Bast fibres: the role of hemp (*Cannabis sativa* L.) in remediation of degraded lands

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11.1 Introduction

The use of lignite as a source of energy is still valid in many countries of the world. This causes a lot of disturbances in the ecology of the natural environment caused by, among others operation of open-cast mines. Open-cast mining works lead to significant geomechanical transformations, to degradation of: the natural structure of the soil profile and the layers of the natural cover of humus. This contributes to the disruption of natural water relations, the quality and quantity of surface waters also change. Water must not interfere with the mining process; therefore, it is necessary to perform drainage of the excavation so as to lower the water level to the pit of the excavation.

Lowering the water level causes drying of watercourses and ponds as well as water falling in lakes and wells. The areas adjacent to the excavation are also subjected to drying. Post-mining lands for long years are excluded from agricultural use. The functioning of the open pit also plays an important role in anthropogenic changes occurring in the soil, causing huge negative transformations in the natural environment. Topsoil (soil cultivation layer) created for thousands of years disappears and the anthropogenic infrastructure is fundamentally changing, many villages and farms disappear and enterprises are shutdown (Mańkowski et al., 2014).

High emission of contamination, mainly due to the developed industrial activity, is characteristic for some areas of Europe. The contamination results from the combustion processes of liquid fuels, coal and gas as well as mechanical, chemical and thermal processing of the obtained mineral raw materials. The pollutants come mainly from emissions of gases and dust to the atmosphere, containing in their composition, among others, carbon monoxide and dioxide, sulphur dioxide, nitrogen oxides, as well as fluorine compounds, sulphides, phenol, aliphatic and aromatic hydrocarbons, etc.

Dust pollutants are mainly: fly ash, dolomite-lime powders, metallurgical dusts with a high content of toxic heavy metals such as: lead, cadmium, zinc, copper, iron,

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manganese, nickel, chromium, mercury, etc. Industrial pollution emitted to the surrounding atmosphere, they get into the soil relatively easily, along with atmospheric precipitation and dust fall. In the next stage during vegetation they are taken to plant organisms, where they can become a source of danger for the human body, especially when their level exceeds the acceptable standards (Kozłowski et al., 1991).

Abandoned post-mining areas, without plant cover, excluded from agricultural use, are exposed to wind erosion with all negative effects, including blowing out and blowing mineral material.

Picture 11.1 Backfilling of an open-pit mine.

11.2 Key issues in recultivation of polluted lands

The intense economic development that could be observed from the 19th through the 20th century has left its mark (stigma) on the condition and quality of the natural environment. The development of industry and the exploitation of natural resources have largely contributed to the degradation of the soil environment and its pollution.

Locating industrial centres was dependent on many factors. The most important of them are:

- raw material base and raw material availability (e.g. occurrence of deposits);
- access to water;
- sales markets and employee qualifications;
- technical infrastructure;
- relevant legal regulations.

The development of industry was possible due to the presence of raw materials (e.g. mineral resources, such as: coal, brown coal, ore of: iron, sulphur, zinc, copper, rock salt, potassium salt, crude oil and natural gas), as well as a well-developed hydrographic network. Forming industrial districts have become specialized in the production of specific products. Each industry is characterized by a specific spectrum of pollution and the level of exposure of natural resources, environmental components to specific anthropogenic threats: physical, biological or chemical.

One of the problems associated with industrialization is the degradation of soils, often used previously in agriculture, caused by the lignite mining industry. Coal is extracted after removing the soil overburden, which is a layer of soil with a thickness of several dozen metres of rock material along with infrastructure, flora and soil. After mining, a lifeless excavation remains, which is constantly filled with material from soil overburden. After levelling the terrain, the layer that was below the surface is located in the arable part. Such top layer is characterized by a trace of humus content and does not have fully developed soil, i.e. a biologically active surface layer.

The problem of developing post-mining areas is a global problem. Lignite is extracted on a large scale in Europe, Australia and the United States (Table 11.1).

In Poland, the area of degraded land currently exceeds 60,000 ha, of which only a small part is recultivated annually. The main direction of remediation is agricultural remediation (Table 11.2).

Phytoremediation is defined as the process of removing or detoxifying pollutants from the environment using so-called higher plants. This technology is based on the ability of certain species and varieties to tolerate high concentrations of toxic compounds, uptake, accumulation and metabolism of these compounds in large quantities in their own organs or to convert them into non-toxic compounds.

Agricultural remediation (remediation) is carried out through cultivation of plants in the polluted areas, which after harvesting are used industrially for energy, food or fodder purposes. These plants are often subject to diseases and pests, which is why they are not a wholesome food for both humans and animals. Plant yields are low, which affects the profitability of the crop. Acquiring low quality crops from degraded areas does not accelerate their remediation.

Table 11.1 The main producers of brown coal in the world (million tonnes).

Country	2012	2013	2014	2015	2016
Germany	185.4	182.7	178.2	178.1	171.5
United States	71.6	70.1	72.1	64.1	66.2
Russian Federation	77.3	73.7	68.9	73.2	73.7
Poland	64.3	65.8	63.9	63.1	60.2
Turkey	68.1	57.5	62.6	50.4	50.4
Australia	71.4	62.3	60.5	65.4	59.7
World total	887.2	834.7	815.7	807.4	783.3

Based on: Prof. dr hab. Eng. Zbigniew Kasztelewicz. Report on the condition of the brown coal industry in Poland and Germany, together with a diagnosis of activities for the development of this sector in the first half of the 21st century.

Table 11.2 Devastated and degraded land requiring remediation and development as well as land reclaimed and developed in Poland in the years 2000−2016.

Specification	2000	2005	2010	2015	2016
	In hectares				
Devastated and degraded lands	71,473	64,978	61,161	63,374	64,651
Land reclaimed during the year	2,235	1,861	1,222	1,807	1,449
Including: For agricultural purposes	456	555	634	1,262	925
Forests	1,345	608	440	282	282
Land developed within a year	1,222	1,132	581	855	587
Including: For agricultural purposes	254	374	299	627	367
Forests	830	266	212	98	137

Based on: Data of the Polish Ministry of Agriculture and Rural Development.

Picture 11.2 Areas before starting the remediation process.

Picture 11.3 Areas before starting the remediation process.

The second important problem is the pollution of post-industrial areas with heavy metals. The content of trace elements in soil can be shaped both by natural and anthropogenic factors. The concentration of heavy metals in soils is conditioned and correlated with many parameters, including with the content of humic compounds, pH, or oxidation-reduction potential.

The first ones include, among others mineralogical composition of the parent rock and the nature and development of soil-forming processes. Depending on the climate, soil properties and geochemical properties of a given element, it undergoes leaching or accumulation processes (Alloway, 1990; Kabata-Pendias and Pendias, 1999). Anthropogenic factors that play the most important role in soil chemistry and their contamination with heavy metals include industrial emissions and improper waste management.

Anthropogenic emission of pollutants in relation to specific compounds is characterized by a certain repeatability resulting from technological progress, widespread use of specific technologies or installations. It is assumed, inter-alia, that the development of certain industries fosters the emission and accumulation of specific types of pollutants and substances that may cause pollution risks, including, among others, heavy metals deposition.

Electroplating, production of dyes, batteries, accumulators, plastics and paints, chemical industry, polymer stabilizers, production of plant protection chemicals, printing, printing and graphic industries – they have an affinity to cadmium emission.

Production of dyes, accumulators, batteries, fertilizers, automotive, energy and electrochemical industry, production of plant protection chemicals – contribute to the emission increase of toxic products, including lead.

Emissions and soil pollution with chromium are accompanied by the functioning of a galvanizing plant, tannery, wood impregnation plant, textile industry, printing and printing companies as well as the production of dyes and plastics.

The metallurgical, dyeing and textile industries, as well as the production of plant protection products and fertilizers, can be associated with increased copper contents in soils.

Usually quicksilver emissions are associated with the production of batteries, phosphoric acid, caustic soda, the operation of pulp and paper mill, production of plant protection products, production of metallic quicksilver, but also with hard coal-fired combustion plants.

The production of fertilizers, paper industry, refineries, steel mills and galvanizing plants can be a source of nickel emission to the ground.

Increased zinc contents in soil and ground are often correlated with the production of batteries and paints, the textile industry, the production of plastics, polymer stabilizers, graphic and printing plants.

Acidification of soils mobilizes and activates most heavy metals in the soil profile, causing the activation of toxic trace elements, their leaching into waters and, as a consequence, disturbance of the balance in the environment in the soil and water environment (Kabata-Pendias and Pendias, 1993; Rosada, 2008). It is estimated that in areas with increased industrial dust emission on average, 70%–90% of the metal content in plants comes from atmosphere (Rosada et al., 1995; Siebielec, 2008).

11.3 Methods of recultivation and remediation of polluted lands

There are three main directions of remediation and development of degraded areas:

- agricultural; creation of arable land, permanent grassland for agricultural purposes, meadows, pastures, orchards, shrub plantations,
- forestry; afforestation of reclaimed areas that have a production or protective function (e.g. soil protection or water protection),
- special; water, recreational, ecological or aesthetic – protective management (Karczewska, 2008).

At the Institute of Natural Fibers and Medicinal Plants in Poznań, Poland a project related to the agricultural remediation of post-mining sites was implemented: LIFE11 ENV/PL/445, Acronim: EKOHEMPKON, Remediation of degraded land in the region of Lignite Mine Konin by cultivation of industrial hemp (2012–18). Remediation was carried out in the area of 25 ha. Cultivated crops selected in the developed method were fibrous hemp and alfalfa. All organic matter produced fell into the soil by mowing and ploughing. A combination in the crop rotation of hemp; producing a lot of lignocellulosic biomass with the predominant composition of cellulose containing carbon, oxygen and hydrogen with alfalfa growing rich in nitrogen content and leaving organic matter as a green manure, created a specific biological 'composite' in the soil that facilitates the relatively rapid formation of humus, increased soil nutrient abundance, improved water and air conditions and created conditions for the multiplication of soil microorganisms beneficial for the fertility of soil.

Hemp is an annual plant, the height of which is up to 3–4 m, yielding a very high yield of dry matter, which in agricultural conditions is about 10 tons/ha. In addition, hemp has a well-developed root system of the pile type with a depth of about 1.0–1.5 m, the root system produces natural, organic channels, drains, allowing access of air and the flow of water and soil gases. Under such conditions, the development of soil microorganisms having basic meaning in the formation of humus occurs. In the remediation implemented, a Polish cultivar of fibrous hemp Białobrzeskie was used. It is a variety bred by the Institute of Natural Fibres (Mańkowski et al., 2017a,b).

Picture 11.4 Hemp grown in reclaimed areas.

The second one used in the remediation of plants was alfalfa, which unlike hemp is a perennial plant. Alfalfa is also characterized by a large yield of green mass and a deep root system. An important feature of alfalfa as a legume plant is its ability to symbiosis with rhizobia-type rhizobia bacteria with the ability to bind molecular nitrogen. Bound nitrogen serves the plant for the synthesis of proteins. In addition, significant amounts of nitrogen compounds get into the soil and serve as a source of nitrogen for other plants growing simultaneously or afterwards in crop rotation. This is very important in post-mining areas where nitrogen in the soil occurs in trace amounts and is an essential element for the creation of plant proteins and soil microorganisms.

Picture 11.5 Alfalfa grown in reclaimed areas.

Agrotechnical works were carried out in order to prepare areas recultivated for the sowing of selected plants, including hemp *Cannabis sativa* L. sowing and alfalfa. The following works were performed: sowing hemp and alfalfa, care treatments, harvesting and ploughing of biomass obtained.

The main agrotechnical activities included: disking fields, deep ploughing, drying and pre-seeding soil tillage, fertilizing, sowing, mowing, spraying with preparations to accelerate humification and ploughing of biomass. Biomass of hemp and alfalfa, thanks to the fact that it remained in the soil, provided organic matter to accelerate the restoration of the humus layer. Dead parts of plants and microorganisms undergoing humification contributed to the formation of such an important part of the soil as humus.

Remediation was carried out over a 6-year period. The reclaimed area was divided in half for hemp cultivation and alfalfa cultivation. Hemp as an annual plant was sown annually. The sowing of alfalfa due to long-term cultivation was repeated after 3 years. Alfalfa was sown every year only in the places where its cultivation was interrupted. After 3 years, the crop rotation was carried out. In the field after hemp, alfalfa was sown and *Cannabis sativa* L. seeds were sown in the fields after alfalfa cultivation.

Lime fertilization was used only in the first year of remediation. Calcium oxide so-called oxide lime was sown in the amount of 6 tons/ha. Every year in April, fertilizers were sown, in the following doses: nitrogen (N) under hemp in the quantity 150 kg N/ha, while nitrogen fertilization is not used for alfalfa. The cultivation of hemp and alfalfa was fertilized with phosphorus (P_2O_5) in the amount 150 kg/ha, as well as with potassium (K_2O) in the amount 215 kg/ha.

In case of alfalfa, there were mowing operations to limit the growth of weeds, mainly white hepatica (*Chenopodium album* L.). The growing weeds could lead to the suffocation of the sown alfalfa. The problem of the appearance of weeds in hemp was not observed.

Every year in September, treatments related to mowing hemp and alfalfa were carried out. Hemp was mowed using a mower equipped with three cutting bars that cut the stalks in three places. Such cutting facilitated the subsequent ploughing of biomass. After mowing, cut biomass was sprayed with EM (Effective Microorganisms) to accelerate its decomposition and enrich the soil microflora. Immediately after the spraying, stubble disking was performed in order to improve the effectiveness of the microorganisms. The last annual agrotechnical operation performed in November was a deep tillage, to cover the cut biomass (Mańkowski et al., 2017a,b).

The degradation of soils is influenced not only by lignite open-cast mines but also by the presence of heavy metals, mainly from emissions of dust, fumes, as well as from the sewage and industrial waste. Additional contamination of agricultural areas along roads is caused by motorization. It should be emphasized that there is a significant amount (zones around industrial centres, stripes along communication routes), which are not formally excluded from agricultural use, and create a significant threat to human health in the case of cultivation of consumer plants on them.

Methods for the remediation of heavily contaminated soils are based on two main methods. The method of immobilization of metals in soil and the method of extracting metals and removing from soil (Karczewska, 2008) (Table 11.3).

The development of a number of industries related to energy processes, causing emissions into the air, affects the soil environment both directly and indirectly. Presented factors degrading the natural environment occur in varying degrees of severity in each industrialized area.

The most toxic elements are: mercury (quicksilver), cadmium, lead, copper and zinc. Heavy metals that pollute the environment pose a serious toxicological problem, and hazards to human are caused mainly due to the consumption of contaminated food. Cereals, vegetables and fruits are plant products that are a source of human food. For this reason, the presence of heavy metals in them, especially if their amount exceeds the acceptable standards, can become a danger to the human body.

The dynamically developing industry and automotive industry adversely affect components of the biosphere, i.e. water, air and soil, causing systematic degradation of the natural environment. The negative influence of human activity factors on the soil is very long-lasting and often irreversible. The above phenomenon causes a quick loss of land used for agriculture.

Table 11.3 Potential soil pollution by various industries.

No.	Branch of the industry	Potential contamination of soil and ground with substances
1	Oil refineries, installations for the production of petroleum lubricants, Installations for gasification and liquefaction of coal or bituminous shale, plants Mining of hydrocarbon extraction with boreholes, coking plants	Aliphatic hydrocarbons, polycyclic aromatic hydrocarbons, Phenols, cresols
2	Seaports and port installations for handling crude oil and products Petroleum and other chemical cargoes and metal ores	Hydrocarbons Aliphatic, gasoline; Polycyclic aromatic hydrocarbons, pesticides and other impurities Organic, heavy metals
3	Chemical plants that produce organic products from chemical processing Coal	Aliphatic hydrocarbons, polycyclic hydrocarbons Aromatic, phenols, cresols, cyanides
4	Plastic plants, adhesives, resin and polymer production	Phthalates, Phenols, cyclohexane, chlorinated hydrocarbons
5	Production of paints, solvents and varnishes	Aromatic hydrocarbons, Chlorinated hydrocarbons, zinc, lead, chromium and barium
6	Substations and power substations	Polychlorinated biphenyls
7	Conventional power plants, combined heat and power plants and other combustion installations	Polycyclic aromatic hydrocarbons, heavy metals
8	Smelting plants for pig iron and steel and production of non-ferrous metals,	Heavy metals, cyanides, phenols, aliphatic hydrocarbons, polycyclic hydrocarbons Aromatic hydrocarbons
9	Ceramic plants	Cadmium, lead
10	Plants related to the production of lamps and measuring devices	Mercury
11	Galvanizing plants, plants producing and coating wire and cables	Heavy metals And cyanides
12	Investments related to the use or disposal of waste Dangerous and related to the thermal treatment of waste	Pesticides, aliphatic and aromatic hydrocarbons, polycyclic hydrocarbons Aromatic hydrocarbons, heavy metals

Continued

Table 11.3 Continued

No.	Branch of the industry	Potential contamination of soil and ground with substances
13	Chemical plants for the production of pesticides, pesticide warehouses and burial sites	Pesticides
14	Rubber production	Lead, tetrahydrofuran
15	Tanneries	Chromium, mineral salts, organic sewage
16	*Produkcja styropianu* Production of expanded polystyrene	Styren styrene
17	Liquid fuel stations, transport bases, large vehicle service stations, parking lots Car or parking lots	Aliphatic hydrocarbons – oils Mineral, gasoline, polycyclic aromatic hydrocarbons
18	Construction and repair facilities for 'aircraft', production and repair facilities Railway equipment, production plants for vehicles or equipment Mechanical and engine production	Aliphatic hydrocarbons, Polycyclic aromatic hydrocarbons, heavy metals

Based on: Stuczyński, T., Siebielec, G., Maliszewska-Kordybach, B., Smreczak, B., Gawrysiak L., 2004. Wyznaczanie obszarów, na których przekroczone są standardy jakości gleb, poradnik metodyczny dla administracji. Biblioteka Monitoringu Środowiska, Warszawa.

Depending on the nature and degree of identified pollution, remediation methods are set individually for a specific site. However, the remediation process is always very expensive. In highly contaminated areas, physical and chemical methods of soil cleaning are preferred. In addition to the phytotoxicity of pollutants, this is probably also supported by the fact that pollution of ground or underground water often appears after soil contamination.

Remediation activities (physical and chemical methods) can therefore be applied comprehensively with respect to the soil and water in a more controlled manner and provide faster results. However, the possibility of bioremediation as supporting conventional remediation processes – should not be excluded.

Chemical and physical methods besides generating high costs can also irreversibly affect soil properties, destroying their biological life, biodiversity and making them useless as an environment of plant growth (Padmavathiamma and Li, 2007).

11.4 The results

11.4.1 Results of reclamation work

In each year of the project related to the reclamation of lignite open-cast mine areas, soil analysis was conducted to determine the progress in reclamation. Analyzing the soil, the content of nutrients such as nitrogen, phosphorus, potassium, magnesium, manganese, zinc, copper, boron, sulphur as well as and the pH of the soil was determined. All tests were carried out in accordance with the applicable standards. Below, a comparison of data before reclamation and derived from studies from the last year of work.

Before starting the reclamation, the content of boron in the recultivated fields was low. As a result of the reclamation (remediation), the level of boron increased to medium. The copper content was on an average level throughout the reclamation period. Similarly, the iron and manganese content was on an average level. The content of zinc as a result of reclamation increased the level of potassium on reclamation sites before the start of work varied from low to medium (Figs 11.1−11.9, based on the IWNiRZ research).

As a result of the reclamation, the potassium content in the soil increased to very high level. Before reclamation, the magnesium content varied widely (from medium to very high). As a result of reclamation, it stabilized at a very high level. The phosphorus level increased from very low to very high. The sulphur content in the soil was at a very high level. Recultivated areas were characterized by alkaline pH of the soil.

Both in the case of fibrous hemp and alfalfa there was noticed and reported a significant increase in the biomass yield. In 2016, when in Poland drought occurred,

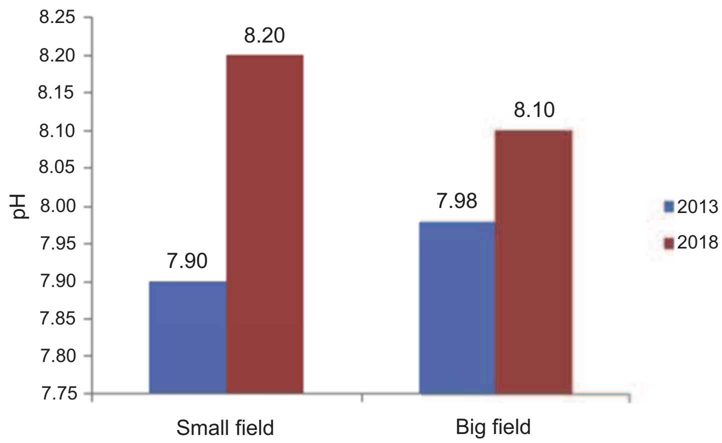


Figure 11.1 pH of soil from recultivated areas, 2013 and 2018.

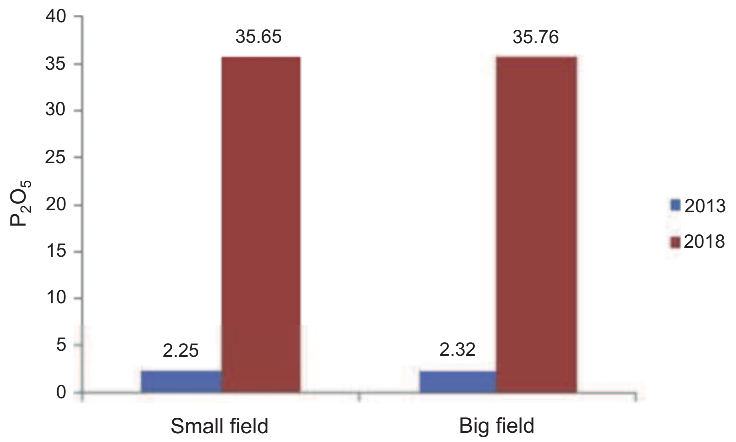


Figure 11.2 Phosphorus content (mg/100 g) of soil from recultivated areas, 2013 and 2018.

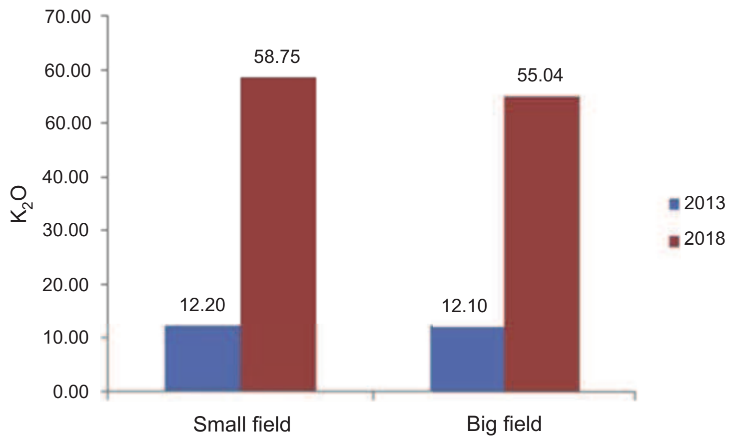


Figure 11.3 Potassium (K) content (mg/100 g) of soil from recultivated areas, 2013 and 2018.

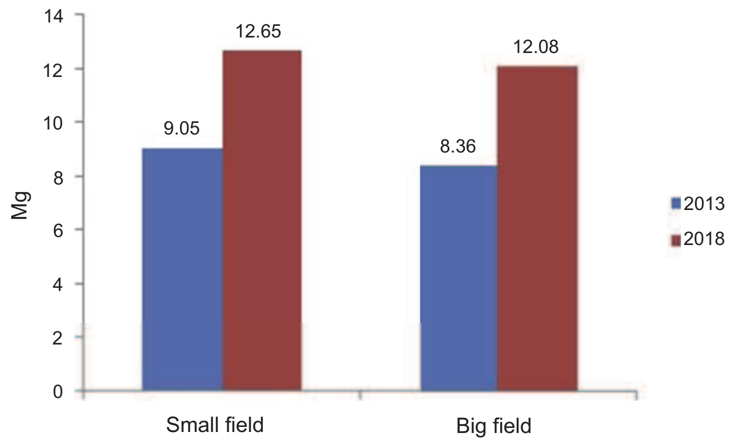


Figure 11.4 Magnesium (Mg) content (mg/100 g) of soil from recultivated areas, 2013 and 2018.

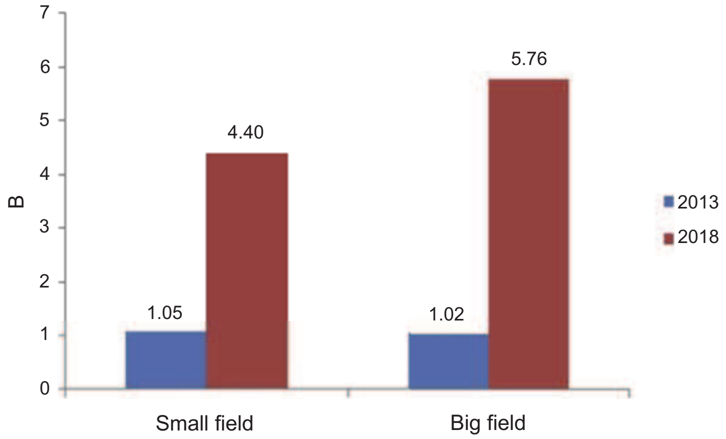


Figure 11.5 Boron (B) content (mg/1000 g) of soil from recultivated areas, 2013 and 2018.

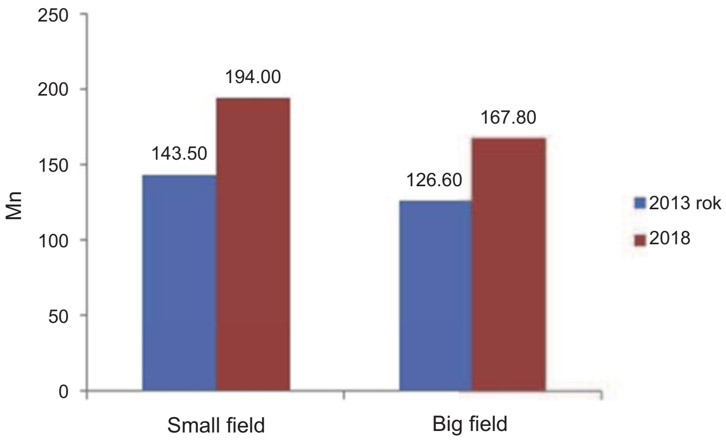


Figure 11.6 The content of manganese (Mn) (mg/1000 g) of soil from recultivated areas, 2013 and 2018.

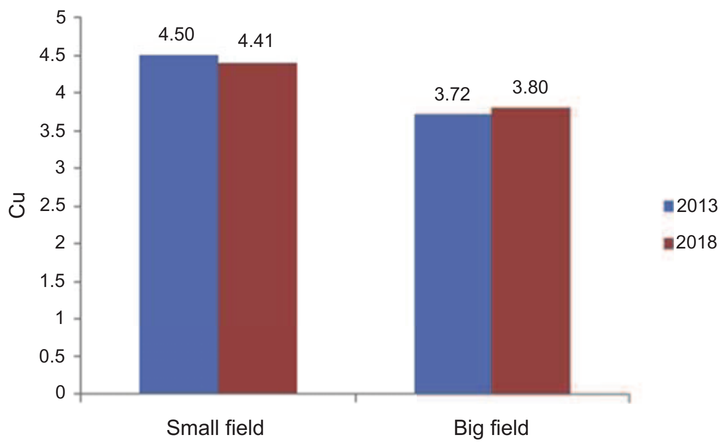


Figure 11.7 Copper (Cu) content (mg/1000 g) of soil from recultivated areas, 2013 and 2018.

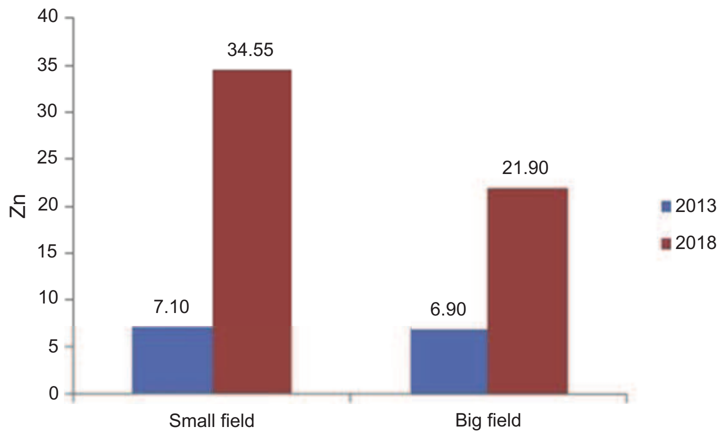


Figure 11.8 Zinc (Zn) content (mg/1000 g) of soil from recultivated areas, 2013 and 2018.

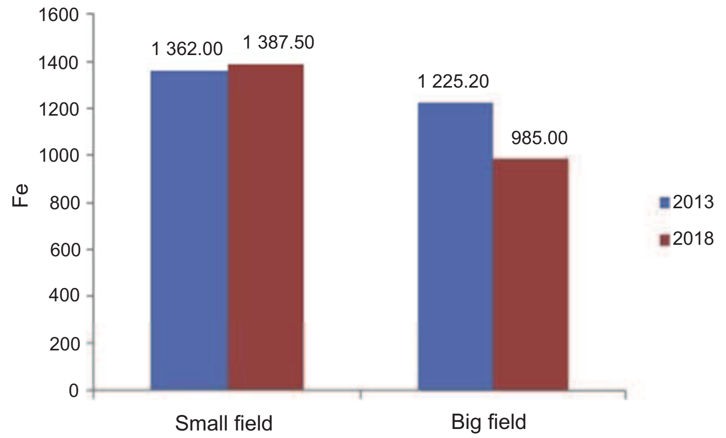


Figure 11.9 Iron (Fe) content (mg/1000 g) of soil from recultivated areas, 2013 and 2018.

fibrous hemp and alfalfa which are characterized by a well-developed deep root system, perfectly coped with unfavourable weather conditions. In 2016, the field rotation was applied. It was the first year of alfalfa cultivation on the fields after fibrous hemp, cultivation, hence the lower yield of alfalfa plant were noticed. However, this yield was higher than alfalfa yield in the first year of reclamation.

In 2017, hemp crop suffered due to long-lasting intense rainfall. A large amount of precipitation in the period immediately after emergence led to the loss of many plants. Due to the compact, impermeable recultivated layer, even slight rainfall led to the formation of large water stalls. The standing water displaced oxygen from the soil which led to the suffocation of many plants (Table 11.4).

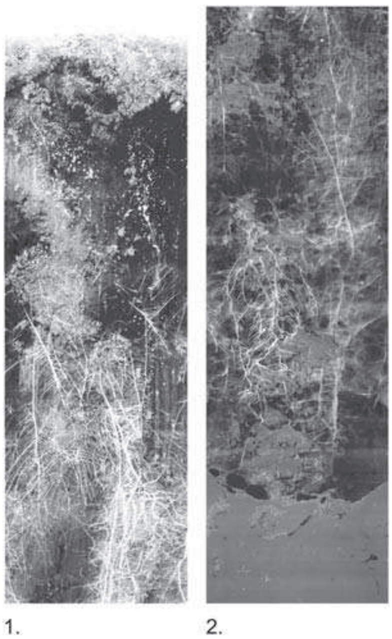
The recultivation carried out using the agricultural method of cultivation, applying the fibrous hemp and alfalfa crop rotation and subsequent ploughing of plant biomass resulted in an increase in the level of humus on the reclaimed site during the 6-year research period (Mańkowski. et al., 2018) (Table 11.5).

Table 11.4 Average amount of biomass obtained from reclamation areas (kg/ha).

Plant	Stanowisko Habitat	Years					
		2013	2014	2015	2016	2017	2018
Fibrous hemp	Small field (9 ha)	2500	2300	6300	6800	5000	6900
	Big field (16 ha)	1800	1600	5300	5900	3500	6300
alfalfa	Small field (9 ha)	1040	4800	5600	2500	6600	7200
	Big field (16 ha)	840	4200	5500	2400	6550	7000

Table 11.5 The maximum and minimum level of humus specified in the areas reclaimed from 2013 to 2018.

Field	Sample	Level of humus (%)					
		2013 (before remediation)	2014	2015	2016	2017	After project termination
1	Min.	1.30	1.91	1.10	3.10	1.03	2.41
	Max.	1.51	2.16	2.20	3.20	2.41	2.41
2	Min.	0.76	0.75	0.80	0.60	1.90	2.24
	Max.	1.49	1.77	1.20	1.20	2.93	2.59



Picture 11.6 The root system of fibrous hemp (1) and alfalfa (2) cultivated in reclaimed areas.

The roots of hemp and alfalfa overgrown to a depth of over 100 cm, have expanded to a large extent and ventilated, aerated and scarified the recultivated soil.

There was noticed a significant difference in the behaviour of the root system of fibrous hemp grown in the post-mining areas in relation to agricultural areas. Hemp having a pile type root system, in agricultural areas has grown deeper than in post-mining lands, where the roots, due to the compact layer of the soil, formed a larger mass in the topsoil.

α-Proteobacteria is a fairly diverse group of microorganisms. Most of them are Gram-negative bacteria. The microorganisms classified in the genus *Rhizobium* and *Bradyrhizobium* are of particular importance from the agricultural point of view, symbiotic bacteria (with legumes − including alfalfa) capable of assimilating atmospheric nitrogen. The presence of the proper host plant in the field habitats is an element strongly stimulating the increase in the population size of the relevant microsymbionts present in the soil. The increase in the number of this group of bacteria was observed at all sites covered by reclamation according to the developed method (Figs 11.10−11.15).

β-Proteobacteria covers a range of groups of aerobic or facultatively aerobic bacteria. They differ quite significantly in the scope of organic matter decomposition, but many of them are important in the processes of assimilating atmospheric nitrogen by several agricultural crops (e.g. *Nitrosomonas*). On the examined objects in the last 3 years of the field experiment, the number of this group of microorganisms increased the most in all the habitats of the large field (initially much poorer compared to the small field).

The reversal of the unfavourable trend of limiting the population of this group of microorganisms, observed in previous years, may be gratifying. This is particularly evident in the large field (PD) sites, which are characterized by less homogeneous soil-forming processes compared to the small fields (PM), where the agrotechnical reclamation was carried out even before the start of the research.

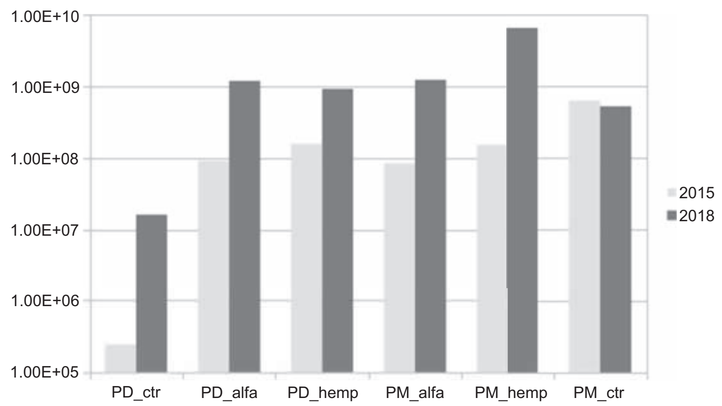


Figure 11.10 Population of α-Proteobacteria population in 2015 and 2018 at field sites.

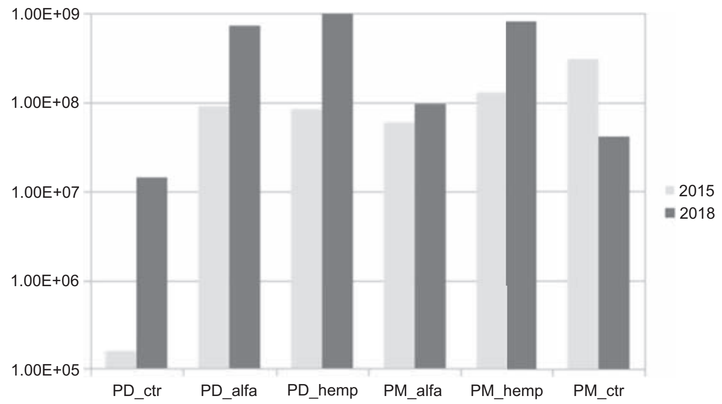


Figure 11.11 The size of the β-Proteobacteria population in 2015 and 2018 at field sites.

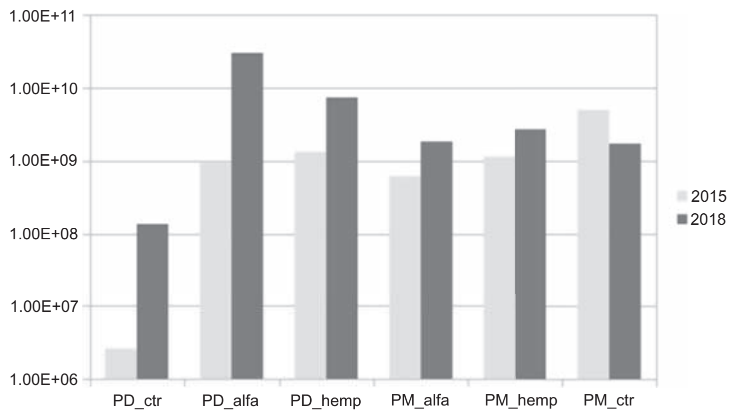


Figure 11.12 Population of the *Actinobacteria* population in 2015 and 2018 in field positions.

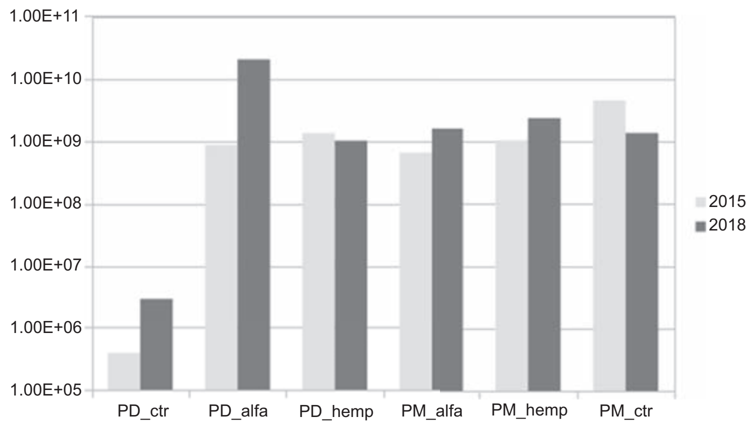


Figure 11.13 The population numbers of *Firmicutes* in 2015 and 2018 in field positions.

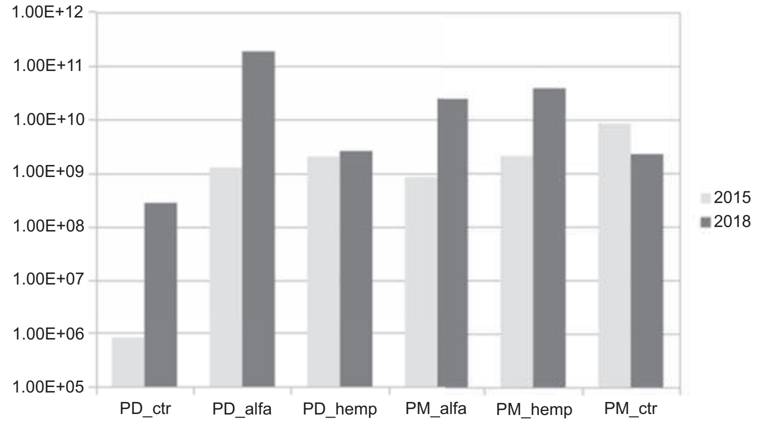


Figure 11.14 Population of the *Bacteroidetes* population in 2015 and 2018 at field sites.

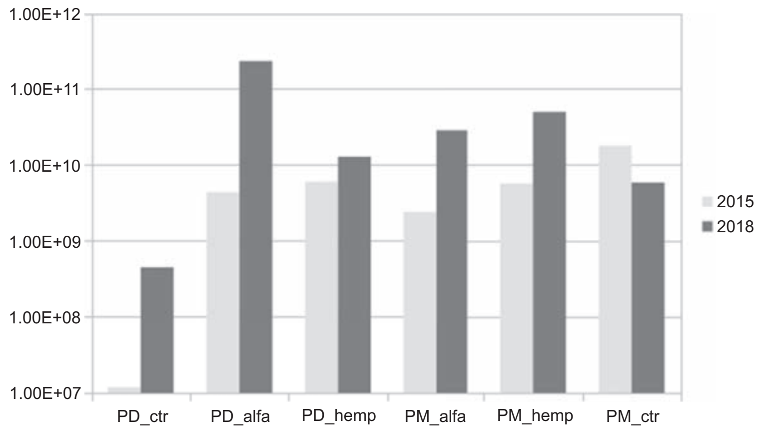


Figure 11.15 Total number of bacterial populations in 2015 and 2018 at field sites.

The proportion of two successive analyzed groups of microorganisms i.e. *Actinobacteria* (actinomyces) and *Firmicutes*, was significantly higher than that of *Proteobacteria* and reached 30% or even over 50% (PD_hemp site) and the total pool of bacteria. Actinomycete are prokaryotic organisms that form a row of Gram-positive bacteria whose main location is soil. They are characterized by very good adaptability to the prevailing environmental conditions. They also occur in the roots of plants, fallen leaves and even in desert sand.

Both groups (*Actinobacteria and Firmicutes*) contribute to the decomposition of plant and animal residues, polysaccharides and hardly decomposable compounds, such as cellulose, chitin, higher fatty acids and aromatic compounds. On the objects studied, a clearly beneficial effect of reclamation on the share of the population of these two groups in the total pool of bacteria was observed regardless of the plant cultivated. Particular attention is paid to a significant increase in the number of actinoblasts

(*Actinobacteria*) on less recultivated PD fields. This may indicate that the effect of the organic matter introduced systematically on the number of population capable of decomposing plant remains has been stimulated after 6 years of project activities.

The next analyzed group, with the highest percentage share in the bacterial pool, were microorganisms classified within the *Bacteroidetes* area. This group is gram negative, often anaerobic bacteria. This is also a diverse taxon encompassing microorganisms that inhabit very different locality from soil and sewage sludge to seawater and animal digestive tracts.

Such a large representation of the bacteria belonging to this group in the studied objects indicates the continuing difficult air-water relations on the analyzed sites and the excessive anaerobic conditions with the availability of nutrients coming from the introduced organic matter already in comparison with control objects.

The graph above shows changes in the population size of soil microflora on the investigated sites. The increase in the number of bacteria observed on all reclaimed objects indicates the unambiguously beneficial effect of cultivation and conducted tillage procedures on the recultivated sites for the total number of soil microorganisms and the structure of their population in comparison with the control. The general beneficial effect of cultivation was more clearly visible on the initially less reclaimed large field facilities, however, the beneficial effect of the cultivation operations was also noted at small field sites (PM) (Pudełko et al., 2014).

Remediation results of contaminated soils.

The highest concentrations of heavy metal impurities in soils usually show a humus level, which is related to the affinity of these elements to organic matter (Kabata-Pendias and Pendias, 1993; Motowicka-Terelak and Terelak, 2002; Maciejewska, 2003; Rosada, 2008). From among the whole range of possible contaminants, the most investigated and the most popular form of applying plants in phytoremediation processes is the extraction of heavy metals from the substrate, the so-called phytoextraction.

Due to the special features of hemp (Kumar et al., 1995) i.e. high ability to accumulate metals in aboveground parts of the plant, rapid biomass growth, local origin, resistance to diseases, pests and weather whims, the possibility of growth on contaminated and degraded areas and the possibility of collecting more than one trace element from the soil, Antonkiewicz (2013) recommends fibrous hemp *Cannabis sativa* L. as one of the plants recommended for phytoremediation of soils.

Comparative studies of the phytoremediation potential of plants performed at the end of the 1990s (Grzebisz et al., 1998) confirmed that the content of heavy metals in hemp depended on the analyzed element. Cadmium accumulated in aboveground parts of hemp in an amount almost three times greater than in roots. In addition, hemp showed a much greater affinity to pick up lead and copper from the ground. Analyzes of the Pb and Cu contents extracted from the contaminated soil with biomass gave the basis for the conclusion that among bast plants *Cannabis sativa* L. can play a significant and key role in phytoremediation processes of heavily contaminated soil (Antonkiewicz and Jasiewicz, 2002).

A study published in 2009 regarding the impact of cadmium soil contamination on biomass growth including the roots of industrial plants (Gangrong and Qingsheng,

2009) showed that at low concentrations of Cd (50 mg/kg) no reduction in root growth was observed for all tested plants, including hemp. Soil treatment with a dose of 100 mg/kg Cd suppressed root growth in six out of eight experimental crops. The exception was rapeseed and hemp. High doses of Cd (200 mg/kg) resulted in significantly reduced root growth of all species of studied plants (the most sunflower — by 47%, hemp — by 43%, flax — by 32%). Under the same conditions, the content of Cd in soil (200 mg/kg) in all tested plant species, with the exception of cannabis, the shoot length decreased with a gradual increase in the Cd concentration in the soil. At the Cd concentration limit of 200 mg/kg, the reduction in shoot length was also observed in flax (35%) and then in hemp (43%) (49% for soybeans) and peanut (58%).

Hemp to a certain point is characterized by tolerance to cadmium content. Only high concentrations of this element lead to impairment of the plant growth process and to the decrease of biomass production.

The research conducted at the Institute of Natural Fibres and Medicinal Plants (IWNiRZ) showed that fibrous hemp compared to the cultivation of legume plants shortened the reclamation carried out by half, and the content of heavy metal ions in reclamation soil decreased by 80% after 3 years of reclamation.

The research concerned agricultural development of contaminated areas through the cultivation of industrial plants. The introduction of fibrous plants for technical purposes into areas contaminated by civilization factors has led to their gradual remediation and restoration of the agricultural nature of their utilization.

The non-food nature of crop rotation has eliminated heavy metals from the human food chain and the obtained biomass of fibrous plants could be used in ecological production by the textile, pulp and paper, chemical or fuel-energy industry.

The research showed that the plants were growing properly, did not get sick, and the presence of heavy metals in the soil did not adversely affect the yield (Table 11.6).

The obtained results show that the highest concentrations of metals, and therefore their strongest extraction, were found in hemp. Also for flax and oil flax the level of extraction is higher than for the compared crop plants. The high biomass of fibrous hemp yield accumulates significant amounts of heavy metals (Table 11.7).

The introduction of fibrous plants devoted for technical purposes into areas contaminated by civilization factors leads to their gradual remediation. The selected plant is fibrous hemp *Cannabis sativa* L., which is not negatively influenced by the presence of heavy metals in the soil. Plants on such soils do not get sick and develop properly (Baraniecki et al., 1995; Kozłowski et al., 1993).

Table 11.6 The content of Cu. Pb. Zn and Cd in seeds in mg/kg s.m.

Element	Hemp	Fibrous flax	Linseed	Triticale	Oat
Cu	26.2	15.9	10.0	5.7	3.5
Pb	1.7	1.0	0.1	2.8	1.0
Zn	77.0	74.7	77.0	18.3	19.0
Cd	0.20	0.30	0.40	0.05	0.10

Table 11.7 The content of metals in plant stems.

Element	Hemp	Fibrous flax	Linseed	Triticale	Oat
Cu	72.6	4.1	5.7	20.9	7.8
Pb	20.0	2.0	1.0	12.9	7.4
Zn	64.9	27.3	23.7	12.4	7.3
Cd	0.3	0.6	0.4	0.1	0.1

11.5 Future trends

The process of phytoremediation of soils with the use of hemp can allow, on the one hand, extraction of harmful substances from the soil and parallel use of plants for energy purposes, e.g. for the production of bioethanol, biogas or possibly oil production for energy purposes from oil varieties (Kabata-Pendias and Pendias, 1993). Phytoremediation is considered a relatively new method of soil cleaning, and sewage sludge in situ.

Studies on the assimilation of lead and cadmium in the phytoremediation process using hemp sowing showed an increase in the amount of trace elements extracted while supporting the remediation process with appropriate doses of urea and EDTA (acidum edeticum). The best effects of the extraction of elements were obtained using (in the reported experiments) the ratio of Urea – 2.500 ppm with EDTA – 100 ppm (increased values of T4 urea). The study showed greater plant growth, increased biomass production and much more effective uptake of Pb and Cd by various parts of the plant (Astel et al., 2014).

Genetic studies carried out by scientists in Pakistan using fibrous hemp (Ahmad et al., 2015) have shown that the level of accumulation of metallic elements in a plant (Cu, Cd, Ni) correlates with the presence of specific genes responsible for the tolerance level of stress in the plant. This discovery brings a new light for the further development and improvement of the phyto-accumulative and extraction capabilities of hemp. Therefore, interference with the genetic code of a plant is not excluded, as a result of which a variety resistant to very high concentrations of heavy metals in soil or ground will be created, and, at the same time, it will allow the growth of phytoremediation potential of new industrial hemp varieties.

The work carried out by Sonia Campbell et al. (2002) on an attempt to remedy soil contaminated with polycyclic aromatic hydrocarbons (PAHs) also showed that hemp may also be useful in phytoremediation of PAHs. The growth rate of hemp in soils contaminated with chrysene and benzopyrene in concentrations from 25 to 200 μg/g was satisfactory, and PAH pollution was reduced.

Research is being carried out on the resistance of some plants, including hemp for cultivation on saline soils e.g. the HaloSYS project – 'Integrated system of bioremediation – biorefinering using halophyte species' is being implemented at IWNiRZ. Due to the increase in population and industrialization in the world, the reclamation of soils with biological methods will become more and more important.

11.6 Conclusion

The phenomena of soil degradation and contamination have a spatial dimension, and should therefore be documented and analyzed in a quantitative way using appropriate databases, models and algorithms that interact with geographic information systems (Stuczyński et al., 2004).

Soil-forming processes are very long-lasting; they last for at least several hundred years. Experiments carried out in just a few years, conducting remediation of post-mining areas, showed a positive effect of hemp and alfalfa cultivation on the initiation of soil-forming processes and a gradual improvement of the fertility of the initial substrate. Hemp also proved to be a plant capable of absorbing heavy metals from degraded soils.

High resistance of plants to diversified weather condition, diseases and pathogens, reasonable agrotechnical and fertilizing requirements, relatively low maintenance costs of phytoremediation *Cannabis sativa* L. plantation, and finally the possibility of industrial biomass use create hemp a leader in phytoremediation among domestic industrial plants e.g. in Poland.

The presence of heavy metals in the soil does not adversely affect the development and yield of fibrous plants. The content and distribution of heavy metals in particular parts of plant varies and depends mainly on the plant species and the concentration of heavy metals in the soil. The highest concentration of Cu was found in the seeds, whereas Pb in the stems and then in the fibre.

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