

OVERVIEW: THE PROSPECT OF THE USE OF ENERGY CROPS FOR BIOLOGICAL RECLAMATION OF DISTURBED LANDS

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Abstract. The article deals with the theoretical principles of the biological reclamation of disturbed lands. The best types of plants to be used for biological reclamation of disturbed lands are determined. The successful experience of biological land reclamation in Ukraine as a result of mining and extraction works is analyzed. The possibility of application of such energy crops as miskanthus, switchgrass, poplar, willow and paulownia.

Key words: recultivation, phytoremediation, disturbed lands, energy crops, miskanthus, switchgrass, poplar, willow, paulownia.

1. Introduction

Rapid urbanization and the ever-increasing needs of society in minerals, energy resources and building materials cause not only anthropogenic pressure on all components of natural landscapes, but also the alienation of large areas of land. Millions of hectares of land are directly affected by industrial development, which results in the changes of the relief of the earth's surface and destruction of vegetation and soil cover. Among the great variety of ways of disturbing the soil, mining operations in the open way have the most negative consequences because the transformation and even complete destruction of the soil and vegetation cover change the ecological situation of the territory in which the technogenic landscape changes the hydrological and hydrogeological regimes, and toxic elements and compounds are frequently introduced into the biological cycle. [1, 2].

According to [3,4], the total area of disturbed lands in Ukraine currently exceeds 265 thousand hectares, including over 82 thousand hectares occupied by peat extractions. Most of these lands are allocated to the mining industry, as a result of which about 8 thousand hectares of land belonging to agriculture or forestry are attracted annually for its needs. Thus, due to the large volumes of minerals mining, the problem of the restoration of territories affected by open developments is inherent to almost all industrialized countries. Therefore, in order to reduce the negative effects of the impact on the environment of the developed openings of quarries, measures should be taken to reclaim the dumps by creating a permanent vegetation cover. The possibility of involving energy crops for biological reclamation is also worth considering.

2. Presentation of the main material

Reclamation of disturbed lands is a part of the problem of rational use of natural resources and environmental protection. According to literary sources, land reclamation is a complex of engineering, mining, reclamation, biological, sanitary – hygienic and other measures aimed at the return of the areas affected by the industry to various uses – agricultural, forestry, etc. [5–7]. Reclamation objects can be career pits, waste heaps, dumps, tailing pits and settling tanks, as well as the areas affected during extraction and enrichment of minerals. As a result of technological processes, during which the land is disturbed, a lot of breeds of different composition and properties are placed on the earth's surface. In view of this, the possibility and direction of reclamation of the affected areas are determined.

The process of reclamation of disturbed territories is mainly divided into two main stages: mining- technical and biological. The mining-technical stage of land reclamation involves the formation of terraces, bringing slopes and quarries into the steady state, their terracing, strengthening of the surface of dumps against water and wind erosion, the utilization of rocks of dumps, etc. [8]. The biological stage of reclamation, in its turn, is aimed at the final restoration of fertility and biological productivity of disturbed lands, creation of agricultural and forestry lands. With this method of reclamation, the restoration of the fertility of the land can be carried out in several ways, such as:

- continuous application of the soil layer on the affected earth;
- cultivation on the rocks by planting and fertilizing;
- stimulation – cultivation on rocks by introducing bioactive reagents and structurally forming polymers;
- cultivation on rocks by introducing a small amount of soil and planting perennial rapidly growing plants;

- cultivation on rocks by introducing reagents and microorganisms, etc.

The choice of direction of reclamation of disturbed lands is usually subject to the sole objective of rational and efficient use of land resources, the creation of landscapes that would meet the economic, environmental and sanitary needs of the community. The direction is determined taking into account the natural environmental conditions, the composition of the cavity soil mixtures, the provision of their elements of mineral nutrition and moisture.

At present, the greatest attention is paid to agricultural land reclamation. Grain and legume crops are grown on the open-air lands, perennial grasses are sown, and garden agro-crops are created [9, 10]. Since mining activity negatively affects the physical and chemical properties of the soil and the survival of plants, their restoration can be achieved by using such plant species that are able to tolerate specific soil properties within the mine workings. In Table 1 the types of plants used for land reclamation are shown [11, 12].

Table 1

Types of plants used to restore affected lands

Type of plants	Type of mine, country	Influence, profit
<i>Ailanthus altissima</i> (aylant the highest)	Open Coal Mine, China	Mixed forest contributed to the absorption of C.
<i>Alnus glutinosa</i> (black alder)	Open Sand Mine, Poland	Stimulating the development of microbial communities and the restoration of soil
<i>Cercis canadensis</i> (Cherassis Canadian)	Coal Mine, USA	Help in initial changes
<i>Dalbergia sissoo</i> (farbergly)	Coal and sulfur mine, India	Soil restoration, biological recovery
<i>Eucalyptus camaldulensis</i> (Eucalyptus kamandulsky)	Calcite, phosphorus and other non-metallic mine dumps, Mexico	Increasing the diversity of mycorrhiza and rhizospheric mushrooms
<i>Fraxinus</i> spp.(ash)	Coal Mine, USA	The growth of biomass
<i>Larix decidua</i> (larch European)	Mine of sand and sulfur, Poland	Changing microbial biomass
<i>Liriodendron tulipifera</i> (yellow ash)	Coal Mine, USA	The growth of biomass
<i>Pinus tabuliformis</i> (pine)	Open Coal Mine, China	Mixed forest contributed to the absorption of C.
<i>Pinus sylvestris</i> (pine usual)	Open sandstone, mine from brown and coal, Poland	Stimulating the development of microbial communities and the restoration of soil, the growth of biomass
<i>Populus suaveolens</i> (poplar perfume)	Open mines, the north-east of Germany	The growth of biomass
<i>Ulmus pumila</i> (dwarf elm)	Open Coal Mine, China	Mixed forest contributed to the absorption of C.
<i>Quercus</i> spp. (oak)	Coal Mine, USA	The growth of biomass
<i>Quercus robur</i> (ordinary oak)	Coal Mine, Italy	High carbon uptake after 34 years of growth

As one can see from Table 1, great advantage in the restoration of land mines and dumps is given to woody plants. As a result of their planting there is an improvement in the physical, chemical and microbiological properties of soils.

In addition, during developing the ways and methods of biological reclamation of dumps, the results of their natural overgrowth are of great importance. At the initial stages of dumps overgrowing, seeds of woody and herbaceous plants that are characterized by high

germination energy, a long period of similarity preservation, intensive root system growth, drought tolerance, etc. are deposited on them from adjacent territories. According to studies [13–17], natural overgrowing of loamy and clay dumps begins in the first year of retrieval, where germination of such weeds as *Oberna behen*, *Convolvulus arvensis* L. (field bindweed) and *Ambrosia artemisiifolia* L. (common ragweed) is mostly observed. After 5–10 years, germination of dense- and non-dense bushy cereals such as *Elytrigia repens* (couch grass), *Poa angustifolia* L., *Festuca valesiaca* Gaudin (volga fescue) is observed in the dumps: as well as two- and multi-year grasses such as *Melilotus officinalis* (yellow melilot), *Medicago romanica*, *Reseda lutea* L. (yellow mignonette), *Salvia tesquicola* etc.

Natural overgrowing of ferruginous-quartzite shale dumps is carried out after 5–10 years of filling. The plant world in this case is represented by some types of weeds: *Melilotus albus* (white melilot), *Hieracium virosum* (hawkweed), *Polygonum aviculare* L. (common knotgrass). Then, at 10–15 year old dumps, conditions for the growth of the ruderal species such as *Artemisia absinthium* L. (wormwood), *Salsola tragus* L., *Bromopsis inermis* (smooth brome) and others are formed.

At present, the greatest experience in the field of biological reclamation of mining areas in Ukraine has been acquired in the coal industry. Thus, in the course of restoration of land in the Dnipro brown coal basin, a layer of fertile soil is applied; lime and brown coal ash are introduced, with the subsequent cultivation of perennial grasses. The experience of successful land reclamation is within the Donbas and the Lviv-Volyn Basins. At the enterprises of the ferrous metallurgy the lands which were disturbed during the time of the open development of deposits of iron and manganese ores are the subject of reclamation. Among the iron ore enterprises, the Komish-Burunskyi Metallurgical Plant possesses the greatest experience that, as a result of land reclamation, transferred more than 600 hectares of rehabilitated areas for agricultural use. There were received 17 c/ha of wheat and 280 c/ha of green corn on this territory. At the same plant there is an experience of using dump for planting gardens [3].

At “Ordzhonikidzevskyi GOK”, a phased system of land reclamation was carried out, which after the first stage resulted in the transferring of the restored lands to agricultural enterprises for temporary use (from three to five years) for multi-year grass cultivation. At the second stage of the re-cultivation, the area is re-planned and covered with a layer of black earth. The yield of perennial grasses on re-cultivated land is 45 c/ha, annual crop is 27.5 c/ha, winter wheat – 34.5 c/ha, corn for grain – 38.2 c/ha, maize for silage – 287 c/ha.

A successful recovery project is also the reconstruction of the Ankivskyi career in Kryvbass. Maple, acacia, poplar and other trees were planted in the dumps, which got accustomed well. The average growth of trees was 0.36–0.60 m/year. At the dumps in Polissia and the forest-steppe of Ukraine the recommendations for improving the productivity and sustainability of forest stands have been worked out by introducing black alder and perennial lupine phytocoenoses into crops [3, 8].

Also, in Ukraine there were successfully carried out works on forest reclamation of waste dumps: Stryzhivskyi brown coal (196 hectares were planted) and ilmenite ores (825 hectares) in Zhytomyr region; Yurkivskyi brown coal (640 hectares were planted) and Novoselytskyi kaolin clay (50 hectares) in Cherkassy region; Aleksandriia brown coal (1407 ha) in the Kirovograd region; nickel and iron ores (834 and 409 hectares were planted respectively) in the Dnipropetrovsk region; Chasovoyarskyi, Komsomolskyi and Druzhkovskyi ore managements (269 hectares) in the Donetsk region [2].

Despite the examples of successful reclamation of disturbed lands, hundreds of thousands of hectares of land are still degraded in Ukraine, mainly due to significant financial and energy costs for the implementation of this process. Therefore, for solving this problem, it is necessary to look for new ways to reclaim the lands. One of such methods may be the cultivation of energy crops on technogenically disturbed lands, which in the future may reduce the cost of conducting bio-reclamation, and eventually compensate them.

Energy crops are plants that are specially cultivated for direct use as a fuel or for biofuel production. Among such crops the most widespread are *Salix* spp., *Populus* spp., *Mischantus* spp., *Paulownia* spp., *Panicum virgatum* and others [18, 19].

From 130 to 140 thousand hectares have been provided for growing energy crops in the European Union. Table 2 provides data on the area of energy crops allocated in some countries of the European Union [20, 21].

As can be seen from Table 2, the largest area of cultivating energy crops is in Great Britain for *Miscanthus* and in Poland for Willows. This is mainly due to the fact that the European Union has a large potential of lands available for growing energy crops. The cultivation and the yield of energy crops directly depend on climatic, soil and other conditions, as well as on frost and drought tolerance. Table 3 shows the characteristics of energy crops in relation to growing conditions [22].

Table 2

Areas under energy crops in the EU, ha

EU countries	Willow	Poplar	Miskanthus
United Kingdom	1500-2300	–	10000-11000
Netherlands	–	–	90
Austria	220–1100	880–1100	800
Sweden	11000	550	450
Ireland	930	–	2200
Germany	4000	5000	2000
Poland	5000–9000	300	–
Lithuania	550	–	–
Denmark	5600	2800	60

Table 3

Characteristics of energy crops in relation to growing conditions

Kind of culture	Need for water	Frost resistance	Drought tolerance
Willow (<i>Salix</i> spp.)	high	high	low
Poplar (<i>Populus</i> spp.)	average	average	average
Switchgrass (<i>Panicum virgatum</i>)	average	high	average/high
Miskanthus (<i>Mischantus</i> spp.)	average/high	average	low

According to many studies, it is promising to grow such energy crops as Miskanthus, Switchgrass (proso millet), Willow and Poplar on polluted or technogenically disturbed lands.

Miskanthus is a perennial rhizome grass. After a single planting, the culture can be harvested annually for 15 years or more. Miskanthus has a well-developed root system, characterized by rapid growth and good resistance to low temperatures. Soils of medium density with a low level of groundwater are suitable for growing of such culture. It should be noted that due to the low ash content of biomass and nutrient content, their removal is small, and fallen biomass is effectively used in soil formation processes, so it can be effectively used to preserve and enhance soil fertility and, accordingly, to rehabilitate lands that have been disturbed by mineral extraction [23–25].

Switchgrass, or millet, refers to perennial grasses. It can grow on all types of soils. It is insensitive to the moisture content and nutrients in the soil, resistant to pests and diseases. It is a drought-tolerant plant with well-developed root system. It can grow for 10–15 years in one place. Like miskanthus, it can be used to reclaim broken lands after coal mining [26, 27]

Energy willow is a tree-like culture that allows creating high-yield plantations with a long life span. The

culture is characterized by high growth rates in the length. Willow plantations remain productive for 20–30 years, and the crop during this period can be harvested every 2–3 years. The degree of evaporation of willow is 3–5 times lower than of grain crops, besides, about 60–80% of nutrients return to the ground with the fallen leaves. Positive is the fact that the willow is resistant to frost and drought, it can grow on different types of soils, in wet lands that provide good water supply, even on unproductive lands that require reclamation [28].

Poplar as well as willow refers to perennial tree-like energy crops. It is resistant to pests, can grow on poor soils and contaminated lands, but it is less frost-resistant. Similar to other energy crops such as miskanthus and ivitchgras, poplars can also grow on weakened or technogenically disturbed lands [29].

In addition to the above-mentioned energy crops, *Phalaris arundinacea* and *Paulownia* spp (*Pavlovnia*) are common in the European Union.

Reed canary grass (*Phalaris arundinacea*) is a tall, rhizome grass. It is a moisture-loving culture that grows well on flood and wetlands, also withstands prolonged flooding. It should be noted that if the previous plants are new for the conditions of Ukraine, the reed canary grass until recently has been widely used as a fodder crop.

According to studies [30], this crop ought to be used in the reclamation of developed peatlands. Considerable attention was paid to this crop for the rehabilitation of the produced peatlands in Finland, where its positive impact on the ecological component, in particular, the improvement of the use of nutrients from the soil was noted. In addition, it has been established that the cultivation of reed canary grass on the land with high groundwater levels is more productive even than the miskanthus.

Paulownia is a fast-growing tree-like crop. It has a well-developed root system. It is unpretentious to fertility and moisture of the soil and can grow on degraded soils. Paulownia is resistant to pests and can withstand low temperatures. After cutting it is restored for three years. Paulownia has a high coefficient of fixation of carbon [31, 32]. It can be used for the reclamation of disturbed lands [33].

Considering the above, energy crops can form a high potential for yield, under different climatic conditions. Upon completion of the vegetation, these crop plants can be processed, which can result in biofuels. In addition, the cultivation of energy plants in on the lands disturbed by mining will allow returning them to rural or forest use.

Conclusion

In the conditions of the existing technogenic influence on the biosphere, measures to eliminate the damage caused to nature become relevant. There is a need for the transition from modern industrial to environmental production. In solving this problem the biological reclamation of lands becomes very important.

Restoration of disturbed lands by means of biological remediation is an important component of the problem of rational use of natural resources and environmental protection. Thanks to biological reclamation, hundreds of thousands of hectares of degraded land can be returned to agriculture and forestry. When developing ways and methods of biological reclamation of disturbed lands, the results of their natural overgrowing are of great importance. At the initial stages, seeds of woody and herbaceous plants characterized by high energy of germination enter disturbed lands from adjoining territories. In addition, crops are cultivated on such lands. In Ukraine, there are examples of successful land reclamation caused by mining operations, where wheat, corn and other crops are grown.

In recent decades, due to the decrease of agricultural land in Ukraine and in the world, scientists are considering the possibility of cultivating energy crops on degraded lands which at the same time are phytorecultivators of such lands. Growing such crops on degraded lands will increase the agronomic value of these soils.

High productivity of energy crops biomass can turn the technology of biological reclamation into a profitable business for the bioenergy industry.

Consequently, the use of energy crops as phytorecultivators will solve energy, economic and environmental problems.

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