Theoretical framework of sand pits recultivation in Western Siberia

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Abstract. Mining of non-metallic minerals by an open method inevitably leads to disruption of the ecological state of the territory. After development of quarries, a stage of their reclamation comes, which has to prevent development of erosion processes, to provide restoration of vegetation. The biological stage of reclamation of sand pits is due to the creation of a fertile soil layer and the sowing of perennial grasses. Traditional artificial soil used in the reclamation of quarries is considered peat-sand mixture. However, it initially has adverse physical, mechanical and water-physical properties. Its use leads to a rapid washout of peat and nutrients, which leads to the death of sown perennial grasses. The proposed method for creating an artificial fertile soil mix is based on simulation of the most fertile soils of heavy granulometric composition. The ratio of the component composition of artificial soil mixture was determined by mathematical modeling. The resulting soil mixture had the properties of a humus layer of black soil and was resistant to erosion processes. The ratio between sand, peat and clay was 1:2:7, respectively. To improve the nutritional regime after mixing 100 kg of the mixture, 0.5 kg diammophoska and 0.2 kg of dolomite are added. The created experimental sample of the soil was characterized by a medium loam composition, the optimum acid-alkaline characteristics (pH 6.5) and balanced nutrition for herbaceous plants.

1. Introduction.
Active construction of cities, road transport communications, large factories and other industrial enterprises in Western Siberia requires a huge amount of building materials of natural origin. One of them is the sand, the deposits of which are determined in the region quite accurately. To reduce the cost of construction work, sand is mined in the immediate vicinity of large-scale construction sites, creating new sand pits each time [1, 2]. This is accompanied by a significant anthropogenic impact on the natural environment and inevitably leads to imbalance in the ecosystem. Development of sand deposits is carried out in a short time, without exceeding a 10-year time interval. In the South of the Tyumen region there are units of quarries, whose age is 20 years or more.

The phase of recultivation of anthropogenic disturbed areas comes after complete removal of sand or during a decrease in the need of it [3, 4]. Until recently, Russian law has not stipulated the mandatory reclamation, as it was assumed as a rapid overgrowing native flora [5, 6, 7]. However, as the practice of observations of the developed quarries has shown, the process of overgrowing in Western Siberia is extremely slow and mainly due to the small number of woody plants [1, 8]. Herbaceous cover is represented with weed vegetation with a small admixture of grasses, able to form a full sod, thereby to prevent the development of erosion processes.
Recultivation includes several stages after the development of sand pits. The first and fundamental stage is the technical one, which includes the layout of the surface, the strengthening of the sides of quarries, the construction of congresses and roads. This stage is completed by applying a fertile layer of soil. Agrotechnological measures in the form of plowing, harrowing, disking or cultivation are carried out at the second stage of recultivation; mineral fertilizers are applied, planting of tree and shrub plantings is carried out. As a result of all activities, the man-made disturbed area should be brought in accordance with the natural landscape zoning of the region.

As practice shows, the first stage of reclamation of sand pits is fulfilled well enough, and often does not cause complaints from ecological services; however the biological stage, where seeding and planting of plants are carried out, has not been fulfilled till now. This leads to partial or complete destruction of grassy vegetation at the early stages of its development. The reason for this is the mismatch of the soil mixture used for perennial grasses that require soil enriched with nutrients and heavy granulometric composition. Peat-sand mixtures used for reclamation are similar to fertile land only in appearance, and a layman in this area is extremely difficult to understand the features of the preparation of optimal for herbaceous plants soil [9, 10].

The aim of the work was to develop the optimal composition of artificial soil on the basis of a mathematical model of the fertility of Chernozem soils providing favorable conditions for the growth of perennial grassy vegetation during the reclamation of sand pits.

2. Materials and methods.

The data of the chair of soil science and Agrochemistry of State Agrarian University of the Northern Urals on particle-size analysis of Chernozem soils were used to create an optimization model. The granulometric composition was determined by the laser granulometer Analysette-22; the ratio of components for artificial soil mix was calculated using a program made on the basis of the Microsoft Excel software product. The optimized composition of artificial soil was created and tested for fertility elements at the Department of soil science and Agrochemistry of State Agrarian University of the Northern Urals.

3. Results and discussion.

Historically, perennial vegetation has grown and evolved on the soils of the heavy granulometric composition, which belong to loamy or clayey varieties of any soil. Analysis of the herbaceous cover of virgin black soil showed that the most favorable is the middle-loamy granulometric composition of the root zone. Phytomass was 18.8 tons per hectare, whereas on sandy loam soil it was almost two times less. The reason for this is the unfavorable nutrient and water regimes of soils of the light granulometric composition.

Chernozem or chestnut soils with high natural fertility are usually formed under herbs. First of all, these soils should have high moisture capacity, water permeability and water-lifting capacity, as they are formed in conditions of water scarcity [11, 12]. Soil moisture is preserved by herbaceous vegetation, which forms a powerful turf through which water passes freely deep into the soil and thus does not flow down the surface. Sod prevents evaporation, creating the effect of mulch. Therefore, for normal growth of grassy vegetation on artificial soils, it is necessary, first of all, to achieve the speedy formation of the sod.

The common peat-sand mixture, which is used in the reclamation of man-made disturbed areas, can retain a sufficient amount of water, since the moisture capacity of certain types of peat can reach 1000% of its volume [5]. Sand also creates conditions for good water permeability. However, few people know that in the case of drying, this happens on the sands; peat for a long time loses its water-holding capacity. It becomes lighter than water and are easily removed during snowmelt or during heavy rains. Another negative point will be the fact that the peat-sand mixture does not have a water-lifting capacity due to the lack of a capillary network, which is created only in the soil with a high content of silt particles. For Western Siberia, there is another drawback of such mixture – peat is an excellent heat insulator, but in harsh winter conditions, the freezing of the soil under the peat layer
occurs, but thawing is very slow [9]. This leads to the formation of a superficial root system of perennial grasses and premature death because of drying in summer.

The next feature of black soil with a heavy granulometric composition is a high absorption capacity (capacity of cation metabolism), which is responsible for the retention of nutrients in the upper layer, preventing their premature washout by rain or snowmelt. The most important physico-chemical (exchange) and chemical absorption capacity – they hold phosphorus and potassium in the soil, making it available to plants. Black earth soils initially have a high absorption capacity of up to 40 mg-EQ/100 g of soil, while sand is characterized by very low values – no more than 10-12 mg-EQ/100 g of soil. The reason for this is the presence of silty particles in the soil, whose dimensions are less than 0.001 mm, colloids, the core of which is the active humus [13]. However, humus substances in peat are inert because they were formed centuries ago [14]. Therefore, the problem of nutrient regime of peat-sand mixtures due to the use of mineral fertilizers cannot be solved, because they will be washed in the first year. For the retention of phosphorus, it is necessary to have a sufficient amount of calcium cations in the soil mixture, constantly replenished by calcium carbonate, which initially is not in the turf or in the sand.

To create the optimal soil mixture for perennial grasses, it is necessary to conduct a detailed analysis of the granulometric composition of the Chernozem. On average, it is necessary up to 25% of the totality of the particles on the fraction of sand. Moreover, it should be noted that this fraction is represented by a small fraction (0.25-0.05 mm). This is a characteristic feature of the soils of the Siberian region [6]. In nature there is black soil, formed in forests where the sand is practically not represented; however, these black soils are characterized by low permeability that in Siberia can lead to the appearance of surface runoff. 30% accounts for a large fraction of dust and silt – it is a combination that allows formation of a favorable particle size distribution. It should be noted that in the Tyumen region, especially in the Northern regions, the sand which is extracted from local quarries, in its granulometric composition, refers to sandy loam with a high percentage of coarse dust. However, as the main ingredient in the creation of artificial soil, they are not suitable. Their mineralogical composition is represented mainly by highly crushed quartz, which does not contain nutrients and cannot not serve as a basis for the primary structure.

Lakes propel can be a source of silt particles for artificial soil. Also very good raw material can be clay, seized in the construction or development of quarries. In any case, a detailed analysis of the granulometric composition is necessary for inclusion in the design of the model. When using clay as the basis of a mineral matrix, it is possible to refuse separate addition of the basic fractions of elementary soil particles. It initially has a relatively favorable particle size distribution.

When using clay as an ingredient in the preparation of soil mixture, it is necessary to check for the presence of water-soluble salts that can have a harmful effect on the development of herbaceous vegetation. That is why we do not recommend replacing the clay with sludge deposits remaining during oil production, despite the relatively favorable granulometric composition [8].

When creating artificial soils with a given physical characteristic, it is better to use the calculation methods. Their determination in laboratory conditions is difficult and in natural conditions is not possible. The reason is the violation of the natural addition in the seizure of the soil. Calculation of the total porosity, based on the granulometric composition, carried out by equation 1.

$$\epsilon = 0.805 - 0.183X_1 + 0.285X_2 + 0.057X_3 - 0.266\rho$$

(1)

where \(\epsilon\) is the total porosity, %; \(X_1\) – silt content; \(X_2\) – fine dust content; \(X_3\) – fine sand content.

The optimal total porosity for artificial soils is 50-55 of volume. Therefore, using the formula, it is easy to calculate the ratio of the main granulometric fractions in the mineral ingredient.

The most important indicator of water properties is the lowest moisture capacity, which characterizes the ability of soils, and soils for a long time to retain a certain amount of moisture, thereby ensuring the life and development of plants. This figure depends on not only the granulometric composition, but also the humus state.
If during creation of artificial soils, one uses mineral raw materials (clay, sand, sapropels, drilling slurries), the calculation of humidity of the corresponding smallest moisture capacity of the created soil can be calculated using formula 2:

$$W_{HB} = 0.15 + 0.085X_1 + 0.515X_2 + 0.142X_4 - 0.145X_6$$

(2)

where $W_{HB}$ - humidity corresponding to the smallest water holding capacity, %; $X_1$ – the content of silt; $X_2$ – content of fine dust; $X_4$ – dust large; $X_6$ – sand medium.

Since artificial soils are often used on the backfilling slopes or on the slopes of sand pits, it is often necessary to take into account the boundary of fluidity – the humidity under which the soil from the plastic state passes into the fluid. With this humidity, the bond between the particles is broken due to the presence of free water, whereby the soil particles are easily displaced and disconnected. As a result, the adhesion between the particles becomes insignificant and the soil loses its stability. The regression formula is as follows (formula 3):

$$W_{pt} = 0.082 + 1.163X_2 + 0.287X_3 - 0.107X_6 + 0.145\varepsilon$$

(3)

where $W_{pt}$ - moisture content corresponding to the yield strength, %; $X_2$ – the content of fine dust; $X_3$ – dust medium; $X_6$ – sand medium.

As a result of the analysis of black soil fertility elements, we have developed an optimization model of the composition of artificial soil, which has the properties of black soil and is favorable for the development of sown perennial grasses (4):

$$Y = (0.45x_1^{26.2} \exp(-3.4x_1^4)x_2^{0.7} \exp(-0.005x_2)x_3^{0.17} x_4^{0.08} x_5^{0.04} x_6^{0.05} + 1.48\exp(0.003x_7) +$$

$$+ 0.75\exp(0.01x_8) - 1.85)$$

$$R^2 = 0.89; s = 0.18$$

(4)

where $Y$ – biomass of herbage, t/ha; $x_1$ - density of addition, g/cm³; $x_2$ - reserves of productive moisture, mm; $x_3$ - physical clay content, %; $x_4$ - nitrate nitrogen content, mg/kg; $x_5$ - mobile phosphorus content, mg/100 g of soil; $x_6$ - content of mobile potassium, mg/100 g of soil; $x_7$ - amount of lime, kg/t; $x_8$ - sand content (1.00-0.05 mm), %; $R^2$ – determination coefficient; $s$ – standard deviation of the model.

As the mineral matrix, we used the sand taken from the quarry near the city of Tyumen; the clay is used from the place of construction of multi-storey houses; the peat – from Reshetnikovskoe field. Before mixing, the clay was dried, milled and sifted through a sieve with a hole diameter of 2 mm. The use of crushed clay does not give uniform mixing with peat. The ratio between sand, peat and clay was 1:2:7, respectively. After mixing 100 kg of the mixture, 0.5 kg diammophoska and 0.2 kg of dolomite were added. The created experimental sample of the soil was characterized by a medium loam composition, the optimum acid-alkaline characteristics (pH 6.5 units) and balanced nutrition for herbaceous plants.

**Conclusion**

The use of the peat-sand mixture as a fertile layer for the reclamation of sand pits in Western Siberia is unacceptable. According to its agrochemical and water-physical properties, this mixture can not ensure the normal long-term development of herbaceous plants, especially in the initial stages of their development. As a standard for the formation of optimal artificial soil, it is necessary to use the characteristic of fertility of local soils, on which herbaceous plants initially grow. As an integral ingredient, it is necessary to use clay, fine sand, low-lying peat in the ratio obtained in the calculation of the optimization model. The mixture is characterized by favorable agrochemical and water-physical properties, similar in parameters to the black soil.

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