The effect of leaf area index on potatoes yield in soils contaminated by some heavy metals

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ABSTRACT

A method of growth analysis was used to evaluate the yield results in experiments conducted during years 1999–2001 on School co-operative farm in Žabčice. In sequential terms of sampling from two potato varieties with different duration of growing season, the effect of leaf area index (L, LAI), on yield of tubers in soils contaminated by cadmium, arsine and beryllium, was evaluated. From a growers view the phytotoxic influence on development of assimilatory apparatus and yields during the growth of a very-early variety Rosara and a medium-early Korela were evaluated. These varieties were grown under field conditions in soils contaminated by graded levels of cadmium, arsenic and beryllium. The yields of tubers were positively influenced by duration of growing season and increased of leaf area index during three experimental years. On the contrary, graded levels of heavy metals had negative influence on both chosen varieties. The highest phytotoxic influence was recorded of arsine and the lowest of cadmium. Significant influence of arsenic and beryllium on size of leaf area index in the highest applied variants was found. The influence of experimental years on tuber yields was also statistically significant.

Keywords: growth analysis; leaf area index; tuber yield; duration of growing season; varieties; heavy metals; terms of sampling

The high productive ability of present potato varieties (in The Czech Republic there are 110 of them registered) requires high levels of all techniques of growing to ensure sufficient yields of quality potatoes.

The share of solar energy for an increase of dry matter and tubers produced from a potato plant, is determined between a production of photosynthetic apparatus, especially by leaves and loss caused by this apparatus as well as by non-photosynthetic organs. Nátr (1972) mentions that, the produced dry matter is created by photosynthesis of the whole assimilatory system. It is influenced by respiration, translocation, distribution and accumulation of produced assimilators in storing organs of a plant. Hamouz (1991, 1993) refers to a positive influence of higher rates of nitrogen and irrigation to dynamics of yield in early potato varieties.

Nečas (1968, 1974) and Zrůst (1983, 1984) observed the rate of photosynthesis of different genotypes of potato varieties and photosynthetic productivity of potato plants. Nečas et al. (1966), in their first work, engaged the growing analysis as a method of evaluation of potato productivity while creating their biological and agricultural yield. They pointed out that the final result of biosynthetic and biological processes is the substantial and energetic state of a plant. Its dynamic expression is its growth and development. The formation of tubers of early varieties is more complex, because they have to be formed in a relatively short time (Zrůst 1991, Zrůst and Čepl 1991). Zrůst and Jůzl (1996) observed rate of photosynthesis, development of foliage, growth of dry matter and productivity of four very early potato varieties. The highest rate of LAI was found in variety Impala. They proved the significance of characteristics found out by a method of growth analysis for phytotechnical and cultivated evaluation of potato varieties. Hlušek et al. (1997, 1998) observed the dynamics of growth of tubers and the accumulation of heavy metals in tubers of different potato varieties. Zrůst et al. (1999) studied the relation of several characteristics of growth and yields from very early potato varieties. The yield of tubers influenced genotype and modification, however most by year and location. A higher level of nitrogen in soil positively influenced the rate of growth. Jůzl (1991, 1993, 1994) studied the effects of graded nitrogen levels on the dynamics of development LAI, achieved yield and content of nitrates in tubers of early potato varieties. Based on results achieved during three experimental years (1990–1992), he thinks that a very-early Impala is the most suitable variety for an early production of tubers, grown with total nitrogen rate at 120 kg $N.ha^{-1}$. Ducsay (2000) refers to phytotoxic effects of heavy metals on plants, which reduce yield and quality. Though cadmium, arsine or beryllium are not necessary for the growth of plants they are absorbed by roots and leaves, they get into plant tissue where they are accumulated, making worse the transport of nutrients, thus growth and quality of produced biomass. Absorption of these elements by plants is also related to risks with their entry into human food chain, they have a toxic and carcinogenic influence.

Hlušek et al. (1997, 1998) observed the effects of yields and content of foreign substances in potato tubers in two different localities with soils containing natural amount of heavy metals. In very-early varieties – Impala, Ukama, Krystala and Koruna a higher accumulation of Cd, Ni, Cu and Zn in tubers was found in both locality. Cadmium was closest to the maximum permissible limit of an element in fresh matter of a potato tuber (0.1 mg $Cd.kg^{-1}$). A variety influence was not statistically proven. Bokyoung et al. (1994) mentions that in contaminated soils the average content of cadmium in tubers can reach level of 1.3–2.2 $mg.kg^{-1}$.

The group of heavy metals is often mentioned with contamination of living environment and that is why this group of heavy metals is regarded as a risky one. For heavy metals are characteristic groups of metal and semimetal elements with atomic density higher than 6 $g.cm^{-3}$ (Tomáš 2000). Richter and Hlušek (1994) mentions that from the microbiologic elements to this group belong Zn, Cu, Mo, Fe and also elements like Cd, As, Be, Pb, Cr, Hg, Ni, which appear in living environment mainly due to anthropogenic activities.

Organic substances, mainly humus, are a safety system, which limits negative influence of various factors on potato growth. A balanced nutrition for well chosen potato varieties limits a negative effect of inorganic elements, which, if highly concentrated, can lead to contamination of plants thus to lower yield and worse quality of tubers.

Our attention was mainly paid to the effects of cadmium; arsine and beryllium on development of leaf area and with connection with this also on achieved yield of potatoes.

MATERIAL AND METHODS

Field experiments were started on 4. 7. 1999, 4. 6. 2000 and 4. 6. 2001 on experimental station MZLU in Žabčice near Brno. Žabčice is located 20 km southeast of Brno, at the altitude of 184 m, with a moderate winter and shorter period of sunshine. From agricultural-production point of view, it is classed in agricultural productive maize area, subtype of barley. Žabčice belongs to our warmest areas with annual mean temperature of 9°C (in growing season 15.6°C). It is one of our driest region, in last 50 years it averages at 553 mm a year, in growing season 356 mm. Period of sunshine varies between 800 and 2000 hours a year. The soils in the experimental areas genetically belong to the group of soils with strong accumulation of organic substances. The influence of ground water displays in gley process. Topsoil is loamy and clay-loamy, base soil is clay-loamy and clayey. Gley horizon is viscous, cold. Capillary elevation is high but slow. During dry years, cracks appear reaching deep. Content of humus is moderate 2.28%. Soil reaction is generally neutral or slightly acidic.

The preparation of soil was made on 4. 1. 1999, 4. 5. 2000 and 4. 4. 2001. Application of levels of each heavy metal was made by a single application on 4. 1. 1999:

Variants	Control	1	2	3	4
Cd ($mg.kg^{-1}$)	0.0	0.4	1.0	2.0	4.0
As ($mg.kg^{-1}$)	0.0	4.5	30.0	60.0	120.0
Be ($mg.kg^{-1}$)	0.0	2.0	7.0	14.0	28.0

In autumn 1999 and 2000, the rest of green manure was ploughed in (mustard). In spring additional fertilisation with fertilisers (vitriol) in total amount of unalloyed nutriment 100 kg $N.ha^{-1}$, 50 kg $P.ha^{-1}$ a 150 kg $K.ha^{-1}$. Planting of graded and pre-sprouted tubers sized 30–50 mm of a very-early variety Rosara and a medium-early variety Korela, was made by hands and stem end on the bottom of a raw, planting space was 75 × 20 cm, which is 66 600 plants per hectare. In two opposite places of the experimental field, catchers on stands were set to catch solid fall-outs, according the methods of ÚKZÚZ. After the emergency a usual cultivation was done, i.e. destruction of weeds, soil crust and chemical treatment against Colorado potato beetle and late blight according the usual methodology ÚKZÚZ. During the growing season, the vegetable material was sampled for a laboratory analysis and analysis of growth, which was done in set intervals with both varieties. The third different term of sampling respected different growing season and thus beginning of physiological maturity of a very early Rosara and medium-early variety Korela (Table 1).

In consecutive terms of samplings a laboratory analysis of each plant parts was done. The total weight in $t.ha^{-1}$ was found, as well as the total weight of fresh green leaves from one plant in grams, from which the leaf area (dm^2) was counted as well as the leaf area index ($dm^2.dm^{-2}$) according to the methodology, which is mentioned by Nečas et al. (1966) and Zrůst (1973). Evaluated was the phytotoxic influence of graded levels of Cd, As and Be on leaf area index (LAI) in $dm^2.dm^{-2}$ and yields of tubers in $t.ha^{-1}$, with both varieties of different growing seasons.

Table 1. Survey of single terms of samplings in Žabčice in years 1999–2001

Sampling	1999	2000	2001	Comment
I.	10. 6.	7. 6.	7. 6.	65 days (1999) and 63 days (2000, 2001) since the set-up of the growth
II.	24. 6.	23. 6.	21. 6.	79 days (1999, 2000) and 77 days (2001) since the set-up of the growth
III.	8. 7.	4. 7.	4. 7.	93 days (1999) and 90 days (2000, 2001) since the set-up of the growth for a very early variety Rosara
IV.	27. 7.	26. 7.	26. 7.	112 (1999–2001) days since the set-up of the growth for a very variety Korela
	18. 8.	22. 8.	22. 8.	134 days (1999) and 139 days (2000, 2001) after the leaves got totally dry

Table 2. Leaf area index ($dm^2.dm^{-2}$) while contaminated by cadmium

Year	Variant	I. sampling		II. sampling		III. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	6.41	5.87	8.35	7.28	7.15	6.17
	Cd-1	5.66	5.75	7.64	6.86	6.35	5.74
	Cd-2	5.01	5.19	7.09	6.44	5.79	5.30
	Cd-3	4.47	4.28	6.18	6.14	5.26	4.80
	Cd-4	3.22	3.17	5.54	5.61	4.46	4.19
2000	control	3.96	3.89	5.83	5.49	5.54	4.29
	Cd-1	3.65	3.59	5.95	5.59	5.27	4.11
	Cd-2	3.62	3.80	5.66	5.37	5.40	4.18
	Cd-3	3.69	3.31	5.75	4.99	4.98	4.08
	Cd-4	3.47	3.18	5.54	5.02	4.91	3.92
2001	control	3.92	2.04	6.03	4.24	5.32	3.76
	Cd-1	3.77	2.01	5.81	4.16	5.24	3.73
	Cd-2	3.29	1.81	5.68	3.95	5.11	3.63
	Cd-3	3.19	1.76	5.58	3.89	4.90	3.44
	Cd-4	3.15	1.70	5.42	3.71	4.74	3.37

For statistical treatment a Unistat 4.53 for Excel. First, an analysis of variance was undertaken, and then testing was done through the Tukey test at levels of 95 and 99%.

RESULTS AND DISCUSSION

Leaf area index (L, LAI) in $dm^2.dm^{-2}$

The achieved results of leaf area index for observed elements cadmium, arsenic and beryllium in experimental years 1999–2001, for Korela and Rosara varieties are shown in Tables 2, 3 and 4. Results of statistical analysis are shown in Tables 5 and 6.

Considering the years, the highest leaf area was achieved in 1999, in second sampling of Korela variety in control variant and was 8.35 $dm^2.dm^{-2}$. During next years, the leaf area gradually decreased. This trend is distinctive for variety Korela. There was a statistically significant difference between years 1999 and 2000 and between 1999 and 2001. Between years 2000 and 2001, no significant difference was found. When comparing the varieties, Korela had greater total leaf area index than Rosara. Highly significant difference was found between these two varieties. The single variant of cadmium decreased the leaf area index, but was not significantly different.

Considering the years the highest leaf area index was achieved again in 1999, with Korela variety in second sampling in control variant (8.11 $dm^2.dm^{-2}$). The influence of years was not statistically significant though. While watching the varieties the trend is similar with those con-

Table 3. Leaf area index ($dm^2.dm^{-2}$) while contaminated by arsenic

Year	Variant	I. sampling		II. sampling		III. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	6.55	5.79	8.11	7.36	6.80	5.78
	As-1	4.65	4.96	6.34	5.47	5.32	5.22
	As-2	3.91	3.50	5.24	4.93	4.74	4.67
	As-3	2.57	2.42	4.20	3.89	3.92	3.93
	Aa-4	1.82	1.73	3.40	2.83	3.31	2.81
2000	control	3.58	3.27	5.98	5.68	5.31	4.15
	As-1	3.43	3.11	5.69	5.43	5.39	4.02
	As-2	3.30	3.20	5.59	5.06	5.09	3.99
	As-3	3.37	2.94	5.35	5.18	4.83	4.04
	Aa-4	3.13	2.86	5.12	4.71	4.53	3.77
2001	control	3.56	1.94	5.77	4.10	4.96	3.63
	As-1	3.54	1.92	5.61	4.02	4.70	3.58
	As-2	3.42	1.84	5.54	3.92	4.54	3.51
	As-3	3.23	1.80	5.36	3.83	4.44	3.43
	Aa-4	3.12	1.71	5.29	3.79	4.34	3.35

Table 4. Leaf area index ($dm^2.dm^{-2}$) while contaminated by beryllium

Year	Variant	I. sampling		II. sampling		III. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	6.66	5.84	7.92	7.44	6.97	6.08
	Be-1	5.01	4.49	7.00	6.61	6.23	5.59
	Be-2	5.10	4.39	5.75	5.30	5.31	5.04
	Be-3	3.63	3.11	5.20	4.17	4.52	4.01
	Be-4	2.82	2.15	4.34	3.32	3.61	3.03
2000	control	3.89	3.48	5.75	5.38	5.47	4.22
	Be-1	3.56	3.33	5.96	5.57	5.58	4.07
	Be-2	3.60	3.23	5.81	5.11	5.25	4.14
	Be-3	3.43	2.97	5.64	4.90	5.02	3.98
	Be-4	3.29	3.04	5.40	4.99	4.73	4.01
2001	control	3.77	1.99	5.95	4.17	5.14	3.70
	Be-1	3.68	1.97	5.68	4.06	4.97	3.69
	Be-2	3.52	1.91	5.62	3.89	4.78	3.60
	Be-3	3.44	1.85	5.48	3.72	4.59	3.43
	Be-4	3.27	1.79	5.37	3.66	4.46	3.38

taminated by cadmium. However, significant difference was found in leaf area index of plants contaminated by arsine. With gradual increase in level of arsenic a decrease in leaf area index occurred. There was found a highly significant difference between control and variant As-3 and As-4. The significant difference was found in variant As-1 and As-4.

The highest leaf area index in soil contaminated by beryllium was achieved in 1999 with Korela variety in second sampling in control variant (7.92 $dm^2.dm^{-2}$). Considering the experimental years the trend of leaf area index is decreasing while contaminated by beryllium, likewise with other observed elements. A highly significant difference was found only between years 1999 and 2001. Variety Korela had a higher leaf area index than Rosara. This characteristic was also proven statistically. The influence of higher levels of beryllium resulted in smaller leaf area index in both varieties. Statistically highly significant difference was found between control variant and Be-4 variant. An evident difference was found between control and Be-3 variant also between Be-1 and Be-4 variant.

Yield of tubers ($t.ha^{-1}$)

Achieved results of tuber yield ($t.ha^{-1}$) while contaminated by cadmium, arsenic and beryllium, during years of 1999–2001, for Korela and Rosara varieties are mentioned in Tables 7, 8 and 9. The results achieved in statistical treatment are mentioned in Tables 10 and 11.

The highest yield of tubers was achieved in 1999, with Korela variety in IV. sampling in control variant, which

Table 5. Analysis of variance for leaf area indexes ($dm^2.dm^{-2}$)

Source of variability	Cd				As				Be			
	sum of squares	stages of latitude	*F*-values	significance	sum of squares	stages of latitude	*F*-values	significance	sum of squares	stages of latitude	*F*-values	significance
Year	47.89	2	566.25	**	9.18	2	71.42	**	19.42	2	197.71	**
Variety	16.17	1	382.43	**	13.55	1	210.82	**	19.95	1	406.06	**
Sampling	58.26	2	688.92	**	54.72	2	425.72	**	51.39	2	523.06	**
Variant	15.47	4	91.49	**	31.48	4	122.47	**	25.97	4	132.17	**
Year × variety	6.42	2	75.96	**	4.55	2	35.38	**	3.86	2	39.33	**
Year × sampling	2.82	4	16.69	**	2.05	4	7.99	**	2.05	4	10.45	**
Year × variant	9.61	8	28.4	**	31.14	8	60.56	**	23.87	8	60.75	**
Variety × sampling	0.74	2	8.74	**	0.11	2	0.82		0.05	2	0.5	
Variety × variant	0.28	4	1.67		0.3	4	1.17		0.06	4	0.32	
Sampling × variant	0.23	8	0.67		0.67	8	1.31		0.56	8	1.42	
Mistake	2.2	52			3.34	52			2.55	52		
Total	160.1	89			151.1	89			149.74	89		

* statistically significant difference
** statistically highly significant difference

Table 6. Subsequent testing by Tukey – a test for leaf area indexes

Year	Cd					As					Be				
	average	*SD*	2001	2000	1999	average	*SD*	2001	2000	1999	average	*SD*	2001	2000	1999
2001	3.95	0.273		*	**	3.79	0.233				3.88	0.2234			**
2000	4.60	0.273	*		**	4.37	0.233				4.49	0.2234			
1999	5.71	0.273	**	**		4.54	0.233				5.02	0.2234	**		

Varieties	Cd				As				Be			
	average	*SD*	Rosara	Korela	average	*SD*	Rosara	Korela	average	*SD*	Rosara	Korela
Rosara	4.33	0.1906		**	3.85	0.1864		**	4.00	0.181		**
Korela	5.18	0.1906	**		4.62	0.1864	**		4.94	0.181	**	

Variants	Cd							As							Be						
	average	*SD*	Cd-4	Cd-3	Cd-2	Cd-1	K	average	*SD*	As-4	As-3	As-2	As-1	K	average	*SD*	Be-4	Be-3	Be-2	Be-1	K
4	4.13	0.3074						3.42	0.2796				*	**	3.70	0.2844				*	**
3	4.48	0.3074						3.82	0.2796					**	4.06	0.2844					*
2	4.80	0.3074						4.22	0.2796						4.52	0.2844					
1	5.05	0.3074						4.58	0.2796	*					4.84	0.2844	*				
C	5.31	0.3074						5.13	0.2796	**	**				5.21	0.2844	**	*			

* statistically significant difference
** statistically highly significant difference
C – control

was 60.61 t.ha^{-1}. Variety Rosara achieved the highest yield also in 1999 in IV. sampling (52.23 t.ha^{-1}). During other years, generally smaller yields were recorded. In statistical treatment of results, a highly significant difference was found between 1999 and 2000 and between 2000 and 2001. Medium-early variety Korela achieved generally higher yield than very early Rosara. In statistical treatment however was not found a statistically significant difference between varieties. In year 1999, a relatively wide variance was recorded in single variants of cadmium. On contrary, the year 2001 was characteristic with narrowing of this variance. In statistical treatment, no significant difference was found between levels of cadmium and achieved yield of tubers.

Korela variety achieved the highest yield in 1999, in IV. sampling in control variant (58.42 t.ha^{-1}). The highest yield had Rosara at 51.64 t.ha^{-1} in 1999. Statistically highest significant difference was found between years 1999 and 2000 also between 2000 and 2001. Even with contamination by arsenic, the yield was overall higher with vari-

Table 7. Yield of tubers (t.ha^{-1}) while contaminated by cadmium

Year	Variant	I. sampling		II. sampling		III. sampling		IV. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	24.78	29.63	42.96	46.05	59.23	49.04	60.61	52.23
	Cd-1	23.35	27.34	39.02	43.22	56.02	46.78	55.12	50.16
	Cd-2	21.53	22.23	35.23	40.56	50.74	44.08	52.44	47.33
	Cd-3	19.77	16.89	30.75	39.01	46.31	39.92	50.36	44.98
	Cd-4	16.84	12.63	26.06	33.09	42.53	37.52	47.34	40.29
2000	control	22.02	25.46	37.60	35.26	49.59	39.69	51.69	42.82
	Cd-1	22.34	28.15	38.89	35.88	51.31	38.95	54.31	44.35
	Cd-2	21.76	23.41	38.52	31.10	46.50	38.94	49.20	40.49
	Cd-3	24.83	20.48	33.55	29.96	48.21	35.01	46.48	41.69
	Cd-4	19.55	21.41	32.73	27.52	43.56	33.36	46.23	37.49
2001	control	7.71	7.16	28.35	24.29	39.20	30.92	44.28	41.16
	Cd-1	7.52	6.62	27.39	23.52	38.62	29.78	44.06	40.65
	Cd-2	6.09	5.82	25.58	21.31	36.56	28.70	41.59	35.86
	Cd-3	5.10	5.01	23.49	20.36	35.29	27.51	39.40	34.73
	Cd-4	4.92	4.72	22.65	19.62	34.32	26.86	38.51	33.54

Table 8. Yield of tubers (t.ha^{-1}) while contaminated by arsenic

Year	Variant	I. sampling		II. sampling		III. sampling		IV. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	22.38	27.13	40.34	42.58	59.58	47.11	58.42	51.64
	As-1	19.13	21.26	32.47	36.51	46.95	40.34	48.87	41.36
	As-2	16.09	16.46	27.82	31.39	42.32	37.73	45.3	39.06
	As-3	12.79	11.4	20.84	28.56	39.38	33.36	40.45	34.43
	Aa-4	6.98	7.35	16.46	22.43	36.08	29.42	37.36	32.72
2000	control	22.26	26.40	37.66	32.18	49.13	38.46	51.44	41.99
	As-1	25.32	24.89	39.46	34.96	47.23	41.13	51.47	40.78
	As-2	20.04	20.39	34.61	30.07	44.55	34.86	48.83	41.13
	As-3	17.96	22.02	31.86	27.74	43.62	32.38	44.44	36.49
	Aa-4	19.25	15.51	29.54	25.35	40.66	29.70	42.60	34.85
2001	control	4.47	9.38	23.45	18.65	34.16	25.95	44.08	35.76
	As-1	4.17	8.90	22.58	18.32	33.08	24.73	39.71	35.31
	As-2	3.83	8.29	21.18	16.88	30.53	23.51	38.15	34.39
	As-3	3.83	7.83	19.71	15.79	29.27	22.43	36.05	32.25
	As-4	3.52	7.25	18.31	14.56	28.64	21.65	34.41	32.07

ety Korela than variety Rosara. However, this was not statistically proven. The influence of arsenic on yield had a decreasing trend in all years, although year 2001 is typical of reduction, compared to year 1999. In statistical treatment was found a highly significant difference between control variant and As-4 variant.

The highest yield was recorded in 1999 with medium-early variety Korela in last IV. sampling in control variant, where the yield was 59.53 t.ha^{-1}. In the same year, sampling and variant the very-early variety Rosara achieved yield 10 t.ha^{-1} less, which was 49.88 t.ha^{-1}. In statistical treatment of results, a highly significant difference was confirmed between 1999 and 2000 and between 2000 and 2001. Considering the varieties, Korela was defined with higher yield than variety Rosara. Increasing level of beryllium had similar negative influence on yields, as other observed elements. In statistical treatment of results a significant difference was not found.

The decrease in yield was caused by increasing levels of heavy metals. This is in agreement with conclusion by Ducsay (2000) in his work, he refers to phytotoxic effects of heavy metals on plants, which decrease their yields and quality. Distinctness, that we found between very early variety Rosara and medium-early Korela, in size of leaf area index and yield of tubers, is the same as McLaughlin et al. (1994), he refers to high variety influence of foreign substances on yield and content of elements in tubers.

Comparing the influence of each element observed, we can state, that the greatest influence on leaf area index had arsenic, then beryllium and the least phytotoxic was cadmium. Vostal and Penk (1989) refer to the same, the

Table 9. Yield of tubers (t.ha^{-1}) while contaminated by beryllium

Year	Variant	I. sampling		II. sampling		III. sampling		IV. sampling	
		Korela	Rosara	Korela	Rosara	Korela	Rosara	Korela	Rosara
1999	control	23.55	29.15	41.36	43.7	58.2	49.83	59.53	49.88
	Be-1	21.53	24.46	36.08	40.02	51.64	43.75	52.87	43.27
	Be-2	18.81	18.06	32.77	36.45	47.75	40.72	48.71	41.09
	Be-3	16.89	12.47	26.86	31.92	42.48	37.09	43.91	37.36
	Be-4	14.33	10.55	24.3	27.34	39.12	34.37	39.97	36.4
2000	control	21.55	26.10	39.47	34.47	48.47	38.96	51.35	43.34
	Be-1	25.59	25.41	39.26	34.03	52.02	40.23	54.98	43.68
	Be-2	23.59	24.04	34.86	33.45	46.67	36.94	47.81	39.89
	Be-3	19.69	23.32	34.81	28.80	43.93	34.17	48.23	37.73
	Be-4	19.11	17.49	36.27	26.46	43.72	33.56	44.88	38.72
2001	control	7.46	8.58	25.96	24.17	40.01	30.00	43.46	40.80
	Be-1	7.18	8.37	25.34	23.93	38.46	28.80	42.91	40.75
	Be-2	6.01	7.66	24.05	21.14	36.98	27.33	41.91	38.82
	Be-3	5.86	7.67	22.74	20.11	35.40	26.84	40.38	37.40
	Be-4	3.65	7.39	21.94	19.39	34.09	25.61	38.91	35.79

Table 10. Analysis of variance for yield of tubers (t.ha^{-1})

Source of variability	Cd				As				Be			
	sum of squares	stages of latitude	*F*-values significance		sum of squares	stages of latitude	*F*-values significance		sum of squares	stages of latitude	*F*-values significance	
Year	4136.46	2	576.37	**	3448.36	2	550.23	**	2796.36	2	419.37	**
Variety	433.01	1	120.67	**	359.29	1	114.66	**	442.37	1	132.69	**
Sampling	13985.5	3	1299.15	**	12122.67	3	1289.54	**	13244.11	3	1324.16	**
Variant	1026.41	4	71.51	**	1762.23	4	140.59	**	1228.92	4	92.15	**
Year × variety	61.86	2	8.62	**	70.11	2	11.19	**	57.17	2	8.57	**
Year × sampling	327.29	6	15.2	**	282.08	6	15	**	371.26	6	18.56	**
Year × variant	230.04	8	8.01	**	657.05	8	26.21	**	433.22	8	16.24	**
Variety × sampling	439.43	3	40.82	**	505.03	3	53.72	**	450.25	3	45.02	**
Variety × variant	0.8	4	0.06		4.86	4	0.39		2.18	4	0.16	
Sampling × variant	18.57	12	0.43		42.93	12	1.14		15.06	12	0.38	
Mistake	265.54	74			231.89	74			246.71	74		
Total	20924.9	119			19486.5	119			19287.62	119		

* statistically significant difference
** statistically highly significant difference

higher tolerance of majority of plants to concentration of cadmium in plants above 50 mg.kg^{-1} in soil. Tlustoš and Pavlíková (1998) refer to phytotoxic influence of cadmium in plants, which is demonstrated by damage of roots, limited growth and red-brown colour of leaves, which turn to chlorosis. Královec and Slavík (1997) say that, entry of cadmium into plant depends on many factors. Firstly soil characteristics (pH, content of Cd and nutrients, content of organic substance), also characteristics of growth (sort of plant, variety, development phase, intensity of growth, part of plant) and climatic conditions. Richter and Hlušek (1994) mention that, cadmium immobilises itself by agrillaceus minerals and humic acids. Content of cadmium in each parts of plant decreases in succession – roots, leaves, stems, reserve organs and least content was found in seeds. Most crops are tolerant of cadmium, i.e. tomatoes and potatoes, on contrary spinach, soya and tobacco are very sensitive to it. Es-

Table 11. Subsequent testing by Tukey – a test for yield of tubers

Year	Cd					As					Be				
	average	*SD*	2001	2000	1999	average	*SD*	2001	2000	1999	average	*SD*	2001	2000	1999
2001	25.4693	1.894		**	**	22.1758	1.8512		**	**	25.5813	1.8772		**	**
2000	36.2573	1.894	**			32.5563	1.8512	**			35.7135	1.8772	**		
1999	39.0993	1.894	**			34.33	1.8512	**			35.9263	1.8772	**		

Varieties	Cd				As				Be			
	average	*SD*	Rosara	Korela	average	*SD*	Rosara	Korela	average	*SD*	Rosara	Korela
Rosara	31.71	1.7013			27.96	1.6436			30.49	1.6315		
Korela	35.51	1.7013			31.42	1.6436			34.33	1.6315		

Variants	Cd							As							Be						
	average	*SD*	Cd-4	Cd-3	Cd-2	Cd-1	K	average	*SD*	As-4	As-3	As-2	As-1	K	average	*SD*	Be-4	Be-3	Be-2	Be-1	K
4	29.30	1.7013						24.4446	2.5341					*	28.06	2.5579					
3	31.63	1.7013						26.87	2.5341						29.84	2.5579					
2	33.57	1.7013						29.47	2.5341						32.31	2.5579					
1	36.39	1.7013						32.45	2.5341						35.19	2.5579					
C	37.16	1.7013						35.1917	2.5341	*					36.64	2.5579					

* statistically significant difference
** statistically highly significant difference
C – control

pecially in danger are crops grown in acidic soils (pH = 4.5–5.5), where about 80% of soil cadmium is capable of migration.

The content of As in plants, in natural conditions varies in range of 0.01–1.5 $mg.kg^{-1}$ in dry matter. Higher content of As in soils also causes higher absorption of this element by roots, which are damaged and plants are limited in growth (Onken and Hossner 1995).

Based on achieved results we can state, that yield of tubers ($t.ha^{-1}$) was positively influenced by higher leaf area index (L, LAI). With higher index of LAI, the yield of both varieties grew as well. Higher levels of heavy metals negatively influenced the yield. Arsenic, of the observed elements, had the greatest phytotoxic influence. Potato growth was the least sensitive to cadmium.

With the longer duration of growing season the yield of tubers increased. Early harvested very-early variety Rosara had higher yields of tubers. With progressing length of growing season the yield of medium-early variety Korela grew significantly. Difference in yields in last term of sampling varied between both varieties 5–10 $t.ha^{-1}$.

Medium-early variety Korela gained, during all three experimental years 1999–2001 at the beginning of physiological maturity, overall higher rates of LAI as well as total yields of tubers, than very-early variety Rosara.

The highest rates of leaf area index were gained in II. sampling of plants, i.e. in 77–79 days after crop establishment, with both observed potato varieties.

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ABSTRAKT

Vliv listové pokryvnosti na výnos brambor v půdách kontaminovaných některými těžkými kovy

Byly hodnoceny tříleté výnosové výsledky v pokusných letech 1999 až 2001 na Školním zemědělském podniku v Žabčicích, dosažené za využití metody růstové analýzy. V postupných termínech odběrů dvou odrůd brambor s rozdílnou délkou vegetační doby byl sledován vliv listové pokryvnosti (L, LAI) na výnos hlíz na půdách kontaminovaných kadmiem, arzenem a beryliem. Z pěstitelského hlediska byl posouzen fytotoxický vliv na rozvoj asimilačního aparátu a na výnosy hlíz v průběhu vegetace velmi rané odrůdy Rosara a polorané odrůdy Korela. Obě odrůdy byly pěstovány v polních podmínkách na půdě se stupňovanými hladinami kadmia, arzenu a berylia. Výnosy hlíz byly ve všech třech pokusných letech kladně ovlivněny délkou vegetační doby a stoupajícími hodnotami listové pokryvnosti. Zvýšené hladiny těžkých kovů naopak působily na výnosy hlíz negativně u obou odrůd. Nejvyšší fytotoxický vliv byl zaznamenán u arzenu a nejnižší u kadmia. Při statistickém zpracování byly nalezeny průkazné rozdíly vlivu arzenu a berylia na velikost listové pokryvnosti v nejvyšších aplikovaných hladinách. Dále byly zjištěny průkazné rozdíly ve vlivu sledovaných ročníků na výnos hlíz.

Klíčová slova: růstová analýza; listová pokryvnost; výnos hlíz; délka vegetační doby; odrůdy; těžké kovy; termíny odběrů

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