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THE YIELD AND CONTENT OF Ti, Fe, Mn, Cu IN CELERY LEAVES (*Apium graveolens* L. var. *dulce* Mill. Pers.) AS A RESULT OF TYTANIT APPLICATION

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Abstract. Celery is a valuable vegetable plants, due to the properties of dietary, medicinal and taste. It is moderately cold climate plant, well yielding in climatic conditions of our country, with proper selection of varieties and soil. A pot experiment carried out in two one-year series (2001 and 2002 year) examined the effect of various concentrations of Tytanit applied once and twice against NPK fertilization, in comparison to the control object and with mineral fertilization applied (NPK), on the yield of the total biomass, petioles and blades of celery, as well as the content of titanium, iron, manganese and copper. Those elements fulfil a primary role in the process of photosynthesis and (according to literature data) titanium also plays an important function in this process. It was found that foliar fertilization with Tytanit had a favourable effect on increasing the test plant yield. The highest yield of celery biomass was obtained after applying the highest dose of Tytanit. The frequency of spraying resulted in slight changes in the yielding of the test plant. A higher average bioaccumulation of titanium, iron and manganese was observed in blades than in petioles, in series I and II of the study. The highest concentration of Tytanit applied once and twice resulted in a decreasing bioaccumulation of Fe and Mn in the examined parts of celery, in series I and II of the study. The highest amounts of Cu were observed on the control object fertilized with NPK and under the influence of Tytanit application in the lowest concentrations. The average uptake of Ti and Mn with the yield of blades was twice as high as the yield of petioles, while in the case of Fe and Cu, it was higher with the yield of petioles than of blades.

Key words: foliar fertilization, mineral composition, yielding

INTRODUCTION

In recent years, there has been increasing interest in preparations belonging to a group of bioregulators. These preparations reduce the humidity and water requirements of

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plants, the degree of freezing, accelerate regeneration of damages and increase resistance to fungal and bacteria diseases – all resulting in higher yields [Klamkowski et al. 1999, Marcinek and Hetman 2007]. A preparation of particular interest is Tytanit, a fertilizer demonstrating biostimulating properties [Janas et. al 2002]. Tytanit activates metabolic processes during the growth and development of plants and increases the intensification of photosynthesis and absorption of nutrients [Dyki et al. 2000, Grenda 2003, Serrano et al. 2004, Dobromilska 2007, Skupień and Oszmiański 2007, Smoleń et al. 2010]. It contains 8.5 g dm^{-3} of chelated titanium. Titanium is one of the elements with the lowest phytoaccumulation indicators, with the exception of plants taking in a lot of silicon, i.e. nettle and certain trees which can accumulate up to 100 mg Ti kg^{-1}. The effect of titanium on plants consists of stimulating the activity of certain enzymes, e.g. catalase, peroxidase, lipoxidase or nitrate reductase. Additionally, this element increases the content of chlorophyll in leaves which has a positive effect on the yield of crops, including vegetables [Dumon and Ernst 1988]. The source of titanium for humans is mainly food and inhaled atmospheric dust. Although Pais [1983] recorded a favourable effect of water-soluble titanium compounds on human health, this element was not included among the components that are necessary for the proper development of animal organisms.

The aim of this study was to analyse the effect of foliar fertilization with Tytanit on the yield of celery and the total content of titanium, iron, manganese and copper in petioles and leaves of this plant, in a pot experiment carried out in two one-year series.

MATERIALS AND METHODS

The experiment was carried out in 2001–2002, in two one-year series. The tested plant was celery of the Dutch variety, Tango F1. Seedlings with 3–4 proper leaves were planted in four plants per pot (of 10 dm^3 capacity), in the first decade of June, in series I and II of the study. The pots were filled with gardening substrate, containing raised peat with loamy sand (according to PTG), in a 3:1 ratio and limed with calcium carbonate according to Hh = 1, a month before planting seedlings, obtaining $pH_{H2O} = 6.60$. The total content of selected macroelements in the substrate was (g kg^{-1}): N – 1.89, P – 0.507, K – 0.653, and the content of Ti – 32.89 mg kg^{-1}. The total content of N in petioles and blades was determined using CHN auto-analyzer (Perkin Elmer). The total content of P, K and Ti was determined on an emission spectrometer with inductively coupled plasma (ICP – AES produced by Perkin-Elmer). The experiment was carried out in a greenhouse, in three replications, in a completely random system. The humidity of soil in the pots during the vegetation period was maintained at the level of 60% field water capacity of the substrate. The experiment involved 16 fertilization objects, taking into account one-time and two-time spraying with Tytanit and its varied concentration, according to the schema provided below: 1) control object (without fertilization); 2) NPK mineral fertilization in 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 corresponds of 0.043 mg to 150 mg of Ti per pot^{-1} dissolved in 500 cm^3 of water. NPK fertilization was applied one week before planting the seedlings and the first spraying with Tytanit was done after plant rooting (i.e. in the first decade of July) the second in the first decade of August (in both the first and second series of studies) and the celery was harvested at the beginning of October (in both series of studies).

The yield of the green matter of the above-ground parts of celery, petioles and blades was determined by the gravimetric method, and of dry matter – by the drying and weighing method, after drying the biomass at 105°C. In series I and II of the study, the total content of Ti, Fe, Mn and Cu was determined in the dry matter of petioles and blades of celery. The dry plant material was ground to obtain a particle size of < 0.25 mm and 1g was weighed out to semi-vitreous chinaware pot, after which the organic substance was oxidized dry at 450°C in a muffle furnace. 10 ml of diluted HCl (1:1) was poured over crude ash in a pot and the ash was evaporated dry on a sand bath to decompose carbonates and separate silica. The content of the pot, after adding 5 ml of 10% HCl, was moved through a solid filter into a 100 ml measuring flask and filled up with distilled water up to the mark. The total content of Ti, Fe, Mn and Cu in the obtained solution was determined on an emission spectrometer with inductively coupled plasma (ICP – AES produced by Perkin-Elmer).

Based on the dry matter yield and the content of titanium, iron, manganese and copper in celery petioles and blades, the intake of those elements was calculated. The obtained results were statistically analysed and the differences between means were assessed using variation analysis (FR Analvar 3.2 software was used for calculation) and the value of $NIR_{0.05}$ was calculated according to Tukey's test for significant differences. Coefficients of a direct correlation between the content of Ti and the content of Fe, Mn and Cu in petioles and blades of celery were calculated for $p \leq 0.05$.

RESULTS AND DISCUSSION

In the majority of cases, the fresh biomass yield of celery and of its separated parts (petioles and blades) grew proportionally to the concentration of Tytanit (tab.1). The highest biomass yield from both series of research (498.0 g pot^{-1}) was obtained after applying a single spray of 3.6% Tytanit solution, almost two times higher than the object fertilized with 0.001% and fertilized with NPK. The concentration of Tytanit had a significant effect on the increase of the green matter yield of the test plant, while the frequency of spraying significantly differentiated only the yield of petioles. Foliar fertilization against mineral fertilization (NPK) had a more favourable effect on the increase of the yield of celery petioles than of celery blades. The obtained green matter yield of celery petioles (the mean of the two series of research) can be arranged in a series of growing values (g pot^{-1}): control object (42.15) < NPK (146.8) < 0.001% (165.0) < 2 × 0.001 (175.5) < 0.01% (184.4) < 2 × 0.01% (185.9) < 2 × 0.1% (208.1) < 0.1% (211.1) < 1% (221.9) < 2 × 1 % (231.7) < 2 × 2.4% (282.5) < 2.4% (284.9) < 1.2% (288.5) < 2 × 1.2% (292.5) < 3.6% (300.8) < 2 × 3.6% (316.4).

The dry matter yield of celery petioles and blades (mean of the second series of research) was significantly varied under the influence of Tytanit concentration. The highest yield of dry matter of petioles was established in the object fertilized twice with

0.001% solution of Tytanit and once with a 1% solution of Tytanit. It appears that celery under the influence of foliar fertilization accumulated more water in its biomass.

Table 1. The yield of celery leaves biomass (g pot $^{-1}$), mean from the results of two series
Tabela 1. Plon biomasy selera naciowego (g wazon^{-1}), średnia z dwóch serii badań

Fertilization object Obiekt nawozowy		Yield (g pot $^{-1}$ F.M.) Plon (g wazon $^{-1}$ św.m.)			Yield (g pot $^{-1}$ D.M.) Plon (g wazon $^{-1}$ s.m.)		
		leaves liście	petioles ogonki liściowe	blades blaszki liściowe	leaves liście	petioles ogonki liściowe	blades blaszki liściowe
Control object Obiekt kontrolny		85.3	42.15	43.1	14.6	6.35	8.25
NPK		247.8	146.8	101.1	48.8	23.1	25.7
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	275.4	165.0	110.4	53.6	31.6	22.1
	0.01% + NPK	318.6	184.4	134.2	68.4	41.0	27.4
	0.1% + NPK	326.2	211.1	115.1	63.7	38.1	25.6
	1% + NPK	371.7	221.9	149.8	69.2	42.4	28.0
	1.2% + NPK	434.1	288.5	145.6	61.1	37.6	23.5
	2.4% + NPK	451.6	284.9	166.7	61.4	35.9	25.5
	3.6% + NPK	498.0	300.8	197.2	73.1	42.1	31.0
	mean – średnia	382.2	236.7	145.6	64.4	38.4	26.2
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	308.0	175.5	132.6	66.1	44.3	21.9
	0.01% + NPK	301.8	185.9	115.9	63.4	39.3	24.2
	0.1% + NPK	324.1	208.1	116.0	64.5	39.5	25.1
	1% + NPK	375.1	231.7	143.4	60.5	31.0	24.4
	1.2% + NPK	450.2	292.5	157.7	62.2	38.9	23.4
	2.4% + NPK	442.2	282.5	159.7	59.8	35.0	24.8
	3.6% + NPK	497.0	316.4	180.5	70.2	40.3	29.9
	mean – średnia	385.5	241.8	143.7	63.8	38.3	24.8
$LSD_{0,05}$ for: – $NIR_{0,05}$ dla: A – number of treatments – liczba zabiegów		n.s./n.i.	0.728	n.s./n.i.	0.512	n.s./n.i.	n.s./n.i.
B – concentration of Tytanit – stężenie Tytanitu		2.14	2.17	5.01	1.52	2.21	2.02
A × B – interaction – interakcja		1.90	1.93	4.45	1.35	1.96	n.s./n.i.
B × A – interaction – interakcja		3.03	3.07	7.09	2.16	3.12	n.s./n.i.

n.s./ n.i. – not significant difference – różnica nieistotna

It was observed that plants sprayed with Tytanit (in comparison with plants from the control object and fertilized with NPK) were darker and were more resistant to fungal diseases – the easily-assimilable form of titanium ions included in this fertilizer probably stimulated metabolic processes in celery tissues [Grenda 2003, Gleń et al. 2006]. The favourable effect of titanium on the increase and quality of plant yield, particularly garden plants, has been confirmed by many authors [Pais 1983, Lopez-Moreno et al. 1996, Dyki et al. 2000, Hetman and Adamiak 2003, Dobromilska 2007, Marcinek and Hetman 2007, Michalski 2008, Gajc-Wolska et al. 2009].

Celery leaves were found to have, on average, almost three times higher bioaccumulation of titanium than in petioles, in series I and II of the study (tab. 2), which confirms the findings of Czekalski [1987] and Kłosowski et al. [2000]. After double spraying with Tytanit, the content of titanium increased in the examined part of celery in both series of the study. The mean content of titanium in series II of the study in celery petioles amounted to 15.27 and 26.76 mg kg^{-1}, in blades 62.83 and 96.07 mg kg^{-1}, in the first series 14.42 and 19.56 mg kg^{-1} and 45.81 and 82.16 mg kg^{-1}, respectively.

Table 2. The total content of titanium in petioles and blades of celery leaves (mg kg^{-1} D.M.), in series I and II, in pot experiment
Tabela 2. Zawartość całkowita tytanu w ogonkach i blaszkach liściowych selera naciowego (mg kg^{-1} s.m.), w I i II serii doświadczenia wazonowego

Fertilization object Obiekt nawozowy		I series – I seria		II series – II seria		Mean for petioles Średnia dla ogonków liściowych	Mean for blades Średnia dla blaszek liściowych
		petioles ogonki liściowe	blades blaszki liściowe	petioles; ogonki liściowe	blades blaszki liściowe		
Control object Obiekt kontrolny		16.06	9.46	14.85	7.15	15.46	8.31
NPK		10.72	9.33	8.99	6.54	9.86	7.94
I spraying of Tytanit I oprysk Tytanitem	0.001%+ NPK	10.89	9.42	7.42	7.35	9.16	8.39
	0.01% + NPK	10.46	11.07	10.53	10.85	10.50	10.96
	0.1% + NPK	10.62	15.90	9.62	18.17	10.12	17.04
	1% + NPK	16.84	64.84	16.85	67.75	16.85	68.12
	1.2% + NPK	14.52	38.18	23.56	91.52	19.04	64.85
	2.4% + NPK	21.78	109.2	18.47	113.4	20.13	111.3
	3.6% + NPK	15.83	72.25	20.43	130.7	18.13	101.5
	mean –średnia	14.42	45.81	15.27	62.83	14.85	54.59
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	9.64	9.43	10.96	9.97	10.21	9.70
	0.01% + NPK	10.80	14.95	11.53	17.89	11.17	16.42
	0.1% + NPK	13.73	22.94	12.42	32.21	13.08	27.58
	1% + NPK	26.28	87.27	33.40	107.9	29.84	97.59
	1.2% + NPK	20.07	91.95	28.80	109.7	24.44	100.8
	2.4% + NPK	26.50	155.8	41.29	225.5	33.90	190.7
	3.6% + NPK	29.94	192.8	48.91	169.3	39.43	181.1
	mean – średnia	19.57	82.16	26.76	96.07	23.15	89.13
$LSD_{0,05}$ for: – $NIR_{0,05}$ dla: A – number of treatments – liczba zabiegów		0.024	0.031	0.152	0.150		
B – concentration of Tytanit – stężenieTytanitu		0.071	0.091	0.439	0.435		
A × B – interaction – interakcja		0.065	0.083	0.401	0.397		
B × A – interaction – interakcja		0.100	0.129	0.621	0.615		

Celery leaves demonstrated higher iron bioaccumulation then petioles, in both series of the study, except for petioles from the control object and fertilized with NPK, in series I (tab. 3). The frequency of spraying significantly differentiated the content of the examined element in petioles in both series of the study. In series II, a higher content of iron was found in the examined parts of celery in comparison to series I. Grenda [2003] reports that the content and the activity of iron ions in plant cells increases under the influence of Tytanit, at the same time increasing the synthesis of assimilation pigments. The highest content of Tytanit (3.6%) brought about a decrease in iron bioaccumulation in the examined parts of the test plant.

Table 3. The total content of iron in petioles and blades of celery leaves (mg kg $^{-1}$ D.M.), in series I and II, in pot experiment
Tabela 3. Zawartość całkowita żelaza w ogonkach i blaszkach liściowych selera naciowego (mg kg $^{-1}$ s.m.), w I i II serii doświadczenia wazonowego

Fertilization object Obiekt nawozowy		I series – I seria		II series – II seria		Mean for petioles Średnia dla ogonków liściowych	Mean for blades Średnia dla blaszek liściowych
		petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe		
Control object Obiekt kontrolny		282.3	126.4	192.8	228.1	237.6	177.3
NPK		133.5	117.4	78.02	207.4	105.8	162.4
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	127.6	113.4	98.24	203.5	112.9	158.5
	0.01% + NPK	114.7	144.3	128.0	195.8	121.4	170.1
	0.1% + NPK	106.8	93.63	139.9	385.6	123.4	239.6
	1% + NPK	153.5	129.4	121.9	206.9	137.7	168.2
	1.2% + NPK	123.9	141.9	186.2	237.1	155.1	189.5
	2.4% + NPK	149.5	191.9	172.7	223.8	161.1	207.9
	3.6% + NPK	105.9	153.2	118.1	194.4	112.0	173.8
	mean – średnia	126.0	138.7	137.9	233.9	131.9	186.3
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	144.0	119.3	121.9	196.6	132.9	158.0
	0.01% + NPK	102.2	102.4	197.3	276.9	149.8	189.7
	0.1% + NPK	125.3	142.7	152.5	304.3	138.9	223.5
	1% + NPK	187.4	148.5	178.0	319.5	182.7	234.0
	1.2% + NPK	136.9	129.7	123.6	218.1	130.3	173.9
	2.4% + NPK	124.3	175.0	155.5	233.7	139.9	204.4
	3.6% + NPK	143.1	162.2	102.5	158.8	122.8	160.5
	mean – średnia	137.6	139.9	147.3	243.9	142.5	191.9
LSD $_{0,05}$ for: – NIR$_{0,05}$ dla: A – number of treatments – liczba zabiegów		4.96	n.s./n.i.	9.39	n.s./n.i.		
B – concentration of Tytanit – stężenie Tytanitu		14.38	33.78	27.20	43.77		
A × B – interaction – interakcja		13.13	30.85	24.84	39.97		
B × A – interaction – interakcja		20.34	47.77	38.46	61.90		

n.s./ n.i. – not significant difference – różnica nieistotna

A similar relation was observed in the case of manganese bioaccumulation under the influence of growing concentrations of Tytanit (tab. 4). The content of manganese found in blades was over twice as high as in petioles, in both series of the study. In series I, the average content of the examined element was higher than in series II. The concentration of Tytanit significantly differentiated the content of manganese in the biomass of the experimental plant. Spraying frequency did not reveal any negative influence on the manganese content found in celery leaves in series I or in the total biomass (petioles and blades) in series II.

Table 4. The total content of manganese in petioles and blades of celery leaves (mg kg $^{-1}$ D.M.), in series I and II, in pot experiment
Tabela 4. Zawartość całkowita manganu w ogonkach i blaszkach liściowych selera naciowego (mg kg $^{-1}$ s.m.), w I i II serii doświadczenia wazonowego

Fertilization object; Obiekt nawozowy		I series – I seria		II series – II seria		Mean for petioles Średnia dla ogonków liściowych	Mean for blades Średnia dla blaszek liściowych
		petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe		
Control object; Obiekt kontrolny		26.11	48.34	18.74	47.22	22.43	48.78
NPK		28.72	51.54	13.86	53.02	21.29	52.28
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	24.82	46.17	16.02	60.60	20.42	53.39
	0.01% + NPK	31.72	57.63	18.47	57.91	25.10	57.77
	0.1% + NPK	18.49	44.05	17.09	61.36	17.79	52.71
	1% + NPK	28.81	85.61	21.95	71.46	25.38	78.54
	1.2% + NPK	16.99	60.15	20.24	61.34	18.62	60.75
	2.4% + NPK	27.52	98.30	18.21	67.34	22.87	82.82
	3.6% + NPK	17.28	58.25	16.40	62.71	16.84	60.48
	mean – średnia	23.66	64.31	18.34	63.25	21.00	63.78
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	25.33	51.62	16.13	49.12	20.73	50.37
	0.01% + NPK	27.41	58.89	18.90	75.01	23.16	66.95
	0.1% + NPK	18.72	43.63	21.96	89.46	20.34	66.55
	1% + NPK	25.39	84.56	21.21	63.18	23.30	73.87
	1.2% + NPK	21.04	57.08	13.67	46.41	17.36	51.75
	2.4% + NPK	23.79	83.19	19.74	63.43	21.77	73.31
	3.6% + NPK	20.57	70.54	16.82	54.17	18.70	62.36
	mean – średnia	23.18	64.22	18.35	62.97	20.77	63.60
LSD $_{0,05}$ for: – NIR$_{0,05}$ dla: A – number of treatments – liczba zabiegów		0.314	n.s./n.i.	n.s./n.i.	n.s./n.i.		
B – concentration of Tytanit – stężenie Tytanitu		0.910	1.97	0.866	2.80		
A × B – interaction – interakcja		0.831	1.80	0.791	2.55		
B × A – interaction – interakcja		1.29	2.79	1.23	3.96		

n.s./ n.i. – not significant difference – różnica nieistotna

In series I, the average copper content of in the examined parts of celery was over twice as high as in series II (tab. 5) and was higher in petioles from the control object than in leaves. It was slightly higher in leaves than in petioles in both series, on average, in objects fertilized with Tytanit. The largest amounts of this element (10.93 mg kg^{-1}) were found in petioles from the control object in series I of the study and the lowest

(1.73 mg kg^{-1}) were in petioles, after a two-time application of Tytanit at a 1.2% concentration, in series II. It was found that copper bioaccumulation decreased under the influence of growing concentration values of Tytanit (particularly in series II of the study).

Table 5. The total content of cooper in petioles and blades of celery leaves (mg kg $^{-1}$ D.M.), in series I and II, in pot experiment
Tabela 5. Zawartość całkowita miedzi w ogonkach i blaszkach liściowych selera naciowego (mg kg $^{-1}$ s.m.), w I i II serii doświadczenia wazonowego

Fertilization object Obiekt nawozowy		I series – I seria		II series – II seria		Mean for petioles Średnia dla ogonków liściowych	Mean for blades Średnia dla blaszek liściowych
		petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe		
Control object Obiekt kontrolny		10.93	8.26	7.41	3.42	9.17	5.84
NPK		9.25	7.93	4.13	5.66	6.69	6.80
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	8.80	7.47	3.18	5.09	5.99	6.28
	0.01% + NPK	9.76	14.92	4.54	3.30	7.15	9.11
	0.1% + NPK	8.34	9.52	2.95	4.04	5.64	6.78
	1% + NPK	9.41	14.49	3.27	3.37	6.34	8.93
	1.2% + NPK	9.47	7.22	2.89	5.63	6.18	6.43
	2.4% + NPK	9.25	6.56	2.44	3.84	5.85	5.20
	3.6% + NPK	8.04	9.47	3.94	2.82	5.99	6.15
	mean – średnia	9.01	9.95	3.32	4.01	6.17	6.98
II spraying of Tytanit II oprysk Tytanitem	0.001% Ti + NPK	9.78	7.23	4.54	4.83	7.16	6.03
	0.01% Ti + NPK	8.82	9.22	6.41	4.72	7.62	6.97
	0.1% Ti + NPK	9.08	18.81	3.71	5.47	6.40	12.14
	1% Ti + NPK	9.30	6.75	3.34	4.91	6.32	5.83
	1.2% Ti + NPK	9.32	7.25	1.73	3.02	5.53	5.14
	2.4% Ti + NPK	7.39	10.09	2.99	3.64	5.19	6.87
	3.6% Ti + NPK	6.38	7.81	3.11	2.73	4.75	5.27
	mean – średnia	8.53	9.59	3.69	4.19	6.11	6.89
LSD $_{0,05}$ for: – NIR$_{0,05}$ dla: A – number of treatments – liczba zabiegów		0.248	n.s./n.i.	n.s./n.i.	n.s./n.i.		
B – concentration of Tytanit – stężenie Tytanitu		0.718	2.93	1.57	1.60		
A × B – interaction – interakcja		0.656	2.67	1.43	1.46		
B × A – interaction – interakcja		1.02	4.14	2.21	2.26		

Table 6 presents Ti:Fe, Ti:Mn and Ti:Cu molar ratios, assuming that Ti = 1. The value of the calculated ratios between the examined elements varied under the influence of the fertilization applied for both celery petioles and blades. The highest value was calculated for petioles and blades from the control object fertilized with NPK and following the application of the lowest concentrations of Tytanit (up to 0.01%). Two-time spraying in the increased concentration resulted in diminished molar ratio values between the examined elements in celery petioles and blades.

Table 6. The ratio of Ti : Fe, Ti : Mn and Ti : Cu for petioles and blades of celery leaves (mean for series)
Tabela 6. Stosunki molowe pomiędzy Ti:Fe, Ti:Mn i Ti:Cu, dla ogonków i blaszek liściowych selera naciowego (średnia z serii badań)

Fertilization object Obiekt nawozowy		Petioles – Ogonki liściowe			Blades – Blaszki liściowe		
		Ti : Fe	Ti : Mn	Ti : Cu	Ti : Fe	Ti : Mn	Ti : Cu
Control object Obiekt kontrolny		13.16	1.26	0.446	18.22	5.10	0.529
NPK		9.17	1.88	0.510	17.53	5.73	0.645
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	10.58	1.92	0.471	16.23	5.55	0.566
	0.01% + NPK	9.91	2.09	0.516	13.32	4.59	0.624
	0.1% + NPK	10.47	1.51	0.422	12.05	2.69	0.301
	1% + NPK	7.02	1.31	0.281	2.12	1.01	0.099
	1.2% + NPK	6.98	0.852	0.244	2.51	0.822	0.075
	2.4% + NPK	6.88	0.990	0.219	1.60	0.655	0.035
	3.6% + NPK	5.30	0.810	0.248	1.47	0.519	0.046
	mean – średnia	8.16	1.35	0.343	7.04	2.26	0.249
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	11.17	1.77	0.531	13.94	4.52	0.468
	0.01% + NPK	11.29	1.81	0.515	9.91	3.65	0.321
	0.1% + NPK	9.12	1.36	0.370	6.94	2.11	0.576
	1% + NPK	8.25	0.681	0.159	2.05	0.657	0.045
	1.2% + NPK	4.57	0.620	0.170	1.47	0.446	0.038
	2.4% + NPK	3.53	0.560	0.116	0.920	0.334	0.027
	3.6% + NPK	2.67	0.413	0.091	0.759	0.302	0.022
	mean – średnia	7.23	1.03	0.279	5.14	1.72	0.214

The relation between the Ti content in dry matter of celery petioles and blades and the content of Fe, Mn and Cu was presented in the form of calculated values of direct correlation coefficients. A significant negative relation was found between the content of Ti and the content of Cu in celery petioles ($r = -0.56$) and a significant positive correlation was found between Ti and Mn in celery blades ($r = 0.52$) in a two-year experiment ($p \leq 0.05$, critical value $r = 0.481$).

Ti removal with the yield of the examined celery parts (on average, in the two series of the study) fertilized by foliar application grew proportionally along with the concentration of Tytanit (tab.7). Fe, Mn and Cu uptake with the celery yield did not explicitly depend on the application of Tytanit. A two-time spraying with growing concentrations resulted in the reduction of Fe, Mn and Cu removal with the petiole yield. The average uptake of Ti and Mn with the yield of celery leaves was twice as high as with the yield of petioles, while for Fe and Cu it was higher with the yield of petioles than of blades. Alcaraz-Lopez et al. [2004], Smoleń [2008] and Smoleń et al. [2010] have confirmed the effect of foliar application of growth regulators or fertilizers containing biostimulants on uptake and the accumulation of mineral components by plants. Skupień and Oszmiański [2007] obtained changes in the chemical composition of fruits after applying titanium in the form of Ti^{4+} in strawberry cultivation.

Table 7. Uptake of titanium, iron, manganese and copper in the yield of petioles and blades of celery leaves (mg pot^{-1}), mean from the results of two series

Tabela 7. Pobranie tytanu, żelaza, manganu i miedzi z plonem suchej masy ogonków i blaszek liściowych selera naciowego (mg $wazon^{-1}$), średnia z dwóch serii badań

Fertilization object Obiekt nawozowy		Ti		Fe		Mn		Cu	
		petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe	petioles ogonki liściowe	blades blaszki liściowe
Control object Obiekt kontrolny		0.098	0.067	1.51	1.46	0.142	0.402	0.058	0.068
NPK		0.228	0.193	2.44	4.17	0.492	1.34	0.155	0.175
I spraying of Tytanit I oprysk Tytanitem	0.001% + NPK	0.280	0.182	3.57	3.50	0.640	1.18	0.189	0.139
	0.01% + NPK	0.431	0.300	4.98	4.66	1.03	1.58	0.293	0.250
	0.1% + NPK	0.383	0.440	4.70	6.13	0.678	1.35	0.215	0.174
	1% + NPK	0.715	2.07	5.84	4.71	1.08	2.20	0.269	0.250
	1.2% + NPK	0.699	1.42	5.83	4.45	0.700	1.43	0.232	0.151
	2.4% + NPK	0.727	2.83	5.78	5.30	0.821	2.11	0.210	0.133
	3.6% + NPK	0.768	3.08	4.72	5.39	0.709	1.87	0.252	0.191
	mean – średnia	0.572	1.47	5.06	4.88	0.808	1.67	0.237	0.184
II spraying of Tytanit II oprysk Tytanitem	0.001% + NPK	0.463	0.212	5.89	3.46	0.918	1.10	0.317	0.132
	0.01% + NPK	0.441	0.397	5.89	4.59	0.910	1.62	0.299	0.169
	0.1% + NPK	0.517	0.962	5.49	5.61	0.803	1.67	0.253	0.305
	1% + NPK	0.925	2.38	5.66	5.71	0.722	1.80	0.196	0.142
	1.2% + NPK	0.951	2.36	5.07	4.07	0.675	1.21	0.215	0.120
	2.4% + NPK	1.19	4.73	4.90	5.07	0.762	1.82	0.182	0.170
	3.6% + NPK	1.59	5.41	4.95	4.80	0.754	1.86	0.191	0.158
	mean – średnia	0.868	2.35	5.41	4.76	0.792	1.58	0.236	0.171

CONCLUSIONS

This study demonstrated the significant effect of foliar fertilization with Tytanit in various concentrations on an increase in the yield of celery biomass in a pot experiment carried out in two one-year series. The highest yield of celery was observed after a single application of the highest concentration of Tytanit. Double spraying resulted in insignificant changes to the test plant yield.

The observed content of titanium, iron and manganese in blades was significantly higher than in petioles, in both series of the study. The content of titanium in the examined parts of celery increased along with the increase in Tytanit concentration, whereas the content of iron and manganese decreased under the influence of the highest concentrations applied once and twice.

The highest bioaccumulation of copper in the plant under analysis was observed in the control object fertilized with NPK and with the lowest concentration of Tytanit and the lowest after applying a two-time spraying of the highest concentrations.

The average uptake of Ti and Mn with the yield of celery leaves was twice as high as the yield of petioles, while in the case of Fe and Cu it was higher with the yield of petioles than of blades.

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PLON I ZAWARTOŚĆ Ti, Fe, Mn I Cu W SELERZE NACIOWYM (*Apium graveolens* L. var. *dulce* Mill. Pers.) POD WPŁYWEM APLIKACJI TYTANITU

Streszczenie. Seler naciowy należy do cennych roślin warzywnych ze względu na właściwości dietetyczne, smakowe i lecznicze. Jest rośliną klimatu umiarkowanie chłodnego dobrze plonującą w warunkach klimatycznych naszego kraju, przy odpowiednim doborze odmian i gleby. W doświadczeniu wazonowym prowadzonym w dwóch jednorocznych seriach (lata 2001, 2002) badano wpływ różnych stężeń Tytanitu stosowanego jedno- i dwukrotnie na tle nawożenia NPK, w porównaniu z obiektem kontrolnym i nawożonym mineralnie (NPK), na plon całej biomasy, ogonków i blaszek liściowych selera naciowego oraz zawartość tytanu, żelaza, manganu i miedzi. Wymienione pierwiastki odgrywają główną rolę w procesie fotosyntezy, dane literaturowe podają, że tytan również pełni istotną funkcję w tym procesie. Stwierdzono korzystny wpływ nawożenia dolistnego Tytanitem na zwiększenie się plonu rośliny testowej. Największy plon biomasy selera uzyskano po zastosowaniu największej dawki Tytanitu. Ilość stosowanych zabiegów spowodowała niewielkie zmiany w plonowaniu testowanej rośliny. Zanotowano średnio większą bioakumulację tytanu, żelaza i manganu w blaszkach liściowych selera naciowego niż w ogonkach liściowych w I i II roku badań. Największe stężenie Tytanitu zastosowane jedno- i dwukrotnie spowodowało zmniejszenie bioakumulacji Fe i Mn w badanych częściach selera w I i II roku doświadczenia. Najwięcej Cu zanotowano na obiekcie kontrolnym, nawożonym NPK oraz pod wpływem aplikacji Tytanitu w najmniejszych stężeniach. Wyniesienie Ti i Mn było średnio dwukrotnie większe z plonem blaszek liściowych selera niż z plonem ogonków liściowych, natomiast Fe i Cu większe z plonem ogonków liściowych niż blaszek liściowych.

Słowa kluczowe: nawożenie dolistne, skład mineralny, plonowanie

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