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EFFECT OF SOIL CONTAMINATION WITH HEAVY METAL IONS ON THE HARMFUL AND USEFUL ENTOMOFAUNA OF BROAD BEANS

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A b s t r a c t. Influence of some selected heavy metals applied into soil as water salt solutions (2 mg Cd, 30 mg Cu, 15 mg Ni, 80 mg Pb and 70 mg Zn/kg soil d.m.) on the growth and development of broad beans and on occurrence of harmful and beneficial insects on the plant was investigated in field conditions. The applied doses of soil contamination with heavy metals strongly affected broad beans development. Plants were characterised by a significantly lower number and length of shoots and a lesser number of pods per plant as compared to the control. Chemical analysis of individual parts of plant revealed big differences in heavy metal contents in roots of plants in contaminated soil as compared to control soil with natural contents of metal ions. In the above ground parts, i.e. leaves and shoots the differences were considerably smaller.

Numbers of beetroot aphids were determined on the selected plants since its appearance to the end of its development. Simultaneously, occupation of aphid colony by predators: ladybirds, *Syrphidae* and *Chrysophidae* larvae was also assessed. The number of plants occupied by aphids at each plot was also estimated. Aphids on plants in soil with increased metal contents formed more numerous colonies, also the insects invaded a bigger number of plants. Ladybird larvae, predators for aphids, occurred in more numerous colonies on plants in contaminated soil. The numbers of other aphid predators: *Syrphidae* and *Chrysophidae* larvae did not reveal statistically significant differences.

K e y w o r d s: heavy metals, soil, *Aphis fabae* Scop., aphidophages.

INTRODUCTION

Heavy metals belong to the most dangerous pollutants of the natural environment. It is due to the easy way they form various ligand complexes in biological systems, thereby they may remain in the environment for a long time and affect living organisms [10].

The main sources of heavy metals in soils are: their natural contents related to the matrix and soil formation processes; natural and anthropogenic pollution (e.g.

organic fertilisers, industrial and traffic dusts, sewage water and sewage sludge or pesticides).

The relation between heavy metal contents in the soil and plants cultivated in it is usually weak. Soil characteristics: cation exchange capacity and reaction mostly determine their phytoavailability. As pH increases heavy metal uptake by plants decreases. Next they reveal highest toxicity for plants in the soils with low cation exchange capacity. The more soil characteristics affect the heavy metal availability for plants, the highest their contents in soil [4]. Heavy metal uptake and tolerance of their increased levels are considerably differentiated not only among plant species but also among varieties [4,8].

As shown in many studies, contaminated soils are not the main source of heavy metal pollution (c.a. 10-30%) but atmospheric dusts which deposit on their surface (c.a. 90-70%) [9,14,15]. Industrial emissions have been considerably limited recently. At the same time the level of plant contamination and further accumulation of heavy metals in soil has also been diminished. However, soil contamination is practically an irreversible process. For example, if the heavy metal influx into the soil were stopped it would last over 500 years to decrease the topsoil lead content by 10% through its removal with yield and washout [5].

Soil contamination with heavy metals leads to pollution of the next chains of trophic chain. Reactions of invertebrates, which feed on contaminated plants are diversified. Regulatory mechanisms of metal levels, which are different in various invertebrate groups are the decisive factor [7]. An increased heavy metal contamination of the environment leads to a raised number of insects with proboscis mouthpart [2].

Aphis fabae Scop. is one of the most dangerous broad bean pests [12]. The shoots affected by it are deformed, bloom less and when heavily affected do not set seeds.

In literature there is no data on the effect of soil pollution with heavy metals on the occurrence and development of pests and their natural enemies.

The aim of the work was to examine the influence of some definite level of soil contamination with heavy metals on growth of broad beans, the occurrence and development of *Aphis fabae* Scop. and its natural enemies.

MATERIAL AND METHODS

Field experiment was conducted in 1998 in Zagaje Stradowskie, in Czarnocin commune within the Świętokrzyskie province. Observations on development of aphid population were carried out on broad beans, White Windsor cv. The plants were cultivated in plastic pots with 6.6 kg d.m. sunk into the ground level in the control soil with natural heavy metal contents (0.6 mg Cd, 12.8 mg Ni, 8.2 mg Cu, 52.9 mg Zn, 28.2 mg Pb/kg d.m. of soil) and in soil contaminated with heavy metal ions (doses: 2 mg Cd, 15 mg Ni, 30 mg Cu, 70 mg Zn and 80 mg Pb/kg d.m. of soil). Water solutions of these metals (2 mg $CdSO_4$ $8H_2O$, $NiSO_4$ $7H_2O$, $CuSO_4$, $ZnSO_4$ $7H_2O$, $Pb(NO_3)_2$) were thoroughly mixed with the soil in April 1998. The plants were sown a week later. The experiment was set up as a completely randomised system in four replications.

The observations started at the moment when the first aphids appeared on the plants. Ten plants per plot were randomly chosen for analysis. *Aphis fabae* colonies were examined once a week. All aphids were counted and also pre-imago stages of *Diptera*, *Syrphidae, Coleoptera, Coccinelidae, Neuroptera, Chrysophidae* and adult ladybirds. The degree of aphid colony parazitising by parazitoids was estimated on the basis of the number of parasitized aphid mummies in relation to total number of aphids per colony. A percentage number of plants settled by aphids was also determined.

Plant material for morphological and chemical analyses was collected when the aphids finished feeding on the plants. The obtained results were subjected to a single factor variance analysis for completely randomised system with significance level 0.05. Chemical analysis of the plant material involved the assessment of heavy metal contents. pH was assayed in the soil in 1 M KCl/dm^3 solution using potentiometric method, humus content by the Tiurin's method, heavy metal contents approximate to total content was determined after soil sample digesting in the mixture of nitric and perchloric acids on water bath. Heavy metal concentrations in the soil filters and in the plant material after its dry mineralization were assessed by atomic absorption spectrophotometry (AAS).

RESULTS AND DISCUSSION

Czarnocin commune is situated in the southern part of the Świętokrzyskie province, far from the greatest sources of air pollution provided by iron and metalworks, cement plants and limestone quarries, sulphur processing plants or agri-food enterprises which are localised mainly in the northern part of the province. The experiment was set up over 10 km from the most frequented communication routes. Evaluation of air pollution level with dusts based upon the analysis of annual cycle of 24 manual measurements and continuous, automatic measurements of air pollution maintained within the province in the frame of "State Environmental Monitoring Programme" in the years 1994-1997 revealed that the mean annual concentrations of suspended dust determined by reflection spectroscopy were much below the allowable level. In 1997 mean dustfall in 30 km distant Busko-Zdrój was 74 g/m^2, with admissible yearly concentration 200 g/m^2 (data supplied by the Main Office for Statistics).

The level of heavy metals in initial soil did not exceed the most frequently reported boundary contents in unpolluted soils (Cu - 20 mg [5], Zn - 100 mg [10], Pb - 30 mg [6], Ni - 25 mg [4], Cd - 1 mg/kg d.m. of soil [13]). On this basis it may be stated that their presence in soil is primarily a result of natural soil forming processes. Soil reaction was acid (pH=5), and organic carbon content was 1.13%.

Soil contamination with heavy metals strongly affected the growth and development of broad beans (Table 1). Plants growing in contaminated soil usually had one shoot less and were lower by almost 15 cm as compared to plants growing in natural soil. They also developed almost 10 pods less per plant. However, the plants did not differ in the number of seeds per pod.

Table 1. Characteristics of broad beans growing in natural (control - K) and contaminated soil (M)

Broad beans growing in	Number of shoots per plant	Length of shoots (cm)	Number of pods per plant	Number of seeds per pod
Natural soil (K)	3.33a	105.87a	16.90a	2.33a
Contaminated soil (M)	2.40b	89.47b	6.53b	2.12a

Values in columns indicated by different letters are statistically significant (p=0.05).

Heavy metals taken up from contaminated soil accumulated primarily in roots. Roots of contaminated plants contained almost 6 times more copper, 12 times more zinc and lead, 15 times more nickel and 7 times more cadmium than plants growing in the natural soil (Fig. 1). In tops the differences in the metal concentrations were clearly smaller. There were no significant differences in copper content, which is connected with this metal weak mobility in plants. Also lead became translocated to the tops only to a small degree. Lead uptake by roots is a passive process and proportional to its soluble form occurrence in the substratum. As the lead concentration in soil solution increases, its amount in roots raises to a far greater degree than in tops [9]. A higher lead content was detected only in shoots of plants growing in contaminated soil. However, visibly bigger differences in metal contents in tops between contaminated plants and growing in the natural soil occurred for nickel and cadmium. Both elements are easily taken up by the root

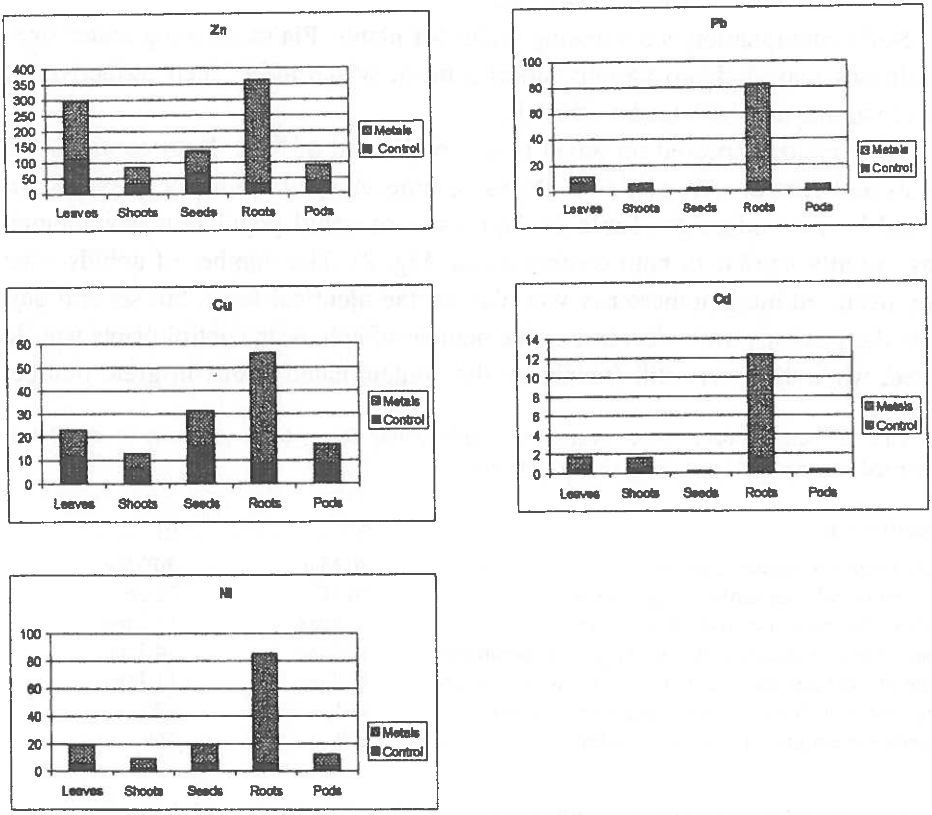

Fig. 1. Contents of copper, lead, zinc, cadmium and nickel (mg/kg of dry mass) in individual parts of broad beans cultivated in natural soil (Control) and in soil contaminated with heavy metals (Metals).

system. They are also easily transported within the plant. In leaves of contaminated plants cadmium content was 4 times higher than in the control. Twice more cadmium and thrice more nickel were found also in these plant shoots. Higher content of zinc was found in the leaves and shoots of contaminated plants. Heavy metal contents in individual parts of plants growing in the contaminated soil diminished in the following way:

Cu - roots>seeds>leaves>pods>shoots

Zn - roots>leaves>seeds>pods>shoots

Pb - roots>leaves>shoots>seeds>pods

Ni - roots>seeds>leaves>pods>shoots

Cd - roots>leaves>shoots>pods>seeds

Soil contamination is a stressing factor for plants. Plants growing under stress conditions may undergo various modifications, which affect their attractiveness for phytophagus which feed on them [1].

First aphids appeared on broad beans by the end of May. Both contaminated plants and control were settled at the same time. A similar number of plants was settled by first migrants (Table 2). Dynamics of aphid population development was initially similar in both combinations (Fig. 2). The number of aphids when they occurred most numerously was also on the identical level, but several days after the peak a visible decrease in the number of aphids on control plants was detected, while they were still feeding on the contaminated plants in great number.

Table 2. Selected data on the occurrence of *Aphis fabae* Scop. and its predators on broad beans cultivated in natural (K) and contaminated (M) soil

Specification	K	M
Date when first aphids appeared	30 May	30.May
Percent of colonies settled by first aphids	20.12	22.26
Date of the most numerous aphid occurrence	11 June	11 June
Date of most numerous *Diptera*, *Syrphidae* occurrence	11 June	14 June
Date of most numerous Col., *Coccinelidae* occurence	11 June	11 June
Number of aphids per 1 *Syrphidae larva* (mean)	152	329
Number of aphids per 1 ladybird (mean)	230	160

Also more contaminated plants were settled by aphids (Fig. 2). One of the reasons might have been the differences in the number of natural enemies of *Aphis fabae* Scop.

Predatory and parasitic organisms are the factor which considerably limited the numbers of these aphids. Among predators *Diptera, Syrphidae* play the most important role. Aphid colony settling by these predators changes during the period of aphid population development [16]. The efficiency is diminished by their delayed appearance [3]. In *Aphis fabae* Scop. colonies on control plants the *Syrphidae* larvae were more numerous (mean 0.22 per colony) than on contaminated plants (mean 0.13 per colony) (Table 3). Their peak numbers coincided in time with a peak in aphid number, while on contaminated plants it was several days delayed. On an average, on control plants twice less aphids fell per one predator larva than on contaminated plants (Table 2). They also settled a greater number of aphid colonies (Table 4).

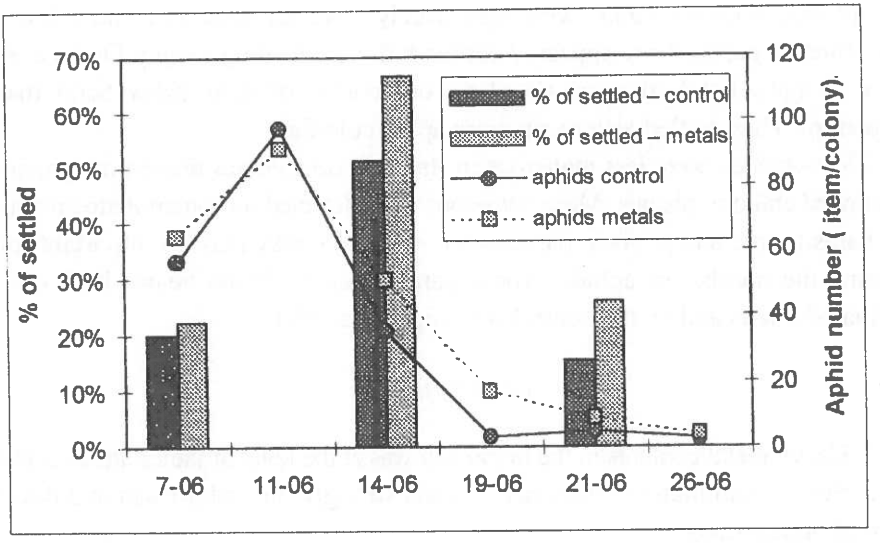

Fig. 2. Dynamics of *Aphis fabae* Scop. population development and percent of aphid settled broad bean plants cultivated in natural (control) and contaminated (metals) soil.

T a b l e 3. Occurrence of *Aphis fabae* Scop. and its predators (items per colony) on broad beans cultivated in natural (K) and contaminated (M) soil

Date	Aphids		*Syrphidae* larvae		Ladybirds		*Chrysopa*	
	K	M	K	M	K	M	K	M
1st decade June	56.75	64.64	0.08	0.08	0.00	0.08	0.00	0.14
2nd decade June	66.74	71.22	0.47	0.31	0.41	0.55	0.04	0.4
3rd decade June	3.68	10.06	0.10	0.02	0.01	0.17	0.00	0.01
Mean	33.5	39.5	0.22	0.13	0.15	0.28	0.015	0.04

T a b l e 4. Settlement of *Aphis fabae* Scop. colonies feeding on broad beans cultivated in natural (K) and contaminated (M) soil by *Diptera, Syrphidae* and *Col. Coccinelidae* (%)

Date	Percent of aphid colonies settled by *Syrphidae*		Percent of aphid colonies settled by *Col. Coccinelidae*	
	K	M	K	M
1st decade June	10	10	0	5
2nd decade June	35.5	32.5	21.5	19
3rd decade June	8.66	3	1.33	13
Mean	17.8	14.3	7.8	13.6

It was the opposite for ladybirds (*Col. Coccinelidae*). Predatory larvae and coleopterons from this family were significantly more numerous in aphid colonies on contaminated plants. They appeared earlier and were feeding longer. On an average twice as many ladybirds were noted per one colony of *Aphis fabae* Scop. than on the control. They settled also twice more aphid colonies.

Chrysophidae were less numerous in *Aphis fabae* colonies than in the previously mentioned enthomophagus. More numerous were detected on contaminated plants.

Parasitic hymenopterous, particularly *Aphididae* may play an important role in limiting the number of aphids. Aphid parasitizing on broad beans, both on contaminated plants and on the control was slight (c.a. 3%).

CONCLUSIONS

1. Heavy metal contents in the initial soil was at the level of their natural contents.
2. Soil contamination with heavy metals strongly limited growth and development of broad beans.
3. Heavy metals primarily accumulated in contaminated plant roots. 2-4 times higher contents of cadmium, 2-3 times higher content of nickel and raised contents of zinc and lead were found in their tops.
4. *Aphis fabae* Scop. occurred in more numerous colonies on contaminated plants. Differences in the numbers were statistically significant in the final period of its feeding. The percent of seized plants was also higher.
5. A significantly higher number of ladybirds (*Col. Coccinelidae*) was detected in the *Aphis fabae* Scop. colonies on contaminated plants. Predatory larvae *Diptera, Syrphidae* were more numerous in colonies on control plants. *Neur., Chrysophidae* were scarce. Parasitizing of aphids by parasitoides was also small.

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