Effect of long-term cattle slurry and mineral N, P and K application on concentrations of N, P, K, Ca, Mg, As, Cd, Cr, Cu, Mn, Ni, Pb and Zn in peeled potato tubers and peels

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ABSTRACT

Little information is available on how fertilizer application affects concentration of many elements in peeled potato (*Solanum tuberosum*) tubers and peels. We analyzed how long-term application of cattle slurry and mineral N, P and K fertilizers affects the yield of tubers, their dry matter content and concentrations of elements. In 2009, potatoes tubers were collected in control, cattle slurry (CS), mineral $N_4P_2K_2$ and combined $CSN_4P_2K_2$ treatment of the Ruzyně Fertilizer and Crop Rotation Experiment established on Illimerized Luvisol in Prague (Czech Republic) in 1955. Amount of N, P and K supplied by CS was 138, 30 and 172 kg/ha and the amount supplied by $N_4P_2K_2$ was 110, 31 and 186 kg/ha. Yield of fresh potatoes ranged from 20.6 in the control up to 31.2 t/ha in $CSN_4P_2K_2$ treatment. Dry matter content of unpeeled tubers, peeled tubers and potato peels was not significantly affected by fertilizer treatments probably because of not excessive N application. Normal cropping practices with application of CS and mineral N, P and K fertilizers did not significantly increase concentrations of trace elements in peeled tubers or potato peels on neutral soil with low trace elements availability. Concentrations of many elements (N, P, K, Ca, Mg, Cd, Cr, Cu, Mn, Ni, and Zn) were higher in potato peels than in peeled tubers, but the differences in the case of trace elements were relatively small.

Keywords: copper; fertilizer and crop rotation experiment; macro and trace elements; *Solanum tuberosum*, zinc

In many European countries, potatoes represent main staple food and therefore consumption of tubers can substantially affect human dietary intake of many elements (Friedman 2006, Hamouz et al. 2010). In countries with high potatoes consumption, potatoes play an important role in human dietary deficiency of Cu or Zn (Kabata-Pendias 2001, Alloway 2004, Cakmak 2008) and are a significant source of natural antioxidants (Hamouz et al. 2011). Potatoes are known to accumulate trace elements such as Cd and Pb which are toxic to humans (McLaughlin et al. 1997, Antonious and Snyder 2007, Mansour et al. 2009). Further, it is known that concentrations of many elements are higher in potato peels than in peeled tubers therefore consumption of unpeeled tubers can increase human dietary intake of trace elements (Dudka et al. 1995).

The high contamination of arable soils and consequently crops by trace elements can be attributed to high aerial deposition of trace elements around mining and smelting areas (Dudka et al. 1996, Piotrowska et al. 1997), city centres and due to the use of contaminated fertilizers (Moral et al. 2008, Hejcman et al. 2009, Yu et al. 2011). Concentration of trace elements in vascular plants is frequently positively correlated with their availability in the soil (Peris et al. 2008, Hejcman et al. 2010, Marković et al. 2010). High inter species, inter organ or inter tissue differences in concentrations of elements can be recorded (Ducsay et al. 2009, Fässler et al. 2010).

Although effect of soil chemical properties on concentration of elements in potato tubers received attention in highly polluted areas (Dudka et al. 1996, Piotrowska et al. 1997), little atten-

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tion was paid to the question how the yield and concentrations of elements in peeled tubers and peels are affected by long-term fertilizer application (McLaughlin et al. 1995). Therefore the aim of this study was to answer following research questions: (1) How fertilizer application affects yield of unpeeled tubers, peeled tubers and potato peels and their dry matter content?; (2) Is there any effect of long-term cattle slurry and mineral N, P, K fertilizers application on concentrations of macro and trace elements in peeled tubers and potato peels?; (3) How do the concentrations of elements in peeled tubers and potato peels differ?

MATERIAL AND METHODS

Site description. The Ruzyně Fertilizer Experiment (RFE) was established on a permanent arable field in 1955 on the western edge of Prague, the capital of the Czech Republic (50°05'15''N; 14°17'28''E). At the study site, the mean annual temperature is 8.2°C and the mean annual precipitation is 422 mm. The soil type is Illimerized Luvisol developed on loess mixed with highly weathered chalk. The arable layer contains 27% clay, increasing to 40% clay at 30–40 cm depth. The soil pH (H_2O) was 6.5 in the top 20 cm before establishment of the experiment in 1955.

Experimental design. In this study, potatoes yield and concentrations of elements were determined in four most contrasting treatments in the strip number IV of the RFE named the 'Classical Crop Rotation'(45% cereals, 33% of root crops and 22% of legumes). In this strip, potatoes followed after spring barley. The individual plot size was 12 m × 12 m and only the central 5 m × 5 m plot was used for experimental purposes. Each treatment was replicated four times. The amount of elements applied directly to potatoes and the mean annual amount of applied N, P, and K over the crop rotation is given in Table 1. Cattle slurry (CS) was applied in the autumn before planting of potatoes and mineral fertilizers during the spring. In autumn 2008, basic soil chemical properties were analyzed in selected treatments. Soil samples were taken as a mixture of ten sub-samples from the arable layer. Plant available P and K concentrations were extracted in Mehlich III reagent (Mehlich 1984). The organic C was determined by the NIRS method in accredited national laboratory. To measure pH (KCl), a 0.2 mol/L solution was used and 20 g of soil was mixed with 50 mL of the solution.

Potato tubers sampling and chemical analysis. The medium-early, medium-size tuber, ware and salad variety Ditta was used in this study and tubers were harvested on 10th September 2009. After collection, unpeeled tubers were weighted and fresh weight yield was determined. Two kilograms of fresh tubers were then randomly selected from each plot. The tubers were washed carefully in deionized water, peeled by a common kitchen scraper (thickness of the peel was 2 mm), cut on strips and dried in 80°C up to total desiccation and dry matter content and dry matter yield were determined. The concentrations of elements in peeled tubers and peels were determined by wet ashing with increased pressure. Exactly 1 g of powdered peeled tubers and peels were decomposed in a mixture of HNO_3 and H_2O_2. The ash was then decomposed using the microwave ashing device CEM 2000 and diluted in *aqua regia*. As, Cd, Cr, Cu, K, Mg, Mn, Ni, Pb, and Zn were measured by optical emission spectrometry with inductively coupled plasma (ICP-OES, Thermo Jarrell Ash, Trace Scan, Franklin, USA). To determine the N concentration, tubers and peels were mineralized in concentrated (98%) H_2SO_4 and N and P concentrations in solution were than measured by flow colorimeter (SAN plus SYSTEM, SKALAR, De Breda, The Netherlands).

Data analysis. One way ANOVA followed by post-hoc comparison using Tukey's test was used to

Table 1. Amounts of N, P and K and amount of trace elements supplied by fertilizers to potatoes in 2009. Mean annual amount of N, P and K supplied over the crop rotation is given in brackets

Treatment	N	P	K	As	Cd	Cr	Cu	Ni	Pb	Zn
	(kg/ha)			(g/ha)						
Control	0 (0)	0 (0)	0 (0)	0	0	0	0	0	0	0
$N_4P_2K_2$	110 (91)	31 (31)	186 (146)	0.78	0.53	15.2	3.67	2.59	0.72	43.4
CS	138 (58)	30 (13)	172 (73)	66.1	15.1	234	2146	196	203	5031
$CSN_4P_2K_2$	248 (149)	61 (89)	358 (204)	66.9	15.6	249	2149	199	204	5074

N_4 – application of ammonium nitrate; P_2 – application of superphosphate; K_2 – application of potassium chloride; CS – application of cattle slurry

Table 2. Results of basic soil chemical properties in arable layer analyzed in 2008

Treatments	pH/KCl	C_{org} (%)	P (mg/kg)	K (mg/kg)
Control	6.5	2.0	22	130
$N_4P_2K_2$	5.6	2.3	76	185
CS	6.7	2.3	46	174
$CSN_4P_2K_2$	6.4	2.6	85	250

C_{org} – content of organic carbon. Plant available P and K concentrations determined in Mehlich III reagent. Treatment abbreviations are given in Table 1

identify significant differences among treatments and differences between peeled tubers and peels.

RESULTS

Soil analysis. Soil reaction was lowest in $N_4P_2K_2$ treatment and highest in the control (Table 2). Suitable plant available P concentrations were recorded in $CSN_4P_2K_2$ and $N_4P_2K_2$ treatments and low in the control and CS treatment. Good plant available K concentrations were recorded in $N_4P_2K_2$, CS and $CSN_4P_2K_2$ treatments and suitable in the control. The content of organic C ranged from 2.0 to 2.6% in the control and $CSN_4P_2K_2$ treatment, respectively.

Yield of tubers. Fresh matter yield of unpeeled tubers was significantly affected by treatment and ranged from 20.6 to 31.2 t/ha in the control and $CSN_4P_2K_2$ treatment, respectively (Table 3). The dry matter content of unpeeled tubers was not significantly affected by treatment and the mean value was 25.8%. The fresh matter yield of peeled tubers was significantly affected by treatment and ranged from 17.5 to 26.5 t/ha in the control and $CSN_4P_2K_2$ treatments, respectively. The dry matter of peeled tubers was not significantly affected by treatment and mean value was 26.9%. Yield of peels was significantly affected by treatment and ranged from 3.1 to 4.7 t/ha in the control and $CSN_4P_2K_2$ treatment, respectively (Table 4). The mean dry matter content of peels was not significantly affected by treatment and was 19.8%.

Concentration of macro elements in peeled tubers. Significant effect of treatment on the concentration of N, P, K, and Mg in peeled tubers was recorded (Table 3). The concentration of N ranged from 11 to 15 g/kg in the control and $CSN_4P_2K_2$ treatment, respectively. The concentration of P ranged from 1.6 in $N_4P_2K_2$ and CS treatments to 1.9 g/kg in the control and $CSN_4P_2K_2$ treatment. The concentration of K ranged from 11 g/kg in the control and CS treatment to 16 g/kg in $N_4P_2K_2$ and $CSN_4P_2K_2$ treatments. The effect of treatment on Ca concentration (0.5 g/kg) was not significant. The concentration of Mg ranged from 0.8 g/kg in the control and CS treatment to 1.0 g/kg in $N_4P_2K_2$ and $CSN_4P_2K_2$ treatments.

Concentration of macro elements in peels. Significant effect of treatment on the concentration of N, P, K and Mg in peels was recorded (Table 4). The concentration of N ranged from 17 to 22 g/kg in the control and $CSN_4P_2K_2$ treatment, respectively. The concentration of P ranged from 1.6 g/kg in CS to 2.0 g/kg in the control and $CSN_4P_2K_2$ treatments and the concentration of K ranged from 21 to 31 g/kg in CS and $CSN_4P_2K_2$ treatments. The concentration of Ca ranged from 0.9 in the control to 1.2 g/kg in $CSN_4P_2K_2$ treatment and finally the concentration of Mg ranged from 0.9 in CS to 1.1 g/kg in $CSN_4P_2K_2$ treatments, respectively.

Concentration of trace elements in peeled tubers and peels. The effect of treatment on concentration of Cd, Cr, Cu, Mn, Ni and Zn in peeled

Table 3. The fresh yield of unpeeled tubers (U) and their dry matter content (U^{DM}), the fresh yield of peeled tubers (PT) and their dry matter content (PT^{DM}), and average concentrations of macro elements in peeled tubers

Treatment	U	U^{DM}	PT	PT^{DM}	N	P	K	Ca	Mg
	(t/ha)**	(%)^{ns}	(t/ha)**	(%)^{ns}	(g/kg)**	(g/kg)*	(g/kg)**	(g/kg)^{ns}	(g/kg)**
Control	20.6^{b}	25.7	17.5^{a}	26.9	11^{a}	1.9^{b}	11^{a}	0.5	0.8^{a}
$N_4P_2K_2$	31.1^{a}	25.8	26.4^{c}	27.0	13^{ab}	1.6^{a}	16^{b}	0.5	1.0^{b}
CS	26.1^{c}	25.7	22.1^{b}	26.9	12^{ab}	1.6^{a}	11^{a}	0.5	0.8^{a}
$CSN_4P_2K_2$	31.2^{a}	25.9	26.5^{c}	26.9	15^{b}	1.9^{b}	16^{b}	0.5	1.0^{b}

According to the Tukey's post hoc test, treatments with the same letter were not significantly different. ^{ns}result of ANOVA analysis was not significant; *; ** result of ANOVA analysis was significant at 0.05 and 0.001 probability level, respectively. Treatment abbreviations are given in Table 1

Table 4. The fresh yield of potato peels (Pe) and their dry matter content (Pe^{DM}), and average concentrations of macro elements in peels

Treatment	Pe	Pe^{DM}	N	P	K	Ca	Mg
	(t/ha)**	(%)^{ns}	(g/kg)**	(g/kg)*	(g/kg)**	(g/kg)^{ns}	(g/kg)**
Control	3.1^{b}	19.1	17^{a}	2.0^{b}	22^{a}	0.9	1.0^{ab}
$N_4P_2K_2$	4.7^{a}	18.2	18^{a}	1.8^{ab}	29^{b}	1.0	1.0^{ab}
CS	3.9^{c}	18.9	18^{a}	1.6^{a}	21^{a}	0.9	0.9^{a}
$CSN_4P_2K_2$	4.7^{a}	19.1	22^{b}	2.0^{b}	31^{b}	1.2	1.1^{b}

According to the Tukey's post hoc test, treatments with the same letter were not significantly different. ^{ns}result of ANOVA analysis was not significant; *; ** result of ANOVA analysis was significant at 0.05 and 0.001 probability level, respectively. Treatment abbreviations are given in Table 1

tubers and peels was significant (Figure 1). No significant effect of treatment was recorded in the case of As and Pb. With the exception of As and Pb, concentrations of trace elements were generally higher in peels than in peeled tubers. Significantly higher concentrations of Cd, Cr, Cu, Mn, Ni, and Zn in peels than in peeled tubers were recorded in the control, $N_4P_2K_2$ and $CSN_4P_2K_2$ treatments, but not in CS treatment.

DISCUSSION

Low concentration of plant available P and suitable concentration of plant available K in the control without any fertilizer P and K input over 53 years is consistent with the results from other field strips of the RFE with different proportion of cereals, legumes and root crops in the crop rotation (Uprety et al. 2009, Šrek et al. 2010). Almost the same values of P and K obtained in unfertilized controls under various crop rotations indicate minimal or rather no effect of different crop rotations on P and K availability in the Illimerized Luvisol. According to experiences from other long-term fertilizer experiments on different soil types in the Czech Republic (Kunzova and Hejcman 2009, 2010, Černý et al. 2010, Hejcman and Kunzova 2010), we concluded that the soil type is more important for long-term ability of the soil to supply the crop with the adequate amount of P and K than long-term spectrum of planted crops or used crop rotation.

In the control, potatoes production was limited by N, P and K availability. To achieve fresh yield of unpeeled tubers above 30 t/ha, application rates for mineral N, P and K was 110, 30 and 190 kg/ha. Similar values for N, P and K application to achieve the same yield were recorded by Šrek et al. (2010) on the strip I of the RFE named 'Cereal Crop Rotation' with the same variety of potatoes in 2008. In the RFE, relatively low mineral N application rates contrast with many other world regions where N application rates over 200 kg/ha were necessary to achieve the tuber yield around 30 t/ha (Long et al. 2004).

No significant effect of fertilizer treatments on dry matter content of tubers and peels was probably given by not excessive application of N. No significant effect of fertilizer treatment on dry matter content of tubers is consistent with the results by Hamouz et al. (2005).

In contrast to N, P and K, concentrations of trace elements (As, Cd, Cr, Cu, Mn, Ni, Pb and Zn) in peeled tubers and potato peels were not strongly affected by fertilizer treatments and were below the Czech legislative limits. Recorded concentrations of As, Pb, and Zn in peeled tubers and potato peels were lower and concentrations of Cd and Cu were higher and concentrations of Ni and Mn were comparable with unpeeled tubers of the same variety collected in the strip I of the RFE in 2008 (Šrek et al. 2010).

This indicates a possible interannual variability in concentrations of some trace elements probably because of different growth conditions in particular years as well as because of different crop rotation. It must be noted that the amount of trace elements supplied by fertilizers was comparable in both strips of the RFE therefore differences in concentrations can hardly be ascribed to differences in the amount of elements supplied by fertilizers.

Mean recorded concentrations of Cu and Zn in peeled tubers and potato peels were consistent with mean European concentrations of 4.5 and 10 mg/kg, respectively (Kabata-Pendias 2001). No positive effect of cattle slurry application which supplied the soil with 2 and 5 kg/ha of Cu and Zn

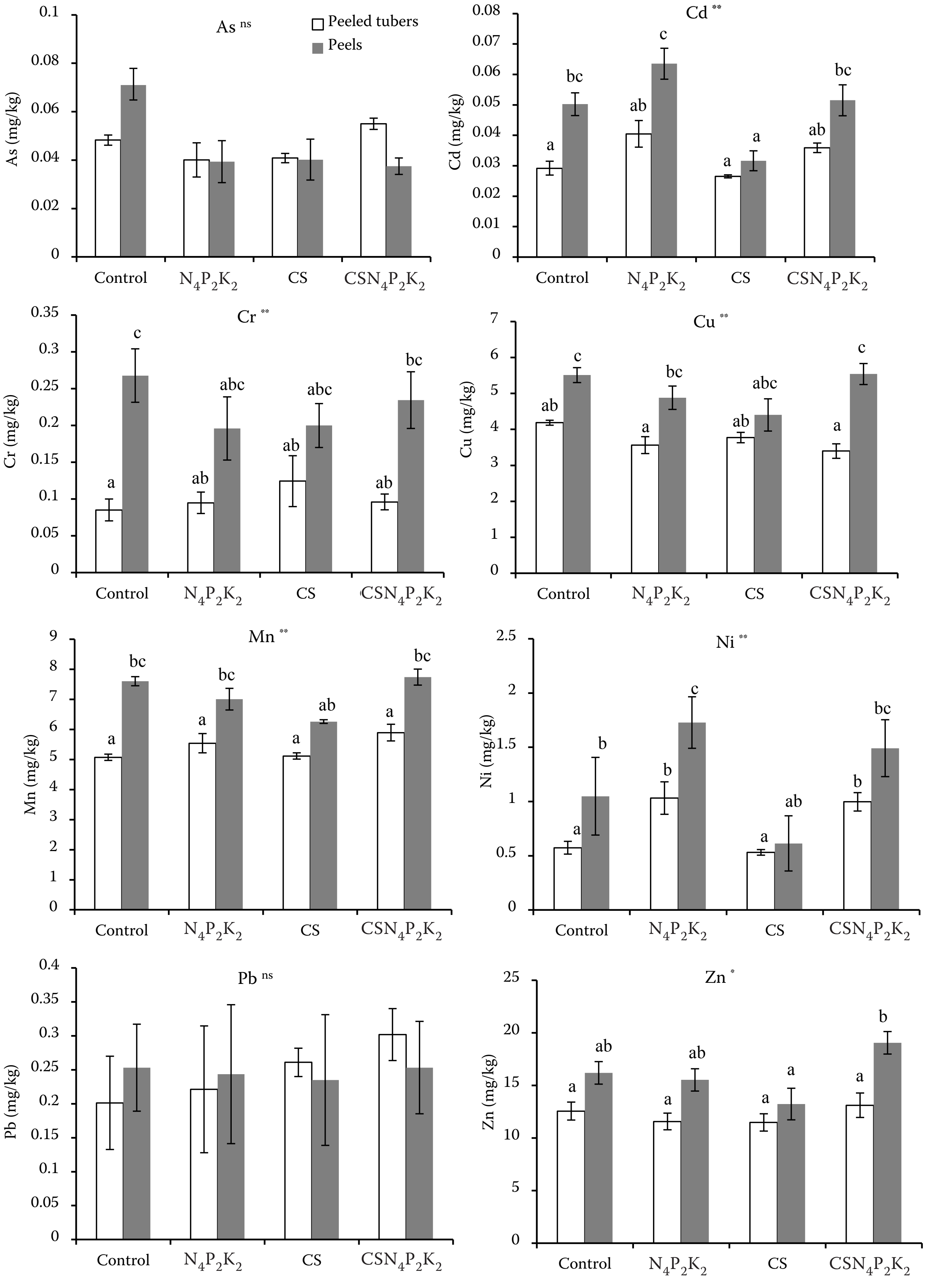

Figure 1. Mean concentrations of trace elements in peeled tubers and potato peels. Vertical lines represent standard error of the mean (SE). nsresult of ANOVA was not significant; *,**result of ANOVA was significant at 0.05 and 0.001 probability level. According to the Tukey's post hoc test, columns with the same letter were not significantly different. Treatment abbreviations are given in Table 1

on concentrations of Cu and Zn in peeled tubers and potato peels can be given because of neutral soil reaction and high amount of applied organic matter and therefore low mobility of applied Zn and Cu (Hejcman et al. 2009). We concluded that the application of cattle slurry in this particular case does not represent any risk for human nutrition as there was no increase in trace elements concentrations in tubers. Furthermore, as the human diet is frequently Cu and Zn deficient (Warman and Havard 1998, Alloway 2004), application of cattle slurry in normal application rates does not solve this problem on the neutral soil.

Concentration of trace elements in potato peels can be more than twice higher that in peeled tubers on highly polluted soils and therefore consumption of unpeeled tubers can be recommended only in unpolluted areas with low mobility of trace elements in the soil (Dudka et al. 1995, Piotrowska et al. 1997). In our study, higher concentrations of Cd, Cr, Cu, Mn, Ni, and Zn in potato peels than in peeled tubers were recorded, but differences were, with the exception of Cr, relatively small. Therefore consumption of unpeeled tubes produced under normal cropping system on neutral soils with low trace elements mobility does not represent any risk for human nutrition. The highest Cd concentration in potato peels recorded in $N_4P_2K_2$ treatment was probably connected with lower soil pH (5.6) than in other treatments. Higher concentrations of Cu in potato peels than in peeled tubers were probably due to extensive surface area of potato peels for Cu adsorption and following intersection of Cu into the potato peels (Aman et al. 2008).

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