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Effect of Tytanit® on the dry matter and macroelement contents in potato tuber

Wpływ Tytanitu® na zawartość suchej masy i makropierwiastków w bulwach ziemniaka

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Abstract

This paper analyses the effect of the dose (0.2 L*ha^{-1} or 0.4 L*ha^{-1}) and date (a single application at the leaf development stage – BBCH 14-16 or at the tuber formation stage – BBCH 41-43, and a double application at the BBCH 14-16 and BBCH 41-43 stages) of the application of Tytanit® (8.5 g Ti per liter in the form of Ti-ascorbate) on the dry matter and macroelement contents in tuber of very early potato cultivars ('Lord' and 'Miłek'). Potatoes were harvested 75 days after planting (the end of June). Tytanit® did not affect the content of dry matter and nitrogen, phosphorus, potassium, calcium, magnesium or sulphur in potato tubers. Following Tytanit® application, there was only an increase in sodium content. The sodium content in the immature potato tubers was higher after the application of 0.2 L*ha^{-1} of the Tytanit®. Regardless of the Tytanit® dose, the sodium content in tubers was the lowest when the growth stimulant was applied only once in the leaf development stage (BBCH 14-16), particularly under the more favorable thermal and moisture conditions for early crop potato culture. Following Tytanit® application, the weight ratios of Ca:P, K:Ca and K:Mg in potato tuber were similar, and the weight ratios of N:S, Na:Ca and Na:Mg were broader compared to the cultivation without the growth stimulant, although the ratio of the sum of univalent cations to the sum of bivalent cations (K+Na):(Ca+Mg) was at the same level, both in the cultivation with and without Tytanit®.

Keywords: ions ratios, mineral elements, new potatoes, titanium

Streszczenie

Badano wpływ dawki (0.2 L*ha^{-1} i 0.4 L*ha^{-1}) i terminu (jednorazowo w fazie rozwoju liści – BBCH 14-16 lub w fazie zawiązywania bulw – BBCH 41-43, dwukrotnie w fazach BBCH 14-16 i BBCH 41-43) stosowania Tytanitu® (8.5 g Ti w 1 litrze w formie askorbinianu tytanu) na zawartość suchej masy i makropierwiastków w bulwach bardzo wczesnych odmian ziemniaka ('Lord' i 'Miłek'). Ziemniaki zbierano po

75 dniach od sadzenia (koniec czerwca). Tytanit® nie miał wpływu na zawartość suchej masy oraz na zawartość azotu, fosforu, potasu, wapnia, magnezu i siarki w bulwach ziemniaka. Stosowanie Tytanitu® powodowało tylko zwiększenie zawartości sodu. Zawartość sodu w młodych bulwach ziemniaka była większa, gdy Tytanit® był stosowany w dawce 0.2 L*ha^{-1}. Niezależnie od dawki Tytanitu®, zawartość sodu w bulwach była najmniejsza, gdy stymulator wzrostu stosowany był tylko jeden raz w fazie rozwoju liści (BBCH 14-16), szczególnie w warunkach termicznych i wilgotności bardziej korzystnych dla uprawy ziemniaka na wczesny zbiór. Po zastosowaniu Tytanitu® stosunek wagowy Ca:P, K:Ca i K:Mg w bulwach był podobny, a stosunek wagowy N:S, Na:Ca i Na:Mg szerszy w porównaniu z uprawą bez stymulatora wzrostu, chociaż stosunek sumy kationów jednowartościowych do sumy kationów dwuwartościowych (K+Na):(Ca+Mg) był na takim samym poziomie, zarówno w uprawie bez jak i ze stosowaniem Tytanitu®.

Słowa kluczowe: młode ziemniaki, składniki mineralne, stosunki jonowe, tytan

Introduction

Potatoes are an excellent source minerals in the human diet (Haase, 2008; Ezekiel et al., 2013). A typical meal with 200 g of boiled potatoes provides up to 30% of the Recommended Daily Amount (RDA) of potassium, 12-18% of phosphorus and 5-15% of magnesium. Potatoes are generally not rich in calcium but can be a valuable source of minor (copper, iron, zinc, manganese) and trace elements (selenium, iodine) if fertilized appropriately (Haase, 2008; Leszczyński, 2012). Mineral elements play an important biochemical function in the human body, assisting in the prevention of nutrition-related diseases and the maintenance of good health (Martinez-Ballesta et al., 2010). Since potato tubers have relatively high concentrations of organic compounds that stimulate the absorption of minerals by humans, the bioavailability of mineral elements in potatoes is potentially high (White et al., 2009). Mineral elements content in potato tubers are influenced by both environmental and genetic factors (Rivero et al., 2003; Sawicka et al., 2016). Abiotic stress can modify the mineral elements content in the field growing crops (Martinez-Ballesta et al., 2010).

In intensive plant production focusing on high value products, plant growth stimulants have been gaining increasing importance. Growth stimulants increase plant resistance to abiotic and biotic stresses, which allows better use of the cultivar production potential under the environmental conditions of the cultivar area (Calvo et al., 2014; Bulgari et al., 2015). Titanium is classified as a beneficial element for plant growth. Water-soluble and pH-stable chelate forms of titanium such as ascorbate, citrate or malate have a beneficial effect on various physiological processes and strengthen stress tolerance, as well as increase the crop yield and can also improve the crop quality (Du et al., 2010; Bacilieri et al., 2017; Lyu et al., 2017). Although titanium stimulates the plants at low concentration, it is phytotoxic at higher concentrations. The uptake and distribution of titanium by the plants depends on the method of nutrition supply – via roots or via leaves. Foliar application is more effective for titanium absorption. When sprayed onto the leaf surface, titanium is distributed about equally between the leaves and roots, whereas if supplied through the roots the majority of titanium taken up remained in the roots (Kelemen et al., 1993; Lyu et al., 2017).

One of the foliar fertilizers containing titanium used in central and eastern Europe for improving crop production is Tytanit® (produced in Poland), which has been categorized as a plant growth stimulant. Titanium® (Ti-ascorbate) foliar application resulted in an increase in the magnesium and sodium content and a decrease in the calcium content in carrot roots, but had no effect on the phosphorus and potassium content (Kwiatkowski et al., 2015). In the study carried out by other authors, Tytanit® foliar application decreased nitrogen, phosphorus and potassium contents in sweet basil (Kwiatkowski and Jaszczuk, 2011) and the calcium content in strawberry fruits (Ochmian et al., 2008), although when supplied with a nutrition solution it did not have any effect on the macroelement content (nitrogen, phosphorus, potassium, calcium or magnesium) in lettuce leaves grown in a greenhouse (Kleiber, 2017). A pot experiment showed that a higher concentrations of Tytanit® resulted in a decrease in the calcium and magnesium content in celery, and an increase in the sodium content (Kalembasa et al., 2014). Titanium foliar application in the form of Ti-citrate resulted in a slight increase in nitrogen and magnesium content in potato tuber and in wheat and barley grain (Tlustoš et al., 2005).

Many beneficial effects, as well as a few adverse effects of titanium application on the mineral content in crop yields, are described in the literature. To date, few studies have been focused on the effect of titanium on potato tuber quality, especially in an early harvest. The growing period for early potatoes is short (50-80 days from planting to harvest). To obtain a high yield of new potatoes in a short period good conditions for plant growth must be ensure. Taking into account the above premises, the hypothesis was made in the study that the stimulation of potato plant growth by titanium foliar application could contribute to an increase in macroelement content in tubers. It was assumed that the potato response to titanium depends on the dose and date of titanium application, and that the result of titanium application depends on the potato cultivar and environmental conditions. The aim of the study was to determine the effect of the dose and date of Tytanit® application on the dry matter and macroelement content in tubers of very early potato cultivars.

Material and methods

Plant material and experimental design

The study material included tubers of 2 very early potato cultivars ‘Lord’ and ‘Miłek’ (Polish cultivars which are registered on the Common Catalogue of Varieties of Agricultural Plant Species CCV with a medium soil requirements and a medium-to-large water requirements) obtained from a field experiment carried out in central-eastern Poland (52°03'N; 22°33'E) during 3 growing seasons (2009, 2010 and 2012), on loamy soil (Luvisol) with an acidic-to-slightly-acid reaction, with a high-to-very high content of available phosphorus, a medium-to-very high content of potassium and a low-to-medium content of magnesium (Table 1).

In this study, the titanium (Ti) source was the foliar fertilizer Tytanit®, which has been categorized as a plant growth stimulant since 2013. Tytanit® contained 8.5 g Ti per liter (0.8% m/m), in the form of Ti-ascorbate. The effect of dose (0.2 L*ha^{-1} and

0.4 L*ha^{-1}) and date of Tytanit® application (a single foliar application at the leaf development stage – BBCH 14-16 or at the tuber formation stage – BBCH 41-43, and a double foliar application at the leaf development and tuber formation stages – BBCH 14-14 and BBCH 41-43) on the dry matter and macroelement contents in tubers of very early potato cultivars ('Lord' and 'Miłek') was investigated. The field experiment was established in a split-block-split-plot design with a control object without Tytanit® in 3 replications. In successive years, 6-week pre-sprouted seed potatoes were planted on the 15th, 13th and 12th of April. Potato cultivation was carried out according to common agronomical practice. Potatoes were harvested 75 days after planting (the end of June).

Table 1. Soil chemical properties at the experimental site

Years	pH_{KCl}	N_{total} (g*kg^{-1})	S_{total} (g*kg^{-1})	Available forms (g*kg^{-1})		
				P	K	Mg
2009	6.6	0.74	0.13	12.8	10.4	3.8
2010	6.1	1	0.11	8.8	12	4.5
2012	4.7	0.7	0.12	12.2	20.8	2.2

Chemical analysis

The soil chemical properties at the experimental site were determined using soil laboratory procedures: pH with potentiometric method in 1 M KCl (Polish Standard, 1997), total nitrogen with the Kjeldahl method (Polish Standard, 2002b), total sulphur with inductively coupled plasma-optical emission spectroscopy (ICP-OES) method (Ostrowska et al., 1991), available forms of phosphorus with spectrophotometric method (Polish Standard, 1996), potassium with flame atomic emission spectroscopy (FAES) method (Polish Standard, 2002c) and magnesium with flame atomic absorption spectroscopy (FAAS) method (Polish Standard, 2004).

Laboratory studies were conducted on samples of 50 different-sized tubers taken from each treatment. The contents of dry matter were determined with the gravimetric method (Polish Standard, 2001), nitrogen (N) with the Kjeldahl method (Polish Standard, 2002a) and the contents of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na) and sulphur (S) were determined using atomic emission spectroscopy with the inductively-coupled plasma method following previous mineralization of potato tuber samples. One gram of potato tuber dry matter was oxidized dry at 450-550 °C in a muffle furnace. Ten milliliters of diluted HCl (1:1) was poured over crude ash in a pot and the ash was evaporated dry on a sand batch to decompose carbonates and separate silica. The total contents of P, K, Ca, Mg, Na and S were determined on an atomic emission spectrometer with inductively-coupled plasma (ICP – AES) Optima 3200 RL produced by Perkin-Elmer. The contents of elements were expressed in grams per kilogram of potato tuber dry matter (DM) and the following weight ratios were calculated: N:S, Ca:P, K:Ca, K:Mg. Na:Ca, Na:Mg and (K+Na):(Ca+Mg).

Statistical analysis

The results of a three-way experiment with a control object were analyzed statistically by means of analysis of variance (ANOVA) for the split-block-split-plot design. An analysis of the results of the study was conducted using orthogonal contrast to compare the control object without Tytanit® with the test objects with Tytanit®. The significance of differences was verified using Tukey's test at P≤0.05.

Weather conditions in potato growing season

Weather conditions in the years of the study were varied (Table 2). The year 2009 was cool and it received the highest amount of precipitation. 2010 was warm with a heavy rainfall in May and a drought in the beginning of June. The most favorable thermal and moisture conditions for early crop potato culture were in the warm and moderately wet growing season of 2012. Over the three-year period of the study, the mean air temperatures in the beginning period of potato growth were above the long-term average. In 2009 total precipitation in potato growing season (April-June) was above and in 2010 and 2012 similar to long-term average, however unevenly distributed during potato growth period.

Table 2. Mean air temperature and precipitation sums in the potato growing season

Months	Temperature (°C)				Rainfalls (mm)				Sielianinov's hydrothermal coefficient		
	2009	2010	2012	Many year	2009	2010	2012	Many year	2009	2010	2012
April	10.3	8.9	8.9	8.1	8.1	10.7	29.9	45.5	0.3	0.4	1.1
May	12.9	14	14.6	11.9	68.9	93.2	53.4	49.7	1.7	2.1	1.2
June	15.7	17.4	16.3	16.7	145.2	62.6	76.2	63	3.1	1.2	1.5

Hydrothermal coefficient value: up to 0.4 extremely dry; 0.41-0.7 very dry; 0.71-1 dry; 1.01-1.3 quite dry; 1.31-1.6 optimum; 1.61-2 quite wet; 2.01-2.5 wet; 2.51-3 very vet; >3 extremely wet (Skowera and Puła, 2004)

Results and discussion

Tytanit® did not affect the contents of dry matter and nitrogen, phosphorus, potassium, calcium, magnesium or sulphur in immature potato tubers (Table 3). Following Tytanit® application, there was only an increase in the sodium content in tubers, on average, by 0.007 $g*kg^{-1}$ DM (over the three-year period) compared to the cultivation without the titanium foliar application, which was confirmed in a study carried out by other authors. A study carried out in the Czech Republic showed that three times titanium foliar application in the form of Ti-citrate during potato grown on Chernozem (at the beginning of June with a plant height of 30 cm and repeated treatment in two-week intervals) in the dose of 10 g Ti*ha^{-1} in each treatment did not have any effect on the dry matter of mature tubers of 'Cordoba' cultivar and resulted only in a slight increase in the nitrogen and magnesium content in tubers (Tlustoš et al., 2005). In a study carried out by other authors, Tytanit® application caused an increase in the magnesium and sodium content and a decrease in the calcium content in carrot roots (Kwiatkowski et al., 2015). Tytanit® caused also an increase in the sodium content and a decrease in the calcium and magnesium content in celery (Kalembasa et al., 2014). The sodium play an important role in both the plant and human physiology. The behaviour of the sodium showing a negative correlation with some elements (Rivero et al., 2003; Martinez-Ballesta et al., 2010).

Table 3. Effect of Tytanit® on dry matter (%) and macroelement contents in potato tuber (g*kg^{-1} DM)

Treatment	Dry matter	N	P	K	Ca	Mg	Na	S
Without Tytanit®	17.85[a]	11.99[a]	2.895[a]	21.87[a]	0.448[a]	0.882[a]	0.063[b]	0.834[a]
With Tytanit®	17.83[a]	12.20[a]	2.883[a]	21.96[a]	0.452[a]	0.887[a]	0.070[a]	0.827[a]

*Means within columns followed by the same letters do not differ significantly at P=0.05

The dry matter content is a one of the important characteristics of early potatoes. In early potato production, when tubers are harvested very early, low dry matter content can makes a soggy potato texture and decreases their quality (Mustonen, 2004). The dry matter content and chemical composition of potato tubers are associated with the physiological indicators of potato growth such as assimilation leaf area, chlorophyll content in leaves or plant growth rate. Reducing the assimilation leaf area along with the increasing the chlorophyll *a* content and simultaneously decreasing the chlorophyll *b* content in leaves results in an increase in dry matter content in tubers (Sawicka et al., 2015). Tytanit® caused an enlargement of the assimilation leaf area and an increase in chlorophyll content in leaves of very early potato cultivars (Wadas and Kalinowski, 2017b), however did not affect the content of dry matter in tubers. According to Sawicka and Mikos-Bielak (1995), an increase in potato tuber yield may be associated with a decrease in levels of certain, but not all, minerals in tubers. Tytanit® as a growth stimulant caused an increase in the plant height and above-ground plant biomass and tuber weight per plant (Wadas and Kalinowski, 2017a), and as the result an increase in the yield of new potatoes of 'Lord' and 'Miłek' cultivars (Kalinowski and Wadas, 2017), but did not affect the macroelement contents in tubers, except for sodium. Leaf-absorbed titanium is translocated to roots via phloem and accumulated in the chloroplasts (Kelemen et al., 1993; Lyu et al., 2017). Potato plants uptake mineral elements primarily from the soil solution through their roots. Most macroelements are taken up by a combination of two mechanisms active and passive (Westermann, 2005). In the present study, Tytanit® caused only an increase in the sodium content in immature potato tubers. The taken up of sodium is essentially a passive process (Blumwald et al., 2000). The concentrations of most mineral elements are higher in the skin than in the flesh of potato tubers. Higher concentrations of minerals in the skin may reflect direct uptake from the soil across the periderm. Direct uptake of minerals into the developing tuber across the periderm is possible, hovewer in a mature tuber it will be limited due to the suberized nature of the periderm (Subramanian et al., 2011).

The dose of Tytanit® application had a significant effect on the sodium content in tubers only in the cold and very moist growing season of 2009 (Table 4 and 5).

Table 4. Effect of experimental factors on dry matter (%) and macroelement contents in potato tuber (g*kg^{-1} DM)

Experimental factors	Dry matter	N	P	K	Ca	Mg	Na	S
Cultivar								
Lord	17.41^{a}	12.06^{a}	2.958^{a}	22.11^{a}	0.472^{a}	0.925^{a}	0.074^{a}	0.793^{b}
Miłek	18.26^{b}	12.28^{a}	2.812^{b}	21.72^{a}	0.431^{b}	0.848^{b}	0.064^{b}	0.864^{a}
Tytanit® dose								
0.2 L*ha^{-1}	17.81^{a}	12.26^{a}	2.917^{a}	22.04^{a}	0.467^{a}	0.89^{a}	0.073^{a}	0.829^{a}
0.4 L*ha^{-1}	17.85^{a}	12.3^{a}	2.85^{a}	21.81^{a}	0.437^{a}	0.884^{a}	0.068^{a}	0.826^{a}
Date of Tytanit® application								
BBCH 14-16	17.58^{a}	12.3^{a}	2.84^{a}	21.8^{a}	0.444^{a}	0.883^{a}	0.065^{b}	0.8^{a}
BBCH 41-43	17.84^{a}	12.09^{a}	2.93^{a}	22.54^{a}	0.455^{a}	0.89^{a}	0.073^{a}	0.843^{a}
BBCH 14-16 + BBCH 41-43	18.08^{a}	12.09^{a}	2.88^{a}	21.44^{a}	0.455^{a}	0.885^{a}	0.072^{a}	0.838^{a}
Year								
2009	17.87^{a}	12.34^{a}	3.07^{a}	24.2^{a}	0.505^{a}	0.838^{b}	0.073^{b}	0.652^{c}
2010	18.16^{a}	11.77^{b}	2.714^{c}	20.03^{bc}	0.498^{a}	0.909^{a}	0.051^{c}	0.991^{a}
2012	17.48^{a}	12.4^{a}	2.871^{b}	21.53^{b}	0.352^{b}	0.912^{a}	0.083^{a}	0.842^{b}

*Means within columns followed by the same letters do not differ significantly at P=0.05

Table 5. Effect of dose and date of Tytanit® application on sodium content in potato tuber (g*kg^{-1} DM)

Dose and date of Tytanit® application	Cultivar		Year		
	Lord	Miłek	2009	2010	2011
Tytanit® dose					
0.2 L*ha^{-1}	0.076[a]	0.068[a]	0.078[a]	0.046[a]	0.093[a]
0.4 L*ha^{-1}	0.072[a]	0.063[a]	0.066[b]	0.056[a]	0.082[a]
Date of Tytanit® application					
BBCH 14-16	0.066[b]	0.063[a]	0.075[a]	0.04[c]	0.079[b]
BBCH 41-43	0.078[a]	0.068[a]	0.075[a]	0.05[b]	0.094[a]
BBCH 14-16 + BBCH 41-43	0.08[a]	0.065[a]	0.067[a]	0.062[a]	0.089[a]

*Means within columns followed by the same letters do not differ significantly at P=0.05

In that year, after the application of 0.2 L*ha^{-1} of Tytanit®, the sodium content in the tubers was higher, on average, by 0.012 g*kg^{-1} DM (19%) compared with the dose of 0.04 L*ha^{-1}. In a study carried out by other authors, the sodium content in both the petioles and leaf blades of celery increased along with the increase of Tytanit® dose (Kalembasa et al., 2014). Regardless of Tytanit® dose, the sodium content in immature potato tubers was the lowest when the growth stimulant was applied only once in the leaf development stage (BBCH 14-16), particularly under the more favorable thermal and moisture conditions for early crop potato culture (Tables 4 and 5). The performed study demonstrated a significant interaction effect of the potato cultivar and the date of Tytanit® application on the sodium content in tubers (Table 5). The date of Tytanit® application had a greater effect on the sodium content in tubers of the 'Lord' cultivar. With the single application of the growth stimulant in the leaf development stage (BBCH 14-16) the sodium content in the tubers of 'Lord' cultivar was lower, on average, by 0.013 g*kg^{-1} DM (16%) as compared with a single application in the tuber formation stage (BBCH 41-43) or in a double application of Tytanit® in the leaf development and tuber formation stages.

The content of dry matter and macroelements in potato tuber depended to a greater extent on the cultivar and weather conditions during the potato growing season than from application of Tytanit® (Table 4). The genotypic variability associated with cultivar features plays a dominant role in the variability of the macroelement contents in potato tubers (Sawicka et al., 2016), which was confirmed in the present study. Regardless of the treatment, the content of dry matter in tubers of 'Miłek' cultivar was higher, on average, by 0.85% than in tubers of 'Lord' cultivar, while tubers of the 'Lord' cultivar accumulated more phosphorus, on average, by 0.146 g*kg^{-1} DM

(5.2%), calcium by 0.041 g*kg^{-1} DM (9.5%), magnesium by 0.077 g*kg^{-1} DM (9.1%) and sodium by 0.01 g*kg^{-1} DM (15.6%) and less sulphur by 0.071 g*kg^{-1} DM (8.2%). The contents of nitrogen and potassium in tubers of both cultivars were similar.

Some comparative studies have shown that higher-yielding potato cultivars have a lower content of mineral elements in tubers than lower-yielding cultivars grown in the same conditions (White et al., 2009), which was not confirmed in the discussed study in the early date of potato harvest. The tuber yield of 'Lord' and 'Miłek' cultivars harvested 75 days after planting did not differ significantly (Kalinowski and Wadas, 2017). Regardless of the experimental factors, the tubers contained the most nitrogen, phosphorus, potassium and calcium and, at the same time, the least magnesium and sulphur in the cool and very moist growing season of 2009. The most sodium was accumulated by potato tubers in the warm and moderately moist growing season of 2012 (Table 4). Wegener et al. (2017) reported that calcium content in potatoes was reduced, while magnesium, phosphorus and potassium contents increased as a result of drought stress. According to Sawicka et al. (2016), environmental conditions, particularly weather, exert the largest impact on magnesium accumulation in potato tubers. A high concentration of this element is favored by high rainfall sums and moderate daily air temperatures, which was confirmed in the present study. Rogóż and Tabak (2015) reported that the contents of calcium and magnesium in the potato tubers decreased slightly along with the increase in the soil pH values, whereas the increase in soil pH values had a variable impact on the phosphorus content, which was confirmed in the present study (Tables 1 and 4).

The nutritional value of potatoes is determined not only by the general content of individual elements, but also by their ratio. Nutrient uptake by plants depends on their phyto-availability in the soil and on their synergism and antagonism interaction, which directly affects the chemical composition of plants (Westermann, 2005; Rogóż and Tabak, 2015). Following Tytanit® application, the weight ratios of Ca:P, K:Ca and K:Mg in immature potato tubers were similar and the weight ratios of N:S, Na:Ca and Na:Mg were broader compared to the cultivation without the growth stimulant application, although the ratio of the sum of univalent cations to the sum of bivalent cations was at the same level, both in cultivations with and without Tytanit® (Table 6).

Table 6. Effect of Tytanit® on the weight ratios of macroelement in potato tuber

Treatment	N:S	Ca:P	K:Ca	K:Mg	Na:Ca	Na:Mg	(K+Na):(Ca+Mg)
Without Tytanit®	11.38	0.155	48.82	24.8	0.141	0.071	16.49
With Tytanit®	14.75	0.157	48.52	24.76	0.155	0.079	16.45

Tytanit® application caused a narrowing of the weight ratio of Ca:Mg and K:Mg in carrot roots (Kwiatkowski et al., 2015). The molar ratios between K:Ca, K:Mg, Na:Ca and Na:Mg in celery were differentiated under the influence of Tytanit®. The ratios between the K:Ca and K:Mg in petioles of celery were higher after applying lower concentrations of Tytanit®, however, the ratios between K:Ca and K:Mg in leaf blades of celery were higher after applying higher concentrations of Tytanit® (Kalembasa et al., 2014). The weight ratio between (K+Na):(Ca+Mg) in the celery fertilized twice with Tytanit® was slightly broader than after a single application of Tytanit®. In the present study, regardless of the dose and date of application, Tytanit® had no effect on the calculated weight ratios of macroelements in new potatoes (Table 7).

Table 7. Effect of experimental factors on the weight ratios of macroelement in potato tuber

Experimental factors	N:S	Ca:P	K:Ca	K:Mg	Na:Ca	Na:Mg	(K+Na):(Ca+Mg)
Cultivar							
Lord	15.21	0.16	46.84	23.9	0.157	0.08	15.88
Miłek	14.21	0.153	50.39	25.61	0.148	0.075	17.03
Tytanit® dose							
0.2 L*ha^{-1}	14.74	0.16	47.19	24.76	0.156	0.082	16.3
0.4 L*ha^{-1}	14.7	0.153	49.91	24.67	0.156	0.077	16.56
Date of Tytanit® application							
BBCH 14-16	15.38	0.156	49.1	24.69	0.146	0.074	16.48
BBCH 41-43	14.48	0.155	49.54	25.32	0.16	0.082	16.81
BBCH 14-16 + BBCH 41-43	14.43	0.158	47.12	24.22	0.158	0.081	16.05
Year							
2009	18.93	0.164	47.92	28.88	0.144	0.087	18.07
2010	11.88	0.183	40.22	22.04	0.102	0.056	14.27
2012	14.73	0.123	61.16	23.61	0.236	0.091	17.1

The ratios of macroelements in potato tuber depended to a greater extent on the cultivar and weather conditions during the potato growing season than from application of Tytanit® (Table 7). The K:Ca, K:Mg and (K+Na):(Ca+Mg) ratios were higher in tubers of 'Miłek' cultivar, whereas the N:S, Na:Ca and Na:Mg ratios were higher in tubers of the 'Lord' cultivar. The most important, for nutritional reasons, that the K:Ca, K:Mg and K:(Ca+Mg) ratios in potato tubers are above the assumed optimum (Sawicka et al., 2016) was also confirmed in the present study. Krzywy et al. (2002) reported that the K:Mg and K:(Ca+Mg) ionic ratios in potato tubers were broader than in cereal grain.

The changes in the reaction of the soils (pH value) had an impact on the Ca:P and Ca:Mg ratios in the potato tubers (Rogóż and Tabak, 2015). In the present study, the Ca:P ratio was narrowest and the K:Ca and Na:Ca ratios were broadest in the potato tubers from soil with lowest pH, whereas the K:Mg ratio was broadest in the potato tubers from soil with the highest pH (Tables 1 and 7).

Conclusions

Tytanit® as a plant growth stimulant did not affect the contents of dry matter and nitrogen, phosphorus, potassium, calcium, magnesium or sulphur in potato tuber. Following Tytanit® application, there was only an increase in the sodium content. The Tytanit® dose (0.2 L*ha^{-1} or 0.4 L*ha^{-1}) had a significant effect on the sodium content in immature potato tubers only under stress conditions in a cold and very moist potato growing season. The sodium content in the tubers was higher after the application of 0.2 L*ha^{-1} of the Tytanit®. Regardless of the Tytanit® dose, the sodium content in tubers was the lowest when the growth stimulant was applied only once in the leaf development stage (BBCH 14-16), particularly under the more favorable thermal and moisture conditions for an early crop potato culture. The date of Tytanit® application had a greater effect on the sodium content in tubers of the 'Lord' cultivar. Following Tytanit® application, the weight ratios of Ca:P, K:Ca and K:Mg in immature potato tuber were similar, and the weight ratios of N:S, Na:Ca and Na:Mg were broader compared to the cultivation without the growth stimulant application, although the ratio of the sum of univalent cations to the sum of bivalent cations (K+Na):Ca+Mg) was at the same level, both in cultivations with and without Tytanit®. The content of dry matter and macroelement in potato tuber depended to a greater extent on the cultivar and weather conditions during the potato growing season than from application of Tytanit®.

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