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INFLUENCE OF FOLIAR NITROGEN AND MAGNESIUM FERTILIZATION ON CONCENTRATION OF ASH MICRONUTRIENTS IN POTATO TUBERS

WPŁYW NAWOŻENIA DOLISTNEGO AZOTEM I MAGNEZEM NA ZAWARTOŚĆ MAKROSKŁADNIKÓW POPIELNYCH W BULWACH ZIEMNIAKA

Abstract: The paper contains a discussion of the results of an experiment concerning the effect of foliar nitrogen and magnesium fertilization on the concentration of ash macronutrients in edible potato tubers of a medium-early cultivar called Zebra. The trials were based on a three-year, two-factorial field experiment, carried out in 2005–2007 at the Research Station in Tomaszkowo, owned by the University of Warmia and Mazury in Olsztyn. The applied fertilization consisted of 80 kgN, 35 kgP and 100 kgK · ha^{-1}. The first experimental factor comprised foliar nitrogen fertilization in the range of doses (8; 40) kgN · ha^{-1} accompanied by simultaneously diminished doses of soil nitrogen fertilization. The second factor included three series: without magnesium, with magnesium introduced to soil in a rate of 24 kg · ha^{-1} and with magnesium sprayed over potato leaves in a rate of 12 kgMg · ha^{-1}. Tuber samples were analyzed for the concentrations of phosphorus, potassium, magnesium and sodium. The content of these macronutrients tended to decrease under the influence of the increasing nitrogen fertilization, with the exception of phosphorus, whose concentration rose in the series unfertilized with magnesium under the effect of 8 and 16 kgN, and the concentration of sodium, which continued to increase in the Mg fertilized series up to the rate of 24 kg of N applied as a foliar fertilizer. The mean Ca : P = 0.28, Ca : Mg = 0.39 and K : Ca = 11.9 ratios suggest very poor calcium supply of the potato cultivar. In contrast, very broad ratios between K : (Ca + Mg) = 3.32 and K : Mg = 4.60 prove that the concentrations of potassium and magnesium were relatively high. The foliar application of nitrogen, tested in this experiment, had a significant effect on the ratios between ash elements in tubers. It has been demonstrated that as the top-dressing rate of nitrogen increased, the Ca : P and Ca : Mg ratios narrowed while the ratios of K : (Ca + Mg) and K : Ca were broader. The applied fertilization had no effect on the K : Mg ratio.

Keyword: macronutrients, mineral fertilizers, magnesium, nitrogen, *Solanum tuberosum*, potato

Chemical composition of tubers is the major determinant of potato quality and value as food or raw produce for processing. The chemical composition is a cultivar-specific

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trait which can be modified by the climate, soil and agronomic practice. Among the cultivation treatments, fertilization has the strongest influence on the quality of potato tubers [1–4]. Owing to rational fertilization of potato, including foliar nutrition, quick supply of deficient nutrients is possible, either when their uptake from soil by potato roots is impaired or when their soil concentrations are low. The main advantage of foliar fertilization of plants is the rapid effect that the applied nutrients have on fertilized crops. Another positive aspect is that they are highly effectively used up by plants [1, 3, 5–9]. Moreover, foliar fertilization means that less nitrogen and magnesium fertilizers can be used, which is good for the environment and the economics of potato cultivation. The up-to-date research on foliar nutrition of potato has focused mainly on investigating the effect of such fertilization on potato yield. Less attention has been paid to the quality of tubers.

The purpose of the present study has been to clarify the influence of foliar nitrogen fertilization as well as foliar and soil magnesium fertilization on the concentrations and ratios between ash macronutrients (phosphorus, potassium, calcium, magnesium and sodium) in potato tubers.

Material and methods

The results originate from a three-year field experiment, set up at the Experimental Station in Tomaszkowo near Olsztyn (53°42′35″ N, 20°26′01″ E) in 2005. The experiment was established on proper brown soil developed from weak loamy sand class IVb in the Polish soil valuation system, classified as good rye complex. According to the FAO/WRB (*World Reference Base for Soil Resources*) [10], this soil belonged to Cambisols – Brown Soils. The effect of foliar nitrogen fertilization combined with foliar and soil magnesium fertilization on concentrations of chlorophyll in leaves of a medium-early potato cultivar Zebra (Plant Breeding Station in Szyldak, Ltd.) was examined. The study involved a two-factorial experiment in random blocks with four replications, including different nitrogen and magnesium fertilization variants, either applied to soil or sprayed over leaves. The experiment consisted of three series: in the first one, nitrogen fertilization alone was applied in a rate of 80 $kgN \cdot ha^{-1}$, with a gradually increasing share of foliar nutrition (0, 8, 16, 24, 32, 40) $kgN \cdot ha^{-1}$ at the expense of soil fertilization, which equalled (80, 72, 64, 56, 48, 40) $kgN \cdot ha^{-1}$; the other two series included additional magnesium fertilization. In the second series, magnesium was introduced to soil in a rate of 24 $kgMg \cdot ha^{-1}$ and in the third one, it was sprayed over leaves in an amount of 12 $kgMg \cdot ha^{-1}$. Phosphorus and potassium fertilization rates were constant in all the treatments and equalled 35 kgP and 100 $kgK \cdot ha^{-1}$. The phosphorus fertilizer, granular triple superphosphate 20 % P ($Ca(H_2PO_4)_2$), and the potassium one, potassium salt 50 % K (KCl), were applied in a single dose to soil before planting potatoes. Nitrogen was used as urea 46 % N ($CO(NH_2)_2$), and magnesium in the form of magnesium sulphate ($MgSO_4 \cdot 7H_2O$). Whole amounts of the fertilizers introduced to soil were applied before planting potatoes, and the ones used for foliar fertilization were sprayed in five doses during the plants' vegetative season. The first spraying treatment was performed after the rows of potato plants became compact and the first flower buds formed. The subsequent treatments were carried out at 7-day intervals. The working concentration of the solutions of fertilizers applied to leaves was 6.9 % of urea and 10.0 % of magnesium sulphate. The rows were spaced at 62.5 cm and the distance between planted potatoes in a row was 40 cm. Thus, the calculated plant density was 40 thousand plants per ha^{-1}. The area of plots for harvest was 12.96 m^2.

After harvest, averaged samples of tubers were collected from each plot for chemical analyses. The samples were washed, dried at 65°C, grounded and mineralized. Samples weighing 1 g each were wet digested according to the EPA Method 3052 (*Microwave Assisted Acid Digestion of Siliceous and Originally Based Matrices*) [11], using microwave heating with a suitable microwave system (MARS-5, CEM Corporation). The K, Ca, Mg, and Na concentrations were determined by *flame atomic absorption spectroscopy* (FLAAS) (VARIAN model SpectrAA – FS240, Varian Inc. Australia). The vanadium molybdate colorimetric method was used to determine the phosphorus content P [12]. Absorbance was measured at the wavelength $\lambda = 470$ nm in a 1 cm path length quartz cuvette using flow spectrophotometer type Specol 220 (Carl Zeiss Jena). Ratios between the nutrients contained in tubers were expressed as equivalent (K, Na, Ca and Mg) and as molar ratios (Ca, P). The equivalent ratios were calculated from the content of the nutrients expressed in $g \cdot kg^{-1}$ d.m. and their gram equivalent weight(+) (K = 39.098, Na = 22.989, Ca = 20.039 and Mg = 12.153 $g \cdot val(+)^{-1}$). Due to the varying valence of phosphorus in chemical compounds, the ratios Ca : P were expressed as molar ones. This is how the Ca : P ratio is presented in available research papers [13, 14]. This ratio was calculated from the concentrations of Ca and P in tubers expressed in $g \cdot kg^{-1}$ d.m. and their molar mass (Ca = 40.078, P = 30.972 $g \cdot mol^{-1}$).

The results were processed statistically with ANOVA at the level of significance of $\alpha = 0.05$, using a Statistica v. 9.0 software package [15]. The correlation between the analyzed factors was established using a simple linear correlation model, with the Microsoft Excel programme [16].

Results and discussion

The foliar nitrogen fertilization in the series without magnesium generally contributed to a decrease in the levels of the analyzed ash nutrients. There were two exceptions, however, such as phosphorus and sodium, which slightly fluctuated under the influence of the above fertilization. The concentration of phosphorus was raised by 5 % at the most under the effect of the foliar application of 16 $kgN \cdot ha^{-1}$ compared with its level in tubers which had only received soil nitrogen fertilization (Fig. 1). The concentration of sodium increased nearly linearly under the applied foliar nitrogen fertilization (Fig. 2).

The applied magnesium fertilization did not demonstrate any significant effect on the content of phosphorus, although it produced such impact on the concentrations of sodium. In the treatments with a soil magnesium fertilization dose of 24 $kg \cdot ha^{-1}$, the concentration of sodium in potato tubers was significantly positively correlated with the rate of the applied foliar dose of nitrogen ($r = 0.83^*$). With respect to the series with foliar magnesium fertilization, a reverse correlation was determined ($r = -0.90^*$). In the light of the available literature, it can be concluded that the results of the present trials

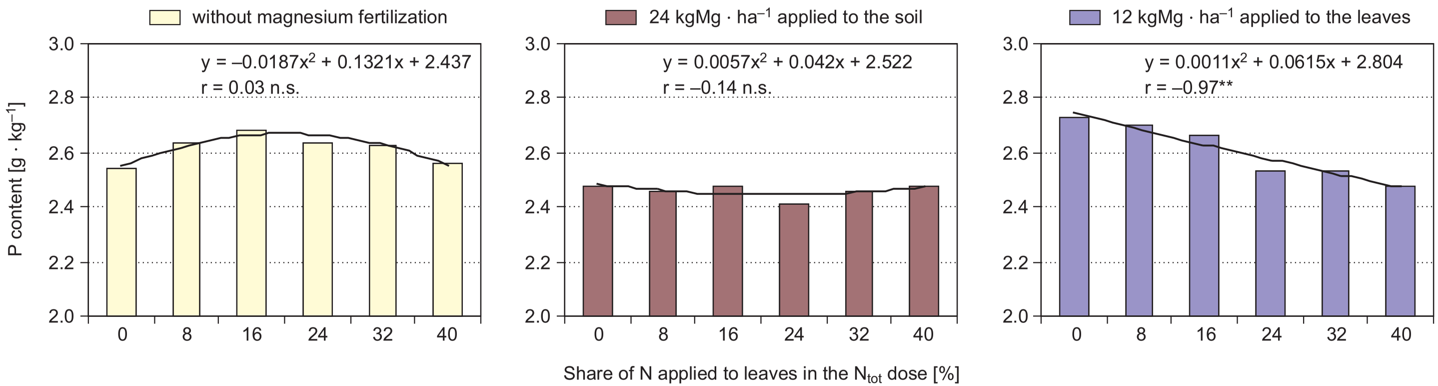

Fig. 1. Effect of foliar nitrogen and two magnesium fertilization technologies on the phosphorus (P) content in potato tubers
* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$

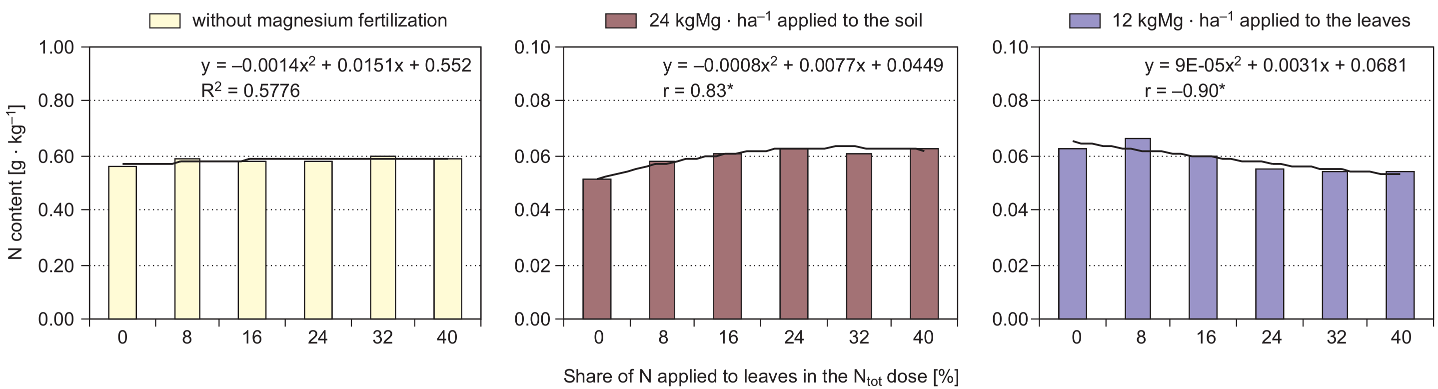

Fig. 2. Effect of foliar nitrogen and two magnesium fertilization technologies on the sodium (Na) content in potato tubers
* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$

are partly congruous with the reports which state that nitrogen fertilization has no influence on the content of phosphorus in potato tubers [17–20], although there are also such data which suggest that under the influence of rising nitrogen fertilization the accumulation of this element in potato tubers is enhanced [5, 21, 22].

The concentrations of the other ash nutrients, *ie* potassium, calcium and magnesium, under the influence of increasing foliar nitrogen fertilization tended to decrease, both in the series without magnesium nutrition and in the ones where magnesium was applied to soil or to leaves (Figs. 3, 4 and 5). At the same time, significant negative correlation coefficients were found between the volume of the foliar nitrogen dose and the concentrations of K, Ca and Mg, which suggest that the applied nitrogen had strongly diminished the content of these macronutrients in potato tubers. These coefficients ranged from r = –0.83* to r = –0.99**.

A highly significant negative correlation (r = –0.92** – r = –0.99**) between the rate of nitrogen sprayed over leaves and the content of in tubers suggests that there is a strong relationship between the rate of the applied nitrogen potassium fertilization and the effect consisting in depressed accumulation of potassium in potato tubers. Numerous studies indicate that nitrogen fertilization causes a decrease in the content of K in tubers [20, 24], or else has no effect on potassium levels [23]. However, reverse relationships were demonstrated in some previous studies [19], in which the accumulation of potassium was stimulated by foliar and soil nitrogen fertilization. In this experiment, the concentration of potassium in tubers was not affected by magnesium fertilization, which coincides with the data reported in the literature [19, 25]. Nevertheless, there are also reports suggesting a large decrease in the concentration of potassium in plants under the effect of magnesium fertilization [26].

The concentration of calcium in the analyzed potato tubers tended to decline under the influence of foliar nitrogen fertilization. No such effect had been found in some earlier investigations [19, 20]. Many researchers claim that magnesium fertilization has had some effect on the increased accumulation of calcium in potato [19, 26, 31]. In the present experiment, no effect of magnesium on the accumulation of calcium in potato tubers has been evidenced.

In respect to the concentration of magnesium, no significant decrease in its content in potato tubers was noted under the effect of foliar nitrogen fertilization. Many researchers claim that the concentration of magnesium does not change significantly under the influence of nitrogen fertilization [23]. The concentration of magnesium in plants tends to increase in response to nitrogen nutrition [27, 28]. What is worrying is that in both our earlier studies [19] and in the present trials, magnesium fertilization in any of the tested technologies did not lead to an increase in the concentration of this nutrient in tubers. Potatoes are one of the staple foodstuffs in an average diet in Poland and therefore are an important source of minerals, including magnesium. Magnesium is the second to potassium intercellular cation which occurs in the human organism. It has been experimentally demonstrated that Poles, compared with citizens of Western Europe, consume too little magnesium, and its deficit may lead to such disorders as hypercalcaemia, tetany, paraesthesia, tremor of the limbs, hypomagnesaemia, etc. [29, 30].

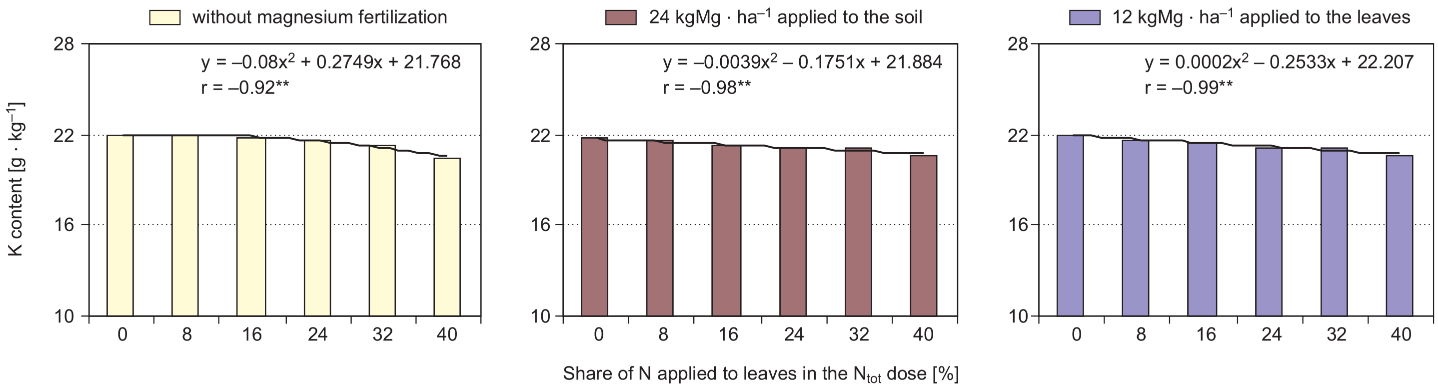

Fig. 3. Effect of foliar nitrogen and two magnesium fertilization technologies on the potassium (K) content in potato tubers
* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$

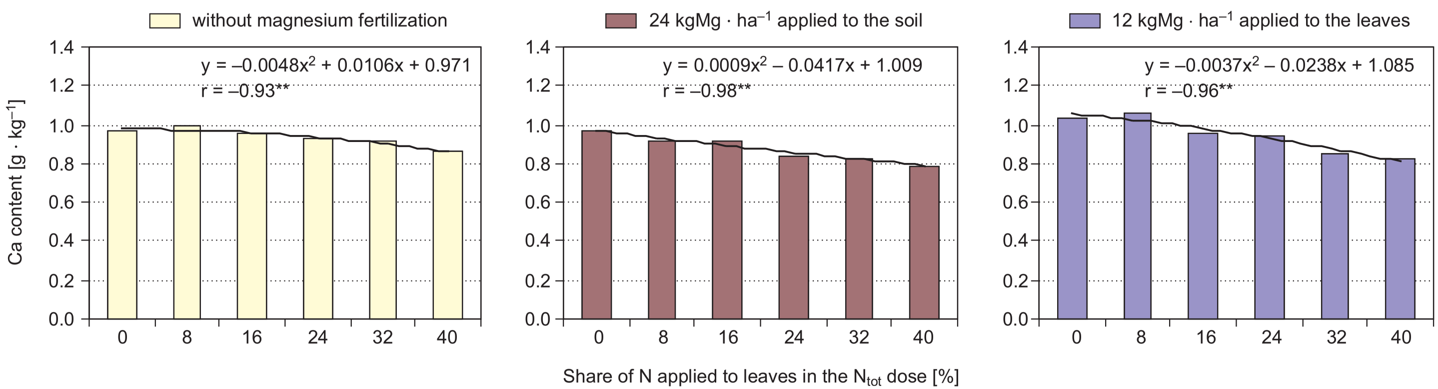

Fig. 4. Effect of foliar nitrogen and two magnesium fertilization technologies on the calcium (Ca) content in potato tubers
* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$

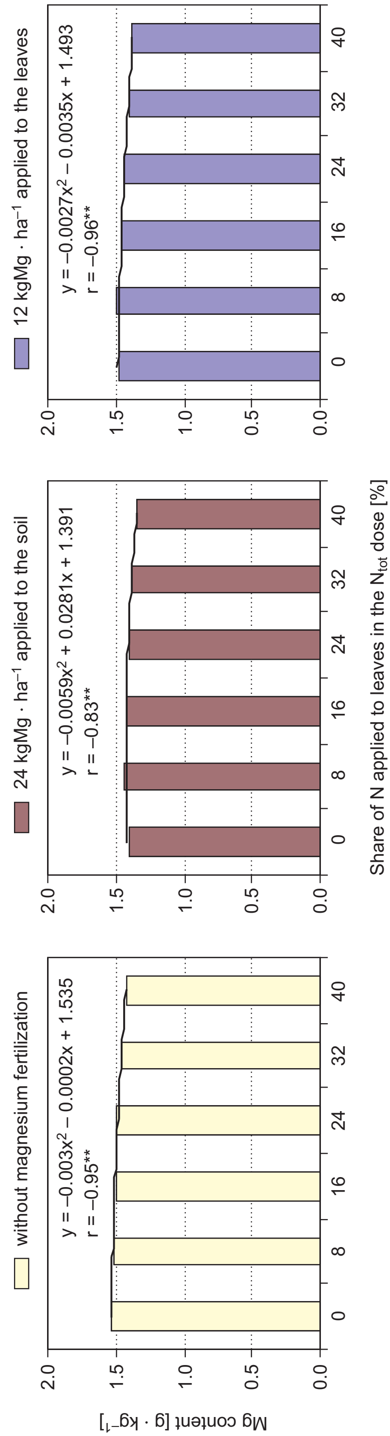

Fig. 5. Effect of foliar nitrogen and two magnesium fertilization technologies on the magnesium (Mg) content in potato tubers
* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$

In general, the decrease in the content of most ash macronutrients in potato tubers, as demonstrated by the present study, was negatively correlated with the rate of nitrogen sprayed over leaves. This effect is attributable to the accumulation of potassium by potato plants, as during this process some kind of ‘dilution’ of minerals occurred as a result of the growing mass of tubers, in which starch and water accumulated. This dilution effect was particularly evident in the treatments receiving a higher rate of foliar nitrogen fertilizer, which led to a decrease in the dry matter of tubers and the ash nutrients it contained.

Beside the general content of macronutrients in tubers, another important determinant of the potato tuber quality is the mutual ratios between these macronutrients, which characterize proportions of particular components in plant products [13]. Ionic ratios in plants are typically highly correlated with soil abundance in nutrients, and the synergistic or antagonists responses between ions in soil solution have a direct influence on the product such as the chemical composition of plants. In plant production, analysis of plant chemical composition may reveal which elements require special attention when making fertilization plans. The ionic ratios in plants cited in many papers [32–34] are mainly the ones found in fodder crops. The authors who are most often cited in the above articles are Korzeniowski [35], Underwood [36], Czuba and Mazur [13] and Falkowski et al [14]. The optimum values of such ratios, as suggested by the above authors, are K : (Ca + Mg) = (1.6–2.2) : 1, K : Mg = 6 : 1, K : Ca = 2 : 1, K : Na = (5–10) : 1, Ca : Mg = (2–3) : 1, K : Ca = 2 : 1 and a molar ratio of Ca : P = 2 : 1.

The optimum value of the Ca : P ratio determined by Underwood [36] is within the range of (1–7). As this proportion in the bone system is 2 : 2, many researchers quote the latter as an optimum value [14]. In the present study, the average value of the Ca : P molar ratio was very narrow, and on average equalled 0.28:1 (Table 1). Such a narrow Ca:P ratio suggests that the analyzed potato tubers had a very poor calcium supply.

This poor calcium supply can be confirmed by a very broad K : Ca ratio, which in fodder crops should equal 2 : 1 [13], whereas in the tubers analyzed in our study the average value of this ratio fell within the range of (11.6–12.4) : 1. The applied nitrogen fertilization contributed to a slight narrowing of the Ca : P ratio. For nutrition, the ratio between divalent cations Ca and Mg is very important. In the analyzed tubers, the value of this ratio was within (0.38–0.40) : 1, which is also indicative of a very poor calcium supply. The applied magnesium nutrition, whether to soil or to leaves, has not been demonstrated to improve this ratio. Potassium plays a very important role in potato fertilization. It is responsible for carbohydrate metabolism in plants. This element improves potato yields, simultaneously raising the content of starch in tubers. However, it is an element which plants take up luxuriously, which may lead to some unbalance between the content of the other elements, especially magnesium. When comparing the optimum values of the K : (Ca + Mg) ratio to the values obtained after potato harvest, very high accumulation of potassium was found in each fertilization series at the expense of divalent cations. The value of the K : (Ca + Mg) ratio ranged on average between (3.41–3.25) : 1, which was double the optimum value, *ie* (1.6–2.2) : 1 [13, 14]. The increasing foliar nitrogen fertilization contributed to the further broadening of this ratio. The computed K : Mg ratios suggest that magnesium was another element present

Table 1

Effect of foliar nitrogen fertilization and two magnesium fertilization technologies on the ionic ratios in potato tubers

Objects			Molar ratio	mval(+) ratios			
NPK fertilization to the soil	foliar N fertilization	Mg fertilization	Ca : P	Ca : Mg	K : (Ca+Mg)	K : Mg	K : Ca
1. N_{80} P_{35} K_{100}	—	series without Mg fertilization	0.30	0.38	3.21	4.44	11.6
2. N_{72} P_{35} K_{100}	N_8		0.29	0.40	3.24	4.53	11.4
3. N_{64} P_{35} K_{100}	N_{16}		0.27	0.38	3.26	4.52	11.8
4. N_{56} P_{35} K_{100}	N_{24}		0.27	0.38	3.25	4.47	11.9
5. N_{48} P_{35} K_{100}	N_{32}		0.27	0.38	3.29	4.53	12.0
6. N_{40} P_{35} K_{100}	N_{40}		0.26	0.37	3.28	4.48	12.2
		Mean:	0.28	0.38	3.25	4.49	11.8
Correlation coefficient between: share of N applied to leaves and ionic ratio			–0.97**	–0.74	0.89*	0.25	0.90*
7. N_{80} P_{35} K_{100}	—	24 kgMg · ha^{-1} applied before planting to the soil	0.30	0.42	3.38	4.79	11.5
8. N_{72} P_{35} K_{100}	N_8		0.29	0.39	3.37	4.68	12.0
9. N_{64} P_{35} K_{100}	N_{16}		0.28	0.39	3.35	4.65	12.0
10. N_{56} P_{35} K_{100}	N_{24}		0.27	0.36	3.42	4.65	12.9
11. N_{48} P_{35} K_{100}	N_{32}		0.26	0.36	3.47	4.74	13.0
12. N_{40} P_{35} K_{100}	N_{40}		0.25	0.35	3.51	4.75	13.4
		Mean:	0.28	0.38	3.41	4.71	12.4
Correlation coefficient between: share of N applied to leaves and ionic ratio			–0.99**	–0.94**	0.88*	–0.02	0.97**

Table 1 contd.

Objects			Molar ratio	mval(+) ratios			
NPK fertilization to the soil	foliar N fertilization	Mg fertilization	Ca : P	Ca : Mg	K : (Ca+Mg)	K : Mg	K : Ca
13. N_{80} P_{35} K_{100}	—	12 kgMg · ha^{-1} applied as foliar spraying	0.29	0.43	3.24	4.62	10.8
14. N_{72} P_{35} K_{100}	N_8		0.30	0.43	3.15	4.51	10.5
15. N_{64} P_{35} K_{100}	N_{16}		0.28	0.40	3.29	4.61	11.5
16. N_{56} P_{35} K_{100}	N_{24}		0.29	0.40	3.27	4.56	11.5
17. N_{48} P_{35} K_{100}	N_{32}		0.26	0.37	3.41	4.67	12.7
18. N_{40} P_{35} K_{100}	N_{40}		0.26	0.36	3.42	4.65	12.9
		Mean:	0.28	0.40	3.30	4.60	11.6
Correlation coefficient between: share of N applied to leaves and ionic ratio			–0.89*	–0.96**	0.86*	0.55	0.93**

* – correlation coefficient significant at $\alpha = 0.05$, ** – correlation coefficient significant at $\alpha = 0.01$.

in tubers in relatively high quantities. The K : Mg ratio was on average (4.49–4.71) : 1, whereas the optimum value has been cited to equal 6 : 1 [13]. By analyzing the relationships between the increasing foliar nitrogen fertilization and the calculated ratios, it was concluded that the Ca : P and Ca : Mg ratios were negatively correlated with the top-dressing rate of N. In turn, positive correlations between the N rate applied as top-dressing fertilizer were determined for the K : (Ca + Mg) and K : Ca ratios. At the same time, it was demonstrated that nitrogen fertilization had no effect on the K : Mg ratio.

Conclusions

1. In general, foliar nitrogen fertilization had a negative effect on the concentrations of phosphorus, potassium, calcium and magnesium in potato tubers. The concentration of sodium in tubers was an exception in that it rose nearly linearly (r = 0.83*) from 0.051 g N · kg to 0.063 gN · kg of tubers^{-1} in the series with soil magnesium fertilization under the effect of foliar application of nitrogen.

2. Magnesium fertilization did not have any significant effect on the concentration of phosphorus, potassium, calcium or magnesium in the tubers of the tested potato cultivar.

3. The calculated ratios of Ca : P, Ca : Mg and K : Ca suggest that the grown potato cultivar was very poorly supplied with calcium; in contrast, the values of K : (Ca + Mg) and K : Mg indicate a relatively high concentration of potassium and magnesium.

4. A negative correlation has been determined between the top-dressing N fertilization and the values of the Ca : P and Ca : Mg ratios and a positive one between the N rate and the values of K : (Ca + Mg) and K : Ca ratios.

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Abstrakt: W pracy przedstawiono wyniki badań dotyczące oddziaływania dolistnego nawożenia azotem i magnezem na zawartość makroskładników popielnych w bulwach ziemniaka jadalnego średnio wczesnej odmiany Zebra. Za podstawę badań przyjęto 3-letnie, II-czynnikowe doświadczenie polowe, które realizowano w latach 2005–2007 na polu Ośrodka Dydaktyczno-Doświadczalnego w Tomaszowie, należącego do Uniwersytetu Warmińsko-Mazurskiego w Olsztynie. Zastosowane nawożenie wynosiło 80 kgN, 35 kgP · ha^{-1} i 100 kgK · ha^{-1}. Czynnik I doświadczenia obejmował nawożenie dolistne azotem w zakresie (8; 40) kgN · ha^{-1} zmniejszając jednocześnie doglebową dawkę azotu. Czynnik drugi uwzględniał trzy serie: bez magnezu, z magnezem stosowanym doglebowo 24 kgMg · ha^{-1} oraz z magnezem stosowanym dolistnie w dawce 12 kgMg · ha^{-1}. Próby bulw analizowano na zawartość fosforu, potasu, wapnia, magnezu i sodu. Zawartość makroskładników w bulwach pod wpływem wzrastającego dolistnego nawożenia azotem generalnie ulegała obniżeniu. Wyjątek stanowiła zawartość fosforu, która wzrosła w serii nienawożonej magnezem pod wpływem 8 i 16 kgN oraz zawartość sodu, która w serii nawożonej Mg rosła do dawki 24 kgN stosowanego dolistnie. Średnie stosunki Ca : P = 0,28, Ca : Mg = 0,39 i K : Ca = 11,9 wskazują na bardzo słabe zaopatrzenie uprawianej odmiany w wapń, natomiast szerokie stosunki K : (Ca + Mg) = 3,32 i K : Mg = 4,60 świadczą o relatywnie wysokiej zawartości potasu i magnezu. Zastosowany dolistnie azot w istotny sposób wpłynął na kształtowanie stosunków pomiędzy składnikami popielnymi w bulwach. Stwierdzono, że wraz ze wzrostem pogłównej dawki N następowało zawężanie stosunku Ca : P i Ca : Mg oraz poszerzenie K : (Ca + Mg) oraz K : Ca. Zastosowane nawożenie nie miało wpływu na stosunek K : Mg.

Słowa kluczowe: makroskładniki, nawożenie mineralne, azot, magnez, solanum tuberosum, ziemniak