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CONCENTRATIONS OF COPPER, ZINC AND MANGANESE IN POTATO TUBERS UNDER THE INFLUENCE OF HERBICIDES

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Abstract

A field experiment was carried out in 2008-2010 at the Agricultural Experimental Farm of the University of Natural Sciences and Humanities in Siedlce, located in Zawady. The experiment was established on light loamy soil which belonged to a very good rye complex. The experiment was designed in a two-factor split-plot pattern with three replicates. The factors examined in the experiment included three cultivars of edible potatoes: Cekin, Satina, Tajfun, and five weed control methods: application of the following herbicides (mixed or alone) Command 480 EC, Command 480 EC and Dispersive Afalon 450 SC, Stomp 400 SC, Stomp 400 SC and Dispersive Afalon 450 SC, while the control consisted of mechanical weeding without chemical protection. The aim was to determine the influence of selected herbicides and their combinations (Command 480 EC, Command 480 EC and Dispersive Afalon 450 SC, Stomp 400 SC, Stomp 400 SC and Dispersive Afalon 450 SC) on the content of copper, zinc and manganese in three potato cultivars. Potato tubers were harvested at full maturity. Samples of potato tubers for chemical analyses were taken from plots during harvest. Microelements in the dry matter of potato tubers were determined by the AAS method. The content of copper was significantly dependent on the cultivars, weed control methods and weather conditions during the growing season. In contrast, concentrations of depended on the cultivars and meteorological conditions, whereas the content of manganese in potato tubers was strongly conditioned by genetic traits of the cultivars.

Keywords: herbicides, potato cultivars, copper, zinc, manganese.

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INTRODUCTION

Owing to its substantial nutritional and culinary value, potato has become a staple food for many Poles. The potato consumption in Poland is quite high, reaching 111 kg per capita in 2011/2012 (ZGÓRSKA 2013). The nutritional value of potato tubers is closely related to their chemical composition, in particular the components which are important for human nutrition, e.g. starch, protein, reducing sugars, dietary fibre, vitamins and minerals (KOLASA 1993, WADAS et al. 2012, ZARZECKA 2013, ZGÓRSKA 2013). The share of minerals, which occur as macroelements and microelements, is 1-1.2%. The role of macroelements in plants is mainly structural, whereas microelements are components of various enzymes and activators. Copper participates in main processes such as photosynthesis, respiration, protein processes, carbohydrate transportation, mechanisms of immunity to diseases. Zinc participates in the metabolism of carbohydrates, proteins and phosphorus compounds. It also regulates the formation of ribosomes, auxins, cell components, and increases resistance to drought and diseases. Manganese takes part in oxidation and reduction processes, photosynthesis and fixation of free nitrogen (LESZCZYŃSKI 2012). Consumption of 200 g potato tubers can supply the body with 8-15% of daily copper, zinc and manganese demand (LESZCZYŃSKI 2012, WIERZBICKA 2012).

The main objective of any potato cultivation technology is to obtain stable, high-quality yields, which will satisfy meet the market expectations (ZARZECKA 2014). The implementation of appropriate agricultural practices and strict control of diseases, pests and weeds reduce the negative effects of harmful factors, thus increasing potato yields, but can also induce changes in tuber chemical composition (BAĆMAGA et al. 2007, WICHROWSKA et al. 2009, GUGAŁA et al. 2012). There is little information in literature on the impact of plant protection chemicals on the content of microelements in crops, including potato tubers (ZARZECKA 2004, GUGAŁA et al. 2011). The aim of this study was to determine the effect of herbicides and their mixtures used to control weeds in potato fields on the copper, zinc and manganese content in edible potato tubers.

MATERIAL AND METHODS

A field experiment was carried out 2008-2010 at the Agricultural Experimental Station in Zawady, which belongs to the University of Natural Sciences and Humanities in Siedlce. The experiment was in a two-factorial, split-plot design with three replicates. It was set up on soil classified into the the category of brown earth soils, the type of eutrophic brown soil, formed from loamy sand and containing from 11.86 to 14.45% of the grain-size fraction <0.02 mm in diameter (Marcinek, Komisarek 2011). It was quality class IVa soil in the Polish soil valuation classification and a very good rye complex in respect of agricultural usefulness. The soil pH ranged from 4.99 to 5.91 (1 mol KCl dm^{-3}), that is slightly acid and acid soil reaction. Selected chemical soil properties were tested prior to the experiment and the results are presented in Table 1. The soil was high and very high in phosphorus, low and medium in potassium, very low and medium in magnesium, low and medium in copper, high in zinc and medium rich in manganese.

Table 1

Chemical properties of the soil

Specification	Years		
	2008	2009	2010
Organic matter (g kg^{-1})	15.4	17.8	18.1
Soil pH (1 M KCl)	4.99	5.15	5.91
Content of available nutrients (mg kg^{-1})			
P	90.6	95.9	73.5
K	124.5	74.7	112.1
Mg	41.0	28.0	45.0
Cu	2.0	1.3	2.2
Zn	7.5	7.8	7.3
Mn	80.8	100.0	80.1

The factors examined in the experiment included:

I – three potato cultivars – Cekin, Satina, Tajfun;

II – five weed control methods – application of herbicides in the following combinations:

1) control object – mechanical weed control prior to and following potato emergence;
2) mechanical weed control + herbicide Command 480 EC (clomazone 480 g dm^{-3}) at the dose of 0.2 dm^3 ha^{-1};
3) mechanical weed control + spraying a mixture of the herbicides Command 480 EC (clomazone 480 g dm^{-3}) at 0.2 dm^3 ha^{-1} + Dispersive Afalon 450 SC (linuron 450 g dm^{-3}) at 1.0 dm^3 ha^{-1};
4) mechanical weed control + herbicide Stomp 400 SC (pendimethalin 330 g dm^{-3}) at 3.5 dm^3 ha^{-1};
5) mechanical weed control + spraying a mixture of the herbicides Stomp 400 SC (pendimethalin 330 g dm^{-3}) at 3.5 dm^3 ha^{-1} + Dispersive Afalon 450 SC (linuron 450 g dm^{-3}) at 1.0 dm^3 ha^{-1}.

All the herbicides were applied prior to the emergence of potato plants. Farmyard manure and mineral fertilisers, excluding nitrogen, were applied in the autumn at the following doses: 25.0 t FYM ha^{-1}, 44.0 kg P ha^{-1} (*triple* superphosphate 46%) and 124.5 kg K ha^{-1} (potassium salt 60%). Nitrogen fertiliser was applied in spring at 100 kg N per 1 ha (ammonium nitrate 34%). Potato tubers were planted manually, in mid-April, at the row spacing of 67 cm and in-row spacing of 37 cm. They were harvested in early September, at the stage of technological maturity. Immediately before harvest, tubers from 10 plants were sampled and divided into fractions. Samples of edible tubers, that is tubers with the diameter of over 35 mm and no external or internal defects, were taken (12-15 potatoes) to conduct chemical analyses. The copper, zinc and manganese content was determined by atomic absorption (AAS) after tubers had been cut, dried and mineralised in a laboratory oven.

Results from three replicates were statistically analysed by means of 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 $P = 0.05$.

Table 2 presents the weather conditions during the potato growing seasons, including precipitation sums, average air temperatures and the Selyaninov's hydrothermal coefficient (HTC) values. In 2008, precipitation was higher than the long-term sum and its distribution was favourable for potato growth and development. The temperatures were similar to the long-term averages. In 2009, precipitation was distributed unevenly, temperatures were higher and values of the HTC ranged between 0.26 and 3.08. The 2010 growing season was the warmest, very wet and had stable HTC values (1.15-1.74) in the months of yield accumulation (June, July, August).

Table 2

Weather conditions during potato growing seasons according to the Zawady Meteorological Station

Years	Months						
	Apr	May	June	July	Aug	Sept	Apr-Sept
Rainfalls (mm)							sum
2008	28.2	85.6	49.0	69.8	75.4	63.4	371.4
2009	8.1	68.9	145.2	26.4	80.9	24.9	354.4
2010	10.7	93.2	62.6	77.0	106.3	109.9	459.7
Multiyear sum (1987-2000)	38.6	44.1	52.4	49.8	43.0	47.3	275.2
Air temperature (^{o}C)							mean
2008	9.1	12.7	17.4	18.4	18.5	12.2	14.7
2009	10.3	12.9	15.7	19.4	17.7	14.6	15.1
2010	8.9	14.0	17.4	21.6	19.8	11.8	15.6
Multiyear mean (1987-2000)	7.8	12.5	17.2	19.2	18.5	13.1	14.7
Selyaninov's hydrothermic coefficients*							mean
2008	1.04	2.18	0.94	1.25	1.36	1.73	1.39
2009	0.26	1.72	3.08	0.44	1.48	0.57	1.28
2010	0.40	2.14	1.20	1.15	1.74	3.10	1.61

* Coefficient value (Bac et al. 1998): < 0,5 – severe drought, 0.51-0.69 – mild drought, 0.70-0.99 – weak drought, ≥ 1 – fault drought

RESULTS AND DISCUSSION

The plant content of copper varies over a wide range, depending on the plant organ, development phase, species and cultivar, copper concentration in the soil, weather conditions and application of copper-based plant protection chemicals. On average, the potato tuber content of copper is 4.0-5.2 mg kg^{-1} (Wierzbicka, Trawczyński 2011), but can vary from 3.0 to 13.7 mg kg^{-1} of tuber dry matter (Klikocka 2011, Wierzbicka 2012 et al.).

In the present study, the copper content in potato tubers was between 6.145 and 6.274 mg kg^{-1} d.m., being significantly affected by a cultivar, weed control method, including herbicides and their mixtures, and the weather conditions during the growing season (Tables 3, 4). Similar amounts of copper in potato tubers have been reported by others (Arvin et al. 2005, Manzelli et al. 2010, Klikocka 2011). According to Arvin et al. (2005), Wierzbicka and Trawczyński (2011), the copper content in potato tubers was significantly dependent on potato varieties, whereas Manzelli et al. (2010) demonstrated the dependence of this element in potato tubers on the years of their research.

The herbicides and their mixtures applied to control weeds in potato crops reduced the concentration of copper in tubers compared to the control, where only mechanical weed control was used. The reduction of Cu was found in tubers from all the herbicide-treated plots and all the cultivars except the Command 480 EC-treated Satina, which indicates that the concentration of copper was decreased by herbicides. Gugała et al. (2011) have observed a decline in copper following an application of insecticides. Among the cultivars examined in the current study, Satina accumulated more copper than Cekin, whereas Tajfun did not differ significantly from the latter. The effect of a cultivar on the potato tuber content of copper was also mentioned by Manzelli et al. (2010), Gugała et al. (2011), Wierzbicka and Trawczyński (2011).

In addition, the concentration of copper in potato tubers was affected by the weather conditions during the growing season (Tables 2, 4). Most cropper

Table 3

Content of copper (Cu) in dry mass of potato tubers depending of cultivars (mg kg^{-1})

Weed control methods (II)	Cultivars (I)			Mean
	Cekin	Satina	Tajfun	
1. Control object – mechanical weeding	6.233	6.274	6.242	6.250
2. Command 480 EC	6.186	6.244	6.195	6.217
3. Command 480 EC + Dispersive Afalon 450 SC	6.169	6.219	6.172	6.187
4. Stomp 400 SC	6.186	6.199	6.201	6.198
5. Stomp 400 SC + Dispersive Afalon 450 SC	6.169	6.197	6.182	6.183
Mean	6.189	6.228	6.198	6.205
$LSD_{0.05}$ for:				
cultivars – I				0.032
weed control methods – II				0.034
interaction I x II				n.s.

n.s. – not significant at $P_{0.05}$

Table 4

Content of copper (Cu), zinc (Zn) and manganese (Mn) in dry mass of potato tubers (mg kg^{-1})

Years (III)	Cultivars (I)			Mean
	Cekin	Satina	Tajfun	
Copper				
2008	6.191	6.219	6.216	6.209
2009	6.145	6.227	6.151	6.174
2010	6.230	6.238	6.228	6.232
Mean	6.189	6.228	6.198	6.205
$LSD_{0.05}$ for:				
cultivars – I				0.032
years – III				0.032
interaction I x III				n.s.
Zinc				
2008	20.29	19.47	20.04	19.93
2009	21.33	19.49	20.66	20.49
2010	20.13	18.71	18.83	19.22
Mean	20.58	19.22	19.84	19.88
$LSD_{0.05}$ for:				
cultivars – I				0.35
years – III				0.35
interaction I x III				n.s.
Manganese				
2008	20.53	20.68	20.61	20.61
2009	21.04	21.54	21.41	21.33
2010	20.37	20.50	20.29	20.38
Mean	20.65	20.91	20.77	20.77
$LSD_{0.05}$ for:				
cultivars – I				0.25
years – III				n.s.
interaction I x III				0.65

n.s. – not significant at $P_{0.05}$

was determined in 2010, when the precipitation and temperatures were high, while the soil was acidic and the poorest in this micronutrient. Also, CIEĆKO and WYSZKOWSKI (2000) as well as KLIKOCKA (2011) found the highest copper content in tubers grown in a wet year. The lowest content of copper in tubers was detected in 2009, when the temperatures were higher than the long-term mean and the precipitation was unevenly distributed over the individual months. It can be inferred that extreme moisture and thermal conditions during tuber formation (June and July) as well as the amount of copper in the soil were not conducive to its uptake. No interaction between the cultivars and weather conditions in the study years was found.

The zinc content in potato tubers ranged from 18.71 to 21.33 mg kg^{-1} dry matter (Table 4) and was similar to levels reported by other authors (CIEĆKO, Wyszkowski 2000, Musilova et al. 2009, Manzelli et al. 2010, Wierzbicka, Trawczyński 2011). In this study, there was no effect of the herbicide-based weed control methods on zinc accumulation in potato tubers. It was probably due to the high soil content of zinc, although Petryk and Bedla (2010) demonstrated that the soil content of the elements they studied (Cr, Zn, Pb, Fe) was not significantly correlated with the respective concentrations in potato tubers. Gugała et al. (2011) observed no changes in the zinc content caused by an application of insecticides. However, the above authors found that the zinc content depended on moisture and thermal conditions as well as on potato cultivars. In our experiment, most zinc was accumulated by the cultivar Cekin, while the other two cultivars contained significantly less zinc. In addition, the highest content of zinc was found in 2009, which was a warm year with unevenly distributed rainfall, and the soil was acidic and characterized by the highest abundance of this element. In contrast, the least Cu was found in a humid year (2010), when the experiment was conducted on slightly acidic soil with the lowest abundance of copper. Filipek and Skowrońska (2013) showed that the bioavailability of micronutrients (Fe, Mn, Zn, Cu) increased with soil acidification owing to the improved solubility of the soil compounds.

The effect of a cultivar on the accumulation of zinc has been confirmed elsewhere (Arvin et al. 2005, Manzelli et al. 2010, Gugała et al. 2011). Conversely, Wierzbicka and Trawczyński (2011) found no differences between cultivars, although the cultvation years had an effect on the amount of zinc accumulated in potato tubers.

The average manganese content in tubers was 20.77 mg kg^{-1} d.m., ranging from 20.23 to 21.56 mg kg^{-1} (Tables 4, 5). These results resemble literature data (Ciećko, Wyszkowski 2000, Klikocka 2011). The concentration of manganese in tubers harvested in our experiment was significantly affected by the cultivars. The highest amount of manganese was accumulated by

Table 5

Content of manganese (Mn) in potato tubers depending on years of study (mg kg^{-1})

Weed control methods (II)	Years (III)			Mean
	2008	2009	2010	
1. Control object – mechanical weeding	21.17	21.56	20.69	21.14
2. Command 480 EC	20.57	21.33	20.30	20.73
3. Command 480 EC + Dispersive Afalon 450 SC	20.35	21.21	20.23	20.60
4. Stomp 400 SC	20.58	21.31	20.41	20.77
5. Stomp 400 SC + Dispersive Afalon 450 SC	20.36	21.26	20.29	20.64
Mean	20.61	21.33	20.38	20.77
$LSD_{0.05}$ for:				
weed control methods – II				n.s.
years – III				n.s.
interaction II x III				1.14

n.s. – not significant at $P_{0.05}$

cv. Satina, followed by cv. Tajfun, while cv. Cekin contained significantly less manganese. The effect of cultivar-specific traits on the manganese content in potato tubers has been confirmed by Zarzecka (2004), Arvin et al. (2005) as well as Wierzbicka and Trawczyński (2011). In contrast, Sawicka (1996) found no effect of cultivar-related characteristics on the manganese content. The author *did* confirm the impact of meteorological conditions during the study years. In our experiment, interactions between study years/cultivars and study years/weed control methods were verified (Tables 4, 5). In all the years, most manganese was accumulated by cv. Satina and least by cv. Tajfun in 2010, which manifests the fact that different varieties respond differently to the weather and soil conditions.

CONCLUSIONS

1. Herbicides and their mixtures applied to control weeds in potato crop reduced the copper content in tubers compared with the control. However, no changes in the zinc or manganese concentrations were observed.

2. Cultivar-specific traits affected the accumulation of copper, zinc and manganese. The cultivar Saina was the richest in copper, cv. Cekin contained most zinc and cv. Tajfun accumulated most manganese.

3. The concentrations of copper and zinc were significantly affected by the weather conditions during the growing season and by the soil properties. The highest concentration of copper in potatoes was determined in a wet and warm season (2010), on the soil rich in this micronutrient. Potato tubers with the highest zinc content were collected in 2009 (which was warm, with unevenly distributed rainfall) grown on the soil that was acidic and rich in Zn.

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