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THE EFFECT OF GRADED DOSES OF SELENIUM IN THE SOIL ON YIELD–FORMING PARAMETERS AND SE CONTENT IN POTATOES

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Abstract

JŮZL, M., HLUŠEK, J., ELZNER, P., LOŠÁK, T.: *The effect of graded doses of selenium in the soil on yield–forming parameters and Se content in potatoes*. Acta univ. agric. et silvic. Mendel. Brun., 2007, LV, No. 1, pp. 71–80

In 2004 and 2005 we explored the effect of graded doses of selenium in the soil (0, 12, 24, 48 and 72 kg $Se.ha^{-1}$) on yield–forming parameters (total plant weight, number of stems per hill, number of tubers per hill and hectare yields) in two varieties of potatoes of different vegetation periods. The content of selenium as an important anti–oxidant was monitored in potato tubers and tops. Selenium in the form of sodium selenite was applied in the respective doses into the soil before planting the potatoes. Samples for growth and chemical analyses were taken after 90 and 99 days of vegetation (variety Karin and Ditta, respectively). Increasing doses of selenium had a negative effect on most of the yield–forming parameters. With an increasing dose of Se the hectare yields as well as the number of tubers in the hill and total weight of the plant decreased. Chemical analyses were performed using the AAS method and showed that the concentration of selenium in the individual parts of the potato plant increased with increasing Se doses in the soil. The content of selenium in tubers of the variant Se_{72} (4.13 mg $Se.kg^{-1}$ of dry matter) increased as much as 20 times when compared to the control (0.22 mg $Se.kg^{-1}$ of dry matter).

potatoes, yield–forming parameters, soil application of selenium, content of selenium

In human nutrition potato tubers (*Solanum tuberosum* L.) are an important source of anti–oxidants (Lachman et al., 2000). The most frequent anti–oxidants in potatoes are L–tyrosine, scopoline and ferulic acid (Lachman and Hamouz, 2005). Anti–oxidants comprise a large group of secondary metabolites usually found in higher plants and they are substances with potential curative effects. They belong to the group of substances, which had recently won great attention as dietary components of potential importance for human health. Basing on their chemical structure anti–oxidants can be divided into polyphenols (flavonoids, anthokyans, phenolcarboxylic acid and coumarin), carotenoids (carotenes – precursors of vitamin A and xantophylls) and tocopherols. L–ascorbic acid (vitamin C) and selenium also show strong anti–oxidation activity (Lachman et al., 2005).

In lower concentration selenium is a basic trace element, but in higher concentrations it becomes toxic (Bedwal et al., 1993). Selenium is of principle importance for human health. As a component of selenoproteins it has a structural and enzymatic role (Arthur and Becket 1994). In other connections selenium is best known as a catalyst for the production of the active hormone of the thyroid gland (Rayman, 2000). A low concentration of selenium was discovered in the blood plasma of patients with AIDS, trisomia –21, Crohn's and Down's syndrome, phenylketonuria, Keshan's disease and cancer (Bedwal et al., 1993).

Soils in Central and North Europe are poor in selenium and this causes a latent deficiency of this important micro–element in the whole food chain (Paeffgen, 2004). In recent years the insufficient supply of selenium in the human organism has often been discussed. According to some sources one third to one half of the population is in a state of mild to serious selenium deficiency (Hlušek et al., 2005). They say that food provides only one half of the recommended daily amount, i.e. 0.030–0.050 mg.day^{-1}, against the recommended 0.100–0.120 mg.day^{-1}. The low intake of selenium is due to the low content of the element in the soil and consequently in plants, animals and other parts of the food chain (Ducsay and Ložek, 2006). In terms of human nutrition the biologically active forms of selenium in foodstuffs are of a higher order and are more reliable than the mineral form. Mineral selenate has oxidation properties and at the moment of its intake it is contra–productive. That means that it triggers stress instead of reducing it. By means of plant nutrition it is possible to supply the entire food chain adequately with biologically active selenium of high quality (Paeffgen, 2004).

Se is an antioxidant or it activates protective mechanisms, which can alleviate oxidative stress in the chloroplasts of potatoes and Se supplementation improves the recovery of chlorophyll content following light stress (Seppanen et al., 2003). The selenium content in plants changes considerably according to its concentration in the soil. Some authors recommend supplementing fertilisers with selenium as an effective measure to increase its content in the soil, or in the plant (Hartikainen, 2005, Carvalho et al., 2003). Plants convert selenium mainly into Se–methionine and incorporate it into proteins instead of methionine (Tapiero et al., 2003). The amount and form of selenium uptake by plants depends on the concentration and chemical form of Se in the soil solution and also on conditions in the rhizosphere, such as pH and presence of sulphates of phosphates, which compete with selenium in uptake by plants (Sors et al., 2006). After application, selenium is immediately taken up by plant roots and transferred into the plant apex. It appears either in the amino acid fraction or as inorganic selenate depending on its original form in the nutritive solution (Poggi et al., 2000).

Koutník (1996) monitored the content of selenium in the potato–growing regions of the Czech Republic and reported that the concentrations of selenium in potato tubers ranged between 0.048 and 0.458 mg.kg^{-1} of dry matter. According to Turakainen et al. (2004) treatment of potato plants with selenium resulted in higher concentrations of starch in the upper leaves of young plants; these authors also reported that tuber yields of selenium–treated plants were higher and contained relatively fewer larger tubers. Poggi et al. (2000) discovered that selenium fertilisation was successful as a suitable way of increasing the level of selenium in potatoes. However, they also discovered that selenium concentration in tubers increased with the dose of selenium applied.

The objective of the present study was to explore to what extent did applications of graded doses of selenium to the soil prior to planting potatoes affect the experimental potato plants in terms of the uptake of Se and Se accumulation in the tops and tubers, including the final effect on some yield–forming parameters. We also explored how high the dose of Se in the soil must be to result in such a concentration in the plant, which begins to show signs of depressive and toxic effects. In other words, to specify the dose of Se in the soil, which the potatoes tolerate, and which has no toxic effect.

MATERIAL AND METHODS

Exact small–plot field trials were established in two years (2004 and 2005) in the locality of the School Farm in Žabčice near Brno. Before establishment of the trial the soil was analysed according to Mehlich III (CH_3COOH, NH_4NO_3, NH_4F, HNO_3, and EDTA); results of the analyses are given in Tab. I. To determine the content of available phosphorus in the extract we used the colorimeter, for potassium the flame photometer, for magnesium and calcium AAS. The content of selenium in the soils was determined using AAS in an extract of 2 M HNO_3.

I: *Agrochemical characteristics of the soil (mg.kg^{-1})*

	Year	
	2004	2005
pH/$CaCl_2$	6.90	6.84
P	115	64
K	219	175
Mg	409	421
Ca	4854	4540
Se	0.1	0.1

In both years the trials were established in 5 variants and 4 replications using two genotypes differing in the length of the vegetation period (early variety Karin and semi–early variety Ditta). The size of one plot (replication) was 20.25 m^2. Planting was performed in early April, spacing was 750×250mm, i.e. stand density 53.300 plants.ha^{-1}. In addition to the unfertilised control variant, 4 variants were established where doses of 12, 24, 48 and 72 kg Se.ha^{-1} were applied, respectively. Selenium was applied in the form of a solution of sodium selenite on the soil surface two days before planting and then during soil preparation it was incorporated into the entire arable profile to set a balance between the soil solution and solid soil phase.

Samples to be used for yield analyses were taken at the stage of table maturity, i.e. at the time the potatoes get to the consumer. In concrete terms, in both experimental years the varieties Karin and Ditta were sampled after 90 and 99 days of vegetation, respectively. From each variant and each repetition we sampled the aboveground part of 4 hills and the underground part of 10 hills. The samples were analysed and the following yield–forming parameters were evaluated: total weight of one plant ($g.hill^{-1}$), number of stems ($stem.plant^{-1}$), number of tubers ($tuber.hill^{-1}$), and tuber yields ($t.ha^{-1}$). The results were processed statistically using the method of variance analysis (ANOVA) and method of follow–up testing with Tuckey's test by means of analytical tools in the MS Excel 2000 programme. Remediation of the supplied selenium was conducted by removing the soil from the trial plot after potato harvest.

On the same dates as sampling for yield analyses (i.e. after 90 and 99 days of vegetation) samples were taken for chemical analyses. The tops were sampled separately and after drying at 60 °C in the laboratory drier they were homogenised on the laboratory grinder. Tuber samples were processed in a routine way – rinsing in clean and safe water, peeling, cutting into slices, drying and homogenisation. To guarantee homogeneity, all samples were put through a 1mm mesh sieve according to the principles of processing. After homogenisation the samples were decomposed in a mixture of HNO_3 and H_2O_2 in the microwave equipment MILESTONE MLS 1200 MEGA. After conversion to the defined volume the sample was analysed on the UNICAM 939 atomic absorption spectrophotometer using the method of production of hybrids by means of the UNICAM VP 90 vapour system. Selenium was calibrated to the certified calibration solution CZ 9051 (Analytika Praha). The entire procedure was verified on certified reference material of CRM 402 white clover (Belgium).

RESULTS

Growth analyses gave the following results; in 2004, in the first year of trials, the total weight of the plant was not influenced by the dose of selenium or the variety (Tab. II). In 2004 the control variant (Fig. 1) achieved the highest average weight of the hill, i.e. 1115.3 $g.hill^{-1}$, and the Se_{72} variant the lowest, i.e. 932.7 $g.hill^{-1}$, (72 kg $Se.ha^{-1}$). In 2005 again there was no statistically significant difference among the varieties; however the total plant weight in 2005 was influenced by the applied dose of selenium (Tab. II). The control variant and the Se_{12} variant showed the highest average weight of plant (i.e. 1544.5 $g.hill^{-1}$ and 1584.5 $g.hill^{-1}$, respectively), and these values were statistically significantly higher (Fig. 2) than the average weight of variant Se_{72} (1163.5 $g.hill^{-1}$). Also the effect of the conditions of the year was highly statistically significant; in 2005 the average weight was 1379 $g.hill^{-1}$, and that was 344.6 $g.hill^{-1}$ more than in 2004.

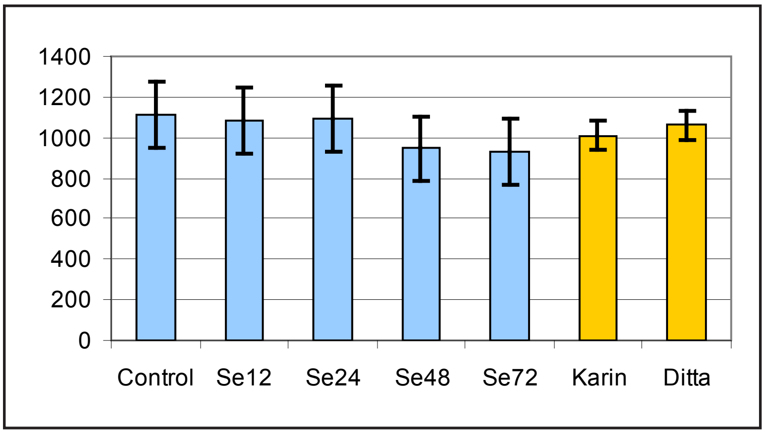
The variety did not affect the number of stems per hill in either year (Tab. III). Selenium fertilisation had a statistically significant effect only in 2005 (Fig. 3) when the number of stems per hill was statistically highly significantly higher in the Se_{12} variant (5.13 $stems.hill^{-1}$) than in the Se_{72} variant (2.53 $stems.hill^{-1}$). In 2004 no significant difference in the number of stems per hill between the individual variants was detected (Fig. 4). The conditions of the year had a statistically highly significant effect on this parameter; the number of stems per hill was higher in 2004 (4.97 $stems.hill^{-1}$) than in 2005 when it was only 3.76 $stems.hill^{-1}$.

Another evaluated yield–forming parameter was the number of tubers per hill. In both years it was affected by the variant of selenium fertilisation (Tab. IV). In 2004 the number of tubers per hill was statistically highly significantly higher (Fig. 5) in the control variant (11.7 $tubers.hill^{-1}$) than in variants Se_{48} (7.6 $tubers.hill^{-1}$) and Se_{72} (7.7 $tubers.hill^{-1}$). In 2005 (Fig. 6) the difference between the Se_{12} and Se_{72} variants was statistically significant (i.e. 9.3 and 6.3 $tubers.hill^{-1}$, respectively). The effect of the variety on the total number of tubers per hill was not confirmed in the trials and was not statistically significantly influenced by the conditions of the year.

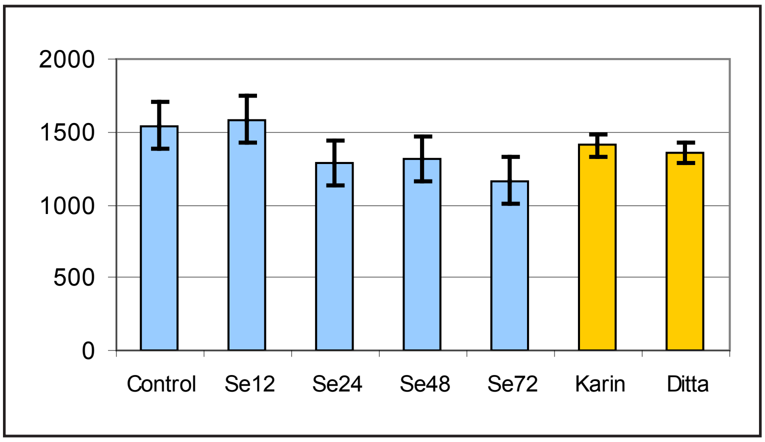
Tuber yields were affected by the variety in both years; in 2004 (Fig. 7) and in 2005 (Fig. 8) the Ditta variety gave higher yields. The effect of the variant of selenium fertilisation was statistically significant only in 2005 when yields of tubers per hectare of the Se_{72} variant (Fig. 8) were statistically highly significantly lower (28.6 $t.ha^{-1}$) than the control (43.4 $t.ha^{-1}$) and Se_{12} variant (41.7 $t.ha^{-1}$) (Tab. V). In both years it was discovered that with increasing dose of soil selenium the hectare yields decreased, although statistically significant differences were detected only between the above variants. The effect of the year on tuber yields per hectare was not statistically confirmed.

The results of chemical analyses are as follows. The level of selenium in potato tops and tubers increased with increasing level of selenium in the soil. Even an application of only 12 kg $Se.ha^{-1}$ resulted in a multiple increase in the level of selenium in the dry matter of potato tops compared to the control variant. The level of selenium in tops of the Se_{72} variety increased 34 times (7.49 mg $Se.kg^{-1}$ of dry matter) compared to the control variant (0.22 mg $Se.kg^{-1}$ of dry matter); in 2005 the increase was lower – from 0.354 mg $Se.kg^{-1}$ of dry matter in the control variant to 6.37 mg $Se.kg^{-1}$, i.e. 18 times more than the variant Se_{72} (Tab. VI).

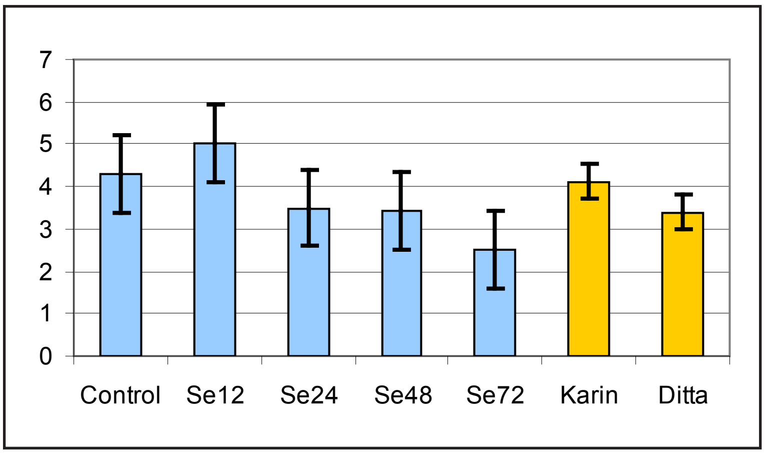
Selenium levels in potato tubers (Tab. VII)) were similar to the tops where the level increased with increasing dose of selenium in the soil. In both years the selenium level in tubers of the Se_{72} variety was 20 times higher than the control. The selenium level increased adequately also in the Se_{12} variant, i.e. variant where the lowest dose of Se was applied; compared to the control variant here the Se level in tubers increased 10.3 times in 2004 and 3.27 times in 2005. It was also discovered that potato tubers took up about half the amount of selenium than the tops. Comparisons between the experimental years showed that the content of selenium in tops and tubers was higher in 2004.



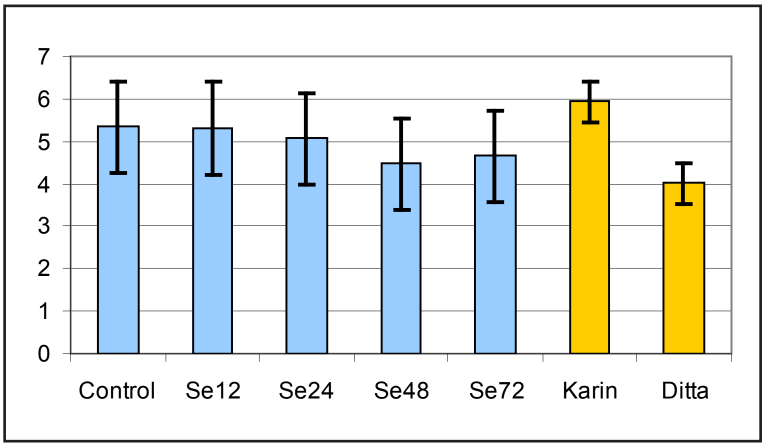
1: *Weight of one plant (g.plant^{-1}) in 2004*



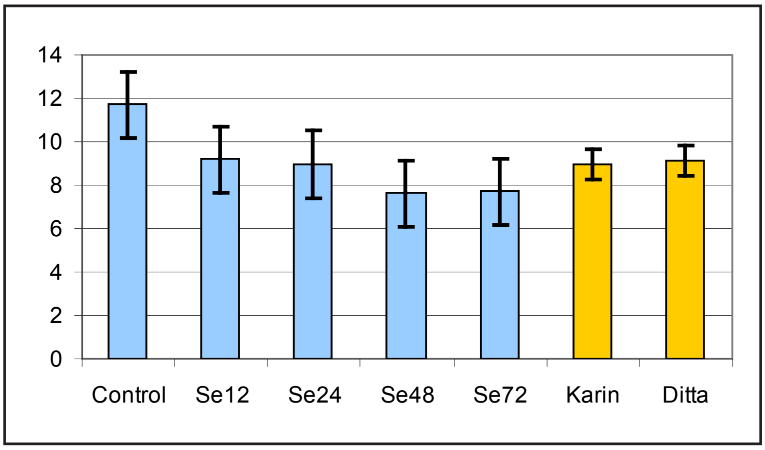
2: *Weight of one plant (g.plant^{-1}) in 2005*



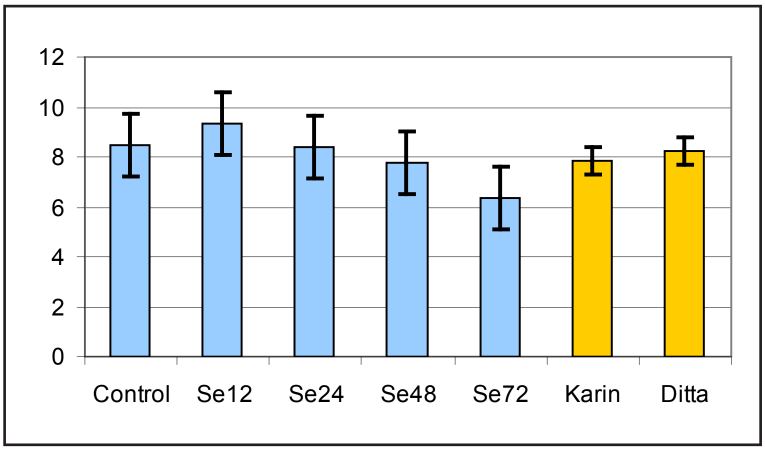
3: *Number of stems (stems.plant^{-1}) in 2005*



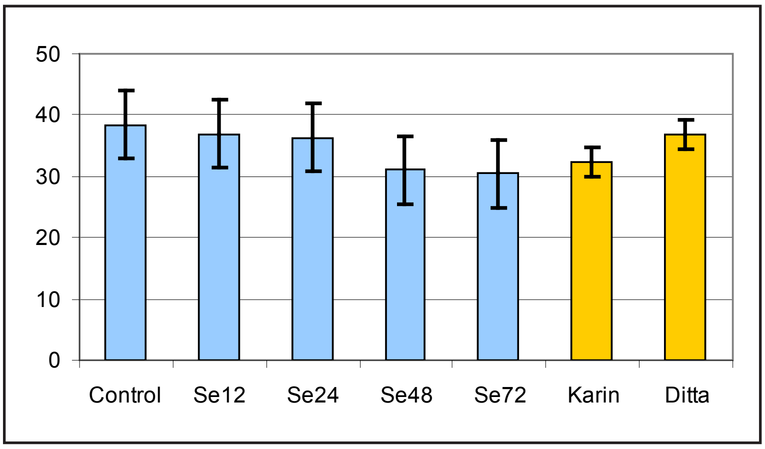
4: *Number of stems (stems.plant^{-1}) in 2004*



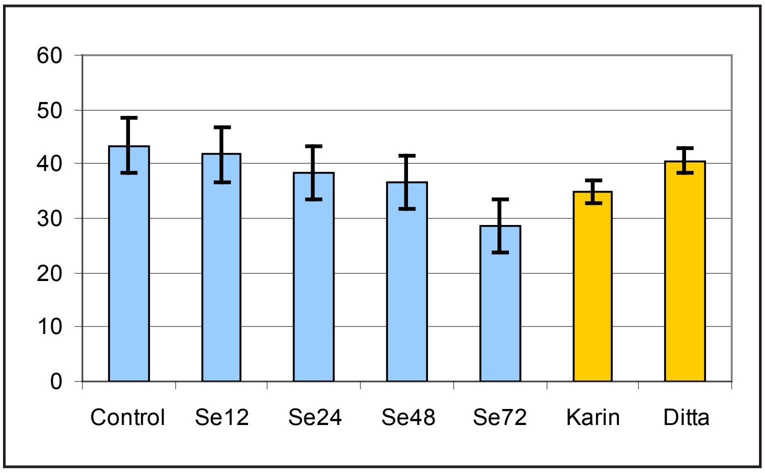
5: *Number of tubers (tubers.plant^{-1}) in 2004*



6: *Number of tubers (tubers.plant^{-1}) in 2005*



7: *Yield of tubers (t.ha^{-1}) in 2004*



8: *Yield of tubers (t.ha^{-1}) in 2005*

II: *Total weight of one plant (g.plant^{-1})*

	Variant						Variety		
Year	Control	Se12	Se24	Se48	Se72	$SD_{0,95}$	Karin	Ditta	$SD_{0,95}$
2004	1115.29	1081.83	1097.05	944.84	932.71	324.47	1008.26	1060.42	144.48
2005	1544.46	1584.48	1288.36	1314.10	1163.48	316.63^{**}	1406.01	1351.95	140.99

III: *Number of stems (stems.plant^{-1})*

	Variant						Variety		
Year	Control	Se12	Se24	Se48	Se72	$SD_{0,95}$	Karin	Ditta	$SD_{0,95}$
2004	5.34	5.31	5.06	4.47	4.66	2.16	5.93	4.01	0.96
2005	4.31	5.03	3.50	3.41	2.53	1.83^{**}	4.11	3.40	0.82

IV: *Number of tubers (tubers.plant^{-1})*

	Variant						Variety		
Year	Control	Se12	Se24	Se48	Se72	$SD_{0,95}$	Karin	Ditta	$SD_{0,95}$
2004	11.73	9.20	8.95	7.61	7.70	3.06^{**}	8.97	9.11	1.36
2005	8.45	9.31	8.38	7.75	6.33	2.50^{*}	7.86	8.23	1.11

V: *Yield of tubers (t.ha^{-1})*

Year	Variant						Variety		
	Control	Se12	Se24	Se48	Se72	$SD_{0,95}$	Karin	Ditta	$SD_{0,95}$
2004	38.38	36.85	36.35	31.01	30.47	11.03	32.39	36.83	4.91
2005	43.39	41.74	38.39	36.63	28.61	9.97**	34.88	40.62	40.44*

VI: *Selenium content in leaves (mg.kg^{-1} dry matter)*

Year		Treatment				
		Control	Se12	Se24	Se48	Se72
2004	Se content	0.22	5.40	5.89	7.39	7.49
	Index	1.00	24.55	26.75	33.57	34.05
2005	Se content	0.35	1.86	4.83	4.92	6.37
	Index	1.00	5.27	13.65	13.91	18.01

Index = ratio of appropriate variant/control variant

VII: *Selenium content in tubers (mg.kg^{-1} dry matter)*

Year		Treatment				
		Control	Se12	Se24	Se48	Se72
2004	Se content	0.21	2.16	2.92	3.36	4.31
	Index	1.00	10.29	13.90	16.00	20.52
2005	Se content	0.21	0.67	2.01	2.64	4.12
	Index	1.00	3.27	9.80	12.88	20.08

Index = ratio of appropriate variant/control variant

DISCUSSION

The results achieved in field trials in 2004–2005 showed that applications of graded doses of soil selenium before planting potatoes had a negative effect on the majority of yield–forming parameters. With increasing dose of selenium the tuber yields per hectare, total number of tubers per hill and total weight of the plant decreased. Our results differ from the results of Turakainen et al. (2004) who reported that selenium treatment increased potato yields. In our case it was obviously the result of applying several times higher doses of selenium (4–24 mg.kg^{-1} soil) than Turakainen et al. (2004) who applied only 0.3 mg.kg^{-1} of selenium in the soil. Se levels applied in the present study inhibited growth and development of potato plants. Results similar to those of Turakainen et al. (2004) were discovered in the number of tubers per hill where selenium application reduced the number of tubers. In practice we do not intend to use such high doses of selenium for potatoes. For environmental and economic reasons we also tested the effect of selenium of two orders lower (100–400 g Se.ha^{-1}) in the form of foliar application.

Results of chemical analyses proved that selenium fertilisation of potatoes before planting may be a suitable way of increasing the content of this essential element and anti–oxidant in the potato plant. Similar to Poggi et al. (2000) and Turakainen et al. (2004a) it was discovered that the concentration of selenium in tubers grows with the applied dose of Se. After summing up the above results our recommendation for practical potato production is to apply a dose of not more than 12 kg Se.ha^{-1}; the level of selenium is sufficiently high but does not severely reduce hectare yields and other yield–forming parameters. The achieved results are also in accordance with findings of Munshi and Mondy (1991) who reported that the level of selenium in potato tubers increased from 0.47 ppm to 0.93 ppm when the Se content in the soil increased from 5.6 to 16.2 kg Se.ha^{-1} after the application of sodium selenite, and did not affect the concentrations of other nutrients or ascorbic acid in the tubers. At the same time we can state that the content of selenium in potato tops is approximately twice as high as in tubers. This is in accordance with results of Slekovec and Goessler (2005) who detected the highest Se levels in vegetative parts of vegetables.

As a consequence the new technology in growing potatoes of higher consumer quality, particularly potatoes with a higher content of anti–oxidants including selenium, could become an important alternative to the existing technologies of potato growing based on the respective commercial trends and in this way contribute to the production of safe foodstuffs of high quality. Consumption of potatoes with a higher content of selenium could be one of the preventive measures against cardiovascular (Salonen et al., 1982) and oncological (Salonen et al., 1984) diseases, to which a deficit amount of this essential element may contribute.

SOUHRN

Vliv stupňovaných dávek selenu v půdě na výnosotvorné prvky a obsah selenu u brambor

Ve dvou pokusných letech 2004–2005 byl u dvou odrůd brambor s rozdílnou délkou vegetační doby sledován vliv stupňovaných dávek selenu v půdě (0, 12, 24, 48 a 72 kg Se.ha^{-1}) na výnosotvorné prvky (celková hmotnost rostliny, počet stonků na trs, počet hlíz na trs a hektarový výnos). Dále byl sledován obsah selenu, jako významného antioxidantu, v hlízách a nati brambor. Selen byl aplikován v příslušných dávkách do půdy před výsadbou brambor ve formě seleničitanu sodného. Odběry vzorků pro růstové a chemické analýzy byly provedeny po 90 (odrůda Karin), resp. 99 dnech vegetace (odrůda Ditta). Stupňované dávky selenu měly negativní vliv na většinu sledovaných výnosotvorných prvků. Se stoupající dávkou Se klesal jak hektarový výnos, tak počet hlíz pod trsem i celková hmotnost rostliny. Chemické analýzy provedené metodou AAS ukázaly, že koncentrace selenu v jednotlivých částech bramborové rostliny roste se vzrůstající dávkou tohoto prvku do půdy. Obsah selenu v hlízách se u varianty Se_{72} (4.13 mg Se.kg^{-1} sušiny) zvýšil ve srovnání s kontrolou (0.22 mg Se.kg^{-1} sušiny) až dvacetkrát.

brambory, výnosotvorné prvky, půdní aplikace selenu, obsah selenu

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