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EFFECT OF FOLIAR FERTILIZATION WITH TYTANIT ON THE CONTENT OF SELECTED MACROELEMENTS AND SODIUM IN CELERY

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Abstract

Foliar application of growth regulators or fertilizers containing biostimulators can influence the uptake and accumulation of mineral elements by plants. A pot experiment carried out in two annual series (year of experiment I and II) examined the effect of various concentrations of Tytanit applied once or twice against mineral fertilization (NPK), in comparison with the control object (without fertilization) and the object with mineral fertilization (NPK), on the total content of potassium, calcium, magnesium and sodium in petioles and leaf blades of celery. The experiment involved the application of various concentrations of Tytanit, ranging from 0.001% to 3.6%. The content of selected elements in the plant material was determined after dry mineralization, using the ICP – AES method. The total content of potassium in petioles of celery fertilized with NPK + 3.6% was higher or the same as in the control and in plants fertilized with NPK (I and II series). The results were similar in the case of leaf blades (except for series I). The highest concentration of Tytanit (3.6%) resulted in a reduction of the total calcium content in both of the tested parts of celery and magnesium in petioles, compared with the control. On the other hand, the total content of sodium increased along with the growth of the fertilizer concentration. The highest bioaccumulation of calcium was observed in celery cultivated in the object without fertilization (control). A significantly higher potassium content (mean from both series of research) and over two-fold higher content of calcium were found in celery leaf blades than in petioles, while a higher content of magnesium and sodium appeared in petioles than in leaf blades. The values of (K+Na) : (Ca+Mg) ratios in leaf blades were found to be over two-fold higher than in petioles of celery fertilized with Tytanit.

Key words: petioles and leaf blades of celery, Tytanit concentration, potassium, calcium, magnesium, sodium.

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WPŁYW DOLISTNEGO NAWOŻENIA NAWOZEM TYTANIT NA ZAWARTOŚĆ WYBRANYCH MAKROELEMENTÓW I SODU W SELERZE NACIOWYM

Abstrakt

Stosowanie tytanu w formie oprysku nawozem Tytanit jest jednym z zabiegów agrotechnicznych, których celem jest stymulowanie kwitnienia, zawiązywania owoców i produktywności roślin. W doświadczeniu wazonowym, w dwóch jednorocznych seriach (I i II rok doświadczenia), badano wpływ różnych stężeń Tytanitu stosowanego jedno- i dwukrotnie na tle nawożenia mineralnego (NPK), w porównaniu z obiektem kontrolnym (bez nawożenia) i nawożonym mineralnie (NPK), na ogólną zawartość potasu, wapnia, magnezu i sodu w ogonkach i blaszkach liściowych selera naciowego. W doświadczeniu zastosowano zróżnicowane stężenia Tytanitu – od 0,001 do 3,6%. Zawartość wybranych pierwiastków oznaczono metodą ICP – AES, po mineralizacji materiału roślinnego ,,na sucho". Zawartość potasu w ogonkach liściowych selera nawożonego Tytanitem o stężeniu 3,6% + NPK była większa niż w obiekcie kontrolnym lub nawożonym tylko NPK, lub utrzymywała się na tym samym poziomie (I i II seria). Podobnie było w przypadku blaszek liściowych (z wyjątkiem I serii). Największe stężenie Tytanitu (3,6%) wpłynęło na zmniejszenie zawartości ogólnej wapnia w badanych częściach selera naciowego oraz magnezu w ogonkach liściowych, w porównaniu z obiektem kontrolnym. Zawartość ogólna sodu zwiększała się wraz ze stężeniem nawozu. W blaszkach liściowych selera stwierdzono znacznie większą zawartość potasu (średnio z obydwu serii badań) oraz ponad dwukrotnie większą wapnia niż w ogonkach liściowych. Zawartość magnezu i sodu była większa w ogonkach niż w blaszkach liściowych. Stwierdzono ponad dwukrotnie węższe wartości stosunków (K+Na) : (Ca+Mg) w blaszkach niż w ogonkach liściowych selera naciowego na obiektach nawożonych Tytanitem.

Słowa kluczowe: ogonki i blaszki liściowe selera naciowego, stężenie Tytanitu, potas, wapń, magnez, sód.

INTRODUCTION

Celery (*Apium graveolens* L. *var. dulce* Mill. Pers.) is a valuable vegetable plant owing to its nutritional, flavour and medicinal properties (DYDUCH 1987). Cultivated forms developed from wild celery *Apium graveolens var graveolens* grow also in the wild, mainly along the seacoasts of some of the continents. It is a plant of moderately cool climates, yielding well under the climatic conditions of Poland, provided the right choice of cultivars and soil. A high volume and quality of celery yield can be obtained in soils abundant with organic substances and nutrients. To date, the celery production output in Poland has been very low. However, with the current promotion of its nutritive values, constant supply (mainly imported celery) and new cultivation technologies, a rapid increase in the domestic production of this valuable vegetable can be expected.

For some years now, there has been an increased interest in preparations from the group of bioregulators, which have significantly improved the production of plants, particularly vegetables. Foliar application of growth regulators or fertilizers containing biostimulants can affect the uptake and accumulation of mineral components by plants (BĄBELEWSKI, DĘBICZ 2006, Smoleń, Sady 2009, Smoleń et al. 2010). An active substance of the Tytanit fertilizer is 0.8% titanium (8.5 mg dm^{-3}). This preparation, as indicated in various studies on floriculture, fruit-growing, vegetable-growing, seed production and agriculture, affects growth, quality and development of plants and, consequently, their yield and the quality of sowing material (Hetman, Adamiak 2003, Serrano et al. 2004, Adamiak, Hetman 2007, Marcinek, Hetman 2007, Skupień, Oszmiański 2007, Radkowski, Radkowska 2010).

The aim of the experiment was to examine the effect of the foliar application of Tytanit against mineral fertilization (NPK) on the total content of selected macroelements (potassium, calcium, magnesium) and sodium in petioles and leaf blades of celery and on the weight and molar proportions of those elements in the test plant.

MATERIAL AND METHODS

The experiment was carried out in 2001-2002, in two annual series (year I and II of the experiment). The tested plant was celery of a Dutch cultivar, Tango F_1. Seedlings with 3-4 proper leaves were planted at four plants per pot (of 10 dm^3 capacity) in the first decade of June, in the first and second series of the research. Pots were filled with gardening substrate, containing raised peat with loamy sand (according to PTG), mixed in a 3:1 ratio, and limed with calcium carbonate according to Hh = 1 a month before planting transplants, so that pH_{H_2O} = 6.60 was obtained. The total content of selected macroelements in the substrate was (g kg^{-1}): N – 1.89; P – 0.507; K – 0.653; Ca – 11.55; Mg – 1.08; Na – 0.086, and the content of Ti was 32.89 mg kg^{-1}. The content of nitrogen was determined on a CHN auto-analyzer produced by Perkin –Elmer and the content of the other elements was determined using the ICP-AES method after dry mineralization. This greenhouse experiment was set up in a completely random system with three replications. The soil moisture in the pots during the plant growing period was maintained at 60% of the substrate field water capacity. The experiment involved 16 fertilization objects (48 pots), including single and double spraying with Tytanit and its varied concentrations, according to the following design: 1) control object (without fertilization); 2) NPK mineral fertilization in a 1:0.8:1.5 ratio (150 kg N ha^{-1}- ammonium nitrate, P – triple superphosphate, K - potassium sulphate); foliar fertilization with Tytanit against NPK: 3) 0.001%; 4) 0.01%; 5) 0.1%; 6) 1%; 7) 1.2%; 8) 2.4%; 9) 3.6%, which corresponded to 0.043 - 150 mg Ti per pot^{-1} dissolved in 500 cm^3 of water. NPK fertilization was applied one week before planting the seedlings; the first spraying with Tytanit was applied after plant rooting, i.e. in the first decade of July, and the second one was in the first decade of August, in both the first and second series of research. Finally, the celery was harvested at the beginning of October, in both research series.

In the first and the second series, the total content of K, Ca, Mg and Na was determined in the dry matter of petioles and leaf blades of celery. The dry plant material was ground to a particle size of < 0.25 mm, after which a 1g batch was weighed out and transferred to a semi-vitreous chinaware pot, in which the organic substance was oxidized dry in a muffle furnace at 450°C. A dose of 10 ml of diluted HCl (1:1) was poured over crude ash in the pot and the ash was evaporated dry on a sand bath to decompose the carbonates and to separate silica. The content of the pot, after adding 5 ml of 10% HCl, was passed through a solid filter into a 100 ml measuring flask and replenished with distilled water up to the mark. The total content of K, Ca, Mg and Na in the solution was determined on an emission spectrometer with inductively coupled plasma, ICP – AES, produced by Perkin-Elmer. The uptake of the selected macroelements with the yield was calculated on the basis of the dry matter yield from petiole and leaf blades in the first and the second series of research (Malinowska, Kalembasa 2012).

The results were statistically analysed with variation analysis for a two -factor experiment (using FR Analvar 3.2 software for calculations). The significance of differences between means was assessed with the Tukey's test, assuming the significance level of $\alpha = 0.05$ (the control object and the NPK object were not included in the statistical analysis). The values of direct correlation coefficients between the content of K, Ca, Mg and Na and the content of Ti (Malinowska, Kalembasa 2012) in petioles and leaf blades of celery were calculated at $p \leq 0.05$ (Statistica, Version 9.1 StatSoft).

RESULTS AND DISCUSSION

In a two-year experiment on the application of Tytanit in the cultivation of celery, the bioaccumulation of potassium was found to be higher in celery leaf blades than in petioles after a single application of Tytanit, in both research series (Table 1). As a result of the double spraying with Tytanit, the content of the elements in petioles, as compared to leaf blades, increased only in the first series of research. A higher mean content of potassium was found in the examined parts of celery in the second experimental series than in the first one. The Tytanit concentration significantly differentiated the bioaccumulation of potassium in petioles and leaf blades and the number of treatments in the petioles. The application of Tytanit against NPK, in the first and second series of experiment, caused a significant increase in the potassium content in petioles and its reduction in leaf blades, particularly in the first series, as compared to the object fertilized with NPK. The highest concentration of Tytanit (3.6%) resulted in the reduced bioaccumulation of potassium in the examined parts of the test plant, as compared to the concentration 2.4%. Radkowski, Radkowska (2010) found a reduction in the potassium content in meadow sward under the influence of higher concentrations of Tytanit.

Table 1
The total content of potassium in petioles and leaf blades of celery leaves (g kg^{-1} d.m.), in series I and II, in pot experiment

Fertilization object	I series		II series		Mean for petioles	Mean for leaf blades
	petioles	leaf blades	petioles	leaf blades		
Control object	19.06	29.51	11.60	19.20	15.33	19.36
NPK	17.02	28.41	21.84	29.97	19.43	29.19
I spraying of Tytanit						
0.001%+ NPK	17.71	26.09	25.75	31.74	21.73	28.92
0.01% + NPK	18.19	21.99	24.80	29.70	21.50	25.85
0.1% + NPK	20.36	18.25	23.34	30.05	21.85	24.15
1% + NPK	27.19	22.91	25.74	30.66	26.47	26.79
1.2% + NPK	20.13	20.71	24.83	31.70	22.48	26.21
2.4% + NPK	24.23	23.64	23.49	29.64	23.86	26.64
3.6% + NPK	21.62	21.81	22.75	27.14	22.19	24.48
Mean	21.35	22.20	24.39	30.09	22.87	26.15
II spraying of Tytanit						
0.001% + NPK	16.36	19.03	31.40	33.57	23.88	26.30
0.01% + NPK	16.82	22.26	28.28	35.18	22.55	28.72
0.1% + NPK	22.60	22.30	27.78	30.27	25.19	26.29
1% + NPK	29.52	24.73	30.73	27.03	30.13	25.88
1.2% + NPK	31.56	24.08	23.50	29.98	27.53	27.03
2.4% + NPK	29.03	24.81	23.53	27.67	26.28	26.24
3.6% + NPK	21.34	21.18	20.96	26.84	21.15	24.01
Mean	23.89	22.63	26.60	30.08	25.24	26.35
$LSD_{0,05}$ for:						
A – number of treatments	0.24	n.s.	1.01	n.s.	1.56	n.s.
B – concentration of Tytanit	0.69	1.43	2.93	1.09	4.56	1.43
AxB – interaction	0.63	1.30	2.67	1.00	n.s.	0.43
BxA – interaction	0.97	2.02	4.14	1.54	n.s.	0.67

n.s. – non-significant difference

The content of calcium in celery was the highest in the control object (Table 2). In the first series of the experiment, it reached 22.81 g Ca kg^{-1} in petioles, twice as much in leaf blades: 44.11 g Ca kg^{-1}, and in the second series: 22.97 and 56.78 g kg^{-1}, respectively. NPK fertilization resulted in decreasing the content of calcium in petioles by almost 30% and in leaf blades by 20% in comparison to the control object. The foliar application of Tytanit against NPK also caused a reduction of this element in comparison to the control object (without fertilizing). Single spraying resulted in obtaining an average 17.58 g Ca kg^{-1} in petioles, 46.47 g Ca kg^{-1} in leaf blades, while a

Table 2
The total content of calcium in petioles and leaf blades of celery leaves (g kg^{-1} d.m.), in series I and II, in pot experiment

Fertilization object	I series		II series		Mean for petioles	Mean for leaf blades
	petioles	leaf blades	petioles	leaf blades		
Control object	22.81	44.11	22.97	56.78	22.89	50.45
NPK	16.63	37.35	15.72	43.10	16.18	40.23
I spraying of Tytanit						
0.001%+ NPK	18.41	36.75	17.53	48.30	17.97	42.53
0.01% + NPK	16.76	39.81	18.43	48.79	17.60	44.30
0.1% + NPK	14.99	34.57	18.21	57.65	16.60	46.11
1% + NPK	20.03	49.97	20.09	54.07	20.06	52.02
1.2% + NPK	15.64	38.27	19.52	56.03	17.58	47.15
2.4% + NPK	18.36	51.10	19.11	48.55	18.74	49.83
3.6% + NPK	13.26	37.23	15.76	49.44	14.51	43.34
Mean	16.78	41.10	18.38	51.83	17.58	46.47
II spraying of Tytanit						
0.001% + NPK	14.70	34.71	16.41	45.95	15.56	40.33
0.01% + NPK	18.20	44.25	20.25	65.20	19.23	54.73
0.1% + NPK	17.19	35.39	23.63	69.03	20.41	52.21
1% + NPK	20.33	49.78	21.70	56.57	21.02	53.18
1.2% + NPK	17.20	35.40	19.27	47.96	18.24	41.68
2.4% + NPK	15.13	42.06	21.62	55.36	18.38	48.71
3.6% + NPK	13.56	36.94	14.87	42.75	14.22	39.85
Mean	16.62	39.79	19.68	54.69	18.15	47.24
LSD $_{0,05}$ for:						
A – number of treatments	n.s.	0.50	0.71	0.74	0.97	n.s.
B – concentration of Tytanit	0.54	1.45	2.07	2.15	1.57	3.62
AxB – interaction	0.49	1.33	1.89	1.97	1.52	4.13
BxA – interaction	0.76	2.06	2.93	3.05	1.81	6.95

n.s. – non-significant difference

double treatment resulted in 18.15 and 47.24 g Ca kg^{-1}, respectively. A higher mean content of calcium was found in the second series as compared to the first one. In the present experiment, the content of calcium in the test plant biomass was significantly differentiated by the Tytanit concentration and number of treatments, except for petioles in the first series of the study.

The content of magnesium in the examined parts of celery was higher, on average, in the second series than in the first one (Table 3). It was significantly differentiated under the influence of the examined factors. In both series of the experiment, the content of magnesium in petioles from the control object was higher than in petioles from the fertilization objects. In leaf blades, the content of magnesium in the first research series was over twofold higher in fertilization objects than in the control or in the object with NPK, while in the second series, it was slightly higher in the control and NPK objects than in fertilization objects. The application of Tytanit at a concentration of 1% and higher resulted in an increase in the content of magnesium in leaf blades only in the first series of the experiment.

The content of sodium in the examined parts of celery was significantly differentiated by the number of treatments and by the Tytanit fertilization

Table 3

The total content of magnesium in petioles and leaf blades of celery leaves (g kg^{-1} d.m.), in series I and II, in pot experiment

Fertilization object	I series		II series		Mean for petioles	Mean for leaf blades
	petioles	leaf blades	petioles	leaf blades		
Control object	3.30	1.18	5.23	3.55	4.27	2.37
NPK	2.84	1.19	3.96	3.47	3.40	2.33
I spraying of Tytanit						
0.001%+ NPK	2.98	1.81	4.22	3.08	3.60	2.45
0.01% + NPK	3.11	2.41	4.55	3.36	3.83	2.89
0.1% + NPK	2.78	2.67	4.80	3.35	3.79	3.01
1% + NPK	2.99	3.87	4.26	3.24	3.63	3.56
1.2% + NPK	3.17	3.32	3.98	3.06	3.58	3.19
2.4% + NPK	2.86	3.92	3.75	3.08	3.31	3.50
3.6% + NPK	2.43	3.16	3.31	2.79	2.87	2.98
Mean	2.90	3.02	4.13	3.14	3.52	3.08
II spraying of Tytanit						
0.001% + NPK	2.54	2.03	4.28	3.61	3.41	2.82
0.01% + NPK	3.06	2.47	4.42	3.58	3.74	3.03
0.1% + NPK	2.88	2.49	4.71	3.41	3.80	2.95
1% + NPK	2.72	3.87	4.25	3.18	3.49	3.53
1.2% + NPK	2.85	3.82	3.75	3.09	3.30	3.46
2.4% + NPK	2.33	4.11	3.73	3.00	3.03	3.56
3.6% + NPK	2.34	3.42	3.11	2.70	2.73	3.06
Mean	2.68	3.17	4.04	3.23	3.36	3.20
LSD $_{0.05}$ for:						
A – number of treatments	0.03	0.04	0.08	0.04	n.s.	n.s.
B – concentration of Tytanit	0.08	0.11	0.23	0.12	0.48	0.41
AxB – interaction	0.08	0.10	n.s.	0.11	n.s.	n.s.
BxA – interaction	0.12	0.15	n.s.	0.18	n.s.	n.s.

n.s. – non-significant difference

Table 4

The total content of sodium in petioles and leaf blades of celery leaves (g kg^{-1} d.m.), in series I and II, in pot experiment

Fertilization object	I series		II series		Mean for petioles	Mean for leaf blades
	petioles	leaf blades	petioles	leaf blades		
Control object	3.00	2.37	7.86	6.73	5.43	4.55
NPK	2.07	2.37	3.05	2.78	2.56	2.58
I spraying of Tytanit						
0.001%+ NPK	2.05	1.94	3.10	3.17	2.58	2.56
0.01% + NPK	2.00	1.94	3.01	2.74	2.51	2.34
0.1% + NPK	1.99	2.09	3.15	3.12	2.57	2.61
1% + NPK	2.74	2.58	4.46	4.36	3.61	3.47
1.2% + NPK	3.26	2.38	4.47	4.53	3.87	3.46
2.4% + NPK	4.03	4.33	5.98	5.11	5.01	4.72
3.6% + NPK	5.03	3.60	5.65	6.00	5.34	4.80
Mean	3.01	2.67	4.26	4.15	3.64	3.42
II spraying of Tytanit						
0.001% + NPK	1.86	1.69	3.70	3.27	2.78	2.48
0.01% + NPK	2.14	2.78	3.39	3.70	2.77	3.24
0.1% + NPK	2.53	1.70	3.90	3.32	3.22	2.51
1% + NPK	3.69	2.32	6.14	5.02	4.92	3.67
1.2% + NPK	5.24	2.48	6.25	5.09	5.75	3.79
2.4% + NPK	6.51	4.93	9.92	7.55	8.22	6.24
3.6% + NPK	8.43	4.87	8.87	8.87	8.65	6.87
Mean	4.35	2.97	6.03	5.26	5.19	4.11
LSD $_{0,05}$ for:						
A – number of treatments	0.04	0.07	0.14	0.09	0.40	0.33
B – concentration of Tytanit	0.12	0.19	0.40	0.26	1.16	0.95
AxB – interaction	0.11	0.18	0.37	0.25	1.06	0.87
BxA – interaction	0.17	0.27	0.57	0.38	1.64	1.35

applied (Table 4). An increasing concentration of Tytanit resulted in an increase in the content of this element in celery as compared to the control and the object fertilized with NPK in the first series of research, and after its double application in the second series. The content of sodium in petioles of celery fertilized once with Tytanit against NPK (an average from both series of research)was 3.64 g kg^{-1}; after double application: 5.19 g kg^{-1}; in leaf blades: 3.42 g kg^{-1} (single application) and 4.11 g kg^{-1} (double aaplication). The bBioaccumulation of this macroelement was higher in petioles than in leaf blades of celery.

The nutritional value of the plants is determined not only by the absolute content of individual macro- and microelements, but also by their proportions. In the case of macroelements, it is difficult to ensure proper ratios of individual elements or their groups in the plant material, e.g. the (K+Na) : (Ca+Mg) ratio in vegetables. The content of potassium, calcium, magnesium and sodium was determined in the plant materialobtained in the experiment, which enabled the caaclulation of the weight ratio of monovalent to divalent elements. The value of the (K+Na) : (Ca+Mg) ratio in petioles of celery (mean from the series of research) ranged from 0.764 to 1.760, and in leaf blades it ranged from 0.453 to 0.746 (Table 5). Over two-fold higher values of ratios of the analyzed elements were found in celery leaf blades in comparison to celery petioles for the objects fertilized with Tytanit. The narrowest (K+Na) : (Ca+Mg) ratio was calculated for the control objects, i.e. 0.764 in celery petioles and 0.453 in leaf blades. The mean values of weight ratios of the discussed elements in the test plant fertilized twice with Tytanit were slightly broader than after a single application of Tytanit.

Table 5

Weight ratio of (K + Na) : (Ca + Mg) in petioles and leaf blades of celery leaves (mean for series)

Fertilization object	Petioles	Leaf blades	Mean
	(K + Na) : (Ca + Mg)	(K +Na) : (Ca + Mg)	
Control object	0.762	0.453	0.607
NPK	1.120	0.746	0.934
I spraying of Tytanit			
0.001% + NPK	1.130	0.700	0.915
0.01% + NPK	1.120	0.597	0.859
0.1% + NPK	1.200	0.545	0.873
1% + NPK	1.270	0.544	0.907
1.2% + NPK	1.250	0.589	0.920
2.4% + NPK	1.310	0.588	0.949
3.6% + NPK	1.580	0.632	1.110
Mean	1.270	0.599	0.933
II spraying of Tytanit			
0.001% + NPK	1.410	0.667	1.040
0.01% + NPK	1.100	0.553	0.827
0.1% + NPK	1.170	0.522	0.846
1% + NPK	1.430	0.521	0.976
1.2% + NPK	1.550	0.683	1.120
2.4% + NPK	1.610	0.621	1.121
3.6% + NPK	1.760	0.720	1.240
Mean	1.430	0.612	1.024

Table 6

The ratios of K : Ca, K : Mg, Na : Ca and Na : Mg in petioles and leaf blades of celery leaves (mean for series)

Fertilization object	Petioles				Leaf blades			
	K:Ca	K:Mg	Na:Ca	Na:Mg	K:Ca	K:Mg	Na:Ca	Na:Mg
Control object	1.550	0.502	3.030	0.840	2.550	0.198	7.770	0.487
NPK	0.829	0.281	3.780	1.270	1.320	0.126	8.990	0.828
I spraying of Tytanit								
0.001% + NPK	0.837	0.268	4.260	1.341	1.430	0.134	8.770	0.901
0.01% + NPK	0.813	0.285	4.160	1.450	1.690	0.179	10.300	1.170
0.1% + NPK	0.739	0.275	3.180	1.380	1.860	0.208	10.600	1.110
1% + NPK	0.740	0.192	3.390	0.966	1.930	0.222	7.110	1.071
1.2% + NPK	0.762	0.255	2.630	0.880	1.770	0.207	7.110	0.980
2.4% + NPK	0.767	0.223	2.230	0.628	1.850	0.217	5.450	0.714
3.6% + NPK	0.637	0.204	1.510	0.505	1.720	0.200	4.710	0.500
Mean	0.756	0.244	3.140	1.021	1.750	0.195	7.710	0.921
II spraying of Tytanit								
0.001% + NPK	0.694	0.234	3.540	1.190	1.560	0.172	9.900	1.090
0.01% + NPK	0.879	0.273	4.160	1.202	1.870	0.171	9.610	0.878
0.1% + NPK	0.787	0.239	3.690	1.110	1.890	0.180	11.900	1.182
1% + NPK	0.680	0.186	2.590	0.681	2.000	0.222	9.380	1.090
1.2% + NPK	0.666	0.201	1.830	0.540	1.500	0.211	6.810	1.011
2.4% + NPK	0.702	0.192	1.290	0.347	1.800	0.220	4.560	0.583
3.6% + NPK	0.656	0.208	0.940	0.297	1.630	0.211	3.560	0.477
Mean	0.723	0.219	2.580	0.766	1.750	0.198	7.960	0.902

Table 6 presents molar ratios (mean values from the series of research) between K:Ca, K:Mg, Na:Ca and Na:Mg, assuming K = 1 and Na = 1. The values of calculated ratios between the examined elements in petioles and leaf blades were differentiated under the influence of the fertilization applied. The highest values of molar ratios for the K: Ca and K: Mg of the examined elements in leaf blades of celery were calculated for the control object and after applying lower concentrations of Tytanit. The value of molar ratios between K:Ca and K:Mg in leaf blades of celery was the highest for the control object and objects fertilized with Tytanit against NPK, starting with the concentration of 0.1%, while the lowest value was found for the NPK object. According to Majkowska-Gadomska (2009) and Majkowska-Gadomska, Wierzbicka (2013), the ratios between the macroelements in eggplant fruits varied between the cultivars and between plants treated and untreated with Asahi SL.

The relationships between the content of K, Ca and Na, and the content of Ti in the dry matter of petioles and leaf blades of celery and between the examined elements were presented in the form of calculated values of direct correlation coefficients (Table 7). The total content of Ti was discussed earlier, in publications by Malinowska, Kalembasa (2012). A significant positive relation was found in petioles between the content of Ti and the content of Na (r = 0.82) and between the content of Ca and the content of Mg (r = 0.61) in the two-year experiment. A significant positive correlation was also found in leaf blades of the test plant between Ti and Na (r = 0.73), as well as between K and Ca (r = 0.57), Ca and Mg (r = 0.39) and between Ca and Na (r = 0.37).

Table 7

Simple correlation coefficients between the total content of Ti in petioles and leaf blades of celery leaves and the content of K, Ca, Mg and Na, the first and second series of studies

Elements	Petioles					Leaf blades				
	Ti	K	Ca	Mg	Na	Ti	K	Ca	Mg	Na
Ti	1.00					1.00				
K	0.22	1.00				0.02	1.00			
Ca	0.06	0.15	1.00			0.07	0.57*	1.00		
Mg	-0.18	0.13	0.61*	1.00		0.32	0.23	0.39*	1.00	
Na	0.82*	0.11	0.08	0.09	1.00	0.73*	0.20	0.37*	0.24	1.00

n = 32, $p < 0.05$, critical value; r = 0.349

The uptake of K, Ca, Mg and Na with the yield of celery petioles fertilized with Tytanit was almost twice as high as in the object fertilized with NPK and it was several times higher than in the control object (Table 8). As a result of the double application of the preparation, the mean K, Ca and Na uptake with the petiole yield increased, while the uptake of Mg was reduced. It was observed that the K, Mg and Na uptake was much lower with the yield of leaf blades than with the yield of petioles, except for Ca. The mean Ca uptake with the yield of leaf blades fertilized once with Tytanit was 1.220 g pot^{-1}, after double fertilization: 1.170 g pot^{-1}, and with the yield of petioles: 0.674 and 0.690 g pot^{-1}, respectively. The uptake of the discussed elements depended mainly on the volume of celery yield (Malinowska, Kalembasa 2012).

Klamkowski et al. (1999), Klamkowski, Wójcik (2000), Alcaraz-Lopez et al. (2004), Smoleń (2008), Smoleń et al. (2010) confirm the impact of foliar application of growth regulators or fertilizers containing biostimulants on the uptake and accumulation of mineral components by plants. Radkowski, Radkowska (2010) report that foliar application of Tytanit at appropriate concentrations can raise the content of potassium, calcium and magnesium in meadow sward by almost 80%, and the content of sodium by 60% in relation to the control object. According to other authors (Marcinek, Hetman 2008), the application of Tytanit resulted in an increase in the nitrogen content in

Table 8

Uptake of selected macroelements and sodium (mg pot^{-1}) in the yield of petioles and leaf blades of celery (mean from the results of two series)

Fertilization object	Petioles				Leaf blades			
	K	Ca	Mg	Na	K	Ca	Mg	Na
Control object	0.097	0.145	0.027	0.034	0.160	0.420	0.019	0.038
NPK	0.449	0.374	0.079	0.059	0.750	1.030	0.060	0.066
I spraying of Tytanit								
0.001% + NPK	0.679	0.568	0.114	0.082	0.639	0.940	0.054	0.057
0.01% + NPK	0.882	0.722	0.157	0.105	0.708	1.210	0.079	0.064
0.1% + NPK	0.832	0.632	0.144	0.098	0.618	1.180	0.077	0.067
1% + NPK	1.120	0.851	0.154	0.153	0.750	1.460	0.099	0.097
1.2% + NPK	0.845	0.661	0.135	0.146	0.616	1.110	0.075	0.081
2.4% + NPK	0.857	0.673	0.119	0.180	0.679	1.270	0.089	0.120
3.6% + NPK	0.934	0.611	0.121	0.225	0.759	1.340	0.092	0.149
Mean	0.878	0.674	0.135	0.141	0.681	1.220	0.081	0.091
II spraying of Tytanit								
0.001% + NPK	1.060	0.689	0.151	0.123	0.576	0.880	0.062	0.054
0.01% + NPK	0.886	0.756	0.147	0.109	0.695	1.320	0.073	0.078
0.1% + NPK	0.995	0.806	0.150	0.127	0.660	1.310	0.074	0.063
1% + NPK	0.934	0.652	0.108	0.153	0.631	1.300	0.086	0.090
1.2% + NPK	1.070	0.710	0.118	0.224	0.633	0.980	0.081	0.089
2.4% + NPK	0.920	0.643	0.106	0.288	0.651	1.210	0.088	0.155
3.6% + NPK	0.852	0.573	0.110	0.349	0.718	1.190	0.091	0.205
Mean	0.960	0.690	0.127	0.196	0.652	1.170	0.079	0.105

Sparaxis tricolor bulbs, and in a reduction of other macroelements. Our research and investigations carried out by other authors imply that the effect of the foliar application of Tytanit on the chemical composition of plants is closely determined by the concentration of the preparation, plant species and atmospheric conditions.

CONCLUSIONS

1. It was found experimentally that the foliar application of Tytanit against NPK fertilization differentiated bioaccumulation of the examined macroelements (K, Ca, Mg) and Na in petioles and leaf blades of celery. The highest concentration of Tytanit (3.6%) resulted in a reduction of the total content of potassium, calcium and magnesium in the examined parts of the

celery, as compared to the concentration 2.4%. On the other hand, the total content of sodium increased along with the growth of fertilizer concentration. The highest bioaccumulation of calcium was observed in celery cultivated in the object without fertilization (the control).

2. A significantly higher potassium content (mean from both series of research) and an over two-fold higher content of calcium were found in leaf blades of celery as compared to petioles, while the content of magnesium and sodium was higher in petioles than in leaf blades.

3. Foliar application of Tytanit against NPK can ensure an optimal – with resepct to the nutritional value – (K+Na) : (Ca+Mg) ratio in petioles and leaf blades of celery.

4. The uptake of the elements depended mainly on the volume of celery yield. In petioles of celery fertilized with Tytanit, it was almost twice as high as in the object fertilized with NPK, and a few times higher than in the control object. Double application of Tytanit increased the mean uptake of K, Ca and Na with the yield of petioles and reduced the uptake of Mg.

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