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# CONTENT AND UPTAKE OF SELECTED MACROELEMENTS WITH THE YIELD OF POTATO TUBERS DEPENDING ON HERBICIDES AND BIOSTIMULANTS*

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## Abstract

Field trails set up on very light and light soil were conducted in 2012-2014. The experiment was designed in triplicates, using the method of random sub-blocks in a split-plot system. The investigated factors were: I – three varieties of edible potato: Bartek, Gawin and Honorata, II – five ways of management: 1) control object – with mechanical weed control; 2) the herbicide Harrier 295 ZC – 2.0 $dm^3$ $ha^{-1}$; 3) the herbicide Harrier 295 ZC – 2.0 $dm^3$ $ha^{-1}$ with the biostimulant Kelpak SL – 4.0 $dm^3$ $ha^{-1}$; 4) the herbicide Sencor 70 WG – 1.0 kg $ha^{-1}$; 5) the herbicide Sencor 70 WG – 1.0 kg $ha^{-1}$ with the biostimulant Asahi SL – 1.5 $dm^3$ $ha^{-1}$. The aim of the study was to determine the influence of herbicides and biostimulants on the content and uptake of the selected macroelements: phosphorus, calcium and magnesium, with the yield of potato tubers. The content of phosphorus, calcium and magnesium and their uptake with the yield of tubers depended significantly on the varieties, weed control and weather conditions during the growth season. The highest mean phosphorus content was found in the variety Bartek and the highest mean levels of calcium and magnesium were determined in the variety Honorata. The variety Honorata was also distinguished by the highest ability to take up macroelements with the yield of tubers. The highest content and uptake of phosphorus, calcium and magnesium were noted in tubers collected in the treatments (4, 5) where a mixture of Sencor 70 WG herbicide at a dose of 1.0 kg $ha^{-1}$ with the Asahi SL biostimulant at a dose of 1.5 $dm^3$ $ha^{-1}$ was used.

**Keywords**: potato, herbicides, biostimulators, phosphorus, calcium, magnesium.

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## INTRODUCTION

In addition to basic nutrients (starch, protein, total sugars), the fresh mass of potato tubers contains 1-1.2% of mineral compounds, which are classified as macro- and microelements. Macroelements are components taken up by plants in relatively large quantities at different stages of development. They include potassium, phosphorus, magnesium and calcium. These elements are building blocks of plant organisms, play physiological functions in plants and determine their dietary value (Leszczyński 2000, Wierzbicka 2012, Żołnowski 2013). Phosphorus is an essential component of energy-efficient compounds. It is a component of specific proteins and takes part in carbohydrate metabolism. The content of phosphorus in potato tubers, according to Zarzecka and Gąsiorowska (2000), is from 1.9 to 2.0 g $kg^{-1}$ although the phosphorus concentrations in a trial reported by Wierzbicka (2012) varied within 1.8-3.9 g $kg^{-1}$.

Calcium is considered to be an element of good growth and plant development. The calcium content in potato tubers in national research varied from 0.3 to 0.6 g $kg^{-1}$ (Kołodziejczyk, Szmigiel 2005, Wierzbicka 2012). Magnesium is an important component of potato tubers. Its presence in the plant determines the basic processes of metabolism and energy. Magnesium not only participates in about 300 enzymatic reactions but is also an active centre of chlorophyll molecules. The magnesium content in the dry matter in potato tubers determined by Wierzbicka (2012) was 0.8-1.3 g $kg^{-1}$. Similar magnesium amounts were shown by Zarzecka, Gąsiorowska (2000) and Żołnowski (2013).

The environmental and genetic factors affect the concentration of minerals in tubers (Sawicka 2000, Żołnowski 2013, Horvat et al. 2014, Lombardo et al. 2014). Many authors have shown the favourable effect of biostimulants on the chemical composition of potato tubers (Klikocka 2001, Maciejewski et al. 2007, Trawczyński 2014, Wierzbowska et al. 2016).

Therefore, the purpose of the study was to determine the effect of selected herbicides and biostimulants on the content and uptake of phosphorus, calcium and magnesium with the yield of three varieties of edible potato.

## MATERIAL AND METHODS

The field experiments were carried out in 2012-2014 on a farm in the village Wojnów, the District of Siedlce, Mazovia Province. The experiment was set up in a split-plot system in triplicates. Soil samples for analysis were taken each year before the experiment was established. $pH_{KCl}$ = 5.5-6.5 is considered to be in an optimal range of the pH values measured in 1M KCl $dm^{-3}$ ($pH_{KCl}$) solution for potato cultivation (Nowacki et al. 2013).

Table 1

The acidity of the soil and the content of available forms of soil potassium, phosphorus, magnesium and organic matter

| Years | pH (1 mol KCl $dm^{-3}$) | Content of K (mg $kg^{-1}$) | Content of P (mg $kg^{-1}$) | Content of Mg (mg $kg^{-1}$) | Organic matter (g $kg^{-1}$) |
|---|---|---|---|---|---|
| 2012 | 5.60 – slightly acidic | 149.4 (very high) | 68.6 (high) | 50.0 (high) | 15.0 |
| 2013 | 5.60 – slightly acidic | 129.0 ( high) | 73.4 (high) | 51.0 (high) | 16.0 |
| 2014 | 6.35 – neutral | 149.4 (medium) | 110.0 (very high) | 56.0 (high) | 18.7 |

In the years of the experiment, the soil had a variable content of organic matter and available macroelements (Table 1). In 2012 and 2013, the soil was characterised by slightly acidic reaction but in the last year of the r esearch its pH was neutral. The organic matter content varied from 15.0 to 18.7 g $kg^{-1}$. The content of available phosphorus (P) ranged between high and very high, the potassium (K) content varied from average to very high and the magnesium (Mg) content was determined to be high.

The experiment analysed the effect of two factors: I factor – three medium early varieties of edible potato: Bartek, Gawin and Honorata, II factor – five ways of using herbicides and biostimulators: 1) control object – mechanical management; 2) Harrier 295 ZC herbicide at a dose of 2.0 $dm^3$ $ha^{-1}$; 3) Harrier 295 ZC herbicide at a dose of 2.0 $dm^3$ $ha^{-1}$ with the Kelpak SL biostimulant at a dose of 4.0 $dm^3$ $ha^{-1}$; 4) Sencor 70 WG herbicide – 1.0 kg $ha^{-1}$; 5) Sencor 70 WG herbicide – 1.0 kg $ha^{-1}$ with the Asahi SL biostimulant – 1.5 $dm^3$ $ha^{-1}$. Harrier 295 ZC was applied 7-10 days after planting, Sencor 70 WG was used before emergence and the biostimulants Asahi SL and Kelpak SL were supplied twice: during full emergence and during the ridging treatment. Winter wheat was the forecrop for the potato during the research. After harvesting the forecrop, typical post-harvesting soil cultivation was carried out. In the autumn of each year, prior to potato planting, natural fertilisers were used, such as farmyard manure in an amount of 25.0 t $ha^{-1}$, and phosphorus--potassium mineral fertilisation in amounts of 44.0 kg P $ha^{-1}$ and 124.5 kg K $ha^{-1}$ (Lubofos for potatoes 7% P and 25% K) was applied. The fertilisers were incorporated into the soil during a pre-winter ploughing treatment. Nitrogen fertilisers were sown in spring in a dose of 100 kg N $ha^{-1}$ (Saletrzak 27%), mixed with the soil using a cultivator.

Potatoes were harvested in the phase of technological maturity of tubers. The content of phosphorus in potato tubers was determined with the spectrophotometric method. Calcium and magnesium were determined by atomic absorption spectrometry ASA.

The results of the study were statistically tested using variance analysis. Significance of the sources of variability was tested with the Fisher-Snedecor

*F* test, and the significance of differences between the compared means was assessed with the Tukey's test at *P* = 0.05.

The weather conditions in the years of the research were described based on average air temperature and total precipitation data obtained from the Zawady Meteorological Station. The Selyaninov hydrothermal coefficient was calculated from these meteorological data.

The year 2012 was characterised by slight drought (Table 2). This season was characterised by lower total precipitation during the plant growing season than in the other years of research. The total rainfall was 264.9 mm, less than the long-term average by 10.6 mm, and the average temperature in the plant growing season (April – September) was 15.4°C. The year 2013 was extremely humid, with temperatures close to the long-term average. This was confirmed by the K coefficient, which equalled 1.60. The third year of the experiment was warm according to the air temperature parameter (ŁYCZKO et al. 2000), and wet, with the total rainfall of 335.1 mm. The Selyaninov coefficient (*K* = 1.20) values confirm the absence of drought (Table 2).

Table 2

Weather conditions during the potato growing season

| Months | Selyaninov hydrothermal coefficient (K) | | |
|---|---|---|---|
| | 2012 | 2013 | 2014 |
| April | 1.10 | 1.60 | 1.50 |
| May | 1.20 | 2.30 | 2.30 |
| June | 1.60 | 1.80 | 1.20 |
| July | 0.69 | 1.60 | 0.16 |
| August | 0.94 | 0.30 | 1.90 |
| September | 0.27 | 2.70 | 0.62 |
| April-September | 0.95 | 1.60 | 1.20 |
| Rainfall (mm) | 264.9 | 441.3 | 335.1 |
| Air temperature (°C) | 15.4 | 15.0 | 15.3 |

Long-term means for 1987-2000: rainfall 275.2 mm; temperature 14.7°C;
Coefficient value: to 0.5 severe drought, 0.51-0.69 drought, 0.70-0.99 weak drought, ≥1 no drought

# RESULTS AND DISCUSSIONS

## The content and uptake of phosphorus

The research indicates that the varietal features were the dominant factor that significantly affected the phosphorus content in potato tubers (Table 3). The variety that contained the most of this element was cv. Bartek, followed

Table 3

Content of phosphorus in potato tubers (g kg$^{-1}$ DM)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 3.600 | 3.453 | 3.333 | 3.462 |
| Harrier 295 ZC | 3.600 | 3.453 | 3.440 | 3.498 |
| Harrier 295 ZC + Kelpak SL | 3.633 | 3.550 | 3.467 | 3.550 |
| Sencor 70 WG | 3.600 | 3.537 | 3.467 | 3.535 |
| Sencor 70 WG + Asahi SL | 3.767 | 3.577 | 3.503 | 3.616 |
| Mean | 3.640 | 3.514 | 3.442 | 3.532 |
| Gawin | | | | |
| Control object | 3.300 | 3.247 | 3.237 | 3.261 |
| Harrier 295 ZC | 3.300 | 3.253 | 3.250 | 3.268 |
| Harrier 295 ZC + Kelpak SL | 3.400 | 3.410 | 3.277 | 3.362 |
| Sencor 70 WG | 3.483 | 3.483 | 3.283 | 3.416 |
| Sencor 70 WG + Asahi SL | 3.650 | 3.487 | 3.317 | 3.485 |
| Mean | 3.427 | 3.376 | 3.273 | 3.359 |
| Honorata | | | | |
| Control object | 3.350 | 3.143 | 3.183 | 3.225 |
| Harrier 295 ZC | 3.367 | 3.187 | 3.240 | 3.265 |
| Harrier 295 ZC + Kelpak SL | 3.400 | 3.200 | 3.243 | 3.281 |
| Sencor 70 WG | 3.367 | 3.210 | 3.270 | 3.282 |
| Sencor 70 WG + Asahi SL | 3.600 | 3.237 | 3.280 | 3.272 |
| Mean | 3.417 | 3.195 | 3.243 | 3.285 |
| Mean for varieties | | | | |
| Control object | 3.417 | 3.281 | 3.251 | 3.316 |
| Harrier 295 ZC | 3.422 | 3.298 | 3.310 | 3.343 |
| Harrier 295 ZC + Kelpak SL | 3.478 | 3.387 | 3.290 | 3.385 |
| Sencor 70 WG | 3.483 | 3.410 | 3.340 | 3.411 |
| Sencor 70 WG + Asahi SL | 3.672 | 3.434 | 3.367 | 3.491 |
| Mean | 3.495 | 3.362 | 3.319 | 3.392 |
| $LSD_{0.05}$ for: | *a* – 0.062, *b* – 0.077, *c* – 0.062 | | | |

Explanation: *a* – variety, *b* – objects, *c* – years

by cv. Gawin and Honorata. Among the crop protection methods tested in the presented studies, only Sencor 70 WG significantly increased the phosphorus content in tubers of the tested varieties. The use of the biostimulant Asahi significantly improved the effect of this herbicide by further increasing the phosphorus content in tubers. This relationship was not demonstrated by the herbicide Harrier 295 ZC and the biostimulant Kelpak. Another factor that significantly modified the content of phosphorus consisted of the hydrothermal conditions prevailing in the years of the study. A high content of phosphorus was found in tubers harvested in 2012, when the sum of rainfall was 176, being about 70 mm lower than in 2014 (Table 2). The question of the impact of herbicidal protection on the content of nutrients in tubers was investigated by Leszczyński and Lisińska (1985). These authors analysed the influence of the herbicides Sencor, Bladex, Topogard, Afalon and Aresin, showing that the content of phosphorus in tubers was significantly modified only by Afalon and Bladex. In our experiment, a significant impact was also obtained when applying the herbicide Sencor 70 WG alone and in conjunction with the biostimulant Asahi. A reverse direction of changes in the phosphorus content in tubers to the one demonstrated by Leszczyński and Lisińska (1985) was observed by Klikocka (2001), who showed that herbicidal protection with preparations caused a decrease in the content of phosphorus. Similar effects were also obtained by Gugała et al. (2015), who demonstrated a tendency towards a lower phosphorus content in tubers from plots treated with the herbicides Plateen, Racer and Sencor. On the other hand, Ceglarek and Księżak (1992), having examined the influence of Antyperz, Roundup, Fusilade and Afalon, did not report any changes with regard to the phosphorus content in tubers influenced by the above herbicides. In light of the current research, it appears that the content of phosphorus in tubers depends mainly on the type of a herbicide and the mechanism of its impact on plants and on hydrothermal conditions that directly affect the weed infestation of a plantation. In wet years, the weeding of the plantation increases along with the competitiveness of plants, which may result in a lower content of ingredients. In the presented studies, after the application of an effective herbicide (Sencor 70 WG), weed infestation was reduced, thus ensuring a better supply of tubers with phosphorus, an effect additionally supported by the Asahi SL biostimulant, where the phosphorus content increased significantly. The confirmation of these results can be found in the experiment conducted by Wierzbowska et al. (2016), in which the authors showed an increase in the phosphorus content in tubers after Asahi SL and Kelpak SL application. The use of herbicide protection and biostimulants reduces the competitiveness of weeds towards cultivated plants, which allows potato producers to obtain higher crop yields. Potato and other plants take phosphorus, calcium and magnesium from the soil solution in the form of cations. It is assumed that the increasing yield of potato in recent years has caused the reduction in concentrations of minerals in tubers, due to dilution resulting from the plants' faster growth and the ability to accumulate these elements. In this study, the variety Bartek was characterised by the smallest average phosphorus uptake (31.25 kg ha$^{-1}$), and the variety Honorata showed the highest average uptake of the element (34.79 kg ha$^{-1}$) with the tuber yield (Table 4). The highest phosphorus uptake capacity was recorded in the treatments where a mixture of the herbicide Sencor 70 WG and biostimulant

Table 4

Uptake of phosphorus with the yield of potato tubers (kg $ha^{-1}$)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 36.06 | 21.94 | 19.48 | 25.83 |
| Harrier 295 ZC | 38.67 | 24.93 | 22.41 | 28.67 |
| Harrier 295 ZC + Kelpak SL | 47.73 | 26.10 | 23.28 | 32.37 |
| Sencor 70 WG | 46.36 | 27.27 | 26.34 | 33.32 |
| Sencor 70 WG + Asahi SL | 50.30 | 29.31 | 28.56 | 36.06 |
| Mean | 43.82 | 25.91 | 24.01 | 31.25 |
| Gawin | | | | |
| Control object | 34.42 | 23.15 | 21.09 | 26.22 |
| Harrier 295 ZC | 38.03 | 27.57 | 23.61 | 29.74 |
| Harrier 295 ZC + Kelpak SL | 46.39 | 27.57 | 24.68 | 33.42 |
| Sencor 70 WG | 48.58 | 29.97 | 28.03 | 35.53 |
| Sencor 70 WG + Asahi SL | 53.17 | 31.32 | 29.99 | 38.16 |
| Mean | 43.92 | 28.24 | 25.48 | 32.61 |
| Honorata | | | | |
| Control object | 31.82 | 25.81 | 25.45 | 27.69 |
| Harrier 295 ZC | 37.86 | 33.50 | 28.38 | 33.25 |
| Harrier 295 ZC + Kelpak SL | 41.09 | 33.00 | 30.79 | 34.96 |
| Sencor 70 WG | 41.43 | 34.20 | 38.29 | 37.97 |
| Sencor 70 WG + Asahi SL | 44.57 | 36.86 | 38.88 | 40.10 |
| Mean | 39.35 | 32.67 | 32.36 | 34.79 |
| Mean for varieties | | | | |
| Control object | 34.10 | 23.63 | 22.01 | 26.58 |
| Harrier 295 ZC | 38.19 | 28.68 | 24.80 | 30.56 |
| Harrier 295 ZC + Kelpak SL | 45.07 | 29.43 | 26.25 | 33.58 |
| Sencor 70 WG | 45.46 | 30.48 | 30.89 | 35.61 |
| Sencor 70 WG + Asahi SL | 49.35 | 32.50 | 32.48 | 38.11 |
| Mean | 42.43 | 28.94 | 27.28 | 32.89 |
| $LSD_{0.05}$ for: | $a$ – 1.84, $b$ – 2.03, $c$ – 1.84, $b \cdot c$ – 3.52, $a \cdot c$ – 3.18, | | | |

Explanation: *a* – variety, *b* – objects, *c* – years

Asahi SL or the herbicide Sencor 70 WG alone were used. After the application of Sencor 70 WG with the biostimulant Asahi SL at a dose of 1.5 $dm^3$ $ha^{-1}$, the uptake P with the tuber yield was 38.11 kg $ha^{-1}$ . In the analysed plant growing seasons, significant differentiation of the phosphorus uptake with tubers yield was noted. In 2012, the highest phosphorus uptake was achieved by a relatively high yield of 39.80 t of tubers per ha, an effect attributed to better hydrothermal conditions (Table 2). High humidity (as indicated by the coefficient *K* = respectively 1.60 and 1.20) with lower yields (33.37 and 31.68 t $ha^{-1}$) in connection with the lower phosphorus content in tubers resulted in a lower uptake of phosphorus per hectare in 2013 and 2014.

The tested herbicide protection methods produced varied effects on the phosphorus uptake by the yield of tubers, as evidenced by the demonstrated interactions of treatments x years. In 2012 and 2014, the highest amounts of phosphorus were determined in tubers harvested from the treatment protected with the herbicide Sencor 70 WG. A slightly lower but also significant intake of this component was demonstrated after the use of the herbicide Harrier 295 ZC. The biostimulants Asahi SL and Kelpak SL significantly increased the phosphorus uptake by the yield of tubers of the tested varieties. In 2013, a year with the highest rainfall sum in the April-September period, the chemical preparations applied also increased the phosphorus uptake by potato tubers compared to the control plot, but no major differences in the performance of individual preparations were found, and the tested treatments constituted a homogenous group in this respect with the exception of the treatment with Sencor 70 WG + Asahi SL. Żołnowski (2013) stated that the phosphorus content was significantly influenced by a variety whereas the applied NPK fertilisation did not differentiate this property significantly. The cited author also showed that the content of phosphorus in tubers decreased during the growing season.

## Content and uptake of calcium

The tested varieties reacted in a specific way to the prevailing thermal and moisture conditions in the growing seasons, as evidenced by the demonstrated variety x years interaction values. The varieties Bartek and Honorata increased in the calcium content in tubers in the dry year (*K*=0.95) – Table 2. The herbicides Sencor 70 WG and Harrier 295 ZC used in the experiment significantly increased the calcium content in tubers. The use of the biostimulants Asahi SL and Kelpak SL improved the effect of the herbicides by significantly increasing the calcium content in tubers. The effects of the herbicide Sencor 70 WG and biostimulant Asahi SI were influenced by the atmospheric conditions, as indicated by the treatment x years interactions. The herbicide Sencor 70 WG and biostimulant Asahi Sl caused a significant increase in the calcium content in 2012, which was characterised by a favourable distribution of temperatures and precipitation during the potato vegetation (Table 5). Wierzbowska et al. (2016), having analysed the impact of the biostimulants Asahi Sl, Bio-Algen S90 and Kelpak SL, showed that the content of calcium in tubers was significantly modified only by Asahi Sl. Whereas Gugała et al. (2012), who analysed the effects of Plateen 41.5 WG, Sensor 70 WG and Racer 250 EC, showed a significant increase in the calcium content in potato tubers under the influence of these herbicides. In the opinion

Table 5

Content of calcium in potato tubers (g kg$^{-1}$ DM)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 0.650 | 0.700 | 0.713 | 0.688 |
| Harrier 295 ZC | 0.733 | 0.723 | 0.747 | 0.734 |
| Harrier 295 ZC + KelpakSL | 0.800 | 0.723 | 0.767 | 0.763 |
| Sencor 70 WG | 0.817 | 0.743 | 0.753 | 0.771 |
| Sencor 70 WG + Asahi SL | 0.856 | 0.743 | 0.773 | 0.791 |
| Mean | 0.771 | 0.726 | 0.751 | 0.749 |
| Gawin | | | | |
| Control object | 0.647 | 0.620 | 0.710 | 0.659 |
| Harrier 295 ZC | 0.653 | 0.630 | 0.740 | 0.674 |
| Harrier 295 ZC + KelpakSL | 0.673 | 0.625 | 0.770 | 0.689 |
| Sencor 70 WG | 0.660 | 0.657 | 0.720 | 0.679 |
| Sencor 70 WG + Asahi SL | 0.673 | 0.660 | 0.743 | 0.692 |
| Mean | 0.661 | 0.638 | 0.737 | 0.679 |
| Honorata | | | | |
| Control object | 0.700 | 0.730 | 0.740 | 0.723 |
| Harrier 295 ZC | 0.837 | 0.740 | 0.750 | 0.776 |
| Harrier 295 ZC + Kelpak SL | 0.850 | 0.737 | 0.753 | 0.780 |
| Sencor 70 WG | 0.833 | 0.757 | 0.777 | 0.789 |
| Sencor 70 WG + Asahi SL | 0.860 | 0.767 | 0.790 | 0.806 |
| Mean | 0.816 | 0.764 | 0.763 | 0.775 |
| Mean for varieties | | | | |
| Control object | 0.666 | 0.683 | 0.721 | 0.690 |
| Harrier 295 ZC | 0.741 | 0.698 | 0.746 | 0.728 |
| Harrier 295 ZC + Kelpak SL | 0.774 | 0.695 | 0.763 | 0.744 |
| Sencor 70 WG | 0.770 | 0.719 | 0.750 | 0.746 |
| Sencor 70 WG + Asahi SL | 0.796 | 0.723 | 0.769 | 0.763 |
| Mean | 0.749 | 0.703 | 0.750 | 0.734 |
| $LSD_{0.05}$ for: | $a$ – 0.019, $b$ – 0.032, $c$ – 0.019, $b \cdot c$ – 0.056, $a \cdot c$ – 0.033, | | | |

Explanation: $a$ – variety, $b$ – objects, $c$ – years

of Ceglarek, Księżak (1992), chemical plant protection products do not significantly affect the concentration of calcium in tubers. In our experiment, the weather conditions during the research years significantly affected the calcium concentration and the uptake by the yield of potato tubers. The smallest concentration and intake of calcium were determined in 2013, a year characterised by excessive rainfall (441.3 mm) compared to the long-term average sum and the lowest temperatures during the plant growing season among all the years tested. The average calcium uptake in potato tubers depended significantly on the varietal factor (Table 6). The highest calcium uptake capacity with the yield of tubers was noted in the variety Honorata and the lowest one was demonstrated by cv. Gawin. The herbicidal chemicals used in the experiment significantly increased the calcium uptake in all the experimental variants. The highest concentration of calcium was obtained in 2012, which was a year with the smallest average rainfall and the highest air temperature. The smallest concentration and uptake of calcium were obtained in 2013 (Table 6), a year characterised by excessive rainfall compared to the long-term average sum and the lowest temperatures during the plant growing season among all the years tested. The highest calcium intake appeared in 2012, with the highest yield of tubers (39.80 t $ha^{-1}$), when the total rainfall was lower than in 2013 or 2014, equal to 264.9 mm. A significant dependence was demonstrated between years and methods of application of herbicides and biostimulants, which confirms the diverse effects of the preparations used in the seasons on the uptake of calcium with tubers yield. The largest amounts of calcium were absorbed in 2012 and 2014 by potatoes from the plot treated with Sensor 70 WG together with the Asahi SL biostimulant. Lower calcium uptake, but also significant, was shown in the remaining treatments.

**Content and uptake of magnesium**

The research shows that the genetic factor had a significant effect on the magnesium content in potato tubers (Table 7). The interactions between the varieties and the years prove a variety-specific response to the weather conditions in the years of research. The highest average magnesium content was obtained in the variety Honorata in 2012 (with the lowest rainfall). Tubers originating from plots treated with herbicides and biostimulants, relative to the control, were characterised by a significantly higher content of magnesium. The magnesium content in tubers was significantly modified by the herbicide Sensor 70 WG and biostimulant Asahi SL. In the experiment by Wierzbowska et al. (2016), the magnesium content in tubers was significantly modified only by Asahi SL, unlike Bio-Algen S90 and Kelpak SL. Gugała et al. (2012) showed that of the three tested herbicides: Plateen, Racer and Sencor, Sencor caused the highest increase in the magnesium content. Wierzbowska et al. (2016) found a significant effect of the genetic factor on the magnesium levels in potato tubers. The confirmed magnesium content in tubers in studies completed in Poland varies between 0.9 g $kg^{-1}$ and 1.2 g $kg^{-1}$ (Ciećko et al. 2010, Żołnowski, 2010), while abroad Tekalign and Hammes (2005) reported a higher content of this element: 2.4 g $kg^{-1}$ - 2.9 g $kg^{-1}$, and White et al. (2009) demonstrated as much as 5 g $kg^{-1}$ - 10 g $kg^{-1}$. In addition to the varietal factor and the herbicides used, the hydrothermal conditions prevailing in the years studied significantly modified the magne-

Table 6

Uptake of calcium with the yield of potato tubers (kg $ha^{-1}$)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 6.54 | 4.44 | 4.16 | 5.05 |
| Harrier 295 ZC | 7.88 | 5.23 | 4.87 | 5.99 |
| Harrier 295 ZC + KelpakSL | 10.54 | 5.32 | 5.15 | 7.00 |
| Sencor 70 WG | 10.49 | 5.71 | 5.69 | 7.30 |
| Sencor 70 WG + Asahi SL | 10.93 | 6.09 | 6.28 | 7.77 |
| Mean | 9.28 | 5.36 | 5.23 | 6.62 |
| Gawin | | | | |
| Control object | 6.80 | 4.42 | 4.63 | 5.28 |
| Harrier 295 ZC | 7.44 | 5.34 | 5.37 | 6.05 |
| Harrier 295 ZC + Kelpak SL | 9.20 | 5.54 | 5.79 | 6.84 |
| Sencor 70 WG | 9.20 | 5.64 | 6.14 | 6.99 |
| Sencor 70 WG + Asahi SL | 9.80 | 5.93 | 6.73 | 7.49 |
| Mean | 8.49 | 5.37 | 5.73 | 6.53 |
| Honorata | | | | |
| Control object | 6.66 | 5.99 | 5.92 | 6.19 |
| Harrier 295 ZC | 9.41 | 7.78 | 6.57 | 7.92 |
| Harrier 295 ZC + Kelpak SL | 10.29 | 7.59 | 7.14 | 8.34 |
| Sencor 70 WG | 10.33 | 8.07 | 9.09 | 9.16 |
| Sencor 70 WG + Asahi SL | 10.60 | 7.90 | 9.37 | 9.29 |
| Mean | 9.46 | 7.47 | 7.62 | 8.18 |
| Mean for varieties | | | | |
| Control object | 6.67 | 4.95 | 4.90 | 5.51 |
| Harrier 295 ZC | 8.24 | 6.12 | 5.60 | 6.65 |
| Harrier 295 ZC + Kelpak SL | 10.01 | 6.15 | 6.03 | 7.40 |
| Sencor 70 WG | 10.00 | 6.47 | 6.97 | 7.81 |
| Sencor 70 WG + Asahi SL | 10.44 | 6.64 | 7.46 | 8.18 |
| Mean | 9.07 | 6.07 | 6.19 | 7.11 |
| $LSD_{0.05}$ for: | $a$ – 0.48, $b$ – 0.51, $c$ – 0.48, $b \cdot c$ – 0.88, $a \cdot c$ – 0.83 | | | |

Explanation: *a* – variety, *b* – objects, *c* – years

sium content in tubers. The least of this element was accumulated in all varieties in 2014, which was most diverse in terms of humidity. The magnesium uptake by tubers has depended significantly on a variety, a way of applying herbicides and biostimulants and on the weather conditions. This study has shown that the variety Honorata was characterised by the highest

Table 7

Content of magnesium in potato tubers (g kg$^{-1}$ DM)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 1.217 | 1.203 | 1.200 | 1.207 |
| Harrier 295 ZC | 1.243 | 1.230 | 1.223 | 1.232 |
| Harrier 295 ZC + KelpakSL | 1.253 | 1.270 | 1.243 | 1.255 |
| Sencor 70 WG | 1.243 | 1.240 | 1.230 | 1.238 |
| Sencor 70 WG + Asahi SL | 1.257 | 1.270 | 1.267 | 1.265 |
| Mean | 1.243 | 1.243 | 1.233 | 1.240 |
| Gawin | | | | |
| Control object | 1.270 | 1.330 | 1.260 | 1.287 |
| Harrier 295 ZC | 1.350 | 1.340 | 1.270 | 1.320 |
| Harrier 295 ZC + Kelpak SL | 1.350 | 1.363 | 1.270 | 1.328 |
| Sencor 70 WG | 1.357 | 1.353 | 1.263 | 1.324 |
| Sencor 70 WG + Asahi SL | 1.383 | 1.370 | 1.280 | 1.344 |
| Mean | 1.342 | 1.351 | 1.269 | 1.321 |
| Honorata | | | | |
| Control object | 1.433 | 1.346 | 1.303 | 1.361 |
| Harrier 295 ZC | 1.600 | 1.367 | 1.327 | 1.431 |
| Harrier 295 ZC + Kelpak SL | 1.633 | 1.387 | 1.330 | 1.450 |
| Sencor 70 WG | 1.600 | 1.387 | 1.330 | 1.439 |
| Sencor 70 WG + Asahi SL | 1.600 | 1.420 | 1.340 | 1.453 |
| Mean | 1.573 | 1.381 | 1.326 | 1.427 |
| Mean for varieties | | | | |
| Control object | 1.306 | 1.293 | 1.254 | 1.284 |
| Harrier 295 ZC | 1.398 | 1.312 | 1.273 | 1.328 |
| Harrier 295 ZC + Kelpak SL | 1.412 | 1.340 | 1.281 | 1.344 |
| Sencor 70 WG | 1.400 | 1.327 | 1.274 | 1.334 |
| 5. Sencor 70 WG + Asahi SL | 1.413 | 1.353 | 1.296 | 1.354 |
| Mean | 1.386 | 1.325 | 1.276 | 1.329 |
| $LSD_{0.05}$ for: | $a$ – 0.028, $b$ – 0.042, $c$ – 0.028, $a \cdot c$ – 0.048 | | | |

Explanation: $a$ – variety, $b$ – objects, $c$ – years

average uptake, and the variety Bartek took up the smallest average quantitity of this element with the tuber yield (Table 8). Tubers from the plots treated with herbicides and biostimulants (variants 2-5), compared to the control, were characterised by a significantly higher magnesium uptake. The highest uptake of this element was recorded in tubers collected from

Table 8

Uptake of magnesium with the yield of potato tubers (kg ha$^{-1}$)

| Objects | Years | | | Mean |
|---|---|---|---|---|
| | 2012 | 2013 | 2014 | |
| Bartek | | | | |
| Control object | 12.16 | 7.65 | 7.01 | 8.94 |
| Harrier 295 ZC | 13.36 | 8.88 | 7.95 | 10.06 |
| Harrier 295 ZC + KelpakSL | 16.47 | 9.34 | 8.34 | 11.38 |
| Sencor 70 WG | 16.00 | 9.59 | 9.33 | 11.64 |
| Sencor 70 WG + Asahi SL | 16.76 | 10.41 | 10.32 | 12.51 |
| Mean | 14.96 | 9.17 | 8.59 | 10.91 |
| Gawin | | | | |
| Control object | 13.38 | 9.49 | 8.23 | 10.37 |
| Harrier 295 ZC | 15.36 | 11.36 | 9.22 | 11.98 |
| Harrier 295 ZC + Kelpak SL | 18.38 | 11.65 | 9.56 | 13.20 |
| Sencor 70 WG | 18.89 | 11.65 | 10.80 | 13.78 |
| Sencor 70 WG + Asahi SL | 20.18 | 12.30 | 11.57 | 14.68 |
| Mean | 17.24 | 11.29 | 9.88 | 12.80 |
| Honorata | | | | |
| Control object | 13.63 | 11.07 | 10.42 | 11.71 |
| Harrier 295 ZC | 17.99 | 14.37 | 11.63 | 14.66 |
| Harrier 295 ZC + Kelpak SL | 19.75 | 14.30 | 12.63 | 15.56 |
| Sencor 70 WG | 19.77 | 14.77 | 15.57 | 16.70 |
| Sencor 70 WG + Asahi SL | 19.97 | 16.17 | 15.90 | 17.34 |
| Mean | 18.22 | 14.14 | 13.23 | 15.20 |
| Mean for varieties | | | | |
| Control object | 13.06 | 9.40 | 8.55 | 10.34 |
| Harrier 295 ZC | 15.57 | 11.54 | 9.60 | 12.24 |
| Harrier 295 ZC + Kelpak SL | 18.20 | 11.76 | 10.18 | 13.34 |
| Sencor 70 WG | 18.22 | 12.00 | 11.90 | 14.04 |
| Sencor 70 WG + Asahi SL | 18.97 | 12.96 | 12.60 | 14.84 |
| Mean | 16.80 | 11.53 | 10.57 | 12.97 |
| $LSD_{0.05}$ for: | $a$ – 0.83, $b$ – 0.85, $c$ – 0.83, $b \cdot c$ – 1.48 | | | |

Explanation: $a$ – variety, $b$ – objects, $c$ – years

plots sprayed with the herbicide Sencor 70 WG and biostimulant Asahi SL. The plant protection methods used in the experiment had a significant impact on the magnesium uptake with the tuber yield compared to the control. The highest uptake capacity of the element was noted on the treatments where herbicides with biostimulants were used (Table 8). In 2012, characterised by average humidity and thermal conditions, the magnesium uptake with the tubers yield was 16.80 kg ha$^{-1}$. The magnesium content in tubers is closely correlated with the tuber yield. In 2012, the highest magnesium uptake was achieved by a high yield of 39.80 t ha$^{-1}$. This resulted from better hydrothermal conditions (Table 2). In 2013 and 2014, the magnesium uptake was lower because of the worse hydrothermal conditions and lower yields (33.37 and 31.68 t ha$^{-1}$). The magnesium content in aerial mass, determined during the growing season of potato, is significantly dependent on the development phase of plants, variety, and – to a lesser degree – on the level of nitrogen-phosphorus-potassium fertilisation (NPK) – Ciećko et al. (2010).

## CONCLUSIONS

1. The content of macroelements (phosphorus, calcium and magnesium) in potato tubers depended significantly on varieties, treatments and atmospheric conditions in the years of research. The variety Bartek accumulated the most phosphorus, and the variety Honorata had the highest content of magnesium and calcium in tubers. Biostimulants and herbicides increased the concentration of phosphorus, magnesium and calcium in relation to tubers collected from the control plots. The highest values of minerals were contained in tubers after the application of Asahi SL.

2. Varieties, plant protection methods and climatic conditions influenced the uptake of macroelements. The variety Honorata was distinguished by the highest ability to take up macroelements with the yield of tubers. The largest uptake of the macroelements was recorded in tubers after the use of Sencor 70 WG and Asahi SL.

3. The concentration and uptake of phosphorus, calcium and magnesium were influenced by climatic conditions. The highest content and uptake of phosphorus and magnesium were recorded in tubers harvested in a warm and medium wet average season (2012). During that period, the largest calcium uptake with tuber yield was obtained. The highest concentration of calcium was found in 2014, which was warm and characterised by excessive rainfall.

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