American Journal of Plant Sciences, 2022, 13, 1439-1447
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Analysis of Heavy Metals in the Vegetative and Generative Organs of *Paulownia tomentosa* (Thunb.) Steud., 1841

Mamadiyorov Muzaffar Umrzokovich[1*], Djuraev Tulkin Arzikulovich[2], Ergasheva Farogat Sheralievna[2], Khushmatov Shunkor Sadullaevich[2]

[1]Samarkand State University, Samarkand, Republic of Uzbekistan
[2]The Laboratory of Experimental, Gulistan State University, Gulistan, Republic of Uzbekistan
Email: *Mamadiyorov_MU@bk.ru

How to cite this paper: Umrzokovich, M.M., Arzikulovich, D.T., Sheralievna, E.F. and Sadullaevich, K.S. (2022) Analysis of Heavy Metals in the Vegetative and Generative Organs of *Paulownia tomentosa* (Thunb.) Steud., 1841. *American Journal of Plant Sciences*, **13**, 1439-1447.
https://doi.org/10.4236/ajps.2022.1312098

Received: October 4, 2022
Accepted: December 18, 2022
Published: December 21, 2022

Abstract

High concentrations of heavy metals (Pb, Zn, As, Cd) were found in the vegetative and generative organs of *Paulownia tomentosa* (Thunb.) Steud., 1841) in industrial production zones and along transport routes in Samarkand, Samarkand region of the Republic of Uzbekistan. The obtained results confirm the potential of using this plant for phytoremediation purposes.

Keywords

Paulownia tomentosa (Thunb.) Steud., 1841, Heavy Metals (Pb, Zn, As, Cd), Phytoremediation

1. Introduction

Paulownia tomentosa (Thunb.) Steud., 1841 (*Paulownia tomentosa*/*Paulownia imperialis; Paulowniaceae*) is a species of woody plant that grows wild in regions of South/Southeast Asia and is used as an ornamental plant species in urban ecosystems [1] [2] [3].

In agriculture, *P. tomentosa* (Thunb.) Steud., 1841 is considered to protect soils from erosion, restore forests in a short time, and resist adverse climatic conditions in urban areas with developed transport and industrial sectors; it is also an ideal plant for landscaping parks and around roads [2] [4].

The leaves of the plant *P. tomentosa* (Thunb.) Steud., 1841, with a length of approximately ø = ~70 cm, absorb an average of ~4 - 22 kg of CO_2 per year (first-year forests absorb 9.04 ± 1.06 t of CO_2 per year) and release ~6 - 54 kg O_2 due to their surface area [5]. This phoenix tree is also valuable as a natural adsorbent as it purifies ~1000 m^3 of atmospheric air per year (one plant absorbs ~82 kg of dust) [4] [5] [6].

Thus, the rapid formation of *P. tomentosa* (Thunb.) Steud., 1841 biomass and its accumulation of larger amounts of heavy metals from the soil have been noted by many researchers [7] [8] [9] [10]. Therefore, the purpose of this research was to analyse the accumulation of certain heavy metals (As, Cd, Pb, and Zn) in the vegetative and generative organs of the plant *P. tomentosa*, which grows in Samarkand, Samarkand region of the Republic of Uzbekistan.

2. Materials and Methods

This research was carried out in Samarkand, Samarkand region of the Republic of Uzbekistan.

Significant pollution in the environment and atmospheric air has been noted around the industrial zones, and highways of Samarkand city [11] [12]. In the study areas, for several years, the bioecological features of a number of useful plants have been studied under extreme conditions. During the research and preparation of the current article, we used their results and conclusions [13] [14] [15].

Therefore, this research, the Botanical Garden of Samarkand State University (Samarkand city, Oliygoh St.15) (I) was chosen as a territory that is not contaminated with heavy metals (control group). The territory of JSC "Samarkandkimyo" (Samarkand city, Kimyogarlar village) (II) and the area around Rudakiy Avenue (III) in Samarkand were chosen as the experimental groups due to their varying degrees of heavy metals contamination (**Figure 1**).

The city of Samarkand is located in the central part of the Samarkand region. Various industries are well developed in the cities, including the chemical industry. Therefore, heavy metals such as As, Pb, Cd, and Zn accumulate in the soils of the study area. Therefore, the whole plant absorbs these elements, including introducers too.

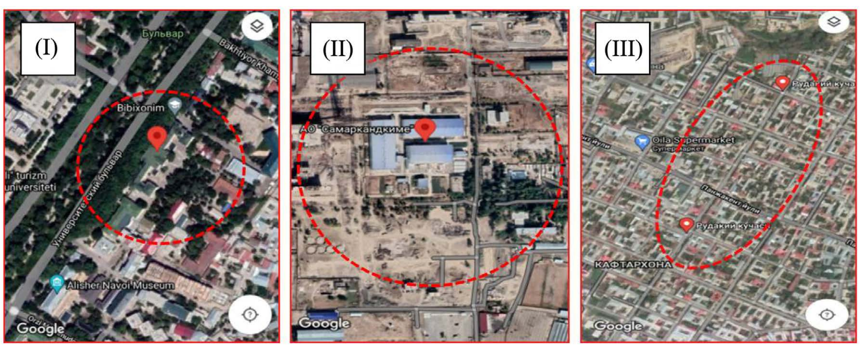

Figure 1. Satellite map images of the research areas. (I) Botanical Garden of Samarkand State University (territory of Samarkand city, Oliygoh Street, 15), (II) JSC "Samarkandkimyo" (Samarkand, Kimyogarlar village). JSC Samarkandkimyo was established in 1949 and specializes in the production of mineral fertilizers (superphosphate, amorphous, phosphorus extraction, calcium sulfophosphate, superphosphate, nitrogen/phosphorus, etc.), and sulfuric acid for agriculture, (III) Rudakiy Avenue, Samarkand city.

Heavy metals such as As, Pb, Cd, and Zn were found in the composition of the soil of the city of Samarkand. These metals are more common in the study area. Therefore, in our study, the development of this element was studied.

2.1. Collection of Biomaterial Test Samples

In these studies, the vegetative and generative organs of *P. tomentosa* (Thunb.) Steud., 1841 were collected from the control and experimental group areas during the growing season, between 8 and 9 o'clock in the morning [16] [17].

2.2. Analysis of Heavy Metals in the Plant Biomaterials

Analysis of heavy metals (As, Cd, Pb, Zn) in the plant biomaterials was carried out by standard methods [4] [9] [18]. The studied biomaterial test samples were dried in a VWR oven (DRY-line, Germany) for 60 minutes at a temperature of +150˚C ± 0.5˚C and weighed according to "FA220 4N" (accuracy level ~0.2 mg; "XY Scale", Germany) using laboratory scales (200 mg). A"MILESTONE" semiautomatic device ("Ethos Easy", Italy) were used for mineralization. Each test sample (200 mg) was added to a test-tube for device, distilled HNO_3 (6 ml) using Distillacid BSB-939-IR (Berghof, Germany) and H_2O_2 (2 ml) as an oxidizer we added, and the mineralization process was carried out at a temperature of +180˚C ± 0.5˚C for 20 minutes. The mineral mixture solution was then transferred a conical volumetric ask, and distilled water (25 ml) was added in a distiller (BIOSAN, Latvia).

In the next stage, each liquid test sample under study was analysed in special test tubes using an Avio200 (Perkin Elmer, USA) inductively coupled plasma optical emission spectrometer (accuracy ~10^{-9} g). Standard heavy metals (As, Cd, Pb, Zn) calibration solutions were also analysed in the experiments for comparison.

2.3. Statistical Analysis

Mathematical and statistical analyses of the experimental results were carried out using standard methods [19] [20] and the software package Origin 7.5 software package (OriginLab Corporation, USA).

3. Results and Discussion

This research analysed the concentration of heavy metals in the biomasses of the vegetative and generative organs of *P. tomentosa* (Thunb.) Steud., 1841 (**Table 1**).

During the studies, the amounts of Zn, Pb and Cd in the leaves of *P. tomentosa* (Thunb.) Steud., 1841 increased in the control group, giving values of 5.8 - 9.23 mg/kg, 23.22 - 35.22 mg/kg and 0.07 mg/kg respectively. In the contaminated soils, these values were 205.33 mg/kg, 50.13 mg/kg, and 3.88 mg/kg, respectively [10].

The potentialto use *P. tomentosa* for bioremediation in soils contaminated with heavy metals (Cd, Pb, Zn, etc.) is great [9] [21].

Table 1. Concentration (mg/kg) (M ± m) of heavy metals in vegetative and generative organs of the plant species *Paulownia tomentosa* (Thunb.) Steud., 1841.

N˚	Paulownia (*Paulownia tomentosa* (Thunb.) Steud., 1841	Concentration (mg/kg) of heavy metals			
		As	Cd	Pb	Zn
		I (Control)			
1.	Root	0.72 ± 0.006	2.65 ± 0.04	1.17 ± 0.08	23.52 ± 2.87
2.	Seedling	0.27 ± 0.004	0.82 ± 0.07	2.46 ± 0.07	47.73 ± 3.18
3.	Leaf	0.54 ± 0.007	1.84 ± 0.05	3.24 ± 0.19	52.65 ± 3.38
4.	Flower/Fruit	0.42 ± 0.005	0.47 ± 0.06	1.78 ± 0.18	14.25 ± 1.47
		II (Control)			
1.	Root	3.10 ± 0.08**	4.34 ± 0.05**	2.45 ± 0.08*	42.04 ± 2.65**
2.	Seedling	3.04 ± 0.05**	1.28 ± 0.08*	3.76 ± 0.03*	54.45 ± 2.34*
3.	Leaf	3.12 ± 0.06**	3.63 ± 0.06**	6.85 ± 0.54**	86.64 ± 2.05*
4.	Flower/Fruit	2.09 ± 0.04**	1.18 ± 0.04*	2.47 ± 0.05**	44.38 ± 3.16**
		III (Control)			
1.	Root	3.24 ± 0.06**	4.73 ± 0.04**	2.76 ± 0.06*	38.18 ± 1.63**
2.	Seedling	3.65 ± 0.04**	1.33 ± 0.06*	3.34 ± 0.17**	51.25 ± 2.35*
3.	Leaf	4.07 ± 0.03**	3.78 ± 0.05**	6.73 ± 0.15**	78.66 ± 3.44**
4.	Flower/Fruit	2.36 ± 0.05**	1.57 ± 0.03**	2.68 ± 0.03**	45.27 ± 2.25**
5.	Average value from certain plants [3] [18] [21] [22]	2.7 - 3.2	0.5 - 4.8	0.1 - 5	15 - 150
6.	Allowed concentration (mg/kg) [22] [23] [24] [25]	0.1 - 1	0.03 - 3	0.4 - 6	10

Note: I. Botanical Garden of Samarkand State University (Samarkand, Oliygoh Street, 15), II. JSC "Samarkandkimyo" (Samarkand, Kimyogarlar village), III. Samarkand city, Rudakiy Avenue (weather temperature t = +38˚C; relative humidity 45.6%). *relative to the control $p < 0.05$, **$p < 0.01$ ($n = 3 - 4$). The obtained results are consistent with the available literature data [21].

The concentrations of heavy metals (maximum allowable concentration/MAC) in the vegetative/generative organs of plant species growing in different soil/climatic conditions differ from each other.

In particular, in this research, the concentration of Cd, Pb, Zn in the soil were 0.2 - 0.66, 7.7 - 10.3; 35.1 - 41 mg/kg (MAC Cd = 0.2 - 0.66 mg/kg under the conditions of 35.1 - 41 mg/kg; MAC Pb = 130 mg/kg (in some studies, MAC Pb

= ~20 - 25 mg/kg (Evtukhova, 2016); and MAC Zn = 220 mg/kg). In the plant leavesthese values were equal to 0.023 - 0.052, 0.28 - 0.31 and 17.7 - 35.1, respectively [26].

It has also been established at Pb and Zn concentrations in the soil of −34.2, and 82.4 mg/kg, respectively. Additionally, in the leaves of *P. tomentosa* (Thunb.) Steud., 1841 that had grown in the same soil conditions, the concentrations of these heavy metals were determined to be 1.07 - 3.16 and 23.4 - 44.5 mg/kg, respectively [21].

In certain plants, the amounts of Pb and Zn were equal to 115.5 and 199.5 mg/kg, respectively (MAC_{Pb} < 120 mg/kg; MAC_{Zn} < 400 mg/kg) [18].

According to some researchers, it has been noted that the concentration of the elements Cd, Pb and Zn in the soil are 0.00001%, 0.000016% and 0.000000083% (REK Sd = 0.03 mg/kg; REC Pb = 0.5 mg/kg (in some studies REC Pb = ~10 mg/kg)). In terms of concentration, amounts of these elements in the plant are 0.06, 0.27 and 10 mg/kg (hyper accumulation is defined as >0.1, >1, and >10 mg/kg, respectively) [27].

In this research, the amount of Asfound in the roots of *P. tomentosa* (Thunb.) Steud., 1841 was 0.72 ± 0.006 mg/kg in the control group (I. Samarkand State University Botanical Garden (Samarkand, Oliygoh Street, 15)). In the experimental groups (II. JSC "Samarkandkimyo" (Samarkand, Kimyogarlar village); and III. Samarkand, Rudakiy avenue.), the concentrations of As were revealed to be ~3.3 fold (330.55%) and ~3.5-fold (350%) greater than the control group, respectively. In the seedlingsthe amount of As was 0.27 ± 0.004 mg/kg ~10.2 fold (1025.93%), and ~13.5-fold (1351.85%) higher, respectively. The leaves showed a concentration of 0.54 ± 0.007 mg/kg for ~4.7 fold (477.78%), and ~6.5-fold (653.71%) increases, respectively. Finally, generative organs (flower/fruit), there was 0.42 ± 0.005 mg/kg), As, increases of ~3.9 fold (397.62%), and ~4.6 fold (461.91%) compared to the control group, respectively.

In addition, a high concentration of As (3.12 ± 0.06 to 0.07 ± 0.03 mg/kg) was found in the leaves of *P. tomentosa* (Thunb.) Steud., 1841 relative to the dry weight. The maximum increase in seedling Ascomposition (~10.2 - 13.5 times) was also found in the control group.

Next, 2.65 ± 0.04 Cd was discovered in the roots of the control group of *P. tomentosa* (Thunb.) Steud., 1841. The experimental groups provides results that increased by ~0.63-fold (63.77%), and ~0.78-fold (78.49%). In the seedlings, the increases were ~0.5 fold (56.09%), and ~0.62-fold (62.19%) compared to the control (0.82 ± 0.07 mg/kg). In the leaves, ~9.7 times (97.28%) and ~1.05-times (105.43%) more Cd was found than that in the control (1.84 ± 0.05 mg/kg). Last, in the generative organs (flowers/fruits) compared with the control Cd level (0.47 ± 0.06 mg/kg), the experimental groups saw increases of ~1.51 fold (151.06%), and ~2.34 fold (234.04%).

A high accumulation of Cd in the range of 4.34 ± 0.05 to 4.73 ± 0.04 mg/kg) in the roots of *P. tomentosa* (Thunb.) Steud., 1841 was noted relative to dry weight. It was also found that the maximum increase in the content of this element occurred in the generative organs (flowers/fruits) (~1.51 - 2.34 fold increase) compared with the control group.

Pb was present at a concentration of 1.17 ± 0.08 mg/kg in the roots of control *P. tomentosa* (Thunb.) Steud., 1841 plants. The experimental groups provided results ~1.09 fold (109.4%), and ~1.35 fold (135.89%) high. The seedling in the experimental groups contained ~5.28 times (52.85%), and ~3.57 times (35.77%) more Pb than the control group (2.46 ± 0.07 mg/kg) whereas the leaves held ~1.11 times (111.42%), and ~1.07 times (107.71%)more than the control (3.24 ± 0.19 mg/kg) of the levels of Pb in the generative organs (flowers/fruits) compared with the control (1.78 ± 0.18 mg/kg), ~0.38 fold (38.76%), and ~0.51 fold (50.56%).

The high accumulation of Pbin the range of 6.85 ± 0.54 to 6.73 ± 0.15 mg/kg) was noted in the roots of *P. tomentosa* (Thunb.) Steud., 1841 relative to dry weight. Additionally, the greatest increase in the Pbcontent was found in the generative organs (flowers/fruits) compared with the control group (~5.28 - 3.57 fold).

Finally, 23.52 ± 2.87 mg/kg Zn was found in the roots of *P. tomentosa* (Thunb.) Steud., 1841 in the control group, and the experimental groups contained 0.78-fold (78.74%), and ~0.62 fold 62.33%) more. In the seedlings, ~0.14 times (14.08%), and ~0.73 times (7.37%) more Zn was found in the experimental groups than that in the control plants (47.73 ± 3.18 mg/kg). The leaves showed increases of ~0.64 fold (64.56%), and ~0.49 fold compared with the control group (52.65 ± 3.38 mg/kg), while these values in the generative organs (flowers/fruits) were ~2.11 times (211.44%) and ~2.17 times (217.54%) greater than that of the control (14.25 ± 1.47 mg/kg). The accumulation of high concentration of Zn in the range of 78.66 ± 3.44 - 86.64 ± 2.05 mg/kg) in the roots of *P. tomentosa* (Thunb.) Steud., 1841 was noted in relative to dry weight. In addition, the greatest increase in the Zn content was found in the generative organs (flowers/fruits) compared with the control group (~2.11 - 2.17 times).

Overall, the obtained results are consistent with the available literature data, including studies that have shown relatively high concentrations of heavy metals (Cd, Zn, Pb, etc.) in the leaves of ornamental trees and shrubs growing near industrial enterprises, highways in urban environments [16].

Due to the differences in accumulation levels of these heavy metals in the vegetative and generative organs of this plant, the concentrations of heavy metals in woody/shrubby plant species in urban environments could be a convenient indicator to assess the level of pollution influenced by the industrial-scale production [16] [28] [29].

P. tomentosa (Thunb.) Steud., 1841 has been noted as a prospective species for phytoremediation in contaminated with heavy metals in industrially developed zones. In particular, the accumulation of Cd in the roots of this plant, and relatively high concentrations of Pb and Zn in the leaves have been revealed [18] [21].

Theaccumulation of high concentrations (flower composition 3 - 3.2, 0.1 - 6.3, 1.17 and 2.3 - 50.5 mg/kg; seedling composition 2.7 - 2.75, 0.1 - 1.75, between 1.1 - 1.17 and 0.15) of heavy metals (As, Pb, Cd, Zn) in the vegetative and generative organs of the plant *Paulownia tomentosa* (Thunb.) Steud., 1841 (the accumulation of Cd, Pb, Zn in the roots is relatively high and follows the order of Pb < Zn < Cd in the vegetative organs) indicates the great potential for the use of plant for phytoremediation purposes [3] [4].

In addition, it has been noted that the concentration of heavy metals in plants depends elements type, their concentration in the environment, the specific bioaccumulation properties of the plant organs, and the distance of the plant from the pollution source [18] [30] [31] [32].

The next study is the influence on the morphological and anatomical structure of the vegetative and generative organs of *Paulownia tomentosa* (Thunb.) Steud., 1841 in the conditions of the city of Samarkand.

4. Conclusion

High concentrations of heavy metals (Pb, Zn, As, Sd) in the vegetative and generative organs of the plant *P. tomentosa* (Thunb.) Steud., 1841 were found in areas of Samarkand with industrial production and along transport routes. Based on the analysis of the obtained results, *P. tomentosa* (Thunb.) Steud., 1841 was denoted a "hyper accumulative" plant species with high potential for use for phytoremediation purposes.

Acknowledgements

The authors are grateful to the Institute of the Laboratory of Experimental of Gulistan State University for providing the space and resources necessary to carry out this work.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Ayan, S., Sivacioglu, A. and Bilir, N. (2006) Growth Variation of *Paulownia* Sieb. and Zucc. Species and Origins at the Nursery Stage in Kastamonu-Turkey. *Journal of Environmental Biology*, **27**, 499-504.

[2] Rahman, A., Rahman, F. and Rahmatullah, M. (2013) *In Vitro* Regeneration of *Paulownia tomentosa* Steud. Plants through the Induction of Adventitious Shoots in Explants Derived from Selected Mature Trees, by Studying the Effect of Different Plant Growth Regulators. *American-Eurasian Journal of Sustainable Agriculture*, **7**, 259-268.

[3] Tyshchenko, E.L. and Yakuba, Yu.F. (2014) *Paulownia* Felt as a Bioindicator of the Degree of Soil Pollution. *Fruit Growing and Viticulture of the South of Russia*, **29**, 2-10.

[4] Miladinova, K., Markovska, Y., Tzvetkova, N., Geneva, M. and Georgieva, T. (2014) Photosynthesis and Growth Response of *Paulownia tomentosa* × *fortunei* Hybrid Plants to Different Levels of Heavy Metals Cd, Pb and Zn. *Silva Balcanica*, **15**, 83-99.

[5] Magar, L.B., Khadka, S., Pokharel, U., *et al.* (2008) Total Biomass Carbon Sequestration Ability under the Changing Climatic Condition by *Paulownia tomentosa* Steud. *International Journal of Applied Sciences and Biotechnology*, **6**, 220-226. https://doi.org/10.3126/ijasbt.v6i3.20772

[6] Uskov, M.K. and Toropov, D.V. (2018) Prospects for Growing *Paulownia* Felt in the Crimea. Experimental and Theoretical Studies in Modern Science: Collection of Scientific Articles. Art. by Mother. *XXIX International Scientific Practical Conference*, No. 20 (28), SibAK, Novosibirsk, 33-36.

[7] Tkachenko, K. (2013) Adam's Tree, or Royal *Paulownia*. *The World of Plants*, No. 12, 26-29.

[8] Wang, J., Li, W., Zhang, C. and Ke, S. (2010) Physiological Responses and Detoxific Mechanisms to Pb, Zn, Cu and Cd in Young Seedlings of *Paulownia fortune*. *Journal of Environmental Sciences* (*China*), **22**, 1916-1922. https://doi.org/10.1016/S1001-0742(09)60339-9

[9] Doumett, S., Azzarello, D.E., Mancuso, S., Mugnai, S., Petruzzelli, G. and Del, M. (2010) Influence of the Application Renewal of Glutamate and Tartrate on Cd, Cu, Pb and Zn Distribution between Contaminated Soil and *Paulownia tomentosa* in a Pilot-Scale Assisted Phytoremediation Study. *International Journal of Phytoremediation*, **13**, 1-17. https://doi.org/10.1080/15226510903567455

[10] Bahri, N.B., Laribi, B., Soufi, S., Rezgui, S. and Bettaieb, T. (2015) Growth Performance, Photosynthetic Status and Bioaccumulation of Heavy Metals by *Paulownia tomentosa* (Thunb.) Steud Growing on Contaminated Soils. *International Journal of Agronomy and Agricultural Research*, **6**, 32-43.

[11] Moschennikova, N.B. (2011) Assessment of the Ecological State of Green Spaces in St. Petersburg. Ph.D. Thesis, Moscow State University, Moscow, 3-14.

[12] Bessmolnaya, M.Ya., Imeskenova, E.G., Tatarnikova, V.Yu., Kisova, S.V., Polomoshnova, N.Yu. and Angapova, N.V. (2018) Assessment of the State of Green Spaces in the Public Gardens of Ulan-Ude. *Vestnik NSAU*, **4**, 7-17. https://doi.org/10.31677/2072-6724-2018-49-4-7-17

[13] Tashpulatov, Y.Sh., Khamdamov, I.Kh. and Nurniyozov, A.A. (2019) Water and Coastal Water Vegetation of Various Types of Waters in the Samarkand Region. *Eurasian Journal of Biosciences*, **13**, 1413-1417. https://doi.org/10.5958/2320-3188.2019.00007.X

[14] Tashpulatov, Y.Sh. (2020) The Anatomical Structure of the Medicinal Raw Material *Acorus calamus* L. in the Conditions of Culture of the Samarkand Region (Uzbekistan). *Bulletin of Pure and Applied Sciences*, **39**, 107-115. https://doi.org/10.5958/2320-3188.2020.00013.3

[15] Isomov, E.E. and Tashpulatov, Y.Sh. (2022) Influence of Soil Salt on Growth, Development and Seed Productivity of Artichoke Varieties. *American Journal of Plant Sciences*, **13**, 557-563. https://doi.org/10.4236/ajps.2022.135036

[16] Tashekova, A.Zh. and Toropov, A.S. (2017) The Use of Plant Leaves as Biogeochemical Indicators of the State of the Urban Environment. *Bulletin of the Tomsk Polytechnic University. Engineering of Georesources*, **328**, 114-124.

[17] Legoshchina, O.M. (2018) Adaptive Reactions and Phytoindicative Ability of Woody Plants in Conditions of Technogenic Pollution. Dissertation for the Competition, Scientist Step, Ph.D. Thesis, Kemerovo State University, Kemerovo, 4-144.

[18] Tzvetkova, N., Miladinova, K., Ivanova, K., Georgieva, T., Geneva, M. and Markovska, Y. (2015) Possibility for Using of Two *Paulownia* Lines as a Tool for Remediation of Heavy Metal Contaminated Soil. *Journal of Environmental Biology*, **36**, 145-151.

[19] Lakin, G.F. (1990) Biometrics. Publishing House "Higher School", Moscow, 271-284.

[20] Zaitsev, G.N. (1990) Mathematics in Experimental Botany. Publishing House "Science", Moscow, 96-101.

[21] Knezevic, M., Stankovic, D., Krstic, B., Nikolic, M.S. and Vilotic, D. (2009) Concentrations of Heavy Metals in Soil and Leaves of Plant Species *Paulownia elongata* S.Y.Hu and *Paulownia fortunei* Hemsl. *African Journal of Biotechnology*, **8**, 5422-5429.

[22] Kamanina, I.Z., Kaplina, S.P. and Salikhova, F.S. (2019) The Content of Heavy Metals in Medicinal Plants. Scientific Review. *Biological Sciences*, **1**, 29-34.

[23] Boriskov, D.E. (2000) Causes and Patterns of Technogenic Pollution by Heavy Metals of the Soil-Plant System in the Conditions of the Forest-Steppe Zone of the Trans-Urals. Dissertation for the Competition, Scientist Step, Ph.D. Thesis, Kurgan State University, Kurgan, 10-168.

[24] Zangelidi, V.V. (2009) Influence of Technogenic Pollution on the State of Soils in the City of Vladikavkaz. Dissertation for the Competition, Scientist Step, Ph.D. Thesis, Vladikavkaz University State University, Vladikavkaz, 5-120.

[25] Evtukhova, M.V. (2016) The Study of Ecological and Biological Variability of Representatives of the Genus *Rosa* L. for Breeding in the Conditions of the South-West of the Central Chernobyl. Dissertation for the Competition, Scientist Step, Ph.D. Thesis, Belgorod State University, Belgorod, 5-54.

[26] Batmanov, A.V. (2017) Accumulation of Heavy Metals by Introduced Varieties of Garden Strawberries in the Steppe Zone of the Samara Trans-Volga Region. Dissertation for the Competition, Scientist Step, Ph.D. Thesis, Ufa State University, Ust-Kinelsky, 3-19.

[27] Titov, A.F., Kaznina, N.M. and Talanova, V.V. (2014) Heavy Metals and Plants. Karelian Scientific Center of the Russian Academy of Sciences, Petrozavodsk, 10-194.

[28] Kabata-Pendias, A. and Pendias, H. (2001) Trace Elements in Soils and Plants. 2nd Edition, CRC Press, Boca Raton, 365-372. https://doi.org/10.1201/9781420039900

[29] Korelskaya, T.A. and Popova, L.F. (2012) Heavy Metals in the Soil and Vegetation Cover of the Residential Landscape of the City of Arkhangelsk. *Arctic and North*, No. 7, 1-17.

[30] Xiong, Z.T. (1998) Lead Uptake and Effects on Seed Germination and Plant Growth in a Pb Hyperaccumulator *Brassica pekinensis* Rupr. *Environmental Contamination and Toxicology*, **60**, 285-291. https://doi.org/10.1007/s001289900623

[31] Markert, B. (1994) Plant as Biomonitors—Potential Advantages and Problems. In: Adriano, D.C., Chen, Z.S. and Yang, S.S., Eds., *Biogeochemistry of Trace Elements*, Nova Science Publishers, New York, 601-603.

[32] Laidinen, G.F., Titov, A.F., Batova, Yu.V., Kaznina, N.M. and Kulakovskaya, T.V. (2011) Accumulation and Distribution of Heavy Metals in *Phleum pratense* (L.) Plants Growing under Conditions of Industrial Pollution. VII Congress of the Society of Plant Physiologists of Russia "Plant Physiology—The Fundamental Basis of Ecology and Innovative Biotechnologies" and the International Scientific School "Innovations in Biology for the Development of the Agricultural Bioindustry Products". Materials of Reports (in Two Parts). Part II. (Nizhny Novgorod). Mir Nauki, Nizhny Novgorod, 407-408.