24

Heavy Metals Uptake by Aerial Biomass and Grain of Soybean

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1. Introduction

All phases of crude oil exploitation, starting from drilling works to the construction of underground pipeline networks, including transport, processing and storage, are causing interventions and procedures hazardous to the environment. Although modern technical solutions and materials are used in all segments of petroleum industry warrant a high degree of safety, the occurrence of various incidents is unfortunately not fully excluded. Incidents leading to pipeline spillage and crude oil contamination of the environment constitute a hazard to natural resources, primarily soil and water, and depending on their severity can jeopardize, for a shorter or longer time, the intended use of land on which the incident occurred, namely make it unsuitable for plant production. Petroleum and gas fields are located in Pannonian area where cultivation of agricultural crops is dominated and among them the most represented are corn, wheat and soybean.

On the other side, these (petroleum and gas) activities generate waste - drilling fluids which contain different chemical compounds, some of which are ecologically hazardous (hydrocarbons), or toxic substances (heavy metals). As already mentioned, drilling fluids contain increased levels of some heavy metals (barium, zinc and mercury), so their possible application as liming material involves the risk of heavy metal accumulation in soil and plants (Agbogidi et al., 2007). To assess the extent to which such material may be useful or harmful to soil, and thereby to plants grown on it, since pollutants enter the animal and human food chain via soil and plants, investigations into this problem were undertaken (Nelson et al., 1984; Lengrand et al., 2005; Kabata-Pendias & Mukherjee, 2007).

2. Goals of investigation

The research objectives were to investigate the possibility of:

- Effects of different concentrations of crude oil and drilling fluids on the uptake of heavy metals in aerial biomass or grain of soybean, maize and winter wheat,
- Calculate enrichment coefficient for some parts of aerial biomass or grain of investigated crops.

3. Materials and methods

The trial was set up on Luvisols (FAO, 2006) and located near Popovaca (N 45º31′49′′ – E 16º34′48′′) in the Pannonian agricultural part of Croatia. The total trial field covered 1.25

hectare, the size of each trial plot was 96 m^2 (6.0 m x 4.0 m x 4 replications). At the beginning of investigations in May 2006, before preparing the seedbed layer, crude oil and drilling fluids were applied on the soil surface. The seedbed was prepared using a tractor-mounted rototiller to the depth of 25 cm. Experiment was set up as a randomized complete block design with four replications of each of the following treatments:

I. Control (unamended soil);
II. Soil contaminated by crude oil - 8 L m^{-2};
III. Soil contaminated by crude oil - 4 L m^{-2};
IV. Soil contaminated by crude oil - 2 L m^{-2};
V. Soil contaminated by drilling fluids - 30 kg m^{-2};
VI. Soil contaminated by drilling fluids - 20 kg m^{-2}, and
VII. Soil contaminated by drilling fluids - 10 kg m^{-2}.

Soybean (*Glycine max* L. *Merr*), Maize (*Zea mays* L.) and Winter Wheat (*Triticum aestivum* L.) were grown on the trial field. Composite soil samples (0-25 cm), in four replications, were taken before crops were sown. Composite plant samples (aerial biomass and grain) were taken after crop harvest. The observed results were analyzed using ANOVA analysis, SAS Institute 9.1.3. The significance level was set at 5 % in all statistical tests. Methods used to determine the studied parameters are given in Table 1.

Analysis	Method
Preparation of soil samples for physical and chemical analyses	ISO 11464:2004
Determination of particle size distribution in mineral soil material – Method by sieving and sedimentation	ISO 11277:2004
Determination of organic (TOC/OM) and total carbon (TC) after dry combustion (elementary analysis)	ISO 10694:2004
Soil organic matter (SOM)	Tjurin (wet digestion) - titrimetric
Determination of pH in $CaCl_2$, (1:2.5 (w/v))	ISO 10390:2004
Extraction of trace elements soluble in aqua regia	ISO 11466:2004
Determination of Zn, Pb, Cd, Co, Ni, Cr and Cu using AAS	ISO 11047:2004
Determination of As, Ba, Mo, V and Hg using ICP-MS	ISO 11885:1998 & ISO/DIS 22036:2006

Table 1. Methods used in investigations

4. Results

Particle size distribution of the studied soil is shown in Table 2. Major physical and chemical characteristics of crude oil and water-based drilling fluids (muds) applied in the trial are given in Tables 3 and 4.

		Particle size distribution, %					
Depth,	Soil	Coarse sand	Fine sand	Coarse silt	Fine silt	Clay	Texture
cm	horizon	2-0.2 mm	0.2-0.05 mm	0.05-0.02 mm	0.02-0.002 mm	<0.002 mm	class
0-15	Ap+Eg	2.0	5.40	46.25	27.75	18.60	Silty loam
15-30	Eg+Btg	1.5	6.40	41.80	30.00	20.30	Silty loam
30-45	Btg	0.5	4.30	43.25	29.80	22.15	Silty clay loam

Table 2. Particle size distribution of Luvisols

<table>
<tr><th colspan="3">Components of crude oil</th><th colspan="2">Sum, vol. %</th><th colspan="3">Density at 15 °C, g cm^{-3}</th><th colspan="2">Viscosity at 37.8 °C mm^2 s^{-1}</th></tr>
<tr><td colspan="3">Light gasoline</td><td colspan="2">6.53</td><td colspan="3">0.69</td><td colspan="2"></td></tr>
<tr><td colspan="3">Light gasoline + heavy gasoline</td><td colspan="2">32.00</td><td colspan="3">0.75</td><td colspan="2"></td></tr>
<tr><td colspan="3">Kerosene</td><td colspan="2">10.40</td><td colspan="3">0.82</td><td colspan="2"></td></tr>
<tr><td colspan="3">Gas oil</td><td colspan="2">17.57</td><td colspan="3">0.85</td><td colspan="2"></td></tr>
<tr><td colspan="3">Low viscosity lubricant oil</td><td colspan="2">12.08</td><td colspan="3">0.86 - 0.89</td><td colspan="2">7.5-20.6</td></tr>
<tr><td colspan="3">Medium viscosity lubricant oil</td><td colspan="2">6.75</td><td colspan="3">0.89 - 0.90</td><td colspan="2">20.6-43</td></tr>
<tr><td colspan="3">High viscosity lubricant oil</td><td colspan="2"></td><td colspan="3"></td><td colspan="2">> 43</td></tr>
<tr><td colspan="3">Residue</td><td colspan="2">20.51</td><td colspan="3">0.96</td><td colspan="2"></td></tr>
<tr><td colspan="3">Loss</td><td colspan="2">0.69</td><td colspan="3"></td><td colspan="2"></td></tr>
<tr><td>Water, %</td><td>Total sulphur, %</td><td>Viscosity, 30 °C, mPa</td><td>Viscosity, 30 °C, mm^2</td><td>Pour point, °C</td><td>Coke, %</td><td>Ash, %</td><td>Paraffins, %</td><td>Asfalten, %</td><td>Total nitrogen, %</td></tr>
<tr><td>0.08</td><td>0.433</td><td>5.56</td><td>6.65</td><td>- 8</td><td>2.193</td><td>0.004</td><td>5.57</td><td>0.68</td><td>0.439</td></tr>
</table>

Table 3. Some characteristics of crude oil applied in the trial

	Cd	Hg	Pb	As	Ni	Cu	Cr	Zn	Ba	V	Co	Mo	Ca
Minimum	0.96	0.34	89	6.9	21.2	23	27	116	163	84	5.8	2.3	10 000
Maximum	1.03	37.70	209	9.0	57.5	188	54	755	2 333	132	12.0	5.2	156 000
Average	1.01	20.84	137	8.2	35.6	79	36	437	1 602	95	8.4	4.0	103 000

Table 4. Concentrations of measured elements in drilling fluids applied in the trial, mg kg^{-1}

4.1 Changes in soil pH, soil organic matter, total carbon and nitrogen

Research results show marked and expected heterogeneity of the studied parameters. In trial treatments where drilling fluids were applied (V, VI and VII) soil pH was significantly higher compared to other treatments (Table 5). This was expected because drilling fluids are very rich with $CaCO_3$, CaO, $Ca(OH)_2$, $Ca(SO)_4$ and other calcium compounds. In treatments where crude oil was applied, soil pH was not significantly different compared to the control treatment. These findings indicate that crude oil had no influence on the changes in soil pH. A highly significant difference in SOM concentrations compared to all other treatments was determined in the treatment where the largest amount of crude oil was applied (treatment II). In the control treatment and in treatment with drilling fluids, SOM is mainly composed

of humic compounds and plant debris. In the crude oil contaminated soils, part of the "SOM" is in fact carbon hydrides from crude oil.
Changes in total carbon follow trends and statistical differences that are almost identical to SOM. Compared to the control treatment significantly higher carbon content was recorded in treatments where crude oil was applied (treatments II, III and IV) as well as in treatment with the highest dose of drilling fluids (treatment V). Significantly higher nitrogen content compared to the control treatment, was determined in treatments IV and V. No significant differences in nitrogen content were determined in other treatments.

Treatment	I	II	III	IV	V	VI	VII
Soil pH	5.34 b*	5.41 b	5.23 b	5.26 b	6.58 a	6.59 a	6.92 a
SOM, %	1.83 bc	4.07 a	2.07 bc	1.30 c	2.07 bc	1.83 bc	2.53 b
Carbon, %	1.70 c	2.78 a	2.57 a	2.40 ba	2.42 ba	2.03 bc	1.99 bc
Nitrogen, %	0.184 c	0.200 bac	0.212 ba	0.230 a	0.222 a	0.182 bc	0.197 bac
C /N ratio	9.24 f	13.90 a	12.12 b	10.43 de	10.90 dc	11.15 c	10.10 fe

* Values are means of 4 replicates. For each parameter, values in the same row followed by an identical letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$).

Table 5. Changes in soil pH, soil organic matter, carbon and nitrogen

4.2 Heavy metals in soil

The aim of this chapter is to show the degree to which crude oil or drilling fluids affect changes in heavy metal concentrations in soil. Cadmium concentrations in soil were lower than 0.3 mg kg^{-1} (Table 6). Regardless of the applied material (crude oil or drilling fluids), the detected changes in lead, molybdenum, arsenic, nickel, cobalt, cooper, chromium and vanadium concentrations cannot be associated with the application of the mentioned materials. Compared to the control treatment and treatments were crude oil was applied, significantly higher mercury, zinc and barium concentrations were recorded in treatments with drilling fluids.

Treatment	I	II	III	IV	V	VI	VII
Cd	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
Hg	0.03 c*	0.05 c	0.04 c	0.05 c	0.37 a	0.33 a	0.14 b
Pb	30 a	25 a	22 a	27 a	26 a	25 a	31 a
Mo	0.40a	0.34 a	0.33 a	0.33 a	0.47 a	0.34 a	0.31 a
As	8 a	9 a	9 a	9 a	9 a	10 a	8 a
Ni	20 a	20 a	20 a	20 a	20 a	22 a	21a
Co	12 a	12 a	12 a	13 a	11 a	12 a	11 a
Cu	17 a	17 a	19 a	19 a	20 a	19 a	19 a
Cr	26 a	25 a	25 a	27 a	26 a	27 a	28 a
Zn	62 b	62 b	64 b	65 ba	78 a	78 a	72 a
Ba	96 c	93 c	92 c	91 c	160 ab	194 a	144 b
V	33 a	32 a	34 a	36 a	34 a	35 a	36 a

* Values are means of 4 replicates. For each parameter, values in the same row followed by an identical letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$).

Table 6. Total heavy metal concentrations in soil (mg kg^{-1} soil)

4.3 Plant uptake of heavy metals

Concentrations of heavy metals in aerial biomass and grain of soybean and other crops are presented in Table 7. Higher levels of cadmium, chromium, zinc and barium were recorded in soybean aerial biomass than in its grain almost in all treatments. Soybean grain contained more nickel and copper compared to its aerial biomass. Values determined for molybdenum show no regularity. Higher levels of molybdenum were determined in

Treatment		I	II	III	IV	V	VI	VII
		Soybean						
aerial biomass grain	Cd	0.34 b* 0.12 b	0.21 c 0.14 ab	0.35 b 0.15 ab	0.41 a 0.16 a	0.20 c 0.01 c	0.15 d 0.14 ab	0.11 e 0.16 a
aerial biomass grain	Mo	0.65 e 0.81 c	1.29 a 0.69 d	1.17 b 0.42 e	0.69 e 0.65 d	1.11 c 1.16 b	0.64 e 1.09 b	0.79 d 1.47 a
aerial biomass grain	Ni	4.02 d 8.71 cd	14.00 a 10.00 b	8.56 b 9.21 c	5.74 c 11.6 a	5.56 c 10.3 b	5.18 c 8.91 cd	4.84 cd 8.34 d
aerial biomass grain	Cu	10.3 a 19.4 b	7.23 ed 17.7c	7.12 ed 18.4 bc	7.77 c 19.2 b	8.78 b 22.1 a	6.96 e 19.5 b	7.53 cd 18.4 bc
aerial biomass grain	Cr	2.34 e 1.43 a	6.43 a 1.41 a	3.81 b 1.31 ab	3.18 c 1.35 ab	2.99 cd 1.26 ab	3.14 c 1.16 bc	2.65 ed 0.99c
aerial biomass grain	Zn	94 c 50 e	98 b 54 d	98 b 74 a	109 a 59 c	81 d 67 b	60 e 62c	61 e 50 e
aerial biomass grain	Ba	55 d 5.08 c	60 c 5.99 b	76 b 6.86 a	88 a 6.91 a	57 cd 5.10 c	56 d 4.47 d	42 e 3.69 e
Maize								
aerial biomass grain	Cd	0.13 d 0.09 b	0.24 a 0.09 b	0.24 a 0.05 d	0.16 c 0.07 c	0.13 d 0.09 b	0.20 b 0.08 bc	0.13 d 0.12 a
aerial biomass grain	Mo	0.65 f 0.40 d	0.74 d 0.83 a	0.42 g 0.52 c	0.68 e 0.87 a	1.01 b 0.53 c	1.14 a 0.68 b	0.98 c 0.72 b
aerial biomass grain	Ni	4.19 f 4.86 e	5.03 c 5.44 a	4.95 d 4.48 f	4.47 e 5.13 b	4.96 d 4.93 d	5.84 a 5.05 c	5.46 b 3.96 g
aerial biomass grain	Cu	19.9 e 2.45 c	18.3 f 2.50 c	20.7 d 2.09 d	24.8 a 2.42 c	23.1 b 2.68 b	21.9 c 2.76 a	17.1 d 2.11 d
aerial biomass grain	Cr	3.61 c 1.73 a	5.00 a 1.64 b	4.07 b 1.38 e	3.72 c 1.63 b	3.28 d 1.55 c	3.94 b 1.69 ab	3.18 d 1.46 d
aerial biomass grain	Zn	80 b 21 b	64 e 21 b	79 b 25 a	88 a 22 b	75 c 21 b	67 de 24 a	69 d 20 b
aerial biomass grain	Ba	17.6 d 9.70 b	20.0 b 10.40 a	22.0 a 7.65 e	18.8 c 2.28 f	17.1 d 9.42 c	13.6 e 9.43 c	13.7 e 8.74 d
aerial biomass grain	V	0.62 e 3.98 a	0.79 cd 1.17 c	0.75 cd 1.78 b	1.50 b 1.03 c	0.69 de 0.63 d	0.81 c 0.50 d	2.68 a 0.60 d
Winter Wheat								
aerial biomass grain	Cd	0.13 bc 0.17 a	0.19 a 0.13 b	0.17 a 0.09d	0.14 b 0.11 bc	0.13 bc 0.13 b	0.12 c 0.10 cd	0.08 d 0.18 a
aerial biomass grain	Hg	0.02 a 0.01 a	0.01 a 0.02 a	0.01 a 0.01 a	0.01 a 0.02 a	0.01 a 0.01 a	0.01 a 0.01 a	0.01 a 0.01 a

Treatment		I	II	III	IV	V	VI	VII
		Winter Wheat						
aerial biomass grain	Mo	0.74 d 0.92 cd	1.17 c 0.99 bc	1.51 a 1.14 b	1.42 ab 1.41 b	1.23 bc 0.90 cd	1.24 bc 0.91 cd	1.28 bc 0.72 d
aerial biomass grain	Ni	3.52 d 5.15 b	2.87 e 5.62 a	3.59 d 5.13 b	4.78 b 4.78 de	5.14 a 4.92 cd	5.29 a 5.11 bc	4.39 c 4.64 e
aerial biomass grain	Cu	3.56 e 7.56 d	4.28 c 8.21 bc	4.58 b 8.47 a	4.73 b 8.17 bc	4.98 a 7.98 c	3.91d 8.29 ab	3.54 e 8.04 c
aerial biomass grain	Cr	1.47 d 1.48 d	1.23 e 1.53 d	2.58 c 2.14 c	2.61 c 2.18 c	2.84 ab 2.56 b	2.71 bc 2.72 a	2.96 a 2.69 a
aerial biomass grain	Zn	34 e 49 d	38 d 52 c	42 b 51 cd	35 e 55 b	39 cd 58 a	48 a 52 c	41bc 56 ab
aerial biomas grain	Ba	12.47 b 4.57 d	13.28 a 5.12 c	12.78 b 5.89 a	11.05 c 4.73 d	13.63 a 4.96 c	12.47 b 5.12 c	11.23 c 5.47 b

* Values are means of 4 replicates. For each parameter, values in the same row followed by an identical letter are not significantly different according to Fisher's LSD test ($P \leq 0.05$).

Table 7. Total heavy metal concentrations in aerial biomass and grain of investigated crops (mg kg^{-1} dry matter)

aerial biomass in some treatments while in other treatments higher levels were found in grain. The grains of soybean and wheat contained more cadmium than grain of maize. The higher content of barium was determined in grain of maize than in grains of soybean and wheat. The highest copper content was determined in aerial biomass of maize. The highest copper content was determined in grain of soybean. Compared to the aerial biomass of wheat the aerial biomass of soybean and maize contained a higher content of chromium and zinc.

The higher content of molybdenum was determined in aerial biomass and grain of wheat than in aerial biomass and grain of other two crops. The grains of wheat and maize contained higher content of mercury compared to soybean grain.

4.4 Enrichment Coefficients (EC)

In various literature enrichment coefficient is also called enrichment ratio; translocation coefficient; transfer factor; soil-plant transfer coefficient; accumulation factor; phytoaccumulation factor; bioaccumulation factor; biological adsorption coefficient and uptake coefficient (Zgorelec, 2009). Enrichment coefficient was calculated with equation: $EC = C_{aerial\ biomass\ or\ grain}/C_{soil}$, where $C_{aerial\ biomass\ or\ grain}$ and C_{soil} represent the metal concentration (mass ratio) in the aerial biomass or grain and in the soil on dry weight basis (mg/kg in DM), respectively. Malayeri et al., 2008 grouped plant species according to their heavy metal uptake capacities and sensitivity to metal pollution:

High accumulator plants	EC between 1 - 10
Moderately accumulator plants	EC between 0.1 – 1.0
Low accumulator plants	EC between 0.01 – 0.1
Non accumulator plants	EC < 0.01

The highest enrichment coefficient for all investigated crops was molybdenum (Table 8). In all cases, enrichment coefficient of molybdenum was higher for biomass than for grain.

According to the higher values of enrichment coefficient the next metal is zinc. However, in this case, content of zinc in maize and soybean is higher in biomass than in grain, while in winter wheat higher content of zinc in grain was determined. Investigated crops also had very high enrichment coefficient for cadmium. As for molybdenum, cadmium had higher content in aerial biomass than in grain. High content of copper was determined in maize aerial biomass, while for soybean and wheat higher content of copper was determined in grain than in biomass. Increased content of nickel was determined in biomass as well as in grain of all investigated crops. All other investigated metals and metalloids (Pb, Hg, As, Co, Cr, Ba and V) had very low enrichment coefficient.

Treatment		I	II	III	IV	V	VI	VII
		Soybean						
aerial biomass grain	Cd	1.1 0.4	0.7 0.5	1.2 0.5	1.4 0.5	0.7 0.0	0.5 0.5	0.4 0.5
aerial biomass grain	Mo	1.6 2.0	3.8 2.0	3.5 1.3	2.1 2.0	2.4 2.5	1.9 3.2	2.5 4.7
aerial biomass grain	Ni	0.2 0.4	0.7 0.5	0.4 0.5	0.3 0.6	0.3 0.5	0.2 0.4	0.2 0.4
aerial biomass grain	Cu	0.6 1.1	0.4 1.0	0.4 1.0	0.4 1.0	0.4 1.1	0.4 1.0	0.4 1.0
aerial biomass grain	Cr	0.1 0.1	0.3 0.1	0.2 0.1	0.1 0.1	0.1 0.0	0.1 0.0	0.1 0.0
aerial biomass grain	Zn	1.5 0.8	1.6 0.9	1.5 1.2	1.7 0.9	1.0 0.9	0.8 0.8	0.8 0.7
aerial biomass grain	Ba	0.6 0.1	0.6 0.1	0.8 0.1	1.0 0.1	0.4 0.0	0.3 0.0	0.3 0.0
Maize								
aerial biomass grain	Cd	0.4 0.3	0.8 0.3	0.8 0.2	0.5 0.2	0.4 0.3	0.7 0.3	0.4 0.4
aerial biomass grain	Mo	1.6 1.0	2.2 2.4	1.3 1.6	2.1 2.6	2.1 1.1	3.4 2.0	3.2 2.3
aerial biomass grain	Ni	0.2 0.2	0.3 0.3	0.2 0.2	0.2 0.3	0.2 0.2	0.3 0.2	0.3 0.2
aerial biomass grain	Cu	1.2 0.1	1.1 0.1	1.1 0.1	1.3 0.1	1.2 0.1	1.2 0.1	0.9 0.1
aerial biomass grain	Cr	0.1 0.1	0.2 0.1	0.2 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1
aerial biomass grain	Zn	1.3 0.3	1.0 0.3	1.2 0.4	1.4 0.3	1.0 0.3	0.9 0.3	1.0 0.3
aerial biomass grain	Ba	0.2 0.1	0.2 0.1	0.2 0.1	0.2 0.0	0.1 0.1	0.1 0.0	0.1 0.1
aerial biomass grain	V	0.0 0.1	0.0 0.0	0.0 0.1	0.0 0.0	0.0 0.0	0.0 0.0	0.1 0.0

Treatment		I	II	III	IV	V	VI	VI
		Winter Wheat						
aerial biomass grain	Cd	0.4 0.6	0.6 0.4	0.6 0.3	0.5 0.4	0.4 0.4	0.4 0.3	0.3 0.6
aerial biomass grain	Hg	0.7 0.3	0.2 0.4	0.3 0.3	0.2 0.4	0.0 0.0	0.0 0.0	0.1 0.1
aerial biomass grain	Mo	1.9 2.3	3.4 2.9	4.6 3.5	4.3 4.3	2.6 1.9	3.6 2.7	4.1 2.3
aerial biomass grain	Ni	0.2 0.3	0.1 0.3	0.2 0.3	0.2 0.2	0.3 0.2	0.2 0.2	0.2 0.2
aerial biomass grain	Cu	0.2 0.4	0.3 0.5	0.2 0.4	0.2 0.4	0.2 0.4	0.2 0.4	0.2 0.4
aerial biomass grain	Cr	0.1 0.1	0.0 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.1
aerial biomass grain	Zn	0.5 0.8	0.6 0.8	0.7 0.8	0.5 0.8	0.5 0.7	0.6 0.7	0.6 0.8
aerial biomass grain	Ba	0.1 0.0	0.1 0.1	0.1 0.1	0.1 0.1	0.1 0.0	0.1 0.0	0.1 0.0

Table 8. Enrichment coefficient for investigated crops

5. Discussion

In the presented study, the application of crude oil did not cause elevated levels of heavy metals in soil, but the application of drilling fluids resulted in higher mercury, zinc and barium concentrations. Increased zinc and barium concentrations in treatments involving drilling fluids are attributed to the use of zinc carbonate and barite ($BaSO_4$) in drilling (U.S. Congress, Office of Technology Assessment, 1992). Barium is insoluble, inert and non-toxic (Deuel, 2003), and therefore is not considered to be a great soil problem. Increased mercury concentrations in treatments where drilling fluids were applied are attributed to the source of drilling fluids. The reason why drilling fluids contain a larger amount of calcium compounds is its use as an additive for inhibiting corrosion of oil and gas pipes, or as an additive to increase drilling fluid density (Veil & Dusseault, 2003; Kisic et al., 2009). Also, material with increased calcium compounds is usually added to bind fluids when repairing a pipe break or other incidents.

The problem of increased concentrations of some heavy metals caused by the application of crude oil-based fluids was pointed out by Nelson et al., 1984. When crude oil-based fluids were used as liming material, the expected positive changes in soil pH occurred (Deeley & Canter, 1986).

As optimum soil reaction for the majority of cultivated plants is around the neutral pH value, liming is a desirable practice because under neutral to weakly alkaline conditions bioavailability of some heavy metals (except As, V, Mo, Co and Cr) decreases (Mathur et al., 1991; Dermatas & Meng, 2003). This reduces the possibility of their translocation from roots into the plant itself (Bolan et al., 2003).

Levels of heavy metals detected in aerial biomass or grain of crops in all trial treatments are within the ranges determined in some other studies (Adriano, 2001; Kabata-Pendias & Mikherjee, 2007). A number of authors (Darell et al., 1984; Khan et al., 2000; Lengrand et al.,

2005) report that soil pH, electrical conductivity, mechanical composition, organic matter concentrations, crop type and total heavy metals concentrations have a decisive influence on the heavy metal uptake by plants.

6. Conclusions

In soybean and wheat grain more nickel and copper were determined compared to soybean and wheat biomass. Also, higher content of zinc in wheat grain compared to biomass was determined. In all other cases, higher concentrations of heavy metals in aerial biomass than in grain of investigated crops were determined.
Regarding other investigated crops soybean had the highest enrichment coefficient for cadmium, copper, nickel and zinc.

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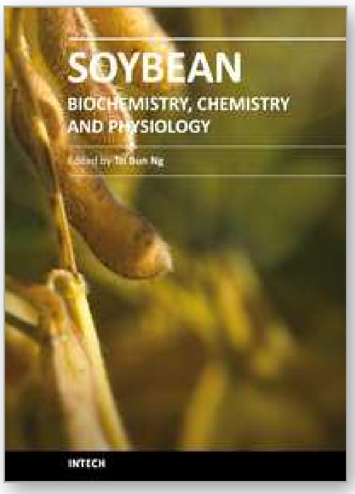

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Soybean is an agricultural crop of tremendous economic importance. Soybean and food items derived from it form dietary components of numerous people, especially those living in the Orient. The health benefits of soybean have attracted the attention of nutritionists as well as common people.