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FLUCTUATIONS OF SODIUM, COPPER, ZINC, IRON AND MANGANESE IN POTATO TUBERS IN THE ORGANIC AND INTEGRATED PRODUCTION SYSTEM

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Abstract

Studies were based on a field experiment performed in Parczew, in 2009-2011. The field trials were located on podzolic soil. The experimental factors were plant production systems (integrated and ecological) and four potato cultivars. Potato tubers were sown at a spacing of 70 x 35 cm. The integrated system included phosphatic and potassium fertilization equivalent to the uptake of the following quantities of nutrients: 110 kg N, 60 kg P, 70 kg K ha^{-1}. Compost supplied in a dose of 35 t ha^{-1} was used only once in a crop rotation, under potato. The chemical plant protection treatments were applied according to the thresholds of damage caused by agrophages. No fertilization or pesticides were introduced in the ecological system, except for an application of a preparation against potato beetle. Two-year-old compost was used under potato in a dose of 35 t ha^{-1}. Weed control in the organic system consisted of harrowing with a weeder until plant emergence, triple hilling and single hand hoeing prior to the last hilling. Potato tubers were harvested at full maturity. Samples of potato tubers for chemical analyses were taken from plots during the harvest. The content of some macro- and microelements in the dry matter of potato tubers was determined by the AAS method. The organic farming system has contributed to a higher accumulation of iron in tubers but the content of zinc was lower in comparison with the integrated system. The two farming systems did not have a significant effect on the content of sodium, copper or manganese in potato tubers. Genetic traits of the analyzed cultivars had the strongest influence on the content of elements in potato tubers. Tubers from the cultivar Irga had the highest content of sodium and copper. The concentration of zinc was the highest in tubers of cv. Satina, iron – in tubers of cv. Bryza and manganese – in tubers of cv. Jelly. The response of potato cultivars to the production systems has proved to be diverse.

Keywords: mineral composition, potato cultivars, systems tillage.

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INTRODUCTION

It is increasingly important to take into account the content of minerals and their mutual relations in an assessment of the nutritional value of potato tubers. Sodium and potassium control the whole management of electrolytes, contribute to the acid-alkaline balance of an organism and play a major role in the conduction of stimuli within all nerve cells. Sodium ions are the major extracellular cations that are necessary to maintain the action potential of cell membranes (BLUMWALD et al. 2000). Deficiency of sodium in plants and humans causes some loss in membrane potential difference in cells and impairment of cell excitability (SUBBARAO et al. 2003, SOETAN et al. 2010). Micronutrients are the nutrients that affect biochemical changes occurring within the plant, hence their optimum concentration stimulates the yield and improves its quality. Any shortage of micronutrients interferes with the plant's uptake of nitrogen, phosphorus, potassium, calcium, magnesium, and iron; also the processes of assimilation as well as sugar, protein, fat and nucleic acid synthesis are affected adversely (KLIKOCKA 2009, SOETAN et al. 2010). Copper is a constituent of plastocyanins, cytochrome and ascorbate oxidases as well as tyrosinase. It occurs in peroxide dismutase with Cu and Zn and nitrate reductase. The synthesis of carbohydrates is affected by deficits of copper in plants. Iron (Fe^{2+}, Fe^{3+}, chelates) is a part of redox enzymes, haemoglobin and myoglobin. It is also a component of cytochromes, ferredoxin, SOD, catalase, peroxidase, nitrate reductase, while over 80% of this element is located in chloroplasts (ARREDONDO, NUNEZ 2005, GRUCA-KRÓLIKOWSKA, WACŁAWEK 2006, LENC et. al. 2012). Manganese, molybdenum and zinc affect the protein biosynthesis, while manganese and zinc regulate the activity of peptidases (LÓPEZ et al. 2007, ŞAT 2008, HAFEEZ et al. 2013). Both deficiency and excess of minerals or their inadequate mutual ratios may have harmful effects on human and animal organisms (ŞAT 2008). Thus, the aim of this study was to determine the effect of varieties and cropping systems on the sodium, copper, zinc, iron and manganese content in potato tubers.

MATERIAL AND METHODS

The results were derived from a field experiment carried out in Parczew (51°64′N, 22°90′E) in 2009-2011. The field trials were set up on podzolic soil, which had the texture of light loamy sand and a slightly acidic pH value. Two crop systems such as integrated and organic farming were one of the two experimental factors, while the other one was composed of four potato cultivars: Irga and Satina (medium early) as well as Bryza and Jelly (medium late). In each of the systems, different rotations and production technologies were applied. In the integrated system (potato, spring barley, beans, winter wheat + white mustard catch crop), phosphorus-potassium nutrition was introduced in such amounts as to balance the uptake of 110 kg N, 60 kg P, 70 kg K. Compost in a dose of 35 t ha^{-1} was applied only once in a rotation, under potato. Full chemical protection against potato blight and potato beetle was used, taking into account the threshold values of damage caused by agrophages. The weed control consisted of mechanical treatments performed until germination and herbicides applied just before potato emergence. Chemical plant protection treatments were carried out using agents in recommended doses. In the organic system (potato, spring barley, clover with grass performed for 2 year, winter wheat + white mustard and spring vetch catch crop), no mineral fertilizers were used but a pesticide against potato beetle was sprayed. Two-year-old compost in a dose of 35 t ha^{-1} was supplied under potato. Mechanical and manual weed control was applied. Soil samples were submitted to the following determinations: soil textural composition, soil abundance of available phosphorus, potassium and magnesium (according to standard methods), pH in 1 mol dm^{-3} KCl and the organic carbon content (C_{org}).

When harvesting, samples of 50 different-sized tubers were collected from each plot for chemical analyses. Determinations of the content of the analyzed elements in dry matter of tubers were carried out in three replications. The amount of raw ash was subsequently determined gravimetrically. Proper ash was obtained from raw ash by separating silica and decomposing carbonates. To this end, an excess of 6 mol HCl dm^{-3} was added until the carbonates decomposed completely. Cations formed during the mineralisation of the plant organic matter were transformed into chlorides. Subsequently, the excess of hydrochloric acid was evaporated on a sand bath and silica was simultaneously deposited. The deposit remaining in the evaporator was dissolved in 10 cm^{3} of 5% hydrochloric acid and transferred to a measuring flask, with silica being separated on hard filter paper. The solution in the measuring flask was replenished to the specific volume, yielding the basic stock solution, in which the content of selected macro- and microelements and trace elements was determined in an Optima 3200 RL atomic absorption spectrometer with inductively coupled plasma (ICP-AES), manufactured by Perkin Elmer. Statistical analysis was based on a tripartite model analysis of variance (Anova) and multiple t-Tukey tests (SAS 9.2 2008). The weather during the experiment was changeable. In 2009, the first half of the plant growing period was humid and warm; June, August and September were dry while October was wet. In 2010, the beginning of the plant growing period was humid and cold, June and July were dry, the weather conditions in August and October were average and there was an extreme drought in September. In 2011, the period from May to June was wet and cold, while the other months were dry or droughty and warm.

RESULTS AND DISCUSSION

The soil reaction in both systems was slightly acidic; more acidic soils were found in the organic rather than in the integrated management system. The soil abundance of available nutrients was significantly higher in the integrated than in the organic production system (Table 1). In 2009, i.e. eight years after the onset of the organic cultivation system, the soil abundance of available potassium was just 5.8 mg of K_2O, which was very low. In the case of phosphorus, depletion of this component in soil was observed in the organic system down to the lower limit of the average abundance. The soil abundance of available magnesium was high, although lower in the organic than in the integrated management system.

Table 1

The acidity of the soil and the content of available forms of soil potassium, phosphorus, agnesium and humus

Years	pH		Content of K		Content of P		Content of Mg		C_{org}	
	(1 mol KCl dm^{-3})		(mg kg^{-1})		(mg kg^{-1})		(mg kg^{-1})		(g kg^{-1})	
	A*	B**	A	B	A	B	A	B	A	B
2009	5.301	6.000	48.17	83.85	37.14	42.34	9.660	48.87	1.460	1.572
2010	5.500	6.102	43.20	86.42	44.16	55.86	9.660	50.67	1.382	1.488
2011	5.799	6.308	48.15	89.74	45.87	65.07	44.05	48.32	1.468	1.480

* organic system,** integrated system

The content of organic carbon in *epipedonic agric* of the tested soil was similar and remained low with fluctuations from 1.38 to 1.57 g kg^{-1}; however, its content was higher in the integrated management system (Table 1). According to Gruca-Królikowska, Waclawek (2006), the mobility of metals in soils with low pH decreases. However, the effect of pH on metal mobility in soil is variable and dependent on the content and type of organic matter.

The cultivation systems modified only the iron and zinc content in potato tubers. A higher zinc concentration was found in tubers from the integrated system, while more iron was detected in tubers from the organic management system (Table 2). Changes in the mineral composition of potato tubers caused by various tillage systems and fertilization levels have also been reported by Kraska, Pałys (2005), Sawicka, Barbaś (2007), Klikocka (2009) and Kraska (2011). Applying the plough tillage system increased the content of phosphorus, potassium and magnesium in potato tubers as compared with no-tillage cultivation. Hunter et al. (2011) found that the levels of micronutrients were more often higher in organic foods than in conventional ones. According to Gruca-Królikowska, Wacławek (2006) and Hajšlová et al. (2005), the biochemical cycles in natural ecosystems are characterized by a certain regularity, while man's interference causes disturbances (excess or

Table 2

Effect of a production system on the chemical composition in potato tubers (mean from 2009-2011)

Specification	Crop production system		$LSD_{0.05}$
	*A**	*B***	
Sodium	150.3	152.9	ns***
Copper	5.790	5.910	ns
Zinc	13.19	14.84	0.420
Iron	77.24	75.00	2.181
Manganese	10.11	10.20	ns

* organic system, ** integrated system, *** not significant at $p_{0.05}$

deficiency of elements). SUBBARAO et al. (2003) as well as GRUCA-KRÓLIKOWSKA, WACŁAWEK (2006) suggest that plants react quickly to chemical changes in the environment, and they often adjust easily to new conditions, which has a poweful effect on the further existence of an ecosystem. In the opinion of STARCK (2014), the weak action of a physiological barrier in plants to absorption of chemical components from the environment poses a high risk of incorporating trace elements into a food chain system. Hence, an increase in total pollution can cause some loss of productivity in plant ecosystems.

In our experiment, genetic characteristics of the cultivars determined the content of elements in potato tubers to the greatest extent (Table 3). The cultivar Irga was characterized by the highest sodium concentration, whereas cv. Jelly had the lowest content of Na; the cultivars Irga and Bryza as well as Jelly and Satina proved to be homologous with respect to this trait. The most stable cultivar in terms of the Na content was cv. Bryza, unlike cv. Jelly, which demonstrated the most variable content of sodium in tubers. The highest content of copper was recorded in tubers of cv. Irga while the lowest one was found in tubers of cv. Satina. Irga and Jelly as well as Satina

Table 3

Influence of the cultivars on the chemical composition of potato tubers, mean from 2009-2011 (mg kg^{-1})

Specification	Cultivars								
	Satina		Irga		Jelly		Bryza		$LSD_{0.05}$
	Mean	*V**	Mean	*V*	Mean	*V*	Mean	*V*	
Sodium	144.0	59.50	161.5	64.90	141.4	67.20	159.5	57.20	15.16
Copper	4.350	27.30	5.62	37.30	5.560	41.00	5.470	35.90	0.350
Zinc	17.27	20.00	12.95	61.50	12.40	59.30	13.44	36.00	0.840
Iron	69.45	62.40	69.12	23.60	81.34	35.50	84.63	63.30	4.570
Manganese	9.040	14.50	10.17	22.40	10.92	31.80	10.51	52.60	0.610

* Variability coefficients (%)

and Bryza appeared to be homologous in terms of that feature. The zinc content in potato tubers oscillated around 12.40-17.27 mg kg^{-1}. Regarding this element, Satina was the most abundant cultivar while the medium late cultivar Jelly was the poorest one. The most stable cultivar in terms of the content of this element in tubers was cv. Satina, while the most variable one was cv. Irga. The highest concentration of iron was found in tubers of cv. Bryza, while the lowest one was in tubers of cv. Irga; Satina and Irga as well as Jelly and Bryza cultivars appeared to be homologous in respect to this feature. Irga was the most stable and Bryza was the most variable in terms of the Fe content of tubers. The largest proportion of manganese was accumulated by the medium late cultivar Jelly, while the smallest one was determined in medium early Satina. This feature proved to be fairly stable with the variability coefficient from 14.5% (cv.Satina) to 52.6% (cv. Bryza) – Table 3. Most of the analyzed features demonstrated high genotypic variability, depending on various factors in the habitat (Sawicka, Barbaś 2007, García-Bañuelos et al. 2014, Tamasia et al. 2015).

There was a diverse response of potato cultivars to the production systems (Table 4). The cultivar Jelly responded to the organic farming system with an increase in the sodium concentration, while Satina, Irga and Bryza accumulated more iron, in addition to which cv. Bryza increased the amount of manganese in tubers. The integrated farm management system, in turn, contributed to an increase in the zinc content in tubers of Satina, Irga and Bryza as well as to an increase in the concentration of manganese in tubers of Satina and Irga. Most varieties grown in the organic cultivation system increased the content of this element in tubers. The medium late cv. Jelly, whose growth was distrubed by *Phytopthora infestans*, showed no such response to the management system.

Table 4

Influence of the production systems and cultivars on the chemical composition of potato tubers (mean from 2009-2011)

Cultivars	Content (mg kg^{-1})									
	sodium		copper		zinc		iron		manganese	
	*A**	*B***	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
Satina	128,0	160.1	4.860	3.851	15.80	18.95	72.63	66.28	8.331	9.750
Irga	173.9	149.2	6.710	4.530	12.81	13.82	74.99	63.24	9.442	10.90
Jelly	159.7	123.1	6.710	4.412	12.23	12.29	66.75	95.94	10.72	11.11
Bryza	139.8	179.1	6.441	4.500	12.90	14.29	94.57	74.70	11.96	9.060
$LSD_{0.05}$	30.30		ns***		1.810		9.141		1.220	

* organic crop production system, ** integrated crop production system, *** not significant at $p_{0.05}$

The content of the analyzed elements in potato tubers, except manganese, also depended on the combination of an agricultural production system and soil and climate conditions during the study (Table 5). Sodium, copper

Table 5

Effect of years and the production systems on the chemical composition of potato tubers (mean for cultivars)

Years	Content (mg kg^{-1})									
	sodium		copper		zinc		iron		manganese	
	*A**	*B***	*A*	*B*	*A*	*B*	*A*	*B*	*A*	*B*
2009	161.0	161.1	4.120	5.620	2.181	3.490	61.47	63.35	6.680	7.350
2010	147.6	148.5	6.652	7.531	17.51	21.55	69.95	80.79	6.351	6.551
2011	141.3	113.7	6.610	4.570	19.89	19.47	100.4	80.97	17.32	16.71
LSD$_{0.05}$	22.70		0.531		1.261		6.850		ns***	

* organic crop production system, ** integrated crop production system, ***not significant at $p_{0.05}$

and iron in tubers were significantly higher in the organic system in 2011, when the weather was warm and dry while the soil in this system was characterized by the highest abundance of potassium, phosphorus and magnesium. Tubers from the integrated management system were characterized by a higher concentration of copper and zinc in 2009-2010, as well as iron in 2010. In those years, the soil was distinguished by lower soil acidity, slightly higher abundance of bioavailable magnesium and significantly higher moisture content. Similar correlations were observed by SAWICKA, BARBAŚ (2007). ROGÓŻ, URBANIAK (2007) as well as LENC et al. (2012) suggest that – besides soil properties, climatic conditions and soil content of elements and their available forms – the mineral content of plants is determined by ionic synergism and antagonism. An example is the antagonism between copper and zinc, since zinc excess lowers copper bioavailability. According to WIŚNIOWSKA-KIELIAN, KLIMA (2007), availability of metals to plants is limited by the forms in which they appear in soil, which depends on soil characteristics, e.g. high soil acidification increases the possibility of metal transition to plants (MILLALEO et al. 2010, GARCÍA-BAÑUELOS et al. 2014).

CONCLUSIONS

1. Systems of crop cultivation significantly modified the chemical composition of potato tubers. The organic management system contributed to a higher accumulation of iron, in tubers, while the zinc accumulation was lower than in the integrated system.

2. Genetic characteristics of the cultivars determined to the largest extent the content of elements in potato tubers. Tubers of cv. Irga were characterized by the highest content of sodium and copper. The concentration of zinc was the highest in tubers of Satina, iron – in Bryza, and manganese – in Jelly.

3. The response of the potato cultivars to the production systems proved to be diverse. The cultivars Irga and Jelly responded by an increase in the sodium concentration in tubers, the cultivars Satina and Irga presented an increase in the iron content, whereas the cultivar Bryza demonstrated an increase in the amounts of iron and manganese when grown in the organic system of farming. The integrated cultivation system contributed to an increase in the zinc content in tubers of cv. Irga, Satina, and Bryza, and in the content of manganese in tubers of cv. Satina and Irga, as compared to the organic system.

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