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PROSPECTS FOR THE USE OF TREE CROPS IN THE PHYTOREMEDIATION OF SOILS CONTAMINATED WITH HEAVY METALS AND PESTICIDES (review)

Abstract. The article presents a review of the literature on the problem of soil contamination with heavy metals and pesticides, natural and anthropogenic factors affecting their bioavailability, plant resistance mechanisms to these pollutants, and prospects for using tree crops in soil phytoremediation technology.

Heavy metals (HM) and pesticides are the most highly toxic environmental pollutants. Currently, the volumes of pollutants containing HM and pesticides are increasing annually. This situation undermines the existing ecological balance and adversely affects people's health. However, some plant species have developed tolerance or resistance to these metals naturally. Some species are able to accumulate high concentrations of HM, but tolerate them; others - reduce their flow due to their barrier functions. The most effective and cost-effective technologies for disinfecting soil and water resources are biological methods, in particular, phytoremediation. Phytoremediation is based on using the ability of plants to accumulate pollutants in aboveground and underground organs and to cause the degradation of xenobiotics in the rhizosphere zone. The primary task in the development of phytoremediation technology is to search for plants capable of accumulating environmental pollutants in the root system, and then translocate them into the aerial part. For this process, fast growing plants are ideal, creating a large biomass in a short period. The most promising species for these studies are tree cultures of the genus *Polus, Salix* and *Paulownia*. The use of these plant species in the technology of phytoremediation of HM and pesticides will reduce the level of pollution and increase the productive value of contaminated soils. Phytoremediation with the use of tree species is a modern, promising environmentally safe and cost-effective technology that can be implemented in large areas.

Key words: heavy metals, pesticides, phytoremediation, tree crops.

Introduction. Nowadays, the problem of contamination with heavy metals and pesticides has a global importance, and recently has acquired particular relevance for Kazakhstan. A preliminary study of the ecological status and rational use of the land funds of the republic showed that there is a strong pollution of the soil with various pesticides, heavy metals and an intensive decrease in its fertility. According to the land balance data, as of November 1, 2017, there are 245.4 thousand hectares of disturbed land in the republic, about 100 thousand hectares of which are subject to radical revegetation. The largest number of disturbed land is located in Karaganda, Kostanay, Mangystau, Akmola, East Kazakhstan, Aktobe, Pavlodar regions.

In all industrial regions, there are environmentally hazardous exposure zones, the total area of which is more than 60 thousand hectares [1]. In addition, in almost every region of our republic there are numerous foci of pollution with obsolete unsuitable for use pesticides - the territory of the former repositories of plant protection products and the surrounding land. More than 1.500 tons of such pesticides and their mixtures are located in warehouses and repositories of the republic, some of which are stored in unsuitable, dilapidated premises. About 10% of them belong to pesticides with POPs properties. Inventory of pesticides with POPs properties covers only 20% of the country [2].

One of the most serious aspects is that the HM, pesticides and their transformation products that have entered into the soil, are absorbed by plants and accumulate in them in concentrations that are dangerous to human and animal health. Discharges of industrial wastes that contain cadmium, lead, copper and chromium pose a potential risk to the aquatic environment, animals and people due to pollution of air, soil deposits, vegetation and water. Contamination with heavy metals causes a number of environmental problems, including a reduction in microbial activity, soil fertility and crop yields. The pollution with heavy metals usually coincides with the growth of industrialization of a given region and becomes more serious when there is neither control nor adequate environmental standards [3]. More than 55.000 different chemical compounds have been found in the environment, many of which can pose a certain hazard to various types of living organisms. Pesticides account for about 3% of this number, but they occupy one of the first places due to their harmful effects on the environment. Excessive use of these agrochemicals, as well as violation of sanitary and environmental requirements of their use, transportation and storage, leads to their sustainable accumulation in environmental objects and creates serious environmental problems [4].

Regarding to this, in order to reduce the environmental risk associated with the accumulation of polluting substances resistant to degradation in the environment, it is necessary to search for new, safe and often unconventional methods to control pollution and to develop a technology for the restoration of polluted soils. For example, phytoremediation using tree species, which is the most economically and environmentally promising, practical and successful technology. Woody species of phytoremediators with high biomass production, deep root system, high growth rate, high ability to grow in poor soils and high ability to accumulate pollutants in aboveground organs, can be an alternative for restoring soil contaminated with HM and pesticides.

The main objectives of this review are to describe the resistance of plants to HM and pesticides, the main methods of bioremediation, to demonstrate the importance of searching tree species as hyperaccumulators of these pollutants and the possibility of their potential use in the process of phytoremediation of soils with high levels of pollution.

The natural and anthropogenic factors affecting bioavailability of heavy metals and pesticides. In the structure of the chemical pollutants of the environment that able to render a significant impact on the health of the population, heavy metals and pesticides occupy a special place. This is due to their persistence in the environmental objects (soil, water, plants), pronounced by biological activity and the ability to migrate and in some cases circulate in natural biocenoses. Heavy metals are a natural component of the lithosphere whose geochemical cycles and biochemical processes have been radically altered by anthropological activity [5].

More than 40 chemical elements of the Periodic system of Mendeleev D.I., whose mass of atoms is higher than 50 atomic units, are heavy metals. The migration of the heavy metals in the agroecosystems is determined by their chemical properties, soil conditions and the biological characteristics of plants. In recent decades, the anthropogenic activity has been intensively involved in the processes of HM migration in the environment. The number of the chemical elements entering the environment as result of technogenesis, in some cases, significantly exceeds the level of their natural intake. For instant, global release of lead from the natural sources is 12 thousand tons per year, and anthropogenic emissions is 332 thousand tons [6]. By engaging in natural migration cycles, anthropogenic flows lead to the rapid spread of pollutants in the natural components of the urban landscape, where their interaction with humans is unavoidable. Volumes of pollutants containing HM annually increase and damage the natural environment, undermine the existing ecological balance and adversely reflects on the human health.

The size of the anthropogenic activity can be judged according to the data below: the contribution of the technogenic lead is 94-97% (the rest is from natural sources), cadmium – 84-89%, copper - 56-87%, nickel - 66-75 %, mercury - 58%, etc. At the same time, 26-44% of the global anthropogenic flow of these elements falls on Europe, and the share of the European territory of the former USSR is 28-42% of all emissions in Europe [7]. The level of technogenic fallout of HM from the atmosphere in different regions of the world is not the same and depends on the availability of production fields, the degree of the mining and concentrating and industrial fields, transport, urbanization of territories, etc.

The application of huge amounts of chemical fertilizers, pesticides, industrial wastes into the soil contributes to the formation of territories with altered soil composition and properties. Micronutrient pollution of the environment poses the greatest danger to industrialized countries. About industrial enterprises form technogenic regions with a high content of lead, arsenic, fluorine, mercury, cadmium, manganese, nickel and other elements in the biosphere, which represent a real danger of direct and indirect effects on the human body.

The processes and phenomena that reduce soil fertility, destroying the land resources of a country, can be divided into 4 groups: natural processes whose adverse effects on the soil surface cannot be prevented; natural processes that a person can to a certain extent prevent or reduce the negative impact on the soil, the treatment of the fields of crop rotation; natural processes, the intensive manifestation of which is due to unreasonable economic activities, such as desertification of territories, and deforestation; phenomena fully associated with human economic activity [8].

Release of heavy metals into the environment has reached a large size. This problem is particularly relevant for Kazakhstan. Metal-mining industrial complexes were built in regions with fertile soils and open water sources for irrigation. As a result, high concentrations of solid metals are found in wastewater, soil, abandoned mines, city dumps and septic tanks. A significant area of land suitable for use in agriculture is also contaminated with metals to an extreme degree and their exploitation is unsafe.

The general source of the pesticide distribution is the processed agricultural lands. In the process of pesticide application, their significant part (until 70%) gets into the soil surface that creates the prerequisites for their migration on soil-water-air and food chains, since soil is the surrounding of the basic accumulation and initial step of the movement of pesticides [9].

Mechanisms of plant resistance to HMs and pesticides. Mechanisms of plant resistance to an abundance of HM can manifest in different directions: some species able to accumulate high concentrations of HMs, but be tolerant to them; others seeks to reduce intake by maximizing their barrier functions.

For most plants, the first barrier level is the roots, where the greatest amount of HMs is retained, the next is the stems and leaves, and finally, the last is the organs and parts of plants responsible for reproductive functions.

One of the reasons for plant resistance to technogenic factors is the transport of HMs and pesticides from the root system to the aboveground part through the xylem [10]. Therefore, when developing the technology of soil phytoremediation, the paramount task is to search for plants capable of accumulating environmental pollutants in the root system, and then translocate them into the aboveground part, i.e. plants with a high coefficient of translocation. Nurzhanova A.A. and co-authors showed in their researches that in species *Artemisia annua* and *Xanthium strumarium* the coefficient of biological absorption of the underground part of plants is an order of magnitude higher than aboveground, and concluded that the root system is an active accumulator of various kind of harmful substances. Reducing the amount of pesticides in the soil also depends on the plant species. For example, some high-accumulating species (*Artemisia annua*, *Kochia scoparia* и *K. sieversiana, Rumex confertus, Erigeron canadensis*) ability to accumulate of pesticides in the rhizosphere zone after the experiment was higher than in the experiment without plants, the species *Xanthium strumarium, Solanum dulcamara* and *Aegilops cylindrical,* on the contrary, was much lower [11].

Despite substantial variability of different plants to the accumulation HMs, bioaccumulation of elements has a definite tendency, allowing them to be ordered in several groups: 1) Cd, Cs, Rb – intensive absorption elements; 2) Zn, Mo, Cu, Pb, As, Co – elements of moderate absorption; 3) Mn, Ni, Cr – weak absorption elements and 4) Se, Fe, Ba, Te – elements hard-to-reach for plants.

Another way for HMs to enter plants is non-root (foliar) absorption from airflows. It occurs when significant precipitation of metals from the atmosphere on the foliar apparatus, most often near the large industrial enterprises. The entry of elements into plants through leaves (or foliar absorption) occurs mainly by non-metabolic penetration through the cuticle. HMs absorbed by the leaves can be transferred to other organs and tissues and be included in the metabolism. Metals that are deposited with dust emissions on the leaves and stems do not pose a danger for human if the plants are thoroughly washed before eating. However, animals eating such vegetation may receive a large amount of HMs.

Heavy metals entering the soil undergo various types of transformation depending on the soil properties and the biological characteristics of the plants. The main factors affecting on the mobility of HMs in the soil, their transformation and availability for plants are the solubility of heavy metal salts, the pH of the soil environment, the content of organic matter in the soil, the particle size distribution and cation exchange capacity, the type of HMs and level of soil pollution by them, species and biological features of cultivated crops. For soils contaminated by HMs, methods that reduce their translocation into plants are based on the translation of heavy metal cations into forms that are not easily available to plants or to mobile compounds, followed by leaching. The most common methods are based on the conversion of metal cations into sedentary forms using high doses of organic fertilizers, liming, phosphate rocking and claying, as well as the use of zeolites [12, 13].

One of the most effective diagnostic indicators of soil pollution is its biological state, which can be assessed by the viability of soil microorganisms inhabiting it. It should also be borne in mind that microorganisms play a large role in the migration of HMs in the soil. In the process of life, they act as producers, consumers and transporting agents in the soil ecosystem. Many soil fungi exhibit the ability to immobilize HMs, fixing them in the mycelium and temporarily excluding from circulation. Studying the peculiarities of Pb, Cd, As and P migration in the soil-plant system under the influence of biological preparations of azotobacterin, phosphobacterin and silicon bacterin allowed to establish patterns of the influence of rhizosphere bacteria on the mobilization and immobilization of HMs and arsenic in the soil-plant system under technogenic conditions, and to identify the main factors affecting their migration, determine their ability to biosorbtion of HMs and arsenic from polluted soils [14].

This has a great practical importance for new biotechnologies in crop production and for phytoremediation of soils.

The interactions that occur in the soil-plant system are complex. The uptake of trace elements by plants varies greatly depending on the condition of the soil. At the same time, high concentrations of metals in the soil do not always indicate a correspondingly high level of these metals in plants. Toxic metal ions penetrate cells using the same processes of absorption of essential trace elements. The amount absorbed by the plant depends on the concentration and speciation of the metal in the soil solution, as well as on its successive movement from the soil to the root surface and from the root to the aboveground part [15]. The movement of metal ions to the aerial part depends on the plant species, metal, and environmental conditions [16]. Their genotoxic effects depend on the oxidation state of the metal, their concentration and the duration of exposure, and they are more pronounced at high concentrations and after a long exposure time [17].

The problem of soil pollution by pesticides is also very relevant for our republic, since in Kazakhstan almost every district has old storage facilities for chemical plant protection products. Tolerant plant species have been identified that are capable to accumulate and degrade the pesticides in the territories of former pesticide storage facilities located in the Talgar district of the Almaty region [18]. The degree of pesticide accumulation by the studied species of annual and perennial plants was different and was their specific feature. It was established that due to phytostabilization and phytoaccumulation, wild-growing species reduced the content of chlorine-containing pesticides to 28%. According to their ability to reduce or increase the concentration of pesticides in the pericheral zone, phytoaccumulators or herbal stabilizers were identified. Common phytoaccumulator plants were the common cocklebur *(Xanthium strumarium),* the sweet wormwood *(Artemisia annua)* and the common ragweed *(Ambrosia artemisifolia).* The root system of these species is able to extract pesticides from contaminated soils and accumulate them in aboveground organs. Such plants as the upland cress *(Barbarea vulgaris),* the ruderal hemp *(Cannabis ruderalis)* and amaranth *(Amaranthus retroflexus)* kept the content of pollutants in the soil at a low level and are phyto-stabilizers.

The main methods of bioremediation of pollutants. Physical, chemical and biological methods can be used for revegetation of contaminated regions. There are technologies that can eliminate and / or reduce the presence of HMs in industrial effluents, such as precipitation and coprecipitation, galvanization and electrocoagulation, membrane separation, solvent extraction, ion exchange, adsorption and biosorption [19].

However, these methods are expensive and have a large negative impact on the environment. The most effective and environmentally friendly are biological methods for cleaning contaminated areas, i.e. bioremediation, which is characterized by low cost, does not include soil removal, and also does not violate the biological and functional integrity of the soil [20].

. The advantages of bioremediation technologies are related to the capabilities of living systems, especially microorganisms, to metabolize a large number of various organic substances, to the softness of impact on the environment being cleaned, which does not lead to significant changes in the basic soil indicators. The disadvantages of soil bioremediation include the low rate of biodegradation of toxicants and the need for a thorough preliminary survey of the contaminated area to clarify the modes of biotechnological work. Bioremediation technologies are divided into different types depending on:

– whether they are carried out directly at the site of pollution or beyond;

– whether or not microorganisms are introduced into the polluted environment.

There are three main approach to bioremediation: biostimulation, bioaugmentation and phytoremediation.

Biostimulation allows the natural accumulation of microbial destructors in freshly polluted soil to be accelerated by the addition of microorganisms. Inserted cells are better adapted to the conditions of a particular habitat and the characteristics of a decomposable hydrocarbon substrate. In this case, samples of natural microbiota are extracted from the soil, which are then cultivated in fermenters to increase their remediation characteristics by adding the necessary growth factors and compounds that induce the biodegradation of the target pollutant. Then such microbiota is brought to the place of pollution.

Bioaugmentation (or bio-enhancement) is a process in which specialized microorganisms heterogenous to a given habitat that have been previously isolated from natural sources or specially genetically modified are introduced into contaminated soil. By such a method, biodegradation of hydrocarbons in the natural environment can be accomplished by stimulating the natural oil-oxidizing microflora by creating optimal conditions for its development (introduction of nitrogen-phosphorus fertilizers, aeration, etc.) or introduction of hydrocarbon-oxidizing microorganisms (introduction of active strains) along with additions of nitrogen, phosphorus, lime, etc.

Phytoremediation based on using the ability of plants to accumulate pollutants in aboveground and underground organs and cause degradation of xenobiotics in the rhizosphere zone is one of the widely used methods of bioremediation. Phytoremediation has long been recognized as a cost-effective method of disinfecting soil and water resources. From an economic point of view, phytoremediation has advantages over the "chemical" and "mechanical" methods of soil remediation, since its implementation does not involve large investments, and operating costs for the implementation of this technology are not large. Most importantly, after phytoremediation, the soil does not lose its fertility. Therefore, this technology is environmentally friendly and cost-effective. In the past few decades, studies of phytoremediation to remove various pollutants from the soil show promising prospects [21, 22].

Phytoremediation can occur by phytoextraction, phytostabilization, phyto-volatilization, phytodegradation, risodegradation, or phyto-degradation [23, 24]. This leads to the absorption of pollutants from the soil or water by the roots of plants, translocation and their accumulation in the aboveground organs. These methods are complementary. Plants can also directly degrade organic pollutants with their enzymes to inorganic compounds that accumulate in the plant. The technology of using plants for the degradation of pollutants is called phytodegradation. It is effective against organic pollutants with good mobility in the plant (herbicides, TNT, trichlorethylene).

Nowadays, about 400 plant species have been identified as accumulators of toxic metals. Some plant species have evolutionarily developed resistant forms that can survive on soils with a high concentration of HMs. Existing natural battery plants, which can accumulate large amounts of HMs, most often grow slowly and have little biomass. For the development and application of technology phytoremediation of great importance is the study of various plant species and the selection of the most promising to clean the soil from pollution.

Currently, studies in this direction have been conducted on fodder, vegetable, leguminous, herbaceous plants. For example, the cultivation of such vegetable crops as summer squash, pumpkin and spinach contributed to a decrease in the concentration of dichlorodiphenyltrichloethane (DDT) in the root zone and the rhizosphere is 10 times compared to the soil contaminated by it [25]. DDT can accumulate in large quantities in the leaves of plants and in small quantities in fruits, as well as in humus with pine needles, where it dissolves in the wax substance of pine needles [26]. The effect of the pH of the root medium on the absorption of the sulfanthrazone herbicide was studied on cotton plants. As a result of the experiments, it was found that neutral pH values contributed to an increase in the absorption of herbicide by plant roots [27]. A comparative analysis of the accumulating ability of various pesticides to cereal and herbaceous plants showed that sunflower and Indian mustard contributed to improving the degradation of pyrene and 2,4DDT in soil along with accumulation of metals. This demonstrates the potential of sunflower and Indian mustard for the simultaneous recultivation of metals, PAHs and organochlorine pesticides in mixed contaminated soils [28].

Chirakkara and Reddy [29] conducted a study on the choice of plants suitable for the simultaneous absorption of phenanthrene, lead, copper and chromium by studying the phytoremediation effectiveness of 9 species of plants. It was found that on soils where sunflower, oats, raigrass, fescue and mung were grown, a significant decrease in phenanthrene was observed, although the plants were distinguished by low survival and biomass. Huang et al. studied 23 *Ricinus communis* genotypes (palmchrist) to restore contaminated soil with cadmium and DDT and found simultaneous accumulation of metal and pesticides with some genotypes, even at higher concentrations than previously reported for other plants [30].

The use of tree crops in phytoremediation technology. The choice of plants for this technology is determined by their ability to transport the groundwater to the surface, to break down polluting compounds with the help of their enzymes and to accumulate these compounds in biomass. For plants that can be used for phytoremediation, it is required to rapidly increase their biomass with simultaneous absorption of large amounts of metals (at least 1-3% of their dry weight).

One of the main risks associated with phytoremediation is the ingress of recovered pollutants into the food chain due to the consumption of plants used for phytoremediation. Therefore, one of the promising areas in phytoremediation programs is the use of tree crops, which can be used in phytoremediation as a barrier to water, preventing leakage of contamination into the depths, and the horizontal distribution of polluted groundwater. As many researchers have noted, fast-growing plants are ideal for this process, creating a large biomass in a short period [31].

Studies to determine the mechanisms of translocation and detoxification mechanisms of herbicides in woody plants are insignificant, although many of them may be of great interest for phytoremediation. Matt A. Limmer [32], in studying the effect of perchlorate on willow *(Salix nigra Marsh),* found that perchlorate concentrations in tree sap were proportional to perchlorate concentrations in groundwater. This will allow further use of this plant species for screening of groundwater contaminated with perchlorate. Chard B.K., et al. [33] conducted a research on the accumulation of trichlorethylene and its transformation products in various organs of apple and peach trees. It was established that the greatest accumulation of these substances was observed in the leaves, then in the branches and fruits. At the end of the study, TCE was found only in the roots. Research has been conducted to better understand the potential transfer of organic compounds to edible fruits. Tyshchenko E.L. and Yakub Yu.F. [34] conducted a research of the royal paulownia as a bioindicator of the degree of soil contamination in the growing areas. It has been established that royal paulownia plants are capable to concentrate heavy and rare-earth metal ions in large quantities in wood. The accumulation of these elements in the plant depends on their content in the soil and the biological availability. The results of the research indicate that royal paulownia is a promising tree crop for inclusion in phytoremediation programs on soils containing both inorganic (HMs) and organic (for example, pesticides) pollutants.

Studies have been conducted on the use of eucalyptus trees for the accumulation of volatile organic compounds [35], studied the mechanisms of absorption and loss of trichlorethylene in growing cypress trees [36], investigated the toxicity of PAH on various types of willows [37].

It should be noted that most studies on the use of tree crops for phytoremediation are carried out on poplars. Apparently, this is due to the fact that they have an extensive dense root system, a high level of transpiration, and a high level of synthesis of degradation enzymes.

Extensive atrazine metabolism studies for phytoremediation, conducted by Burken J.G. and co-authors on hybrid poplars *(Populus deltoides x Populus nigra)*, showed that poplars are able to absorb, hydrolyze, and dealkylate atrazine to less toxic metabolites. These studies prove the possibility of vegetative detoxification of pollutants and suggests that hybrid poplars are a very promising type of plant for the phytoremediation of atrazine-contaminated soils [38]. Laboratory studies have shown that fast-growing and deep-rooted poplars also contribute to the successful restoration of groundwater [39]. Contaminated groundwater is absorbed by plants and the contaminants are then converted into organic molecules used for plant growth. This method has already successfully proven itself to restore soil contaminated with atrazine and groundwater. In a number of studies, the potential of phytoremediation using hybrid poplars of such pesticides as 1,4-dioxane, TCE, chloroacetanilide tetrachlorobiphenyl was studied [40-42].

Currently, a significant amount of research is being conducted on the interaction of microorganisms with plants in the rhizosphere and the possibility of using this to eliminate the environment polluted by pesticides. According to preliminary studies, increased degradation of atrazine, metolachlor and trifluralin was observed in polluted soils, where *Kochia sp.* species grew. Increased degradation occurred in the rhizosphere of this herbicide-resistant plant, which indicates the interaction between plants and microorganisms contribute to increased degradation in the presence of pesticides [43]. Jordahl J.L., et al. proved that poplar rhizosphere is capable of enhancing the growth of microbial populations that are involved in natural bioremediation [44]. In the root zone of *Pinus nigra* and *Salix caprea*, there were detected a polychlorinated biphenyl degrading bacteria which contribute to the decomposition of this organic pollutant [45]. All of these studies suggest that biostimulation through rizoremediation is a promising strategy to increase the degradation of various pollutants.

Plant species that are unintentionally exposed by pesticides are considered to be untargeted plants. The separation of plants into target and non-target is very important for the development of effective phytoremediation technologies, since the so-called “non-target” plants may not have a high pesticide storage capacity. At the same time, carrying out the phytoremediation technology on non-target plants will increase the efficiency of cleaning contaminated areas.

Non-target effects of plants are any direct or indirect effects that affect the survival, health or reproduction of non-target plant species. Non-targeted plants can have either one or a combination of reactions to the detoxification of a pesticide. The development of a detoxification mechanism depends on such factors as the concentration and type of pesticide present, environmental conditions and plant characteristics. Comparison of metabolic pathways, detoxification mechanisms and tolerance of various plants to pesticides will contribute to the development of a vegetative processing system for disinfecting soil and water contaminated with pesticides.

The successful application of phytoremediation technology is based on the use of various models to predict the absorption, translocation and elimination of organic contamination by plants [46]. Gopalakrishnan G. et al. [47] proposed a method for estimating the distribution of chlorinated solvents in soil and groundwater using willow and poplar tree branches. Twigs are potentially more economical and easier than mature trees. This approach is used as a quantitative means of monitoring soil and groundwater for the presence of tetrachlorethylene, trichlorethylene and carbon tetrachloride. A study of the accumulation of polychlorinated biphenyls by hybrid poplars under hydroponic conditions has shown that most PCBs are sorbed by the root system [48]. In the article of Ma X.M. and Burken J.G., the sorption and desorption separation of chlorinated solvents of trichlorethylene, 1,1,2,2-tetrachloroethane and carbon tetrachloride between the air and wood biomass of hybrid poplars was investigated. It has established that the distribution coefficients of compounds between air, water and biomass of wood cores and trunks were associated with the physico-chemical characteristics of pollutants. Tissue analysis and determination of separation factors can provide an effective way to assess the concentration of compounds in a transpiration flow in soil or groundwater in an extremely fast and cost-effective way [49].

Conclusion. Thus, the analysis of literature data showed that tree cultures are a very promising object for carrying out phytoremediation of areas contaminated with HMs and pesticides. Firstly, this is due to the fact that, unlike grass and vegetable crops, woody plants are less eaten by animals and thus reduce the risk of ingress of pesticides into animal products. Secondly, tree crops can be widely used for landscaping polluted areas. Thirdly, they are more useful in detoxifying the drains of various pesticides in order to prevent their penetration into reservoirs. In the fourth, trees prevent soil erosion, improve the appearance of contaminated sites, reduce noise and improve air quality. The most promising species for these studies are tree cultures of the genus Polus, Salix and Paulownia, which have a high phytoremediation potential of pesticides and HM. The use of these types of tree crops, on the one hand, will reduce pollution and, on the other, increase the productive value of polluted soils.

Currently, in the framework of the program-targeted financing of the Ministry of Education and Science of the Republic of Kazakhstan «Comprehensive assessment of unutilized and banned pesticides impact on genetics status and health of population of Almaty region» (BR05236379), we conduct research

on the microclonal reproduction of valuable genotypes of poplars and royal paulownia *in vitro* culture, the study of their phytoaccumulative capacity and the possibility of using for cleaning the soils polluted by HMs and pesticides of Talgar district of Almaty region.

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АУЫР МЕТАЛДАРМЕН ЖӘНЕ ПЕСТИЦИДТЕРМЕН ЛАСТАНҒАН ТОПЫРАҚ ФИТОРЕМЕДИАЦИЯСЫНДА АҒАШ ӨСІМДІКТЕРІН ҚОЛДАНУ ЖЕТІСТІКТЕРІ (шолу)

Аннотация. Мақалада топырақтың ауыр металдармен және пестицидтермен ластану проблемалары, олардың биологиялық қолайлылығына әсер ететін табиғи және антропогендік факторлар, ластаушыларға өсімдіктерге төзімділік механизмдері және топырақтың фиторемедиация технологиясындағы ағаштар дақылдарын пайдалану жетістіктері туралы әдебиеттер шолу жасау қарастырылған.

Ауыр металдар (АМ) және пестицидтер қоршаған ортаны анағұрлым улы ластаушылар болып табылады. Қазіргі уақытта, құрамында АМ және пестицидтері бар ластаушы заттардың көлемі жыл сайын артып келеді. Бұл жағдайлар қазіргі кездегі экологиялық тепе-теңдікті бұзады және халықтың денсаулығына зиянын тигізеді.

Дегенмен, кейбір өсімдіктердің түрлері табиғи жолмен осы металдарға толерантты немесе төзімді екендігі анықталды. Кейбір түрлері өзінің бойына АМ-дың жоғары концентрациясын жинайды, бірақ оларға толерантты екендігні, ал басқа түрлері - өздерінің кедергі жасай алатын қызметі есебінде азаятындығын көрсетеді. Топырақ және су ресурстарын залалсыздандырудың ең тиімді және үнемді технологиялары бірі ол биологиялық әдістер, атап айтқанда, фиторемедиация әдісі болып табылады.

Фиторемедиация өсімдіктердің жер үсті және жер асты органдарының ластауыштарын жинау және ризосфералық аймақта ксенобиотиктердің өзгеріске ұшырауын болдыратын мүмкіндіктерді пайдалануға негізделген. Фиторемедиация технологиясының дамуындағы алғышқы міндеттер - тамыр жүйесінде қоршаған ортаның ластауыштарын жинақтауға қабілетті өсімдіктерді іздестіру, сосын оларды жер үстіне ауыстыру болып табылады.

Бұл үдеріс үшін қысқа мерзім ішінде үлкен биомассаны құрайтын жылдам өсетін өсімдіктер алынады. Осы зерттеулер үшін – *Populus, Salix* және *Paulownia* орман дақылдары болып табылады. Осы аталған өсімдіктерді ТМ және пестицидтердің фиторемедиация технологиясында қолданылу ластану деңгейін төмендетеді және ластанған топырақтың өнімділік құндылығын арттырады.

Ағаш сорттарын қолданып жүргізілген фиторемедиация көптеген аймақтарға енгізілуі мүмкін қазіргі заманғы, перспективалық экологиялық қауіпсіз және экономикалық тиімді технология болып табылады.

Түйін сөздер: ауыр металлдар, пестицидтар, фиторемедиация, ағаш өсімдіктері.

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ПЕРСПЕКТИВЫ ИСПОЛЬЗОВАНИЯ ДРЕВЕСНЫХ КУЛЬТУР В ФИТОРЕМЕДИАЦИИ ПОЧВ, ЗАГРЯЗНЕННЫХ ТЯЖЕЛЫМИ МЕТАЛЛАМИ И ПЕСТИЦИДАМИ (обзор)

Аннотация. В статье представлен обзор литературы по проблеме загрязнения почв тяжелыми металлами и пестицидами, рассмотрены естественные и антропогенные факторы, влияющие на их биодоступность, механизмы устойчивости растений к данным загрязнителям и перспективы использования древесных культур в технологии фиторемедиации почв.

Тяжелые металлы (ТМ) и пестициды являются наиболее высокотоксичными загрязнителями окружающей среды. В настоящее время объемы поллютантов, содержащих ТМ и пестициды, ежегодно возрастают.

Данная ситуация подрывает существующее экологическое равновесие и негативно сказываются на здоровье людей. Тем не менее, некоторые виды растений развили толерантность или устойчивость к этим металлам естественным путем. Одни виды способны накапливать высокие концентрации ТМ, но проявлять к ним толерантность; другие – снижают их поступление за счет своих барьерных функций. Наиболее эффективными и экономически выгодными технологиями обеззараживания почвенных и водных ресурсов являются биологические методы, в частности, фиторемедиация. Фиторемедиация основана на использовании способности растений накапливать загрязняющие вещества в надземных и подземных органах и вызывать деградацию ксенобиотиков в ризосферной зоне. Первостепенной задачей при разработке технологии фиторемедиации является поиск растений способных аккумулировать загрязнители среды в корневой системе, а затем транслоцировать их в надземную часть. Для этого процесса идеальны быстрорастущие растения, создающие большую биомассу за короткий период. Наиболее перспективными видами для данных исследований являются древесные культуры рода *Populus, Salix и Paulownia*. Применение данных видов растений, в технологии фиторемедиации ТМ и пестицидов позволит снизить уровень загрязнения и повысить продуктивную ценность загрязненных почв. Фиторемедиация с использованием древесных пород является современной, перспективной экологически безопасной и экономически выгодной технологией, которая может быть внедрена на больших территориях.

Ключевые слова: тяжелые металлы, пестициды, фиторемедиация, древесные культуры.

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