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Bio-accumulation and distribution of heavy metals in fibre crops (flax, cotton and hemp)

V. Angelova[a,*], R. Ivanova[b], V. Delibaltova[b], K. Ivanov[a]

[a] Department of Chemistry, University of Agriculture, Mendeleev Street 12, 4000 Plovdiv, Bulgaria
[b] Department of Plant Science, University of Agriculture, 4000 Plovdiv, Bulgaria

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Abstract

Flax, hemp and cotton, grown in industrially polluted region, were included in the present research. The experimental plots were situated at different distances (0.5 and 15 km) from the source of pollution—the Non-Ferrous-Metal Works (MFMW) near Plovdiv. We investigated the level of pollution and the way heavy metals enter the fibre crops, by taking soil and plant samples. The contents of heavy metals in plant materials (roots, stems, leaves, seeds, flowers) were determined after the method of the dry mineralization. The quantitative measurements were carried out with inductively-coupled plasma (ICP).

A clearly distinguished species peculiarity exists in the accumulation of heavy metals in the vegetative and reproductive organs of flax, hemp and cotton. Flax is the crop that most strongly absorbs and accumulates heavy metals from the soil, followed by hemp and cotton. The distribution of the heavy metals along the plant axis of the studied crops seems to be selective, therefore their contents in flax and hemp are decreasing in the following order: roots > stems > leaves > seeds, while in cotton: leaves > seeds > roots > stems. A strongly exhibited tendency towards decrease of the contents of heavy metals in the fibre crops is observed as the distance from the NFMW increases.

Flax and hemp are cultures, suitable for growing in industrially polluted regions—they remove considerable quantities of heavy metals from the soil with their root system and can be used as potential crops for cleaning the soil from heavy metals.

Keywords: Bio-accumulation; Heavy metals; Fibre crops

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1. Introduction

Growing agricultural crops in industrially polluted regions could elucidate the question on how heavy metals enter the plants and which are the sites of their accumulation. It is necessary to pay attention, above all, on the ability of the crops to absorb heavy metals, giving preference to those which accumulate much heavy metals and are more resistant to the soil and aerosol pollution. Gorlach and Gambus (1992) found out that maize is the most resistant to increased heavy metals concentration in the soil, followed by wheat, barley, sunflower and hemp. Qin et al. (2000) determined that more lead and cadmium are localized in cotton plants' leaves, compared to the leaves of rice, while Schubert (1999) ascertained that flax accumulates more cadmium in the seeds than wheat does.

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[*] Corresponding author.
E-mail address: violina@au-plovdiv.bg (V. Angelova).

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Heavy metals uptake by plants strongly depends on several soil and plant factors. Among the plant factors affecting heavy metal uptake, plant genotype is considered the most important. Many authors unequivocally confirmed existence of significant genotype differences in the heavy metal uptake and distribution (Marquard et al., 1990; Gaudchau and Schneider, 1996; Schneider et al., 1996; Li et al., 1997; Hocking and McLaughlin, 2000). Based on these studies it was found that some genotypes respond sensitively to Cd changes in the soil while others behave relatively independently. Thus, increased Cd soil content may result either in increased transport from roots to above-grounds plant parts or in retaining of Cd in roots An interesting finding was that these genotype differences were restricted to Cd and were no general phenomenon of sink-source transport of micronutrients, e.g. essential metals Zn and Cu (Becher et al., 1997).

Environnment play even more importmant role in heavy metal uptake by plants than genetic deposition. The principal soil factors affecting heavy metals uptake by plants are the soil heavy metal content, sorptive capacity of soil, redox conditions, organic matter and pH (Alloway, 1995). The concentration of bioavailable soil Cd (in contrast to total Cd) is the key factor for uptake and in certain concentration interval it may be proportional to accumulated Cd (Moraghan (1993). This factor mostly dominated over other factors, including significant genotype differences in Cd uptake and accumulation. Growing of flax in naturally metal-rich soils resulted in several times higher accumulation as compared to sites with lower heavy metal content (Schneider and Marquard, 1996; Cieslinski et al., 1996).

In regions of metallurgical enterprises the environmental pollution exerts complex influence on the grown crops, as the plants roots absorb heavy metals from the soil and aerosol pollutants penetrate from the atmosphere into the plant through the leaves' surface. The aerosol concentration changes depending on the source distance, the weather conditions and the size of the particles. They stick to the plant leaves, some of them being absorbed. Lead (Pb) remains as a surface precipitate, while Zn, Cu and Cd can partially penetrate into the leaves (Kabata-Pendias and Pendias, 1992).

In the vicinity of the Non-Ferrous-Metal Works (NFMW) near Plovdiv, more than 5187 area have been polluted by heavy metals Sengalevitch (1991). It is estimated that around 460 t of dust containing mainly Pb, less Zn and Cd, are annually emitted into the atmosphere (Anonymous, 1989, 1990a). The data analysis from the NFMW emissions (Anonymous, 1990b) indicated that the technological and ventilation gases released from lead production are the main source of environmental pollution with lead, zinc, cadmium and sulphur dioxide. Gases from roller workshops and drying furnaces in zinc plants are the second important pollution source. Another environmental-pollution threat is posed by the shaft furnace in the periods of its starting and stopping, as well as in regimes of break-down operations, when the purification installations are turned off and the dust–gas mixture is directly released into the atmosphere.

The studies connected with growing fibre crops on heavy metals polluted soils are limited and incomplete. Spaite et al. (1992) and Schneider et al. (1996) recommend growing flax in industrially polluted regions, while Sengalevitch (1999) and Yanchev et al. (2000) consider cotton and hemp as suitable crops.

The purpose of the present research is to determine the quantities and the sites of accumulation of Pb, Cu, Zn and Cd in the vegetative and reproductive organs of fibre crops (flax, hemp and cotton) and to investigate the possibilities for growing them on heavy metals polluted soils.

2. Material and methods

The research was carried out during the period 1999–2001. Fibre crops (flax, hemp and cotton) grown in industrially polluted region, were included in the research. The experimental plots were situated at different distances (0.5 and 15 km) from the source of pollution—the NFMW near Plovdiv. The field tests were set after the block method in four replications. The size of the test parcel was 20 m^2. The crops were grown after cereal forecrop. Cotton cultivar "Beli izvor", flax cultivar "Kaliakra" and hemp cultivar "Silistrinski" were objects of the present research.

Cotton was sown in May at interrow space 60 cm and sowing density 19 plants per 1 m^2, flax was sown during the first half of April at interrow space 7.5 cm and sowing density 2500 plants per 1 m^2 and hemp—in March, at interrow space 10–12 cm and

Table 1
Soil properties for soil sampled from the Non-Ferrous-Metal Works near Plovdiv

Classification	Distance from NFMW (km)	Depth (cm)	pH (H_2O)	Humus (%)	$CaCO_3$ (%)	Clay (%)
Calcaric	0.5	0–20	7.72	2.19	7.30	29.35
Alluvial soil		20–40	7.75	1.82	7.50	32.23
Calcaric	15.0	0–20	7.47	1.54	8.70	12.71
Alluvial soil		20–40	7.62	1.01	8.94	13.82

sowing density 400 plants per 1 m^2. The plants were grown in accordance with the standard technology. Fifty plants from each replications were used in the analysis.

In order to investigate the level of pollution and the way heavy metals enter the fibre crops, soil and plant samples were taken. Soil samples were taken at depth from 0 to 40 cm and were prepared for analysis by means of treatment with aqua regia, ensuring practically the complete extraction of the heavy metals (Angelova, 1998). Soil chemical and physical properties of the samples are listed in Table 1.

The heavy metal amounts were determined in different parts of the studied fibre crops—roots, stems, leaves, seeds, flowers and fibres. The cotton fibre is located inside three to five nested capsules, while flax and hemp are stem fibre crops. In order to separate stems from fibres, stems were let through a laboratory single device that hammered them in order to facilitate the wood-fibre separation. The stem was split into two bands using a needle and the fibre was carefully separated with the help of nippers.

The contents of heavy metals in the plant material (roots, stems, leaves, seeds, flowers, fibres) were determined after the method of the dry mineralization. A sample was weighed in a quartz crucible to 1 g and put into a furnace ($T = 400\,°C$) until ashing. After cooling to room temperature, 1 ml HNO_3 (1:1) was added, evaporated in a sand bath and put again into the furnace ($T = 400\,°C$). The procedures were repeated until the ash was white. It was finally dissolved in 2 ml 20% HCl, transferred in a scaled 10 ml flask and brought to volume with bidistilled water.

The quantitative measures were carried out with inductively-coupled plasma (ICP) emission (Jobin Yvon Emission, JY 38 S, France). A cross-flow pneumatic nebulizer operated at 1 l agron/min at 20 psi was used for sample introduction into the ICP. The working wave lengths were as follows: Cu 324.8 nm; Zn 213.9 nm; Pb 220.4 nm; Cd 214.4 nm. Detection limit for Pb was 0.1 mg/l, for Cu 0.02 mg/l, for Zn 0.1 mg/l, and for Cd 0.02 mg/l. The calibration was performed using five aqueous standard solutions in 2% (v/v) HNO_3. A commercial multielement standard solution (Merck) with concentration 100 mg/l was used as a stock solution. The calibration standard solutions have the following concentrations: 0, 0.2, 0.5, 2.0 and 5.0 mg/l. The acidity of the standard and sample solutions was the same (2%, v/v HNO_3).

3. Results and discussion

Our results, presented in Table 2, indicated a clearly expressed tendency. As the distance from the NFMW near Plovdiv increased and the soil horizon grew deeper, the heavy metals contents in the soil declined. In the soil samples, taken from the region, situated 0.5 km away from the NFMW, were established values for Pb, exceeding the maximum permissible concentration (MPC: 80 mg/kg)—200.3 mg/kg in the layer 0–20 cm and 181.8 mg/kg in the layer 20–40 cm. In the region that was 15 km away from the NFMW, the contents of Pb were reduced about seven times and there was almost no difference between the two horizons.

The results, obtained for Cu and Zn, were analogous. Values of 536.1 mg/kg Zn and 12.2 mg/kg Cd, which considerably exceeded the MPC, were obtained in the region of the NFMW, while 33.9 mg/kg Zn and 2.1 mg/kg Cd were recorded in the more distant region. The contents decreased more intensively as the depth of the soil horizon increased (to 434.0 mg/kg Zn and 10.0 mg/kg Cd), while in the more distant region the differences between the two soil horizons were not significant. The quantity of Cu in the soil from the region of the NFMW was 95.7 mg/kg while 15 km away from the NFMW it decreased considerably, dropping

Table 2
Content of Pb, Cu, Zn and Cd (mg/kg) in soil

Distance from NFMC (km)	Depth (cm)	Pb ($x \pm$ S.D.)	Cu ($x \pm$ S.D.)	Zn ($x \pm$ S.D.)	Cd ($x \pm$ S.D.)
0.5	0–20	200.3 ± 6.0	95.7 ± 1.8	536.1 ± 4.7	12.2 ± 0.24
	20–40	181.8 ± 5.1	89.9 ± 1.7	434.0 ± 3.2	10.0 ± 0.18
15.0	0–20	24.6 ± 0.7	16.0 ± 0.3	33.9 ± 0.3	2.7 ± 0.04
	20–40	22.7 ± 0.7	13.9 ± 0.2	31.9 ± 0.3	2.5 ± 0.02
MPC		80	260	340	2.5

x: average value (mg/kg) from five repetitions; S.D.: mean standard deviation; MPC: maximum permissible concentration (approved for Bulgaria).

to 16.0 mg/kg. The contents of Cu in the soil from both regions of our experiment were considerably lower than the accepted for Bulgaria MPC (270 mg/kg). As the depth of the soil horizon increased, a weak tendency towards decrease of the contents of Cu in the soil was observed.

The results for the heavy metals contents in the studied fibre crops are given in Tables 3–5. Considerable differences in the metals distribution in the separate plant parts were observed. For all four elements, the main concentrations were accumulated in the roots and their quantity decreased as the distance from the pollution source increased. The highest values were obtained in flax roots, where Pb reached 104.4 mg/kg, Cu 30.5 mg/kg, Zn 211.8 mg/kg and Cd 8.69 mg/kg (Table 3). Lower values were established in hemp roots—38.2 mg/kg Pb, 7.2 mg/kg Cu, 66.8 mg/kg Zn and 1.03 mg/kg Cd (Table 4). Heavy metals quantity, absorbed in cotton roots, was the lowest 3.9 mg/kg Pb, 2.7 mg/kg Cu, 13.9 mg/kg Zn and 0.155 mg/kg Cd (Table 5). The results obtained could be explained with the anatomic and biological features of the plants. A bigger part of the heavy metals that had entered the soil were fixed and accumulated in the flax roots, as flax formed weakly developed root system. Its main mass is situated in the soil layer 20–30 cm. Hemp’s root system is weakly developed. It consists of a spindle-shaped central root, penetrating no further than 40–50 cm, and its side branchings reaching maximum depth of 30–45 cm. The lower values, obtained in cotton, were correlated to its more deeply penetrating root system. Its main root reaching to 3 m depth and the side roots to 1.5 m.

Table 3
Content of Pb, Cu, Zn and Cd (mg/kg) in flax

Object	Distance from NFMC (km)	Pb ($x \pm$ S.D.)	Cu ($x \pm$ S.D.)	Zn ($x \pm$ S.D.)	Cd ($x \pm$ S.D.)
Roots	0.5	104.4 ± 2.8	30.5 ± 0.5	211.8 ± 3.0	8.69 ± 0.2
	15.0	12.2 ± 0.5	14.4 ± 0.2	43.9 ± 0.6	1.94 ± 0.04
Stems	0.5	30.2 ± 0.8	6.2 ± 0.4	62.9 ± 0.9	7.27 ± 0.2
	15.0	3.7 ± 0.1	4.0 ± 0.1	13.2 ± 0.3	1.63 ± 0.01
Leaves	0.5	14.5 ± 0.4	4.7 ± 0.1	32.6 ± 0.5	1.62 ± 0.03
	15.0	1.7 ± 0.1	3.2 ± 0.06	6.6 ± 0.1	0.37 ± 0.001
Flowers	0.5	6.9 ± 0.2	3.3 ± 0.06	24.6 ± 0.2	0.59 ± 0.03
	15.0	1.0 ± 0.01	1.7 ± 0.04	5.3 ± 0.1	0.13 ± 0.002
Fiber	0.5	7.2 ± 0.2	2.1 ± 0.05	25.7 ± 0.4	3.34 ± 0.05
	15.0	2.9 ± 0.1	1.7 ± 0.05	15.3 ± 0.3	0.26 ± 0.01
Seeds	0.5	11.3 ± 0.3	25.2 ± 0.5	97.4 ± 1.4	2.30 ± 0.05
	15.0	1.5 ± 0.01	12.0 ± 0.2	19.8 ± 0.2	0.52 ± 0.02

x: average value(mg/kg) from five repetitions; S.D.: mean standard deviation.

Table 4
Content of Pb, Cu, Zn and Cd (mg/kg) in hemp

Object	Distance from NFMC (km)	Pb (x ± S.D.)	Cu (x ± S.D.)	Zn (x ± S.D.)	Cd (x ± S.D.)
Roots	0.5	38.2 ± 0.9	7.2 ± 0.1	66.8 ± 1.0	1.03 ± 0.07
	15.0	3.8 ± 0.1	4.9 ± 0.1	15.5 ± 0.2	0.35 ± 0.002
Stems	0.5	23.5 ± 0.5	4.9 ± 0.1	54.5 ± 0.7	0.98 ± 0.01
	15.0	2.4 ± 0.06	3.3 ± 0.08	12.7 ± 0.2	0.33 ± 0.002
Leaves	0.5	16.5 ± 0.5	3.6 ± 0.08	40.0 ± 0.7	0.55 ± 0.01
	15.0	1.9 ± 0.1	2.5 ± 0.05	9.3 ± 0.1	0.19 ± 0.01
Flowers	0.5	44.8 ± 1.1	10.2 ± 0.2	78.6 ± 1.1	1.22 ± 0.02
	15.0	4.5 ± 0.1	6.9 ± 0.1	18.3 ± 0.2	0.41 ± 0.002
Fiber	0.5	6.3 ± 0.2	1.8 ± 0.08	18.9 ± 0.2	0.40 ± 0.002
	15.0	2.1 ± 0.1	1.3 ± 0.07	1.3 ± 0.1	0.15 ± 0.001
Seeds	0.5	7.6 ± 0.5	8.9 ± 0.1	73.5 ± 1.0	1.00 ± 0.01
	15.0	1.0 ± 0.1	5.9 ± 0.1	17.8 ± 0.2	0.34 ± 0.002

x: average value (mg/kg) from five repetitions; S.D.: mean standard deviation.

The results for the heavy metals contents in the roots of cotton, hemp and flax, grown in the region 15 km away from the NFMW, were analogous, but the obtained values were far lower. Pb contents varied from 0.9 mg/kg in cotton to 12.2 mg/kg in flax, Cu from 1.4 to 14.4 mg/kg, Zn from 2.9 to 43.9 mg/kg and Cd from 0.045 to 1.94 mg/kg.

Heavy metals movement and accumulation in the vegetative organs of the studied crops differed considerably. Their quantities in the fibre crops' stems were considerably lower compared to the root system, which proved that heavy metals movement along the plants conductive system was strongly limited. Higher quantities of heavy metals were absorbed in flax and hemp stems compared to cotton stems. The highest heavy metals concentrations were obtained in flax stem, where Pb reached 30.2 mg/kg, Cu 6.2 mg/kg, Zn 62.9 mg/kg and Cd 7.27 mg/kg. We found out that Pb, Cu and Zn concentrations in flax and hemp stems were similar, unlike Cd concentrations, which

Table 5
Content of Pb, Cu, Zn and Cd (mg/kg) in cotton

Object	Distance from NFMC (km)	Pb (x ± S.D.)	Cu (x ± S.D.)	Zn (x ± S.D.)	Cd (x ± S.D.)
Roots	0.5	3.9 ± 0.1	2.7 ± 0.05	13.9 ± 0.2	0.155 ± 0.03
	15.0	0.9 ± 0.05	1.4 ± 0.03	2.9 ± 0.06	0.045 ± 0.001
Stems	0.5	1.0 ± 0.1	1.8 ± 0.03	3.5 ± 0.06	0.05 ± 0.002
	15.0	0.8 ± 0.03	1.2 ± 0.02	2.3 ± 0.03	0.03 ± 0.001
Leaves	0.5	29.6 ± 0.8	8.7 ± 0.1	45.4 ± 0.7	0.62 ± 0.001
	15.0	2.6 ± 0.1	6.1 ± 0.1	10.7 ± 0.1	0.20 ± 0.001
Flowers	0.5	2.1 ± 0.1	1.3 ± 0.03	6.6 ± 0.1	0.07 ± 0.002
	15.0	0.8 ± 0.03	1.1 ± 0.03	2.9 ± 0.06	0.03 ± 0.001
Fiber	0.5	5.8 ± 0.2	1.5 ± 0.03	15.5 ± 0.2	0.154 ± 0.03
	15.0	2.5 ± 0.1	1.1 ± 0.01	11.5 ± 0.2	0.069 ± 0.006
Seeds	0.5	1.1 ± 0.1	3.5 ± 0.05	20.7 ± 0.4	0.10 ± 0.002
	15.0	0.5 ± 0.02	3.3 ± 0.05	17.3 ± 0.2	0.05 ± 0.002

x: average value (mg/kg) from five repetitions; S.D.: mean standard deviation.

were considerably higher in flax compared to hemp. As the distance from the NFMW increased, a strong tendency towards decrease of heavy metals contents in the stems of the studied crops was observed.

Heavy metals contents in cotton leaves were higher compared to root system and stems, while the opposite tendency was observed in flax and hemp. Pb in cotton leaves reached 29.6 mg/kg (Table 5), while the obtained values in flax and hemp were very close—14.5 and 16.5 mg/kg respectively (Tables 3 and 4). The results obtained for Cu and Zn were analogous. The higher heavy metals accumulation was probably due to the fact that the cotton leaves were covered with tiny pappus which enabled the embedding of aerosol contaminators on their surface and their absorption into the cotton leaves. Our results corresponded to the ones obtained from Litvinovich and Pavlova (1995), according to which, under conditions of soil and air pollution from pollution (from a factory producing amorphous), considerable quantities of Pb, Cu and Zn were absorbed in the leaves of cotton plants. The obtained results matched well with those of Watson et al. (1985) and Mullins and Burmester (1991), who found that Cd, Cu, Fe, Mn and Zn contents were the highest in cotton leaves.

Heavy metals contents in the flowers of the studied crops was the highest in hemp (44.8 mg/kg Pb, 10.2 mg/kg Cu, 78.6 mg/kg Zn and 1.22 mg/kg Cd). Considerably lower values were obtained in flax and cotton. We ascertained that heavy metals contents in hemp flowers exceeded their contents in the underground and above the ground hemp organs in both regions of examination. This could be explained with the longer duration of the hemp flowering stage that enabled the retaining and the aerosol absorption of heavy metals in the hemp flowers.The obtained values for the heavy metals contents in the seeds of the fibre crops from both regions of examination exceeded the MPC. Again the highest values were established in flax and the lowest in cotton. Probably the heavy metals had been moved to the seed via the conductive system and were being predominantly accumulated there. Our results corresponded to those of Spaite et al. (1992) and Schubert (1999), who ascertained that Cd was accumulated in flax seeds even at low soil concentrations, and did not confirm the results of Kamishentzev (1997), according to whom Pb and Zn were not accumulated in the regenerative organs. The obtained results matched well with those of Sharma and Gupta (1987), who found that the main part of Zn was accumulated in the seeds of cotton.

It was known that flax accumulates in seeds relatively high heavy metal concentrations as compared to other grain crops (Bohm et al., 1992; Moraghan, 1993; Schneider et al., 1996; Schubert, 1999). Hocking and McLaughlin (2000) found that physiological mechanisms preventing Cd translocation from the fruit to the seed are much less effective in flax as compared to several grain crops (canola, lupin, wheat). The extent of fruit to seed translocation is strongly genotype-dependent (Becher et al. (1997).

The highest values for heavy metals contents in fibre were obtained in flax, and the lowest in cotton. The cotton fibre is located inside three to five nested capsules, composed of pure cellulose, while flax and hemp are stem fibre crops and their bast fascicles consist of elementary fibres connected by pectinous substances. In the fibre of flax, grown 0.1 km away from the NFMW, Pb reached up to 7.2 mg/kg, Cu to 2.1 mg/kg, Zn to 25.7 mg/kg and Cd to 3.34 mg/kg (Table 3), while in the fibre of hemp was ascertained 6.3 mg/kg Pb, 1.8 mg/kg Cu, 18.9 mg/kg Zn and 0.4 mg/kg Cd (Table 4). The obtained results matched well with those of Baraniecki and Mankowski (1995), who found that the metals were adsorbed by flax and hemp and stored particularly in their roots and seeds and to a smaller extent in stems.

In the cotton fibre of the crop, grown 0.5 km away from the NFMW, Pb reached 5.8 mg/kg, Cu 1.5 mg/kg, Zn 15.5 mg/kg and Cd 0.154 mg/kg, while in the more distant region were established values 2.5 mg/kg Pb, 1.1 mg/kg Cu, 11.5 mg/kg Zn and 0.069 mg/kg Cd (Table 5). The obtained values for Cu and Zn from both regions of examination were below the MPC, while Pb and Cd exceeded it.

Heavy metals accumulation in the cotton fibre takes place mainly through the atmosphere. If the cotton crop is gathered earlier and the capsules ripening is completed in closed premises, heavy metals quantity in the fibre decreases. This proves that the larger part of the heavy metals enters the cotton fibre through the atmosphere. We searched for a possibility to remove part of the heavy metals, that had penetrated the fibre in result of aerosol pollution, by means of heat treatment with water. It was found out that fibre heat treatment with water reduced heavy metals contents almost twice (data are not presented).

Heavy metal distribution along plant axis of flax, was studied. The most frequently found concentration gradient of some heavy metals in flax organs is following: for Cd and Pb: *roots* > shoots > seeds (Bohm et al., 1992; Baraniecki et al., 1995; Grzebisz et al., 1997), whereas for Cu: roots > seeds > shoots (Grzebisz et al., 1997; Mankowski et al., 1994). Unfortunately, there is an absence of data to explain physiological mechanisms of heavy metal uptake, transport and accumulation in flax, as well as to identify genes responsible for these processes connected with particular behaviour of individual genotypes.

However, the metal's distribution along the cotton plant axis followed the order: seeds > leaves > stems (Sharma and Gupta, 1987).

Our results indicated that heavy metals distribution along the plant axis was selective for the studied crops, therefore their contents in flax and hemp were decreasing in the following order: roots > stems > leaves > seeds, while in cotton: leaves > seeds > roots > stems.

Our results regarding heavy metals localisation in cotton vegetative organs contradicted to those of Litvinovich and Pavlova (1995, 2000), according to whom Pb was comparatively evenly distributed in cotton roots and stems. Fibre crops extracted heavy metals from the soil through their root system and accumulated them in their parts above the ground. Heavy metals contents in flax and hemp fibre were high and exceeded the MPC which is why these two crops could not be used as raw material for textile industry. Our results corresponded to the ones of Lukipudis (1995, 1997), who ascertained the high contents of heavy metals in flax fibre. Pb and Cd contents in the fibre of the studied flax cultivars were high and it was not a suitable raw material for production of baby's and adults clothes.

A clearly distinguished species peculiarity existed in the accumulation of heavy metals in flax, hemp and cotton vegetative and reproductive organs. Flax was the crop that most strongly extracted and accumulated heavy metals from the soil, followed by hemp and cotton. Our results corresponded to the ones of Litvinovich and Pavlova (2000), who established high cotton resistance to pollution. This was probably in connection with the plats anatomic and biological features, as well as with the presence of protective mechanisms in plants.

Kozlowski et al. (1994), Mankowski et al. (1994), Baraniecki et al. (1995) and Roseberg and Janick (1996) investigated the possibility to use flax and hemp for phytoremediation purposes. It has found that cultivation of oil and fibre flax and hemp plants reduced soil content of copper, zinc, cadmium and lead in the polluted landscape of a copper mining and processing region. According to Baraniecki and Mankowski (1995) flax and hemp could be used for reclamation of heavy metal contaminated soils with further utilisation of biomass produced in the paper industry.

Heavy metals had no influence on the crops' development and productivity. Anthropogenic increase of heavy metal concentration leads to increase uptake of heavy metals by flax, hemp and cotton without evident yield depression or decrease of quality of harvested products (data are not presented). The obtained results matched well with those of Moraghan (1993), Mankowski et al. (1994), Baraniecki et al. (1995, 2001), Grzebisz et al. (1997) and Tsadilas et al. (1999) who state that the yields of stems and seeds were not considerably affected by cultivation in the degraded soils. This fact is of crucial importance for further industrial processing of contaminated biomass. The possibility of further industrial processing will make flax and hemp an economically interesting crops for farmers of phytoextraction technology. Flax does not produce so great biomass as some other annual culture crops, but its advantage is the complete utilisation of the whole harvested biomass for many industrial products. An elevated concentration of heavy metals in these products does not need necessary to have a negative effect on human health or on environment. Flax and hemp could be used in textile industry, pulp and paper industry, building and furniture industry, chemical industry and etc. Only increased content of heavy metals in fibre processed for clothing would represent some healthy risk and should be carefully monitored.

4. Conclusions

The following conclusions can be made on the grounds of the results for heavy metals contents in the studied fibre crops:

1. A clearly distinguished species peculiarity exists in heavy metals accumulation in flax, hemp and cotton vegetative and reproductive organs. Flax is the crop that most strongly extracts and accumulates heavy metals from the soil, followed by hemp and cotton.
2. Heavy metals distribution along the plant axis of the studied crops is selective, therefore their contents in flax and hemp is decreasing in the following order: roots > stems > leaves > seeds, while in cotton: leaves > seeds > roots > stems.
3. Flax and hemp are crops, suitable for growing in industrially polluted regions, as they remove considerable quantities of heavy metals from the soil with their root system and can be used as potential crops for cleaning soil from heavy metals.

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