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Efficiency of Vegetative Reclamation of Coal Spoil Heaps

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ABSTRACT
Coal spoil-heaps cause man-made pressure on the environment of the coal mining area. Coal mining, and in recent years the mass closure of mines, have been accompanied by a negative impact on natural objects and engineering structures; the basements of houses and buildings are flooded, walls and wooden fences rot, crops, trees and bushes are destroyed. Reclamation is carried out on spoil-heaps of coal mines to reduce the man-made pressure. However, in the process of rock dumping on the spoil-heaps ,a neorelief begins to emerge causing the vegetation development. The emergence of vegetation groups is a positive phenomenon, as phytomass decomposition promotes the formation of humus. The development of vegetation on the surface of coal spoil-heaps is called vegetative reclamation or phytomelioration. The efficiency of vegetative reclamation is calculated in points and is an indicator of the suitability of a particular man-made object for natural overgrowth. The aim of the work was to establish the features of spatial arrangement of plants in populations on the surface of coal spoil-heaps. It was established that on the coal spoil-heaps, as well as under natural conditions, vegetation tends to aggregate, thus forming phytogenic fields. It should be noted that at different stages of successions, phytogenic fields are formed in different ways. A monocentric phytogenic field arises on the waste heaps during the syngenetic stage of succession. The initial endecogenetic stage of succession provides the formation of phytogenic fields of two types. The first type is the initial polycentric phytogenic field. It is characterized by the ability to combine several individuals of the same species. The second type is a mature polycentric phytogenic field. It is characterized by higher resistance, and plant community is already able to convert geoprocesses. The mature endoecogenic stage of succession is characterized by the development and expansion of tree species, and the phytogenic field is acentric and global. This kind of phytogenic fields is found on tailings with artificial vegetative reclamation.

Keywords: environmental safety, phytogenic field, coal mine, tailing, phytocenosis, forest crops, reclamation.

INTRODUCTION

Mining is followed by intense changes in natural energy and mass transfer. Huge mass of coal, rocks and groundwater is excavated from the subsoil to the surface, which has led to the development of numerous negative phenomena that worsen the ecological state of the region [Petlovanyi et al. 2019]. In the Novovolynsk mining area, which is part of the Lviv-Volyn coal basin, there is a significant transformation of hydrogeological conditions, changes in the balance and regime of groundwater, drainage and fracture of rocks, subsidence of the surface, the formation of highly mineralized acidic waters [Bosak et al. 2020, Gorova et al. 2012].

Coal mining, and in recent years the mass closure of mines have been accompanied by a negative impact on natural objects and engineering structures – the basements of houses and buildings are flooded, walls and wooden fences rot, crops, trees and bushes are destroyed. As a result of such phenomena, deformations of rock massifs, structures, communications, secondary salinization and soaking of soils, the formation of powerful flows of polluted water and gas (methane) take place [Kazankapova et al. 2020, Rudnev 2002].

The coal deposits of the Lviv-Volyn coal basin are characterized by a tense state of the environment, caused by bogging of agricultural lands and forests, subsidence on the surface of 1–3.5 m, negative impact of mines and waste heaps on water intakes, wells in villages and private wells used for drinking purposes; surface waters have a salinity of 0.9–1.6 g/l, and some watercourses contain petroleum products, phenols, nitrates, manganese, iron in the volumes that exceed the MAC (especially in the rivers of the Western Bug, Rata and Studyanka) [Petlovanyi and Medianyk 2018, Skrobala 2020].

Mine tailings, as separate biological systems with their successional processes, require first-priority reclamation. It is known that waste heaps are exploited without complying with normative documents requirements, so the issue of their closure and reclamation does not appear on the agenda of government agencies. The ecological, sanitary, hygienic and epidemiological status of waste heaps does not meet the requirements, and therefore causes significant man-made influence on living organisms [Abramowicz 2021a, Petlovanyi 2019]. The physico-chemical and biogenic processes occurring in the tailings require detailed investigation for reducing the harmful effects on the environment and living organisms [Abramowicz et al. 2021b]. Vegetative reclamation takes into account the renatural approach of geosystems rehabilitation. The bioenergy of phytogenic field is the driving force of endoecological succession, which is relevant for the devastated landscapes of the mining industry and landfills. The active phytogenic field causes the continuum of plant cover. Vegetative reclamation is one of the most effective methods for reducing the ecological hazard of devastated landscapes [Šebelíková 2018, Sýkorová 2018]. The investigation of the natural transformative function of plant communities in disturbed territories is an important task of ecological safety of mankind.

The aim of the work was to establish the features of spatial arrangement of plants in populations on the surface of coal spoil-heaps.

MATERIALS AND METHODS

Investigation of the spatial location of plants on the surface of spoil heaps of coal mines were conducted in the Novovolynsk mining area being a part of the Lviv-Volyn coal basin (Ukraine) in the period 2007–2020. Vegetation development was described for the “Mine № 2 Novovolynska”, “Mine № 6 Novovolynska” and “Mine № 9 Novovolynska” waste heaps. The trial areas were established by using the method of species sites of 10x10 meters for artificial phytocenoses and 1x1 meter for natural phytocenoses. The following methods were used: pedological, phytocoenotic, biological, and ecological.

Variance of individuals in a population was calculated by the formula (1) [Kucheryavyi 2000]:

$$S^2 = \frac{\sum(\bar{x} - m)^2}{n-1}, \tag{1}$$

where: S^2 – variance of individuals; т – number of individuals in the series; п – number of series; $\bar{x}$ – average number of individuals.

RESULTS AND DISCUSSION

The process of natural regeneration on the waste heaps (Mines 2, 6, 9 of Novovolynsk) is observed partially on the slopes and at the foot of the heap. However, woody vegetation undergoes certain physiological changes. At the top there is a natural recovery of *Populus tremula* L., which became dwarf here (Fig. 1). This is due to strong winds and low fertility of the substrate.

While investigating the ecological safety of phytogenic fields on the example of the Novovolynsk mining area, it is necessary to pay attention to the formation of vegetation cover of reclaimed tailings. There is syngenetic (pioneer) succession on the tailings with natural rehabilitation. Pioneer succession in the future should transform into endoecogenetic. In artificial plantations there is an endoecogenetic succession of the initial stage. In this regard, the species planted in waste heaps in the 1980s predominate: English oak, weeping birch, sallow, robinia. In total, 19 non-reclaimed (inefficiently reclaimed) waste heaps were found in the region; three of them are damping. The total area of disturbed land is 116.7 hectares. An important role for

Figure 1. Dwarf *Populus tremula* L. at the top of waste heaps of coal mines

optimization of the disturbed places is played by natural vegetation, since it may be an indicator of the state of the rocks the waste heaps are made of. The investigation of phytocoenoses, which are formed during self-organized vegetation, gives an opportunity to estimate the communities appeared, taking into account the place and role in the plant cover of the region and predict their further development.

During field study the sample areas were chosen in compliance with the terrain. It is caused by the fact that the waste heaps have a complex structure. The top of the waste heap is clearly defined, so the fine particles and nutrients are washed off. Slopes are the transit zone from which the small particles of the rock transport to the foot of the heap. The substances washed away from the top accumulate in the cumulative zone. In this zone, the most favorable conditions for the development of vegetation are created.

On the coal spoil-heaps, as well as under natural conditions, vegetation tends to aggregate, thus forming phytogenic fields. The emergence of vegetation groups is a positive phenomenon, as phytomass decomposition promotes the formation of humus.

The aggregation degree depends on the conditions of location, weather and other physical factors, the nature of species reproduction and its "tolerance." Aggregation enhances the competition between individuals for nutrients and living space (complex phytocoenosis on damping tailings). However, this negative aggregate indicator is positive, as it contributes to the survival of the group. Aggregation is the main factor in the formation and development of phytogenic fields on mine tailings.

In order to investigate the formation of phytogenic fields on the tailings of coal mines, it is necessary to investigate the spatial structure of vegetation on the surface. Variance was used to investigate the spatial structure of vegetation on reclaimed and damping heaps. Estimation of the spatial structure of the population depends on the average density or the method of distribution of individuals.

Let us consider the spatial arrangement of individuals in the phytogenic fields on the waste heaps in the case of the Novovolynsk mining area.

Regular arrangement of the population individuals (reclaimed tailings)

The variance of individuals in a population was calculated as in the case of phytocoenoses with *Robinia pseudoacacia* on reclaimed tailings. Three sample areas with a size of 10×10 m were taken for research, each with 12 acacia individuals. Then the variance was calculated, according to formula 1:

$$S^2 = \frac{(12\text{-}12)^2 + (12-12)^2 + (12-12)^2}{3-1} = 0. \quad (2)$$

Thus, in the Robinia pseudoacacia row planting, the number of individuals in each sample is constant and equals the average, the variance is zero $S^2 = 0$.

Group arrangement of the population individuals (damping tailings)

On the damping tailings plants enter in aggregations at different succession stages. Variance was evaluated for the largest group populations of coenoses with *Plantago lanceolata, Arctium lappa, Daucus carota, Atriplex patula*. Three trial areas, 1 × 1 m in size, were established.

The population of *Plantago lanceolata* comprised 6, 14, 15 individuals in the group, hence the variance is (see formula 1):

$$S^2 = \frac{(11.6-6)^2 + (11.6-14)^2 + (11.6-15)^2}{3 - 1} = 16.2m^2. \quad (3)$$

Therefore, the variance of the species is 16.2 m². The population of *Arctium lappa* in the group was 5, 9, 13 individuals, while the variance is:

$$S^2 = \frac{(9-5)^2 + (9-9)^2 + (9-13)^2}{3-1} = 16m^2. \quad (4)$$

Thus, the variance of the species is 16 m².The population of *Daucus carota* comprised 6, 8, 14 individuals in the group, while the variance is:

$$S^2 = \frac{(9.3-6)^2 + (9.3-8)^2 + (9.3-14)^2}{3-1} = 17.3m^2. \quad (5)$$

The variance of the species within the population is 17.3 m². The population of *Atriplex patula* comprised 7, 8, 14 individuals in the group, hence, the variance is:

$$S^2 = \frac{(9.6-7)^2 + (9.6-8)^2 + (9.6-14)^2}{3-1} = 14.34\,m^2. (6)$$

The variance of common orache within the population is 14.34 m².

Random arrangement of individuals of the population (damping tailings)

This type of arrangement is mostly inherent for the plants that do not try to group together and the phytogenic fields of with are dispersed. The calculations of variance for *Taraxacum officinale, Tussilago farfara, Chamomilla suaveolens* are given below. Individual calculations were carried out on an area of 1 × 1 m.

For *Taraxacum officinale* the number of plants in this area was 13, 18, 20 individuals, then the variance of individuals is as follows (see formula 1):

$$S^2 = \frac{(18.3-13)^2 + (18.3-18)^2 + (18.3-20)^2}{3-1} = 15.6m^2. (7)$$

Therefore, the variance of the species is 15.6 m². For *Tussilago farfara* the number of plants in this area was 15, 21, 27 individuals, then the variance of individuals is as follows (see formula 1):

$$S^2 = \frac{(21-15)^2 + (21-21)^2 + (21-27)^2}{3-1} = 36m^2. \quad (8)$$

Thus, the variance of the species is 36 m².For *Chamomilla suaveolens* the number of plants in the area of 1 × 1 m was 9, 15, 18 individuals, then the variance of individuals is as follows (see formula 1):

$$S^2 = \frac{(14-9)^2 + (14-15)^2 + (14-18)^2}{3-1} = 16m^2. \quad (9)$$

Hence, the variance of the species is 16 m². As a result of the calculations of the individuals variance, it was found out that with regular arrangement in each sample, the number of *Robinia pseudoacacia* individuals is constant and equal to the average value, the variance is zero $S^2 = 0$. Stable plantations, which correspond to the mature endoecogenetic stage of succession, are present. The phytogenic field created by plantations is acentric and provides a further "chain" of vegetative reclamation, which should end with a continuum. This is the best variant of adapting the environment of man-made tailings to living conditions. The results of studies of the variance of individuals in populations are shown in Table 1.

In the case of group arrangement of the population, within the research areas, the ratio of variance to the number of individuals is an intermediate step between uniform and random variance ($S^2 > т$). It involves an initial stage of endoecogenetic succession. Plants, which are predominantly ruderocenosis, are already not capable of forming stable plantings, but are united into groups and create a common polycentric phytogenic field. Polycenteric phytogenic fields at the initial stages of endoecogenesis are formed in two stages: initial and mature. The initial polycentric phytogenic field is formed by 6–8 individuals of the same species. The mature polycentric phytogenic field is formed by 13–20 individuals (plants of single or several species).

Table 1. Dispersion of the species composition of vegetation in the areas of waste heaps

No.	Species composition of vegetation	S^2
1	*Robinia pseudoacacia*	0
2	*Atriplex patula*	14.3
3	*Taraxacum officinale*	15.6
4	*Arctium lappa*	16
5	*Chamomilla suaveolens*	16
6	*Plantago lanceolata*	16.2
7	*Daucus carota*	17.3
8	*Tussilago farfara*	36

At a random arrangement of individuals, the variance is approximately equal to the average value of the plants of the population, while there is a tendency to the accumulation of plants ($S^2 \geq \tau$). Random species distribution is typical for damping tailings with monocentric phytogenic fields.

It should be noted that at different stages of successions, phytogenic fields are formed in various ways. Monocentric phytogenic field arises on the waste heaps during the syngenetic stage of succession. The initial endecogenetic stage of succession provides the formation of phytogenic fields of two types. The first type is the initial polycentric phytogenic field. It is characterized by the ability to combine several individuals of the same species. The second type is a mature polycentric phytogenic field. It is characterized by higher resistance, and plant community is already able to convert geoprocesses. The mature endoecogenic stage of succession is characterized by the development and expansion of tree species, and the phytogenic field is acentric and global. This kind of phytogenic fields is found on the tailings with artificial vegetative reclamation.

The results of the presented research can be used during the biological stage of the reclamation of the waste heaps (tailings) of coal mines.

The results of research of phytogenic fields formation on the devastated landscapes and their relationship with vegetative reclamation are considered for the first time. The academic studies mentioned in this work established the basis for determination the relationship between the phytogenic field and vegetative reclamation.

CONCLUSIONS

The man-made pressure on the environmental safety of coal mining areas was investigated. There were 9 mines in Novovolynsk mining area resulting in 28 waste heaps. These dumps, in addition to man-made pressure, violate the aesthetics of the environment. In order to increase the aesthetic appearance the dumps were reclaimed. However, there were only 3 of them. The rest of the dumps were subject to natural overgrowth.

The spatial structure of phytogenic fields based on the variance is established. The random arrangement of phytocoenoses is observed at the syngenetic succession stage in the case of plants striving to form a community. The uniform arrangement is inherent in artificial phytocoenoses of robinium. With a uniform arrangement there is no competition for living space. Uneven arrangement belongs to species communities on the tailings, where plants form phytogenic fields of populations.

In general, the main geoecological problems of the Novovolynsk mining area caused by the closure of mines are: deterioration of the ecological and hydrological condition of water resources; activation of exogenous geological processes; hydrogeomechanical stresses of the geological environment; change in the landscape-geochemical state of the territory, due to man-made factors and the activation of geochemical processes in soils, the development of salinity with chloride and sulfate ions, as well as a decrease in acidity. In order to overcome these negative factors, waste heaps must be reclaimed.

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