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ESTIMATION OF THE OPTIMAL THICKNESS OF THE SOIL MASS BULK LAYER IN THE LAND RECLAMATION PROFILES

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Abstract

The lands disturbed by iron open pit mining are undergoing a long process of restoration. It is possible to create special-purpose lands in manmade landscapes by varying the thickness of the bulk layer of the black soil mass. The thickness of the applied soil layer on rocks or their mixtures is determined by the genetic parameters of zonal soils, the physical and biological properties of the soil mass, the soil excavation technology, and the adaptive potential of cultivated crops. The potential fertility of the same soil layer of the main mass of the first transitional horizon is 69%, the second transitional horizon is 38%. The mixing of soil masses of the humus and the first transitional horizons (H+Hp) forms the fertility at the level of 90%, the three-humus horizons (H+Hp+Phk) - 72% of the fertility of the humus horizon. The activity of two enzymes is higher in mixtures of genetic horizons than in transitional horizons, but lower than in the humus horizon. The yield of cultivated crops largely depends on the thickness of the bulk layer of soil mass, on the contribution of mineral fertilizers. The optimal thickness of the bulk layer should correspond to 50 cm.

Key words: *open pit mining, soil bulk layer, land reclamation profile.*

INTRODUCTION

Construction of minelands with good quality soil materials and desirable physical properties is essential to attain productivity levels necessary for bond release (Dunker and Darmody, 2005). The thickness of the covering topsoil layer depends on the properties of the soil used in reclamation and the projected land use after reclamation regarding to UNEP environmental guidelines for the restoration and rehabilitation of land and soils after mining activities (UNEP, 1983). The biologically active layer of reclaimed minelands should be at least 80-120 cm thick for farming lands and 120-200 cm thick for the trees. Meantime, topsoil can be placed in 25-40 cm thick layers on well - leveled and stabilized ground surfaces. Both corn grain and biomass yields increased with the addition of topsoil and decreased with the removal of topsoil (Jagadamma et al., 2009). Increased soil thickness is conducive to the storage of more water and available nutrients (Hu et al., 2018). Determination of the optimal thickness of the soil layer and the choice of a favorable underlying rock is of key importance for solving environmental, biological and economic problems (Ignatyeva et al., 2020). An increase in the thickness of the bulk layer of soil mass from an economic point of view is associated with an increase in capital costs for the reclamation of disturbed lands (Terekhov et al., 2021). The thickness of the humus layer of soil and the content of humus and physical clay in the arable layer were chosen as the quantitative indicators, which are stable over time and considerably affect the yield of agricultural crops and fully reflect the essence of soil fertility (Yeterevska et al., 2019). They should not be lower than the fertility of potentially fertile breeds and meet the requirements of agricultural and forestry crops grown in concrete biogeographic zones. Numerous experiments on the restoration of disturbed lands have identified approaches to land reclamation in different countries (Bender J., 1983; Feagley and Hossner, 2000; Beniston et al., 2015; Oggeri et al., 2019). Severe compaction is one of the major factors limiting the achievement of pre-mining yields on land being returned to cropping (Dunker and Barnhisel, 2000). Soil removal and placement influence the degree of soil compaction and

structural breakdown that inevitably occurs during these procedures (Bell, 2004). The main requirement is that the restored lands should not yield to undisturbed zonal soils in terms of fertility. Moreover, it assumed that with the help of reclamation it is possible to create lands of special purpose in man - made landscapes. Sites allocated for open pit mining may have different thicknesses of removal and different thicknesses of stacking of disturbed soil mass.
The main objective of the research is to determine the optimal thickness of the soil layer in the conditions of open pit mining.

MATERIALS AND METHODS

The experiments were conducted at the land reclamation station located on the area of the abandoned quarry “A” of Kamysh-Burun syncline of Kerch iron ore basin. The leveling of the dump surface was carried out in the preparatory period for the creation of an experimental field using a bulldozer. Works on filling the excavations with soil mass of black soil (technical mixture of humus-accumulative and first transitional horizons) with a thickness of 30, 50 and 80 cm were carried out using a scraper complex to the level of the earth's surface (Figure 1).

Figure 1. Leveling the surface of the field with a bulldozer

The excavation of the applied soil layer on rocks or their mixtures is determined by several reasons. The first one are the genetic parameters of zonal soils (as a rule, two genetic horizons are involved in the development - H+Hp or A+B). Second one are additional resources of soil mass (approximately 70-80% of the disturbed lands of the quarry) to return it to biological use including the adjacent slopes and steep slopes of external dumps intended for forestry plantations and hayfields. Third one is the mining technology, when overburden work is carried out by excavators (Figure 2).

Figure 2. Selective excavation of top soil and subsoil at the open pit quarry

The depth increments were assigned to general soil horizons with correspondence to the Russian and Ukrainian soil taxonomy system noted in parentheses: A (H) - upper horizon with very prominent humus accumulation; B_1(Hp) - upper transition horizon, with considerable humus; B_2(Ph) - lower transition horizon, with little humus; C(P) - underlying parent material (Kravchenko et al., 2012).
Averaged samples of the top and subsoil’s were selected for analyses, pot and field experiments. All soil samples were taken in the field situated in three genetic horizons: H (0-38 cm), Hp (38-62 cm) and Phk (62-92 cm).
The use of pea variety Ukosny 5 in the growing experiment as a biological indicator of soil fertility explains as follows. It is known that pea is a moderately demanding crop and, due to nitrogen fixation, to a large extent removes the restrictions caused by the unequal nitrogen content in genetic horizons, i.e. can subtly indicate such changes in environmental conditions to which plants of other ecological-trophic groups are unable to respond. The pot experiment with peas of the Ukosny 5 variety lasted for 104 days under artificial lighting. The experiment was carried out in triplicate in plastic vessels containing 0.8 kg of dry soil mass. The scheme of the pot experiment included the following trials: H - soil mass of the humus horizon; Hp - soil mass of the first transitional horizon; Phk - soil mass of the second transitional horizon; H + Hp - a mix of

soil masses of humus and the first transitional horizons; H + Hp + Phk - a mixture of soil masses of three humus horizons. Each substrate included the following fertilizer options: without fertilizers - control; P - single application of phosphorus; NP - joint application of nitrogen and phosphorus; P + R - joint application of phosphorus with rhizobium bacteria (bacterial fertilizer "Rhizotorphin').

Mineral fertilizers applied when laying soil masses in vessels at the rate of 0.15 g of the active substance per 1 kg of dry substrate. Nitrogen introduced in the form of urea, phosphorus - in the form of double superphosphate. Pea seeds were inoculated with rhizobium bacteria including fertilizer ("Rhizotorphin") before sowing in the fourth fertilizer option. Field experiments with three varieties of peas and three hybrids of corn carried out on a rock-mixed dump containing loess-like loam.

The soil mass of black soil (H+Hp+Phk) was taken off, piled up, and heaped onto the land in three strata: 30, 50, and 80 cm after the rock was replaced. The 30-cm layer of black soil mass covering to a mixture of rocks was taken as a control.

Traditional research methods were applied to estimate soil and crop samples properties (Kharytonov et al., 2004). The statistical data treatment was made using Statistica 6.

RESULTS AND DISCUSSIONS

The most important properties of the soil masses of the genetic horizons of the black soil studied. The texture data of the soil layers is presented in Table 1.

Table 1. Texture of genetic horizons of black soil

Horizon	Soil particle size (mm) and content (%)						Sum of particles < 0.01 mm, %
	1-0.25	0.25- 0.05	0.05-0.01	0.01-0.005	0.005-0.001	< 0.001	
H	1.44	12.35	28.29	8.30	5.21	44.41	57.92
Hp	0.96	3.38	32.85	7.71	11.55	43.55	62.81
Phk	1.06	8.88	22.20	14.49	6.47	46.90	67.86

Fractions of coarse dust and silt prevail in all genetic horizons of the black soil. Humus horizon H has a lighter texture than the first and second transitional horizons.

The general physical properties of the soil masses of the genetic horizons of the black soil are presented in Table. 2.

Table 2. Physical properties of genetic horizons black soil

Horizon	Bulk density, g/cm^3	Porosity, % of soil volume	
		Total	Capillary
H	1.28	51.9	36.0
Hp	1.37	49.4	29.4
Phk	1.46	45.7	27.3

Bulk density of productive natural soils generally ranges from 1.1 to 1.5 g/cm^3. High bulk density limits rooting depth in mine soils (Maiti and Ghose, 2005). An increase in soil bulk density from 1.28 g/cm^3 to 1.37 and 1.46 g/cm^3 (in the first and second transitional genetic horizons) occur with depth. The highest total porosity was in the humus horizon - 51.9%, and the lowest - in the second transitional horizon - 45.7%. A similar trend was recorded also for capillary porosity.

Moisture content in a dump is a fluctuating parameter influenced by the time of sampling, height of dump, stone content, amount of organic carbon, and the texture and thickness of litter layers on the dump surface (Donahue et al., 1990). Several indexes of soil moisture for topsoil and two subsoil present in table 3. A large amount of the clay fraction, high porosity, and differences in the humus content determined the high rates of the lowest water capacity and moisture content of stable wilting of plants in the humus horizon (28.4 and 13.5%, respectively). The range of active moisture allows the accumulation in the horizons of 19.1, 17.3 and 17.7 mm in terms of 10 cm layer of each stratum.

Table 3. Water properties of genetic horizons of black soil

Horizon	Lowest moisture capacity,%	Maximum hygroscopicity,%	Moisture resistant wilting plants, %	Active moisture range, %	Reserve of productive moisture, mm	
					for the whole horizon	for 10-cm layer
H	28.4	10.1	13.5	14.9	72.5	19.1
Hp	25.2	9.4	12.6	12.6	41.4	17.3
Phk	21.9	7.3	9.8	12.1	53.0	17.7

Data on the content and reserves of humus in the soil layers are given in Table 4.

Table 4. Fertility of individual genetic horizons and their main mixtures of black soil, determined by humus reserves

Soil horizons and their mixtures	Humus content, %	Humus reserve, t/ha	Humus reserves per 10 cm layer	
			t/ha	%
H	2.25	111	29	100
Hp	1.47	49	20	69
Phk	0.76	34	11	38
H+Hp	1.95	160	26	90
H+Hp+Phk	1.56	194	21	72

Thus, the potential fertility of the humus horizon is 2.3 times higher than the first transitional horizon and 3.3 times higher than the second transitional horizon. The results of determining the humus reserves made it possible to assess the potential fertility of the genetic horizons of the black soil and their main mixtures as follows:H (100%) > H+HP (90%) > H+HP+Phk (72%) > HP (69%) > Phk (38%). Removal of topsoil from a mining site and mixing it with underlying soil considerably reduces the relative proportion of organic carbon (Visser et al., 1984). The mixing of three genetic horizons forms a soil mass with a humus content of 1.56%, which is 2.0 times more than in the second transitional horizon and 1.1 times than in the first transitional horizon, and 1.4 times less than in the humus horizons. Total humus reserves per 10 cm layer of the humus horizon amounted to 29 t/ha. The results of assessing the productive potential of peas obtained in the growing experiment shown in Figure 3.

The most favorable conditions for the growth of pea plants developed in the trial of a single application of phosphorus with inoculation of seeds with rhizotorphin on all studied substrates. The results of studying the activity of soil enzymes presented in Figure 4.

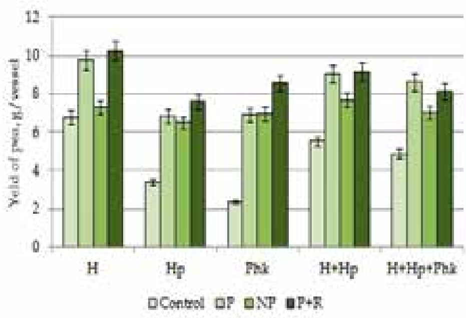

Figure 3. Yield of pea grown on soil mass top, subsoil and their mixtures (g/vessel)

The enzymes activity was highest in the upper accumulative horizon. A decrease in the activity of both enzymes (especially urease) noted in the transitional horizons in all fertilizer trials. An application of rhyzotorphin together with phosphate fertilizer increases the activity of urease in mixtures and reduces the activity of phosphatase. The productivity of three early, mid, and late- ripening pea varieties (Akatsievidny 1, Ukosny 7, and Ukosny 5) was studied in a field experiment with peas (Figure 5). An increase in the thickness of the bulk soil layer to 50 and 80 cm increased the yield of peas, on average for three varieties, by 12.7 and 19.8%, respectively. The greatest responsiveness to increased power (80 cm) shown by the early ripe variety Akatsievidny 1. In the field experiment reported here, heavy metals content in dry aboveground green mass of pea did not exceed the WHO/FAO standards, such feed being safe for animals (Table 5). The results of field experiments with three corn hybrids are presented in Figure 6.

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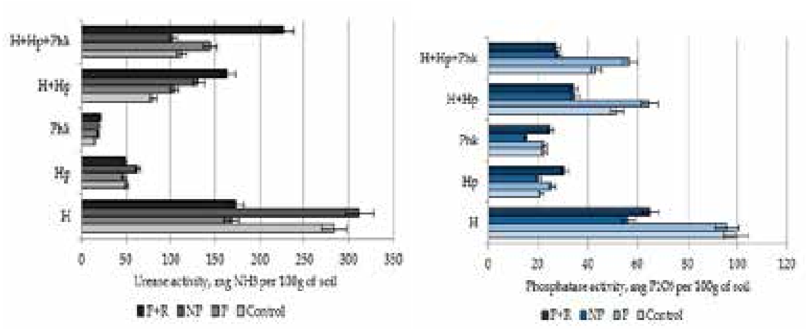

Figure 4. Enzyme activity in the genetic horizons of black soil

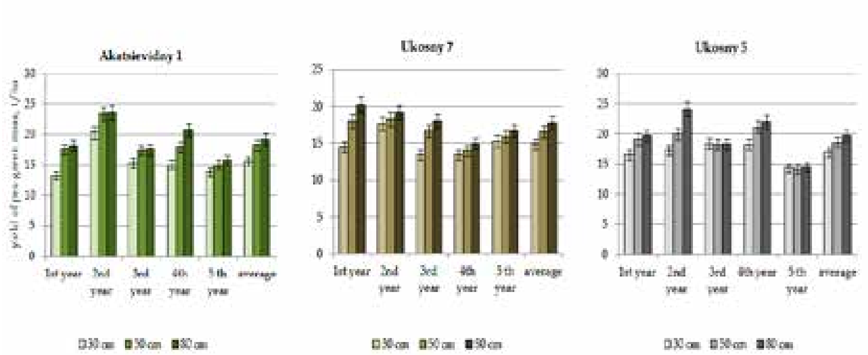

Figure 5. Yield of green mass of pea varieties in trials with bulk layers of black soil, t/ha

Table 5. Heavy metals content in green mass of pea, mg/kg

Trial	Zn	Cu	Mn	Cr	Ni	Cd	Pb
Ukosny 7							
30cm	30.8±2.9	6.7±0.6	50.0±4,1	2.5±0.3	4.1±0.3	0.2±0.02	3.2±0,4
50cm	15.2±1.3	6.1±0.5	43.0±3.6	2.2±0.3	5.6±0.2	0.25±0.02	4.8±0.4
80cm	26.0±2,3	6.4±0.5	37.0±3.5	1.7±0.2	3.5±0.3	0.15±0.01	4.9±0.5
Akatsievidny 1							
30cm	17.4±1.5	7.3±0.6	26.0±2.1	1.9±0.2	5.4±0.4	0.2±0.01	7.3±0.5
50cm	36.6±33	5.8±0.5	26.0±2.2	2.5±0.2	5.0±0.4	0.3±0.02	1.6±0.2
80cm	41.2±3.9	5.3±0.5	35.0±2.9	2.0±0.1	4.4±0.3	0.4±0.023	4.1±0.3

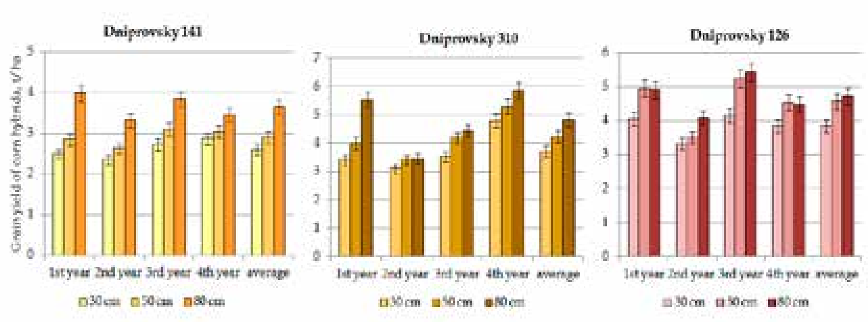

Figure 6. Grain yield of corn hybrids in trials with bulk layers of black soil, t/ha

The yield of corn grain increased with an increase in the thickness of the applied layer of soil mass for all hybrids. The early maturing hybrid Dniprovsky 141 showed the greatest responsiveness to the subsequent increase in the thickness of the bulk layer. Hybrids with longer growing seasons provided a higher yield compared to the early maturing hybrid. The maximum yield increase due to the biological characteristics of the hybrids was in the variant with a 50-cm layer of black soil mass.

Reclamation of mine lands is a very complex process. Most researchers agree that reclamation success is needed in estimation from several points of view including physic-chemical properties of soil horizons, and presence of vegetation on the site (Filip, 2002; Bell, 2004; Sheoran, 2010). The top soil was severely damaged if it was not taken out separately with a view to replace it on the filled void surface area to use it for the next step of land reclamation (Kundu and Ghose, 1998).

The top soil must be uniformly redistributed in a manner which assures placement and compaction compatible with the needs of the species that will be used to restore the distributed area to its pre-mined potential (Ghose, 2005). The question of the thickness of the layer removing and selective extraction in the mining process remains poorly understood (Thomas et al., 1995; Dunker and Barnhisel, 2000). The planning of the restored landscape causes a redistribution of the thickness of the soil mass. This leads to the formation of soil heterogeneity. Backfilling the soil in a 30-cm layer is not a guarantee of overlapping the underlying rocks. The formation of heterogeneity of the arable layer at a thickness of 50 cm practically excluded.

CONCLUSIONS

Fractions of coarse dust and silt prevail in all genetic horizons of the black soil. Humus horizon H has a lighter texture than the first and second transitional horizons. An increase in soil bulk density from 1.28 g/cm^3 to 1.37 and 1.46 g/cm^3 (in the first and second transitional genetic horizons) occur with depth. The highest total porosity was in the humus horizon - 51.9%, and the lowest - in the second transitional horizon - 45.7%. A similar trend was recorded also for capillary porosity. A large amount of the clay fraction, high porosity, and differences in the humus content determined the high rates of the lowest water capacity and moisture content of stable wilting of plants in the humus horizon. Evaluation of the exceptional fertility of each genetic horizon is the main thing with selective withdrawal in identifying and symptomatic them. Taking the value of the upper accumulative horizon as 100%, we expect that the potential fertility of the same soil layer of the main mass of the first transitional horizon is 69%, and the second transitional horizon is 38%. The mixing of three genetic horizons forms a soil mass with a humus content of 1.56%, which is 2.0 times more than in the second transitional horizon and 1.1 times than in the first transitional horizon, and 1.4 times less than in the humus horizons. The results of the study of the activity of soil enzymes urease and phosphatase revealed a strong dependence on soil genetic horizons and a significant proportion of contributions. The activity of two enzymes is higher in mixtures of genetic horizons than in transitional horizons, but lower than in the humus horizon. The planning of the land reclamation leads to the formation of soil heterogeneity. The formation of heterogeneity of the soil arable layer at a thickness of 50 cm practically excluded.

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