to the applied salts also increased significantly leaf yield. Miley and Oosterhuis (1994) also found, in foliar fertilization of cotton plants with KNO_3, K_2SO_4, KCl and K_2CO_3 salts, that potassium nitrate had the most beneficial effect on seed hairs and bolls, whereas Umar et al. (1999) and Restrepo Diaz et al. (2008) did not find any differences in the effect of KCl and K_2SO_4 on the yielding of peanut and olive trees.

Foliar feeding of potassium in spinach plants also affected spinach leaf quality. Plants fertilized with all the potassium salts, except for K_2SO_4, showed a higher protein content in leaves; however, significant differences were found, relative to the control treatment, in the case of KNO_3 and $C_6H_5K_3O_7 \times H_2O$ (Tab. 3). Thus, these results confirm the thesis of Clarkson and Hansen (1980) that a large potassium concentration in the plant is necessary for efficient protein synthesis. Potassium fertilization of plants also increased the nitrate content in leaves (Tab. 3). However, a significant increase in the amount of these substances, compared to the control treatment, was found in the case of feeding of KNO_3 and $C_6H_5K_3O_7 \times H_2O$ salts. The high nitrate content after the last application of KNO_3, which occurred several days before the harvest, proves that the metabolization of these compounds was not completed. But it is difficult to explain why there was such an accumulation of NO_3 in the case of foliar application of potassium citrate. However, the significantly higher amount of protein and nitrates in the plants additionally fed with urea seems to be obvious, since $CO(NH_2)_2$ was a direct source of nitrogen, used mainly for increased protein biosynthesis in leaves, but also partly for nitrate generation (Tab. 3).

Foliar application of potassium salts (except for KCl) also increased significantly the content of chlorophyll and carotenoids in leaves. The leaves accumulated the largest amount of photosynthetic pigments when KNO_3 was applied, and the lowest amount in the case of the application of KCl. The addition of urea to the solutions also had a beneficial effect on the biosynthesis of both groups of pigments (Tab. 4). The beneficial effect of potassium on the synthesis of chlorophyll and carotenoids, as well as on many other important organic substances (sugars, proteins, nucleic acids), should be seen in the fact that this ion is, as reported by Bussakorn et al. (2003), an activator or coenzyme of numerous enzymes. Also, the fact that K^+ is the main ion of osmotic solution of plants (Mengel and Arneke, 1982) and that its accumulation, on the one hand, increases the osmotic absorption of water by roots, and on the other hand, controls transpiration (Hsiao and Läuchli, 1986), which increases the degree of tissue hydration and supports the activity of enzymes, is not without significance.

The increased potassium content in leaves, as a result of foliar nutrition, had a significantly negative effect on vitamin C content. But the urea added to the solutions significantly increased its level in leaves (Tab. 5). It is difficult to express an opinion on these data due to the absence of similar studies on spinach or other leaf vegetables; in particular given the fact that a study by Huang et al. (2000) shows that potassium increased the content of this substance in grape fruits. It can only be presumed that it was associated with the "dilution effect", since the average leaf yield in the conditions of foliar feeding of the investigated potassium salts increased by nearly 27% compared to the control treatment.

Potassium supplied by foliar application also had an effect on the mineral composition of spinach leaves. All the applied potassium salts had a positive influence on iron content; however, a significant increase in potassium content occurred in the application of potassium nitrate and citrate. The other salts as well as the addition of $CO(NH_2)_2$ to the solution did not affect significantly Fe content in leaves (Tab. 5). But the effect of foliar feeding of potassium salts in plants on calcium content in leaves was opposite. The increased potassium content decreased the content of Ca^{++}, though it was not a significant effect in statistical terms. Likewise, the addition of urea to the solutions affected calcium accumulation in leaves (Tab. 6). Similar relations between potassium and calcium were also observed by Uziak and Borowski (1980/1981) in tomato leaves. They probably result from the antagonism between K^+ and Ca^{++} ions, which is known in literature.

The growing medium for sowing and pricking out of plants, used in the present study, contained a sufficient amount of potassium (165 mg $\times$ dm^{-3}), hence, the content of K in leaves of the control plants was high (4.46%). The use of potassium-poorer medium would probably have resulted in the achievement of even more distinct results.

CONCLUSIONS

1. Foliar feeding of potassium salts in spinach is an efficient method of supplementing the level of K^+ in plants during vegetation. Plants fed with KNO_3 had the highest content of potassium in leaves, and those fertilized with K_2SO_4, $C_6H_5K_3O_7 \times H_2O$ and KCl had an only slightly lower potassium content.
2. The application of potassium salt solutions resulted in more intensive gas exchange in leaves (stomatal conductance, photosynthesis, transpiration) and increased leaf yield. Potassium nitrate and citrate influenced most effectively the abovementioned processes.
3. Foliar feeding of potassium salts in spinach resulted in an increased content of protein, chlorophyll, carotenoids, nitrates and iron as well as a decreased content of vitamin C and calcium in leaves.

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Wpływ dolistnego żywienia szpinaku solami potasu i mocznikiem na wymianę gazową, plon i jakość liści

Streszczenie

W doświadczeniu wazonowym prowadzonym w fitotronie badano efektywność odżywiania dolistnego szpinaku *(Spinacia oleracea* L.*)* różnymi solami potasu bez i z dodatkiem 0,5% $CO(NH_2)_2$. Potas zastosowano 3-krotnie w formie 1% roztworów KCl, KNO_3, K_2SO_4 i $C_6H_5K_3O_7 \times H_2O$ wobec wody jako kontroli. Uzyskane wyniki wykazały, że dolistne odżywianie szpinaku solami potasu jest skuteczną drogą uzupełniania poziomu K^+ w roślinach w trakcie wegetacji. Największą zawartość potasu w liściach zawierały rośliny odżywiane KNO_3, a nieznacznie tylko mniejszą żywione K_2SO_4, $C_6H_5K_3O_7 \times H_2O$ i KCl. Aplikacja soli potasu wpłynęła na intensywniejszy przebieg wymiany gazowej liści (przewodność szparkowa, fotosynteza, transpiracja), a w wyniku tego wzrost plonu liści. Najbardziej efektywnie na wymienione procesy oddziaływał azotan i cytrynian potasu. Traktowanie szpinaku solami potasu wpłynęło na wzrost zawartości białka, chlorofilu, karotenoidów, azotanów i żelaza, a spadek zawartości witaminy C i wapnia w liściach.