Purpose. Substantiation of the parameters and development of a program structure of the information system assuring the underground mining safety based on the comprehensive assessment, operational forecasting and prospective scenarios of geomechanical processes.

Methodology. The project of the information system was developed using the methodology of the design of program models of computational processes, mathematical modeling of geomechanical processes performed using the laws of physics of rocks and continuum mechanics.

Findings. The parameters and structure of the new information system for the underground mining safety control based on the geomechanical factors has been developed. It includes: the subsystem that provides effective personnel management at industrial enterprises based on network communications technologies and mobile telephony; reference and information subsystem of decision support, that provides data collection, information on request, the primary analysis of normative and technical documentation, search for reasonable process parameters via the analysis unit; interactive subsystem of mining operations safety assessment based on the geomechanical factor, which takes into account the synthesis of algorithms for evaluation of the control object based on the mathematical apparatus of fuzzy logic, operational forecasting and prospective scenarios of geomechanical processes based on the state of local models of rock massif. The safety is assured through the increase of the staff cooperation effectiveness, disciplinary liability, as well as through the operational forecasting of the rock massif state and making early decisions on the maintenance of workings in the accident-free state.

Originality. The technique of design of the information system for the underground mining safety control has been developed. It takes into account the operational forecasting and prospective scenarios of geomechanical processes.

Practical value. The use of information systems in mining allows us to increase the efficiency and safety of operations by ensuring the transmission and recording of operational information in the process of control over the solving of current problems, and through fast response to the emergencies caused by geomechanical factors.

Keywords: *mining safety, information system, simulation, geomechanics*

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O.H. Iziumova, Cand. Sci. (Biol.)

Zhytomyr State Technological University, Zhytomyr, Ukraine, e-mail: oksanaas1@rambler.ru

FORMATION OF WATER-PHYSICAL PROPERTIES OF SOIL IN RECULTIVATED AREAS

О.Г. Ізюмова, канд. біол. наук

Житомирський державний технологічний університет, м. Житомир, Україна, e-mail: oksanaas1@rambler.ru

ФОРМУВАННЯ ВОДНО-ФІЗИЧНИХ ВЛАСТИВОСТЕЙ ГРУНТУ РЕКУЛЬТИВОВАНИХ ТЕРИТОРІЙ

Purpose. To study the physical processes of formation of physical and water-physical properties of sod-podzolic soil in the areas reclaimed after mining developments for practical measures on full implementation of the ecosystem functions of soil under technogenesis conditions.

Methodology. The methodological basis of research was the concept of environmental monitoring. Conventional methods in ecology, field and laboratory ones, were used for the research. In the field studies, the methods of comparative analogy with regional control were used. The laboratory tests were conducted in accordance with generally accepted in soil science certified and standardized methods.

Findings. Under natural soil conditions, a 30-year period after the remediation is insufficient to restore the evolutionary balanced parameters of physical structure of the soil. The residual effects of its physical abuse appear to change the density compilation, porosity and, consequently, the quantitative characteristics of water-physical constants and forms of soil moisture reserves.

Originality. For the areas reclaimed after opencast mines, the time and quantitative parameters of forming the physical structure and water-physical constants of disturbed soil by natural soil conditions were first established. The possible scenarios for forming stocks of productive moisture in the plow layer of soil were shown.

Practical value. The regularities of forming agrophysical soil properties can be used by mining companies to justify the technical specifications of the restoration of land after opencast mines and by farms to develop measures aimed at regulating elements of disturbed soil fertility and improvement of technological schemes of growing crops on the reclaimed areas.

Keywords*: recultivated area, soil porosity, density compilation of soil, soil moisture, water and physical constants, soil moisture reserves*

Introduction. The intensive use of mineral deposits in Ukraine for a long period has negatively affected the efficiency and environmental condition of the land involved in mining developments. Holding open cast mining seizes large areas of the productive land from agricultural use, destroys the earth relief, and produces large overburden dumps [1]. Therefore, one of the most effective measures for reproduction of the natural state of the soil is the reclamation of areas disturbed by mining development and returning them to the condition which is the most suitable for agricultural production [2].

Unsolved problems. Conducting reclamation is associated primarily with drastic violation of evolutionary balanced indicators of physical structure of the soil, including the soil bulk density. This index serves as the main criterion for the physical constitution of the soil and determines the full range of natural, water-physical and agrochemical soil characteristics and modes. The indicators which characterize the degree of soil damage, except for the compilation density, include the total porosity with ratio between non-capillary and capillary porosity being of great importance. All these factors are interrelated and have a significant impact on the edaphic conditions of plants.

An important factor to optimize the water-air regime of disturbed soils includes water-physical constants: full water capacity (FWC), the lowest (field) moisture (LM), moisture of capillary connection rupture (MCCR) and the index of permanent wilting moisture (PWM). These characteristics reflect not only quantitative extent of wetting of the soil, but also qualitative characteristics of soil moisture regarding the degree of mobility and availability for plants [3].

Analysis of recent research. At the beginning of the second half of the last century, a concept of "natural fertility" of soils was introduced. N.A. Kaczynski was the first to prove the need of studying the physical properties of soils on account of their genetic characteristics. The works by I.B. Revut of the same period described basic theoretical principles of physics on the implementation of the soil, in mining reclamation of waterlogged lands, which were subsequently updated and summarized within ecological studies [4]. In recent times, the research has been focused on setting the parameters of the physical constitution of soil for different soil and climatic regions of Ukraine, together with the technological aspects of growing crops [5–7]. Generally, authors agree that the most favourable conditions for the development of plants develop with total arable soil porosity of 55–60% and ratio between non-capillary and capillary porosity in the range from 1: 1 to 1: 3.

Unsolved aspects of the problem. Despite the scientific and practical relevance of the issue, the accumulation of experimental data on formation of water-physical soil characteristics under conditions of technogenesis is not sufficient. In particular, recovery time characteristics of the physical constitution parameters and water-physical constants of the disturbed soil under natural conditions have not been explored regarding reclaimed areas.

Objectives. The aim is to establish regularities of the processes of restoration of natural and water-physical properties of sod-podzolic soil on the areas reclaimed after mining development.

Main research. The results of studying the water-physical properties of soil are shown on the basis of our studies conducted on sod-podzolic sandy soils of Volodarsk-Volynskiy region of Zhytomyr oblast, located within the territorial limits of Irshans'k ore mining and processing enterprise (lmenite ore). Reclaimed in the mid 80-ies, the industrial area (Fig. 1) with a total of over 80 hectares was not in agricultural use, thus creating conditions for the research of recovering agrophysical characteristics of the soil of the reclaimed areas influenced by natural factors. Undisturbed samples (monoliths) of 0–20 cm soil layers were selected for laboratory testing of parameters of water-physical constants on the reclaimed and control sites; the parameters were determined in 8-times repetition using cylinders with a capacity of 109 cm^3 and height of 5 cm. They featured the following: full water capacity by pouring monolith after its capillary water saturation; lowest moisture using a modified methodology of Dolgov S.I.; moisture of capillary connection rupture using an accelerated method of Mackiewicz V.B.; permanent wilting moisture was determined according to soil moisture on the borders wetting, method by Dolgov S.I. Soil moisture was determined by thermostat-gravimetrical thermal regime of drying of 105° C.

Fig. 1. General view of the reclaimed land (natural herbage)

The research has shown that a 30-year period of undisturbed state of the reclaimed areas was not sufficient to fully restore the indicators of its physical constitution, namely, bulk density and total porosity (Table 1). As the data show, the bulk density for arable (0–20 cm) soil stabilized at 1.14 g / cm^3 during the period and remained significantly lower than the rate in the control region (1.24 g /cm^3). It is worth focusing on the dynamics of this index on the vertical section of the soil profile. While the control region showed gradual growth of density with depth, the reclaimed region had its most significant growth in the upper topsoil. The parameters of the total porosity were changing similarly. It significantly exceeded the control values across the depth of the topsoil and soil was 58.0% for the arable (0–20 cm) which is 5.2% above the reference level.

The total porosity consists of pores of very different shapes and sizes. Obviously, the size of the pores will primarily depend on water, air, thermal and biological properties of the soil. According to modern views, the total porosity in soil is formed by capillary (<0.01 mm) and non-capillary (> 0.1 mm) types of porosity. Developing the concept of "active" and "inactive" pores in the soil, N.A. Kaczynski identifies three kinds of pores: they are between the primary particles of the soil, between microaggregates, and between macroaggregates. According to the author, the capillary porosity includes the first two forms of pores. This division of porosity is based on the different categories of soil moisture regarding its availability to plants. In the capillary pores, the movement of the moisture appears due to the influence of meniscus forces and the forces of the surface energy. Through capillary porosity soil moisture reserves are formed and the capillary rise allows the plants to use soil moisture which is beyond the root layer of the soil.

Table 1

Indicators of bulk density (g/cm^3) and total porosity (%) of soil

Soil, cm	Control		Reclamation	
	g / cm^3	%	g / cm^3	%
Layer indicators				
0–5	1.21	54.1	1.10	60.4
5–10	1.21	53.9	1.14	58.1
10–15	1.26	50.9	1.16	57.4
15–20	1.28	51.2	1.16	56.2
Average indicators				
0–10	1.21	54.0	1.12	59.2
10–20	1.27	51.6	1.16	56.8
0–20	1.24	52.8	1.14	58.0

According to the results of our research it was found out that the indicators of the capillary porosity, unlike the non-capillary porosity, were more stable and changed little in depth of topsoil for both sites. The non-capillary porosity varied significantly in depth. Its stronger performance was inherent to the upper layers of the soil. It was noticeably reduced at other levels of depth. Regularity of this distribution was the most significant in the area of the reclaimed territory. Fig. 2 shows general indicators of the distribution of porosity kinds for the arable (0–20 cm) soil of the experimental plots. From the histogram can be seen that a 30-year period after soil remediation is quite sufficient to restore the physical constitution of the soil in terms of capillary porosity. Its rating for the impaired area was 36.5% and, in fact, showed no difference from the control values (36.9%).

Non-capillary pores, in their turn, play a crucial role in air exchange and aeration of active soil because pores of this size cannot retain moisture for a long period, as consequence they are occupied by the soil air. Unlike the capillary porosity of the soil, its non-capillary forms for topsoil of the reclaim-med land exceeded the control targets by 1.4 times and reached 21.5%, as seen from the Fig. 2.

Changes in the physical constitution of the soil under the influence of remediation affected the nature of the formation of important water-physical constants (Table 2). Soil moisture, which corresponds to the full water capacity of the topsoil, increased by 5.3 to 45.6%. The crucial role in the formation of the productive moisture reserves in the soil belongs to the LM and MCCR which characterize the upper and lower limit of optimal soil watering for plants correspondingly. As it is seen from the data provided, in the reclamation area the soil moisture, which corresponds to the LM and MCCR, was significantly lower and amounted to 29.3 and 18.2%, while in the control region it made 32 and 23% correspondingly. At the same time, the moisture of steady fading on the impaired territory was less dynamic and actually corresponded to the control value.

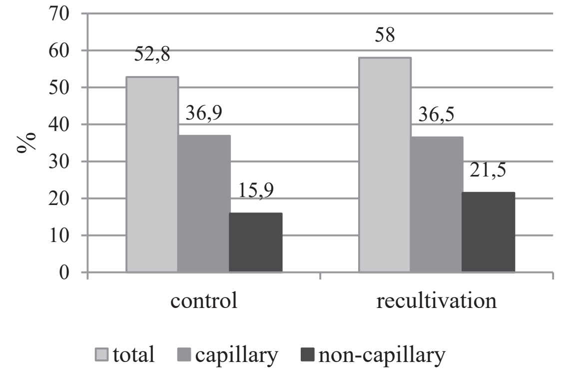

Fig. 2. Indicators of porosity 0–20 cm soil layer

Table 2

Soil moisture for relevant water- physical constants, % in the dry sole

Depth cm	Reclaimed area				Control			
	FWC	LM	MCCR	PWM	FWC	LM	MCCR	PWM
0–10	46.5	29.5	18.4	11.4	42.9	31.8	22.6	11.7
10–20	44.6	29.1	17.9	10.8	37.6	32.1	23.3	11.1
0–20	45.6	29.3	18.2	11.1	40.3	32.0	23.0	11.4

It is known that full water capacity is determined by the total porosity of the soil. It characterizes the state of watering of the soil, when all the pores are filled with water, and thus serves as a criterion of its water accumulating capacity. The research has shown that due to the reclamation the water accumulating ability of the soil increased and the total potential reserves of moisture for the 0–20 cm layer increased from 99.9 mm (control) to 104 mm (Table 3). However, the main role in watering plants is played by moisture reserves, which are lo-cated within the lowest moisture and moisture of capillary connection rupture, as they are the most easily accessible and are held by the ground for a long time. They are formed after free outflow of gravitational moisture and are held by the soil for a long time entirely due to the capillary forces. As it is se-en from the results of the research, the capacity of moisture reserves has decreased from 79.4 to 66.8 mm (LM) and from 57.0 to 41.5 mm (MCCR) as a result of remediation. A similar trend is defined regarding the changing of water reserves that correspond to the boundary of their availability for plants (PWM).

The issue of formation of soil moisture reserves considering the extent of its availability for use by plants is of practical interest. Accordingly, the following categories of soil moisture were identified: the moisture ranging from FW to LM is the most available for plants, but does not contribute significantly to their moisture because of its short occurrence in the root layer of the soil; from LM to MCCR it is available (optimum) moisture for plants; from MCCR to PWM it is difficult for plants to reach, but plays a role in their moisture; below PWM it is practically unavailable for plants [3]. According to the results of our research it is found that the transformation of the physical constitution of the soil, its porosity under the influence of the remediation conducted affects the mobility of soil moisture and its availability for plants for a long period (Table 4). As it is seen from the data provided, slight (7.1 mm) increase in potential reserves of available moisture is observed in the reclaimed area; in our opinion, it occurs due to the growth of non-capillary pore space in the soil. This assumption is confirmed by the significant growth of excess moisture in the soil, which is formed within the range of FW − LM. The volumes of growth of moisture reserves were the highest and amounted 16.7 mm for 0–20 cm of the soil layer. At the same time due to destruction of the soil pore size, the volumes of remote capillary moisture forms decreased from 28.7 mm (control) to 16.2 mm.

Table 3

Potential moisture reserves for the relevant water-physical soil constants, mm

Depth, cm	FW	LM	MCCR	PWM
Reclaimed area				
0–10	52.1	33.0	20.6	12.8
10–20	51.7	33.8	20.8	12.5
0–20	104.0	66.8	41.5	25.3
Control area				
0–10	51.9	38.5	27.3	14.2
10–20	47.8	40.8	29.6	14.1
0–20	99.9	79.4	57.0	28.3

Table 4

Distribution of potential reserves of moisture 0−20 cm of the soil layer by categories of their availability for plants

Category of availability	Reclamation		Control		"+", "–" to control, mm
	mm	%	mm	%	
Total reserves	104.0	100	99.9	100	4.1
Unavailable	25.3	24.4	28.3	27.7	–3.0
Available, total incl.:	78.7	75.6	71.6	72.3	7.1
Hard to reach	16.2	20.6	28.7	40.1	–12.5
Surplus	37.2	47.3	20.5	28.6	16.7
Optimal	25.3	32.1	22.4	31.3	2.9

Among the categories of the soil moisture regarding its availability, the category of moisture reserves, which are limited to the upper (LM) and lower (MCCR) boundaries of the optimal soil watering is of greatest practical interest. According to this indicator, the reclaimed area proved to be the closest to the control area. As it is seen from the data given, the volumes of these water reserves were at the level of 22.4–25.3 mm respectively and made 31.3 and 32.1% of the total available water in the soil.

Conclusions. Reclamation of areas involved in mining development for a long period substantially changes evolutionary balanced physical and water-physical characteristics of the sod-podzolic soil. A 30-year period is not sufficient to restore the physical constitution of the soil and its water-physical constants. The results of the remediation appear in decrease of the ratio of the bulk density of the soil, the lowest water capacity, moisture of capillary connection rupture as well as the growth of indicators of soil porosity and total capacity. The quantitative characteristics of soil moisture reserves on the reclaimed area vary regarding the extent of their availability to plants. Against the general trend toward growth of the total potential reserves of available moisture and their forms (7.1 mm), in the topsoil the volumes of unproductive (surplus) water increase (up to 16.7 mm) and its forms which are difficult to reach decrease (to 12.5 mm). The volumes of the most productive soil moisture reserves which are classified as "optimal" stabilize at a level of 25 mm which practically corresponds to the parameters obtained in the control region.

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Агроекологічний моніторинг та паспортизація сільськогосподарських земель / під. ред. О.Г. Патика, О.Г. Тараріко – К.: Фітосоціоцентр, 2002. – 296 с.

Мета. Дослідження процесів формування фізичних та водно-фізичних властивостей дерново-підзолистого ґрунту на рекультивованих після гірничих розробок територіях для практичних заходів з найбільш повної реалізації екосистемних функцій ґрунту в умовах техногенезу.

Методика. Методологічною основою досліджень була концепція екологічного моніторингу. Під час виконання роботи застосовували загальноприйняті в екології методи: польовий та лабораторний. У польових дослідженнях застосовано метод порівняльної аналогії з регіональним контролем. Лабораторні дослідження здійснювали згідно із загальноприйнятими у ґрунтознавстві атестованими й стандартизованими методиками.

Результати. Встановлено, що за природніх умов ґрунтоутворення 30-річний період після проведення рекультивації є недостатнім для відновлення еволюційно врівноважених параметрів фізичної будови ґрунту. Залишкові наслідки його фізичного порушення проявляються у зміні щільності складення, пористості та, як наслідок, кількісних характеристик водно-фізичних констант та форм ґрунтових вологозапасів.

Наукова новизна. Для рекультивованих після відкритих гірничих розробок територій уперше встановлені часові, кількісні параметри формування фізичної будови та водно-фізичних констант порушеного ґрунту за природніх умов ґрунтоутворення. Наведені можливі сценарії формування продуктивних вологозапасів в орному шарі ґрунту.

Практична значимість. Встановлені закономірності формування агрофізичних властивостей ґрунту можуть бути використані гірничими підприємствами для обґрунтування технологічних регламентів з відновлення земель після відкритих гірничих розробок та сільськогосподарськими підприємствами для розробки заходів, спрямованих на регулювання елементів родючості порушених ґрунтів, удосконалення технологічних схем вирощування сільськогосподарських культур на рекультивованих територіях.

Ключові слова: *рекультивовані території, пористість ґрунту, щільність складення ґрунту, вологоємність ґрунту, водно-фізичні константи, ґрунтові вологозапаси*

Цель. Исследование процессов формирования физических и водно-физических свойств дерново-подзолистой почвы на рекультивированных после горных разработок территориях для практических мероприятий по наиболее полной реализации экосистемных функций почвы в условиях техногенеза.

Методика. Методологической основой исследований была концепция экологического мониторинга. Во время выполнения работы применяли общепринятые в экологии методы: полевой и лабораторный. В полевых исследованиях применен метод сравнительной аналогии с региональным контролем. Лабораторные исследования осуществляли согласно общепринятым в почвоведении аттестованным и стандартизированным методиками.

Результаты. Установлено, что при естественных условиях почвообразования 30-летний период после проведения рекультивации недостаточен для восстановления эволюционно уравновешенных параметров физического строения почвы. Остаточные последствия его физического нарушения проявляются в изменении плотности сложения, пористости и, как следствие, количественных характеристик водно-физических констант и форм влагозапасов почвы.

Научная новизна. Для рекультивированных после открытых горных разработок территорий впервые установлены временные, количественные параметры формирования физического строения и водно-физических констант нарушенной почвы при естественных условиях почвообразования. Приведены возможные сценарии формирования продуктивных влагозапасов в пахотном слое почвы.

Практическая значимость. Установленные закономерности формирования агрофизических свойств почвы могут быть использованы горными предприятиями для обоснования технологических регламентов по восстановлению земель после открытых горных разработок и сельскохозяйственными предприятиями для разработки мероприятий, направленных на регулирование элементов плодородия нарушенных почв, совершенствования технологических схем выращивания сельскохозяйственных культур на рекультивированных территориях.

Ключевые слова: *рекультивированные территории, пористость почвы, плотность сложения почвы, влагоемкость почвы, водно-физические константы, грунтовые влагозапасы*

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