

CLEANING OF SOIL CONTAMINATED WITH HEAVY METALS USING RED CLOVERS

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Abstract. Soil contamination with heavy metals is a relevant problem worldwide to which no universal solution has been found. Phytoremediation is a new and prospective technology for cleaning soils of low contamination rate using plants. To clean heavy metals off soil, this work has chosen the red clovers *Arimaičiai* grown under laboratory conditions. After Cu application on soil it was noticed that after six months the content of Cu in soil had been threefold lower than at the beginning of the experiment. After soil application with Mn it was determined that the *Arimaičiai* had absorbed 30 % of it from soil after six months. When Ni concentration in soil reached 75 mg/kg it was noticed that after six months the *Arimaičiai* had absorbed 32 % of Ni from soil. It was also determined that the red clovers had adsorbed up to 31 % of Cr from soil during the same period. After permanent application of Zn on soil the plant absorbed 17 % of zinc from soil during the six-month period. When Pb concentration in soil reached 100 mg/kg it was noticed that after six months the plants had absorbed 23 % of Pb from soil.

Keywords: the red clovers *Arimaičiai*, heavy metals, phytoremediation, soil contamination.

1. Introduction

Soil is contaminated with heavy metals in any part of the world (Jankaitė 2009). Heavy metals have a negative effect on different parts of the environment: atmosphere, underground water and soil (Jankauskaitė *et al.* 2007). Soil, being the most important environmental filter and detoxicator, is the main accumulator of emissions and wastes from industrial enterprises, vehicles, agriculture and utilities which are toxic for human health (Šleinyš and Rimšelis 2000).

Recently, the issue of contamination with heavy metals has been widely addressed as upon the increase of their concentration in soil, the facts of population intoxication and even death were determined. Many cases of intoxication caused by environment pollution with Pb, Cd and Hg were established. Soil is mostly contaminated by industrial and energy enterprises, vehicles and fertilisers used in agriculture. Contaminants enter soil with precipitation, dust from industrial enterprises, vehicle exhaust emissions, etc. The most important of them are organic and mineral (sulphuric, hydrochloric and nitric) acids, heavy metals, organic pesticides, oil products, radioactive isotopes and detergents (Baltrėnas *et al.* 2003).

Technogenic pollution of the natural eco-systems causes many problems and its effects are difficult to evaluate. One of such problems is the emergence of compounds with a toxic effect (heavy metals, pesticides, *etc.*) in the

nutritional chains of eco-systems, which predetermine an increasing level of mutability in natural populations of animals. 75 % of chemicals accessing the environment in large amounts have been undervalued (Idzelis *et al.* 2008).

A number of different pollutants from industry access the environment and at the same time soil: hazardous wastes which are frequently handled inappropriately, hazardous chemicals which, upon accessing the air, sooner or later settle on the ground, or leak out during various accidents, heavy metals (Cd, Pb, Cr, Cu, Zn, Hg, Ar) which are emitted with atmospheric pollutants, in particular from thermal power plants, incineration plants of waste from metal and chemical industry enterprises. Fertilisers and various plant protection products (used to kill insects, weeds, rodents, etc.) contain a number of different substances (heavy metals, nonylphenol and nonylphenoethoxylate, chlorpyrifos, tin organic compounds, trifluralin, endosulphan, *etc.*), which are highly durable and do not degrade but accumulate in soil, organisms, plants and water bodies. In addition, plant protection products not only protect crop and vegetables but at the same time have an effect on other plants and kill many useful organisms (Cheminė tarša 2008). Transport of heavy metals from soil to plants covers chemical, physical and biological processes (such as diffusion, adsorption, absorption, plant growth, transpiration speed) occurring in soil, rhizosphere and the plant itself (Baltrėnaitė and Butkus 2007).

The currently available data produce sufficient evidence to the negative effect of contaminated soil on plants, animals and humans. This effect is transferred via nutritional chains. The majority of heavy metals, Hg, Cd, Ni, Cr, Cu, Co and others, have at least several or a whole of negative effects on health: cancerogenic, mutagenic, teratogenic or neurotoxic. A particularly harmful for health is the effect of their synergy (Taraškevičius *et al.* 1999).

When assessing the level of soil contamination it is very important to identify the background amounts of micro elements which accumulated as a result of natural geochemical processes, under the influence of global, regional and integrated local transport of technogenic elements (Baltrėnas *et al.* 2009).

Cleaning of contaminated soil through the employment of plants (phytoremediation) is a quite new method which was extensively investigated in the US. Certain varieties of plants are naturally adapted to survive in soils with high concentrations of heavy metals. Most plants can absorb part of metals with their roots, while in some plants heavy metals from roots can access leaves where metals are closed in plant cells. During the transport of heavy metals from soil to roots and the plant metals are combined by proteins and organic acids and consequently metal in plant cells becomes non-toxic (Speitel and Closmann 1991).

Successful phytoremediation can be guaranteed when these naturally selected and adapted plants are economically useful (Jankaitė and Vasarevičius 2007 a). Effectiveness depends on three factors: degree of soil contamination with heavy metals; degree of bio-suitability of metals (chemical and physical aspects); and capacity of plants to accumulate heavy metals in their sprouts.

Soils heavily contaminated with heavy metals can be planted with plants resistant to heavy metals; however, the possibilities of their decontamination are limited by a low biomass production and therefore soil decontamination will not be achieved in due time, i.e. in 10 years (Jankaitė and Vasarevičius 2007 b).

In Belgium scientists carried out a project by applying phytoremediation in order to clean heavy metals off soil. Heavy metals will access rape, corn and wheat more intensely if the bio-acceptability of heavy metals is increased by adding bio-degrading physical-chemical additives and stimulating the capacity of micro biological communities to absorb heavy metals inside and around the plant (Van Ginneken *et al.* 2007).

Plants have good Cd, Cu, Pb, Ni and Zn accumulating properties and phytoremediation, therefore, can be looked upon as one of the best methods for cleaning heavy metals from soil. The most appropriate method for soil cleaning and remediation is selected by taking account of locality's characteristics, materials, concentrations and the amounts of pollutants which can be removed and by envisaging further possible application of the contaminated medium (Jankaitė and Vasarevičius 2005). The shortcoming of phytoremediation lies in the fact that plants absorb heavy metals only from the topsoil.

The aim of research is to evaluate, by carrying out laboratory experiments, the growth and capacity of grass vegetation, i.e. the red clovers *Arimaičiai* (*Trifolium*

pratense L.) to sorb heavy metals (Cu, Cr, Zn, Pb, Mn and Ni) from soil at different concentrations thereof.

2. Methods of the work

Red clover (*Trifolium pratense* L.) is a conventional perennial fodder grass which is the most widely spread one in arable land.

This variety of grass vegetation was selected due to the fact that these plants do not require care and favourable growth conditions. Red clovers (*Trifolium pratense* L.), both early and late maturing ones, have been spread all over Lithuania.

Clean soil is used for growing control plants. Seeds are sown in both clean soil and soil which is periodically contaminated with heavy metals. The periodically contaminated soil means such soil which is continually contaminated with a solution of heavy metals by using it to maintain humidity.

The main indicator for assessing soil contamination with heavy metals is the maximum permissible concentration (MPC) in soil. Table 1 shows the selected concentrations of heavy metals which are close to the maximum permissible concentration in soil.

Table 1. Heavy metal concentration in soil

Mn mg/kg	Zn mg/kg	Cr mg/kg	Ni mg/kg	Cu mg/kg	Pb mg/kg
Medium					
650	150	60	50	45	70
High contamination with heavy metals					
1 200	300	100	75	90	100

For the plant to grow and all physiological processes necessary for its growth to take place the plant needs humidity and therefore the red clovers (*Trifolium pratense* L.) concerned are watered every three days. The red clovers are grown in soil which is continuously contaminated with a 100 ml mixture of heavy metals. A temperature of 22° – 24 °C is maintained, while lighting is natural which changes according to the time of the day. Duration of the experiment is six months.

Plants in control soil and in soil of medium contamination are growing equally without any significant difference noticed between them. In heavily contaminated soil the growth of *Arimaičiai* was much worse (Fig 1).

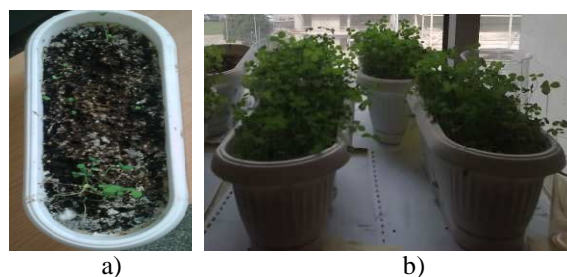


Fig 1. Growing the red clovers *Arimaičiai* in soil with high (a) and medium (b) concentrations of heavy metals

After each of two-, four- and six-month period of contamination with heavy metals the red clovers *Arimaičiai* are pulled up and analysed. Prior to being analysed the plants are washed. 0.5 g of the plant mass is taken as a sample. Solution preparation: a flask is filled with 10 ml of concentrated HNO₃ and 2 ml of H₂O₂ 30 % which are mineralised in a mineralisator for 30 minutes.

Mineralisation completed, the solution is poured into a measuring flask and diluted with up to 50 ml of de-ionised water. A calibration curve is formed on the basis of the solution with known concentrations and the concentration of metals in a sample is measured (Mikalajūnė and Jasulaitytė 2010).

Concentrations of heavy metals are measured with an atomic absorption spectrometer.

3. Research results

Soil can be contaminated with heavy metals due to a number of reasons. The main pollutants of soil are energy, transport and the chemical industry. Heavy metal-contaminated soil poses a threat to ground waters.

Grass vegetation is analysed every two months. The average of the obtained experimental results is found and experiments are repeated three times. The obtained results are presented within 5 % error limits.

Initially, the concentration of heavy metals (Zn, Mn, Cr, Ni, Cu and Pb) in control soil is determined (Fig 2).

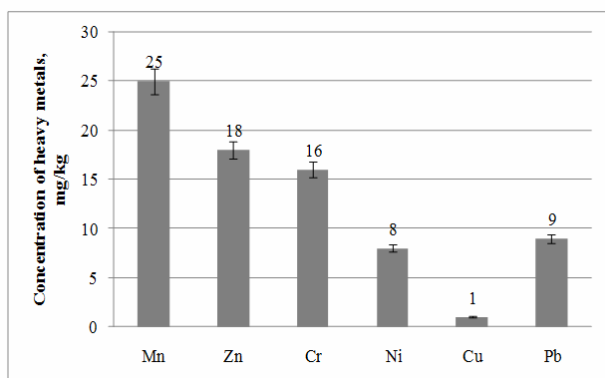


Fig 2. Heavy metals concentrations in control soil

The largest content of Mn, 25 mg/kg, and the lowest amount of Cu, 1 mg/kg, was established in uncontaminated soil.

To some extent Cu is useful for plants and animals as a micro element, but high concentrations thereof destroy cells. Cu is necessary for vital functions of organisms. Plants absorb it from soil, while humans and animals receive it with food (Balžytė *et al.* 2005).

The determined concentration of Cu when soil was steadily contaminated with it is equal to 45 mg/kg. These results are presented in Figure 3.

As Figure 3 shows, after 2 months the red clovers sorbed 4 mg/kg of Cu, after four months – 12 mg/kg and after six months – 23 mg/kg. The *Arimaičiai* sorbed the largest amount of Cu after six months.

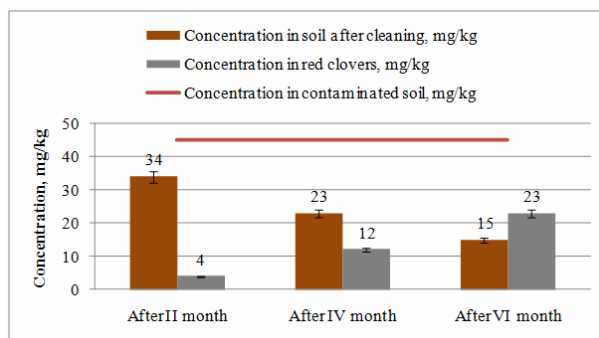


Fig 3. Ability of red clovers *Arimaičiai* to sorb Cu from soil and Cu concentration remaining in soil

As Figure 3 shows, Cu concentration in soil decreased quite insignificantly. Cu concentration in soil after two months was 34 mg/kg, after four months – 23 mg/kg and after six months decreased from 45 mg/kg to 15 mg/kg.

When soil was continuously contaminated with higher concentrations of Cu the germination capacity of the red clovers *Arimaičiai* was very poor and, sorption was not good. After two months the plants contained 8 g/kg and after six months – 25 mg/kg. The *Arimaičiai* sorbed up to 28 % of Cu from soil (Fig 4).

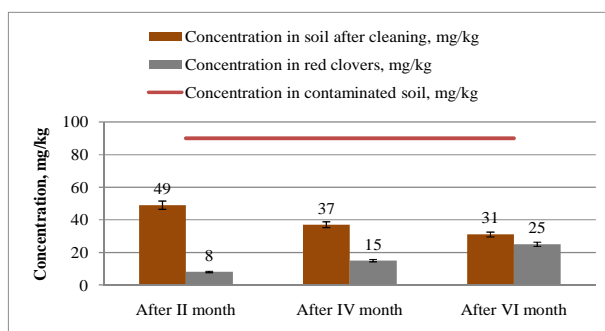


Fig 4. Ability of red clovers *Arimaičiai* to sorb Cu from soil and Cu concentration remaining in soil

Cu concentration in soil decreased as the initial Cu concentration in soil was 90 mg/kg. After two months Cu concentration was 49 mg/kg, after four months – 37 mg/kg and after six months – 31 mg/kg (Fig 4). After six months the *Arimaičiai* sorbed up to 25 mg/kg of Cu. After two months the content of Cu in soil was by 46 % lower compared to the initiation contamination, after six months the content of Cu in soil decreased by nearly three times compared to the initial soil contamination.

Mn content in soil depends on soil pH, the amount of organic matter, humidity and soil aeration. The bivalent Mn found in soil is soluble and has a mobile form and therefore it is easily absorbed by plant roots (Jankaitė and Vasarevičius 2007). Mn is an indispensable element for plant nutrition. Even though the amount of this element necessary for plants is by hundred or thousand times lesser than that of nitrogen or other elements, unfortunately, no harvest will be ever produced without it. However, it is difficult for plants to assimilate Mn in light soils on which large amounts of lime are applied or those after liming (Petrauskas 2006).

When soil was continuously contaminated with Mn its concentration in soil amounted to 650 mg/kg. It was noticed that plants had shown good Mn sorption ability. After two months the *Arimaičiai* sorbed 191 mg/kg, after four months – 226 mg/kg, after six months – 347 mg/kg. Mn concentration in soil decreased significantly – to 499 mg/kg after two months, 382 mg/kg after four months, and 268 mg/kg after six months (Fig 5).

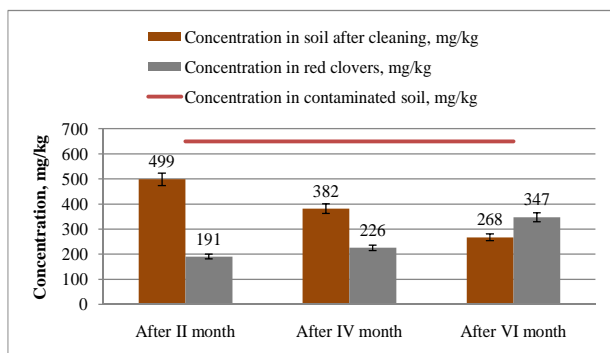


Fig 5. Ability of red clovers *Arimaičiai* to sorb Mn from soil and Mn concentration remaining in soil

Mn concentration in soil fell by 1.9 times compared to Mn concentration in soil after two months.

The *Arimaičiai* were also contaminated with high concentration of Mn – 1 200 mg/kg (Fig 6). The red clovers showed the best Mn sorption capacity after six months of growth, i.e. up to 30 % against the initial concentration.

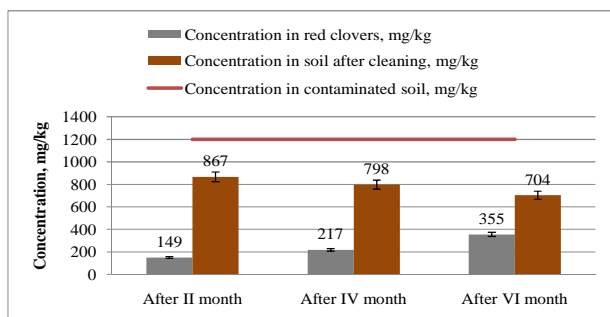


Fig 6. Ability of red clovers *Arimaičiai* to sorb Mn from soil and Mn concentration remaining in soil

As it was noticed, when soil is contaminated with a conditionally high concentration of Mn, more Mn remain in soil and the red clovers sorb Mn poorly. After two months the red clovers contained 149 mg/kg and soil – 867 mg/kg of Mn. After six months Mn concentration in cloves was 355 mg/kg, in soil – 704 mg/kg (Fig 6).

After two months Mn content in soil was by 28 % lower and after six months decreased by up to 1.7 times compared to the initial contamination, while the plant sorbed up to 30 % of Mn from soil.

Ni is an important nutrient for a plant. Plant nutrition depends on Ni, like other heavy metals, getting to the plant, as well as on transport and distribution in the plant (Mažvila 2001).

As Fig 7 shows, after two months the clovers sorbed 8 mg/kg at the initial Ni concentration of 50 mg/kg. After four months the *Arimaičiai* contained 13 mg/kg and after six months – 18 mg/kg of Ni. Change over a six-month period is insignificant compared to the initial Ni concentration. After six months the *Arimaičiai* sorbed up to 36 % of Ni compared to the initial contamination. After two months soil contained 41 mg/kg, after four months – 38 mg/kg, after six months – 31 mg/kg of Ni, when the initial Ni concentration was 50 mg/kg (Fig 7).

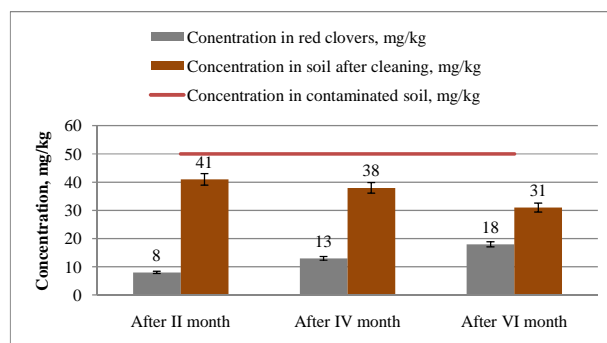


Fig 7. Ability of red clovers *Arimaičiai* to sorb Ni from soil and Ni concentration remaining in soil

Ni concentration in soil changed insignificantly as the *Arimaičiai* show poor Ni sorption capacity. After two months the content of Ni in soil was by 18 % lower compared to the initial contamination. After six months the content of Ni in soil was by 1.6 times lower compared to the initial soil contamination and the plant sorbed up to 36 % of Ni from soil.

Figure 8 shows soil cleaning at Ni concentration in soil of 75 mg/kg. After two months the *Arimaičiai* sorbed around 15 %, after four months – 20 % and six months – 32 % of Ni from soil.

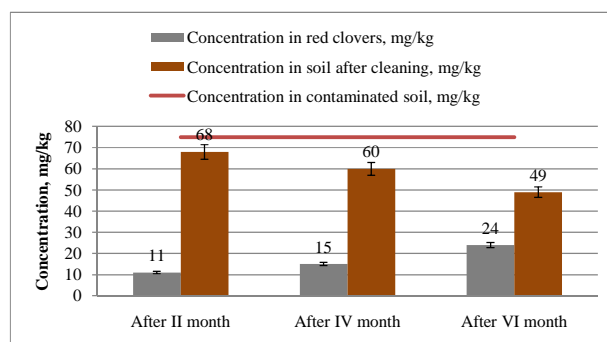


Fig 8. Ability of red clovers *Arimaičiai* to sorb Ni from soil and Ni concentration remaining in soil

The *Arimaičiai* poorly sorbed high concentrations of Ni (75 mg/kg) and the major part of Ni remained in soil. The plants poorly assimilate this heavy metal when its concentrations in soil are high. After two months the clovers contained 11 mg/kg while soil – 68 mg/kg of Ni. After four months Ni concentration in clovers was 15 mg/kg while in soil – 60 mg/kg; after six months Ni con-

centration in the *Arimaičiai* was 24 mg/kg, while in soil – 49 mg/kg (Fig 8).

View of the *Arimaičiai* (*Trifolium pratense* L) which were grown in continuously contaminated soil at Cr concentration of 60 mg/kg is presented in Fig 9. It was noticed with Cr concentration increasing more Cr remained in soil while the *Arimaičiai* sorbed less of it.

After two months the *Arimaičiai* contained 23 mg/kg and soil – 57 mg/kg of Cr. After four months Cr content in clovers was 26 mg/kg, in soil – 45 mg/kg; after six months Cr concentration in clovers was 43 mg/kg, in soil – 31 mg/kg (Fig 9). After two months Cr concentration decreased to 57 mg/kg when contaminating 60 mg/kg. After four months Cr concentration decreased by 1.3 times, after six months – 1.9 times compared to the initiation concentration of Cr in soil. After six months Cr concentration in soil was by 52 % lower than the initial soil contamination.

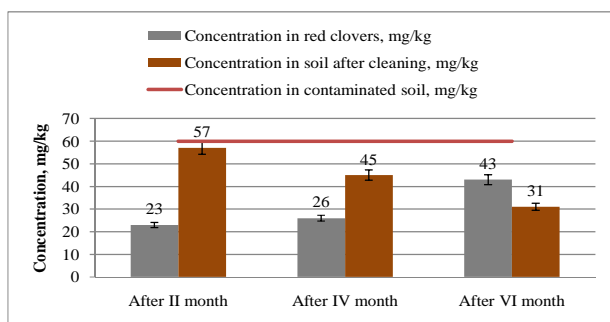


Fig 9. Ability of red clovers *Arimaičiai* to sorb Cr from soil and Cr concentration remaining in soil

It was noticed that upon increasing Cr concentration to 100 mg/kg, the *Arimaičiai* had sorbed still less of Cr (Fig 10). After two months the *Arimaičiai* sorbed 14 %, after four months – 20 % and after six months – 21 %.

After two months Cr concentration in soil was 86 mg/kg, after four months – 79 mg/kg and after six months – 70 mg/kg (Fig 10). After two months the *Arimaičiai* contained 14 mg/kg, after four months – 20 mg/kg, after six months – 31 mg/kg of Cr. After six months Cr concentration in soil decreased by 16 mg/kg compared to the concentration in soil recorded after two months. After two months the content of Cr in soil was by 14 % lower compared to the initial contamination. After six months there remained by 1.4 times less of Cr in soil compared to the initial soil contamination, and the plant sorbed up to 31 % of Cr from soil.

Zn is important for photosynthesis as it participates in the formation of chlorophyll and helps protect it from degradation. It actively participates in sugar formation, protein synthesis and ensures both fertility and rich harvest of seeds. Large amounts of phosphoric and nitric fertilisers enhance the impact of Zn on plants. Zn deficiency results in slowed growth of stems, leaf paling, emergence of brownish or yellowish spots, emergence of white longitudinal streaks among veins on the leaves of gramineous plants, significant decrease in leaf size, non-developed internodes in annual shoots, decrease in the number and size and deformation of

fruit being of low value, and thinner leaves of sprouts (Mikroelementų reikšmė... 2008).

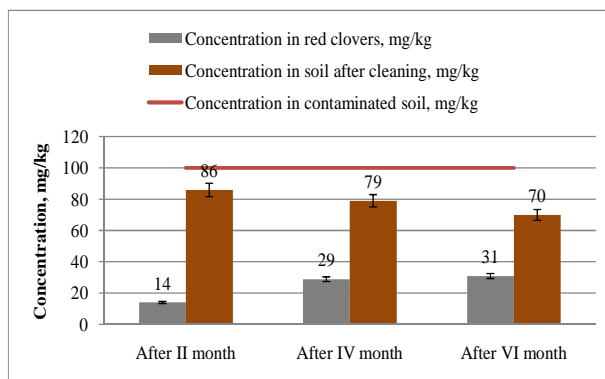


Fig 10. Ability of red clovers *Arimaičiai* to sorb Cr from soil and Cr concentration remaining in soil

Figure 11 shows soil cleaning at Zn concentration in soil of 150 mg/kg. The obtained data show that after two months the *Arimaičiai* contain around 13 %, after four months – 26 % and after six months – 31 % of Zn.

After two months the *Arimaičiai* sorbed 19 mg/kg, after four months – 39 mg/kg, after six months – 47 mg/kg of Zn. The red clovers *Arimaičiai* poorly sorbed Zn when Zn concentration in soil reached 150 mg/kg (Fig 11).

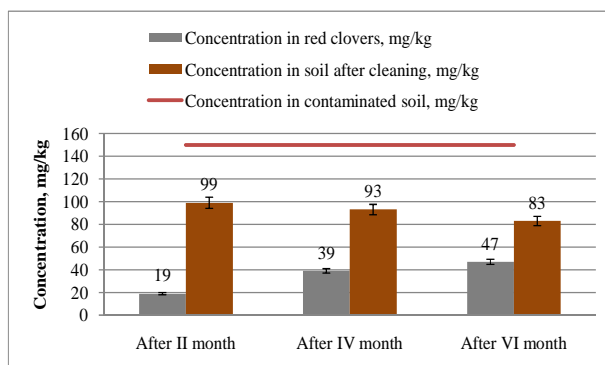


Fig 11. Ability of red clovers *Arimaičiai* to sorb Zn from soil and Zn concentration remaining in soil

After two months, Zn concentration in soil reached 99 mg/kg, after four months – 93 mg/kg, after six months – 83 mg/kg. After two months Zn concentration decreased to 51 mg/kg, showing a 1.5 times decrease against the initial concentration of this metal in soil. After four months Zn concentration decreased by 1.6 times, after six months – 1.8 times compared to the initiation concentration of Zn in soil (Fig 11).

It was noticed that when Zn concentration in soil reached 300 mg/kg, after six months Zn concentration in the *Arimaičiai* had been 18 mg/kg, after four months – 38 mg/kg, and six months – 51 mg/kg. The *Arimaičiai* sorbed Zn poorly. As it was noticed, the bigger was the content of Zn in soil, the lesser amount of it was sorbed by the clovers (Fig 12).

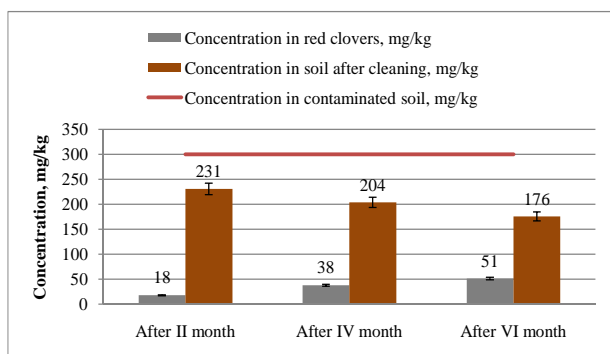


Fig 12. Ability of red clovers *Arimaičiai* to sorb Zn from soil and Zn concentration remaining in soil

As shown in Fig 12, Zn concentration in soil after two months was 231 mg/kg, after four months – 204 mg/kg, after six months – 176 mg/kg. After two months the content of Zn in soil was by 23 % lower compared to the initial contamination. After six months the content of Zn in soil was by 1.7 times lower compared to the initial soil contamination, while the plant sorbed up to 17 % of Zn from soil. The sorption of Zn by the red clovers *Arimaičiai* was weak.

Pb gets into organisms of humans and animals with food. Larger amounts of Pb are contained in vegetables with large surface areas of leaves. Pb may have a chronic effect on the blood and nervous system. So far chronic intoxication with Pb has been noticed at workplaces, which manifests itself in anaemia, decrease of appetite, and digestive and renal disorders. The group of risk also includes children when there is a threat that dust from vehicles containing Pb can get into their organisms when they play outside (*Cheminė tarša* 2008).

The obtained concentration at continuous contamination of soil was 70 mg/kg. After two months the *Arimaičiai* sorbed 14 %, after four months – 23 % and after six months – 31% of Pb. The red clovers *Arimaičiai* conditionally badly sorbed Pb (Fig 13).

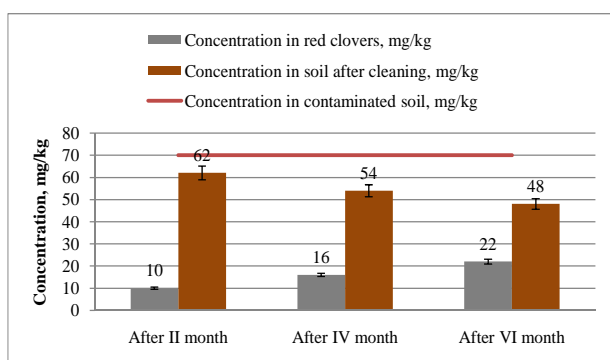


Fig 13. Ability of red clovers *Arimaičiai* to sorb Pb from soil and Pb concentration remaining in soil

After two months the *Arimaičiai* sorbed 10 mg/kg, after four months – 16 mg/kg, after six months – 22 mg/kg of Pb when the initial contamination of soil was 70 mg/kg. After two months the *Arimaičiai* sorbed 62 mg/kg, after four months – 54 mg/kg, after six months –

48 mg/kg of Pb when the initial contamination of soil was 70 mg/kg. After two months the content of Pb in soil was by 11 % lower compared to the initial contamination. After six months the content of Pb in soil decreased by 1.5 times compared to the initial contamination of soil. The highest sorption ability of the *Arimaičiai* was after two and six months (Fig 13).

Soil was continuously contaminated with high concentrations of Pb, i.e. 100 mg/kg. After two months the *Arimaičiai* sorbed up to 12 %, after four months – 19 % and after six months – 23 % of Pb compared to the initial contamination. The ability of the red clovers to sorb Pb was very weak (Fig 14).

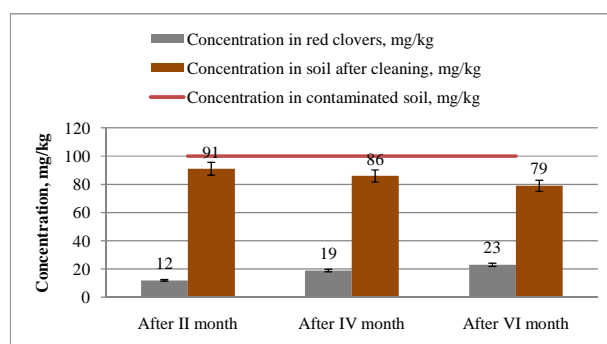


Fig 14. Ability of red clovers *Arimaičiai* to sorb Pb from soil and Pb concentration remaining in soil

After two months the *Arimaičiai* sorbed 12 mg/kg, after four months – 19 mg/kg, after six months – 23 mg/kg of Pb when soil was continuously contaminated with Pb. After two months the content of Pb in soil decreased by 9 % compared to the initial contamination, after six months the content of Pb in soil was by up to 1.3 times lower than the initial soil contamination. The content of Pb in soil after two months was 91 mg/kg, after four months – 86 mg/kg, after six months – 79 mg/kg. The higher is the concentration of Pb in soil the worse is the ability of the *Arimaičiai* to sorb Pb, which is among the metals being the most difficult to sorb.

4. Conclusions

1. Upon contaminating soil with up to 90 mg/kg of Cu it was noticed that Cu concentration in soil after six months had decreased by up to three times compared to the initial contamination of soil.
2. After continuous soil application with Mn it was determined that the *Arimaičiai* had absorbed 30 % of it from soil after six months.
3. After six months the *Arimaičiai* sorbed 32 % of Ni and 31 % of Cr from contaminated soil.
4. After continuous soil application with Zn it was noticed that the *Arimaičiai* had absorbed 17 % of it from soil after six months.
5. After six months the red clovers sorbed 23 % of Pb from soil.

6. The Arimaičiai sorb heavy metals from soil better during the first months of growth, which can be related to the fact that plants need larger amounts of minerals, including heavy metals, and the plants are growing and developing during the first months. Very high concentrations of heavy metals kill plants and they do not germinate.

Acknowledgement

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References

- Baltrėnaitė, E.; Butkus, D. 2007. Modelling of Cu, Ni, Zn, Mn and Pb transport from soil to seedlings of coniferous and leafy trees. *Journal of Environmental Engineering and Landscape Management*, 15 (4): 200–207.
- Baltrėnas, P.; Kliaugienė, E.; Jankaitė, A. 2003. Dirvožemio užterštumas sunkiaisiais metalais prie Via Baltica automagistralės ir Klaipėdos žiedo. *Journal of Environmental Engineering*, 11 (1): 3–10.
- Baltrėnas, P.; Vaitiekūnas, P.; Bačiulytė, Ž. 2009. Geležinkelio transporto taršos sunkiaisiais metalais dirvožemyje tyrimai ir įvertinimas. *Journal of Environmental Engineering and Landscape Management*, 17 (4): 244–251.
- Balžytė, A.; Dėdelienė, K.; Juknys, R.; Martinavičienė, J. 2005. Kadmio ir vario poveikis ir augalų adaptacija prie šių metalų. *Lietuvos sodininkystės ir daržininkystės instituto ir Lietuvos žemės ūkio universiteto mokslo darbai. Sodininkystė ir daržininkystė*, 24 (2): 113–121.
- Cheminė tarša (online). 2008. [Cited 2008 11 16]. Available on the Internet: <http://www.lzuo.lt/nm/l-projektas.-Aplinkos_tarsa/6.htm>.
- Idzelis, R.; Kesminas, V.; Svecevičius, G.; Misius, V. 2008. Sunkiųjų metalų (Cu, Zn, Ni, Cr, Pb, Cd) kaupimasis ešerio *Perca fluviatilis* L. Ir kuojos *Rutilus rutilus* (L.) audiniuose eksperimento sąlygomis. *Journal of Environmental Engineering and Landscape Management*, 16 (4): 205–212.
- Jankaitė, A. 2009. Soil remediation from heavy metals using mathematical modelling. *Journal of Environmental Engineering and Landscape Management*, 17 (2): 121–129.
- Jankaitė, A.; Vasarevičius, S. 2007 a. Use of Poaceae f. Species to decontaminate soil from heavy metals. *Ekologija*, 53 (4): 84–89.
- Jankaitė, A.; Vasarevičius, S. 2007 b. Žolinės augalijos gebėjimas kaupti manganą iš dirvožemio [Grassy vegetation ability to accumulate manganese from soil]. *Mokslas – Lietuvos ateitis*: 122–129.
- Jankaitė, A.; Vasarevičius, S. 2005. Remediation technologies for soils contaminated with heavy metals. *Journal of Environmental Engineering*, 13 (2): 109–113.
- Jankauskaitė, M.; Taraškevičius, R.; Zinkutė, R.; Veteikis, D. 2007. Relationship between landscape self-regulation potential and topsoil additive contamination by trace elements in Vilnius city. *Journal of Environmental Engineering and Landscape Management*, 16 (1): 5–14.
- Mažvila, J. 2001. *Sunkieji metalai Lietuvos dirvožemiuose ir augaluose [Heavy metals in soils and plants in Lithuania]*. Monografija, Kaunas: LŽI. 343.
- Mikalajūnė, A.; Jasulaitytė, G. 2010. Raudonųjų dobilų „Arimaičiai“ panaudojimas dirvožemio valymui nuo cinko [Clean the soil from zinc to used red clovers “Arimaičiai”]. *Mokslas–Lietuvos ateitis*, 2(5): 60–65.
- Mikroelementų reikšmė žemės ūkio augalų derliui ir kokybei (online). 2008. [Cited 2009 10 10]. Available on the Internet: <<http://www.arvifertis.lt/index.php/pageid/572/articlepage/4/articleid/109>>.
- Petrauskas, E. 2006. Lauko augalų tręšimo normos. *Justus Liebig Universitetas Giessene (Vokietija), LŽI. Mano ūkis Nr. 4. 5-8*.
- Speitel, Jr. G. E.; Clossmann, F. B. 1991. Chlorinated Solvent Biodegradation by Methanotrophs in Unsaturated Soils. *Journal of Environmental Engineering*, 117 (5): 541–559.
- Šleinytis, R.; Rimšelis, J. 2000. Dirvožemio technogeninė tarša Lietuvoje [Technogenic soil pollution in Lithuania]. *Lietuva be mokslo – Lietuva be ateities*: 36–44.
- Taraškevičius, R.; Oškiniš, V.; Lesauskaitė, S. 1999. Gyvenamosios aplinkos pagerinimo galimybės įvertinus dirvožemio užterštumą sunkiaisiais metalais [Improving the living environment to assess soil contamination with heavy metals]. *Aplinkos inžinerija*, 7(3): 134–141.
- Van Ginneken, L.; Meers, E.; Guisson, R.; Ruttens, A.; Elts, K.; Tack, F. M. G.; Vangronsveld, J.; Diels, L.; Dejonghe, W. 2007. Phytoremediation for heavy metal-contaminated soils combined with bioenergy production. *Journal of Environmental Engineering and Landscape Management*, 15 (4): 227–236.