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**Research**
**Araştırma**

# PREFERENTIAL WATER FLOWS IN TECHNOGENIC SOILS

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**Abstract:** A technogenic soil (technozem) was created on the surface of the former sludge pond of the iron-ore quarry in the course of land rehabilitation. The upper chernozemic layer in the technozem was underlain by the sandy or loamy layers. The water regime of this soils differed from the water regime of background automorphic natural soils and was characterized by the periods of water stagnation at the boundary between the two layers. In 20 years this type of water regime resulted in the development of a columnar structure in the lower part of the chernozemic layer. The coatings on the ped faces in this part of the profile had an increased content of Fe and Ca ions. There was no differentiation of the carbon of organic substances and carbonates in the soil profile. Field studies of water flows in this soil with the use of starch label and laboratory experiments on infiltration of salt solutions though the soil columns with determination of breakthrough curves demonstrated the existence of preferential water flows in technozem. Rapid infiltration of water through preferential water paths in chernozemic layer after abundant rainfalls and during the snowmelt season leads to the development of perched water above the textural boundary.

**Key Words:** Technogenic soil, Preferential flow, Soil structure

## 1. INTRODUCTION

The problem of land reclamation and rehabilitation of disturbed soils is one of the pressing problems in the world. Reclamation technologies include, in particular, works on the restoration of the fertile humified soil layer via application of the material of soil humus horizons preliminarily removed from the surface upon the territory preparation for mining works (Gerasimova *et al.*, 2003). To apply this material as the fill, the plots are subjected to surface planing. Rehabilitation of the disturbed lands of technogenic landscapes has a nonrecurring character and includes a number of technological procedures, including fertilization. Further works on the ecological monitoring of reclaimed soils are rarely being performed (Abakumov and Gagarina, 2003). At the same time, significant changes in the agrophysical properties of such soils may take place upon their exploitation and result in the development of soil degradation. The essence of the physical processes leading to degradation of reclaimed soils upon their exploitation remains poorly known.

The aim of the work is to study the physical and biological properties, processes and structure degradation in the artificially created layered technogenic soils (technozems).

## 2. MATERIAL AND METHODS

Technogenic soils formed within the reclaimed area of the former sludge pond, the sand-chalk mixture was covered with a thick layer of loesslike loam. After drying of the sand and loam, the material of the humus horizon of a typical chernozem was used as a fill. It was applied in the dry state. The thickness of the applied chernozemic layer was about 60 cm. In 1986, the artificial layered soil was created on the former sludge pond surface. After this, this area was involved in agricultural use. Soil profile was excavated in the southwestern part of the former sludge pond. The technozem included the following layers.

Layer I, 0-22 cm. Dark fray heavy loamy plow horizon with fine crumb structure and smooth lower boundary; numerous roots oriented in both vertical and horizontal directions.

Layer II, 20-26 cm. Dark gray heavy loam; crumb-granular structure; smooth boundary; some aggregates are up to 5 mm in diameter.

Layer III, 26-35 cm. Brownish dark gray heavy loam; angular blocky; the size of peds increases down the soil profile; abundant roots of predominantly vertical orientation.

Layer IV, 35-60 cm. Brownish dark gray heavy loam; coarse angular blocky structure with ped diameters of 20-40 mm; ped faces are covered by brown coatings. In the lower part, the columnar-prismatic structure is clearly seen; roots stretch along the vertical faces; the columnar aggregates are relatively loose and can be mechanically destroyed into separate fragments.

Layer V, > 60 cm. Sand layer; in some places, fragments of a thin (1-2 cm) crust can be seen on the sand surface. This crust could be formed on the sand surface due to the uneven deposition of the sand pulp.

The soil bulk density, solid phase density, and aggregate-size distribution were analyzed by routine methods (Vadyunina, Korchagina, 1986; Shein, 2001). The coefficients of water infiltration for separate layers were obtained according to Horton's equation from the results of infiltration tests with the method of water tubes with variable head, which made it possible to estimate the coefficients of infiltration (unsaturated hydraulic conductivity) in the area close to the saturated hydraulic conductivity (Shein, 2005; Shein, Karpachevskii, 2007). The particle-size distribution analysis was performed with the method of laser diffractometry on an Analysette 22 NanoTec device after the pretreatment with 4% $Na_4P_2O_7$ and ultrasonic dispersion. The results of soil analyses (Laboratory Manual on Agricultural Chemistry, 2001) demonstrated the alkaline reaction of the soil mass and the absence of a clear differentiation of organic matter and carbonates in the soil profiles (Table 1).

The elemental composition of brown films on the surface of peds was determined by the laser spectrometric analysis. The measurements were performed in seven replicates, and the area of measurement points was about 1 μm$^2$. Element spectra with characteristic peaks of separate elements were obtained.

In order to study preferential water flows in the soil, the method of starch label (Shein, Karpachevskii, 2007) was applied in a field experiment. Frames of 16 cm in diameter were installed on the soil surface and filled with 2% starch solution. There were two variants of the experiment. In the first variant, the frames were initially filled with water (about 5 l/frame), after which the starch solution was applied. In the second variant, starch solution was applied without a preliminary filtration of water, which made it possible to trace the formation of water flows in the studied technozems at the initial stage. After the end of the starch solution infiltration the soil was cut down in 5- to 10-cm-thick layers; on their horizontal surfaces (after cutting of the overlying layer), the pattern of water flows was fixed via staining the remaining starch with iodine water. The morphology of such sections was described, and the distribution of starch label was recorded with a digital camera. For the control, it was also plotted on polyethylene films. Then, the areas of starch-impregnated mottles were determined.

The investigations of soil biota structure of chernozemic layer were realized by means of Gas Chromatography Mass Spectrometry (GC-MS) (Osipov et al, 1994).

## 3. RESULTS AND DISCUSSION

The structure of the filled chernozemic layer in the studied technozems differs considerably from the classical granular structure of chernozems, from which this material was taken. In 20 years, the classical chernozemic structure has degraded in the subplow horizons and, particularly, in the lower part of the chernozemic layer (40-60 cm). Field studies demonstrated that the rise in the size of angular blocky (and columnar-prismatic) peds is accompanied by the increase in the soil bulk density (Table 1).

The study of water stability of the aggregates in the upper 10 cm showed that coarse aggregate fractions are completely destroyed upon slaking in water. In the lower part of the upper chernozemic layer, soil aggregates have an increased water stability against the background rise in the soil bulk density. A sharp change in the structural status of technogenic soils with an increase in the content of very coarse aggregates has already been noted in literature (Shein *et al*., 2006; Horn and Peth, 2009). Significant changes in the structural state of the soil and the development of interped fissures have resulted in the very high hydraulic conductivity within the upper (chernozemic) soil layer, particularly below 40 cm.

An analogous change in the structure of chernozems can be observed in natural soils upon the increasing duration of the temporary soil waterlogging. For instance, an increase in the size of aggregates and aggregate water stability down the soil profile has been noted for meadow-chernozemic soils of the Tambov Plain. The peds in these soils acquire prismatic shape (Nikiforova, Stepantsova, 2003). The high content of humus and smectitic clay minerals in the chernozems contribute to the high sensitivity of these soils toward the rise in the soil water supply (Degradation and Conservation of Soils, 2002).

The creation of an artificial layered technozem with abrupt boundaries between separate layers has changed the water regime in the upper chernozemic layer. Even a short-term overwetting of chernozems and alternation of wetting-drying stages lead to the structural rearrangement of the soil profile; often, vertic features appear in the soil. The degree of transformation of separate horizons of chernozemic soils (including filled chernozem in the technogenic soil) largely depends on the degree and duration of the soil waterlogging with water stagnation in the profile. Water stagnation in chernozems leads to a rapid substitution of anaerobic conditions for aerobic conditions. The reverse process upon the gradual soil drying takes a long time. The heavy texture of the studied technozem (Table 1) and the presence of smectites in the clay fraction specify the high water retention capacity in the chernozemic layer. Differences in the texture of the upper chernozemic and underlying sandy or loamy layers may lead to the formation of a horizon with perched water above the litho-logical contact. Such a horizon worsens the water regime of the entire technozem profile. An abrupt boundary between separate soil layers favors temporary water stagnation above this boundary and the horizon of perched water is formed above the boundary between the upper heavy loamy (chernozemic) and the underlying sandy layers. In turn, water stagnation and its spreading over the surface of the underlying layer contribute to the changes in the physicochemical and chemical properties of the soil and to differentiation of the peds into the surface and inner parts. These processes transform the structural state of the soil.

This conclusion is supported by the data on the particle-size distribution in the inner and outer parts of the peds in variant of chernozemic layer on sand: the inner part of the peds has a heavier texture favoring the high water retention capacity (Table 2). The differences in the texture between the inner and outer parts of the peds are most pronounced in a layer of 20-30 cm, in which compact and well-shaped angular blocky peds appear. In the lower layer, this difference becomes less pronounced. In the lowermost chernozemic layer (50-60 cm), it disappears Note that the textural differences between the inner and outer parts of the peds are mainly due to differences in the contents of the fine and medium silt fractions.

Table 1. Some physical and chemical properties of technozem

| Layer, cm | Bulk density g/cm$^3$ | Soil particle density, g/cm$^3$ | $K_{inf}$, cm/min | Sum of water-stable agr. >0.25 mm, % | Granulometric particles content (%) | | | $pH_{H2O}$ | $C_{CaCO_3}$ % | $C_{org}$ % |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sand (0.05-1mm) | Silt (0.002-0.05mm) | Clay (<0.002 mm) | | | |
| 0-10 | 1.04 | 2.62 | 0.72 | 60.4 | 4.37 | 75.26 | 20.37 | 8.73 | 0.69 | 2.99 |
| 10-20 | 1.22 | 2.65 | 0.63 | 61.4 | 3.91 | 76.22 | 19.87 | 8.74 | 0.73 | 2.87 |
| 20-30 | 1.28 | 2.67 | 0.44 | 71.4 | 3.03 | 76.78 | 20.19 | 8.75 | 0.77 | 2.98 |
| 30-40 | 1.22 | 2.68 | 0.93 | 77.2 | 2.53 | 76.88 | 20.60 | 8.71 | 0.78 | 2.83 |
| 40-50 | 1.35 | 2.68 | 1.80 | 84.8 | 2.44 | 76.61 | 20.95 | 8.57 | 0.63 | 2.84 |
| 50-60 | 1.37 | 2.66 | 2.60 | 80.2 | 1.41 | 77.86 | 20.73 | 8.52 | 0.76 | 2.84 |
| 60-70 sand | 1.4 | 2.66 | 9.26 | - | 96.61 | 2.86 | 0.53 | 9.17 | 3.57 | 0.03 |

Note: $K_{inf}$ the coefficient of water inflitration; $C_{CaCO3}$, $C_{org}$ - content of mineral and organic carbon

Such kind of soil mass transformations may due to the specific water regime formation with the dominant of preferential water flow movement through the chernozemic layer and possible stagnation on sand boundary. In order to confirm (or reject) a hypothesis about the transformation of the soil structure in the chernozemic fill under the impact of water stagnation at the boundary between separate soil layers, a field experiment on studying the preferential paths of water flows with the help of starch label was conducted.

The results of this experiment (the distribution of starch mottles in the soil mass within separate horizontal soil sections) are shown in Fig. 1. In our field experiments the frames were installed on the soil surface and at a depth of 45 cm. The distribution of starch mottles shows that a transition from the upper layer with fine crumb structure to the underlying layer with coarse angular blocky structure is accompanied by the strong concentration of the water flow. This is especially well seen in the distribution of starch added with water at a depth of 45 cm. Within the lower part of the chernozemic layer, water infiltration proceeds mainly along the prisms and columns.

The irregular distribution of starch was more distinct in the experiments, when starch was added immediately, without the preliminary adding of pure water. In the case of the preliminary soil moistening with water, the infiltration of starch followed the steady-state pattern; starch label quickly passed downwards through the soil profile along the fissures, so that no distinct coloring of the starch in the soil mass under the frame was seen. However, some bluish tint from the applied starch could be detected on digital photos processed.

From the fig.1 is evident that starch spread over the boundary with the underlying sandy layer and formed extensive zones of continuous coloring. It should be noted that the underlying sandy (sand-chalk) layer also had a layered character, which could not be seen upon the visual morphological description of the soil profile, but was clearly seen from the distribution of starch label. On the vertical wall of the pit, the layered character of the zones of most active starch coloring in the sandy material was clearly expressed.

The morphological study of the soil profile coupled with data on the elemental composition of the soil mass from the inner parts of the peds and the coatings on their faces in a layer of 50-60 cm (chernozem/sand) indicate that the brown coatings on ped faces are enriched in iron, which may attest to a periodical overwetting of this part of the technozem profile. The immobility of iron hydroxide in an alkaline medium (see Table 1) excludes the illuvial origin of these coatings. It is probable that their formation is related to microbiological processes causing some differentiation of the material of the aggregates. In any case, an increased content of iron ions with structural bonds of crystallization type facilitates the stability of the aggregates. In turn, this contributes to the increased interaggregate porosity and, hence, to the increased water infiltration through intraped fissure pores.

Table 2. Contents of physical clay (<0.01 mm)/ sludge (<0.001 mm) particles (%) in the technozem layers

| Layer, cm | Ped faces | Ped interiors |
|---|---|---|
| 20-30 | 46.79/6.92 | 58.08/7.83 |
| 30-40 | 48.02/6.83 | 56.59/9.36 |
| 40-50 | 47.80/6.58 | 54.80/9.47 |
| 50-60 | 48.29/6.88 | 49.25/9.51 |

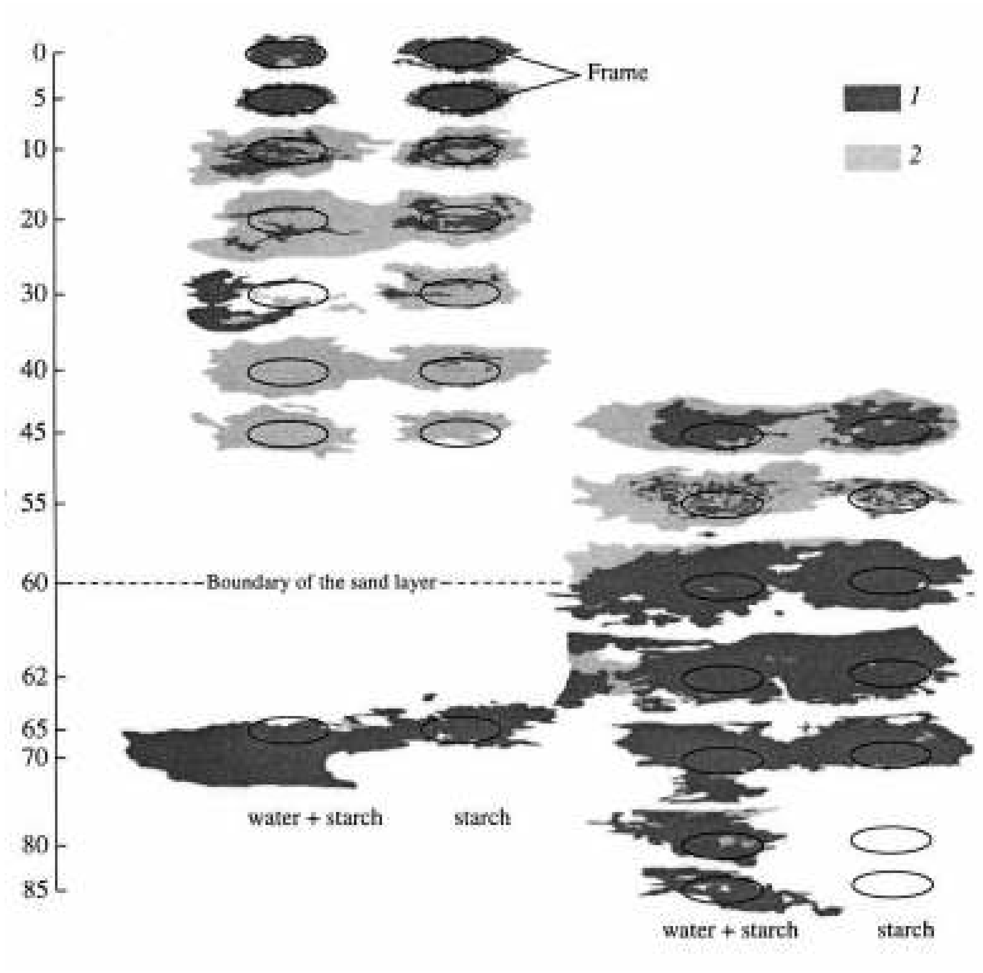

Figure 1. Major paths of water filtration as judged from coloring of the applied starch in pit (chernozem/sand): (1) distinct coloring of the label and (2) indistinct coloring in the zones of capillary sorption of starch

Such changes in the filtration characteristics of the soil mass with the formation of a specific type of the soil water regime have already been described in literature (Bouma, 2006; Shein, Umarova, 2002).

Thus, the inner parts of the peds in this soil layer formed upon the structural transformation of the initial chernozemic material are subjected to relatively long periods with anaerobic conditions. As a result, the zones with the high water content in the central parts of the peds are preserved for a long time even in the case of a general drying of the soil mass. We proposed that such kind of air-water mesoregime of the soil peds may be influenced the distribution and functioning of the soil biota.

The results of the soil biota investigations are represented on the fig.2,3. Total content of the microorganisms are not changed through the depth of soil construction, but the aerobes are dominant (Fig. 2,a). The clear differences are noted in the aerobes and anaerobes distribution on the inner and surface parts of the peds (Fig. 2,b).

On the surface the aerobes are dominant: numbers of aerobes exceed in 3-4 times the anaerobes ones. But in the inner part the numbers of the microorganism decreases and the differences between aerobes and anaerobes are decreased. Depending on the water-air relation and oxidation-reduction conditions the airobes or anaerobes will be developed. In periods of temporal water saturation of the inner part of the ped the anaerobes consortium is functioning (Fig.3, a). This dominant consortium is created from bacterium-anaerobes genera *Clostridium, Butyrivibrio* and *Ruminococcus*. Also the group of Fe-reduction bacteria and other microorganisms with Fe-reduction abilities are developed. So, the processes of the Fe3+ to Fe2+ reduction in the period of the inner part saturation, movement of $Fe^{2+}$ to surface are carried out by the bacterium-anaerobes consortium. And the oxidation $Fe^{2+}$ to $Fe^{3+}$ on the surface ped are carried out by the soil biota. The bacterium of the genera *Ochrobactrum, Rodococcus* and others (fig.3, b) are conducive to this process.

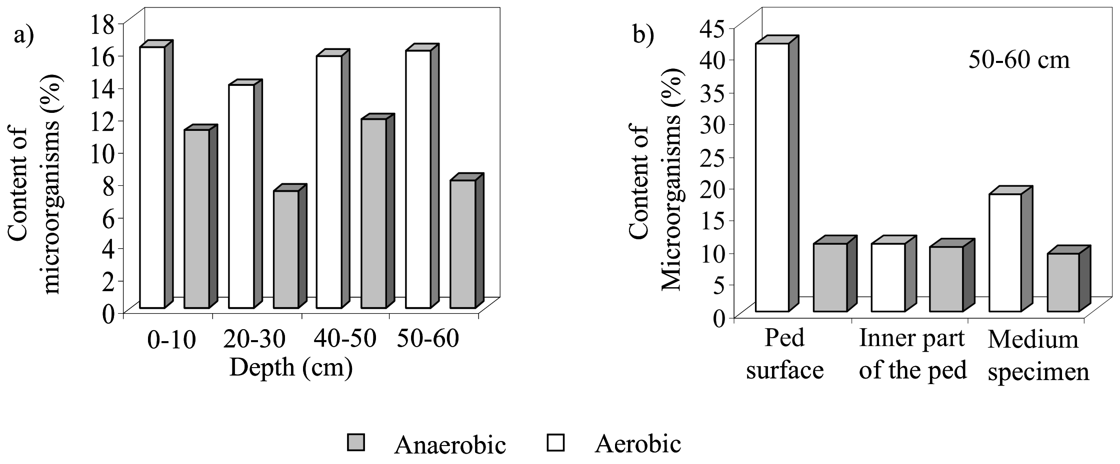

Figure 2. Anaerobes and aerobes contents on the different depth of the soil construction (a) and on the surface, inner parts of the ped and in medium soil specimen (b) on the depth 50-60 cm. Note: In the group "Anaerobic" the obligate and facultative anaerobes were included, but in "Aerobic" group the obligate microorganisms and microaerofiles were included

## 4. CONCLUSION

1. In 20 years of functioning of the artificially created technogenic soil composed of the upper 60-cm-thick chernozemic fill underlain by sand or loam, considerable changes in the soil properties have taken place. From a depth of 35-40 cm, the granular structure of chernozem is transformed into the coarse blocky structure with the high water stability. In the lowermost part of the fill layer, such blocks compose prisms and columns.

2. The indications of temporary water stagnation in this zone are clearly expressed in the form of iron-rich coatings on ped faces, rusty mottles above the contact zone, and vertic features. These features are developed under the impact of a specific water regime in the technogenic soil with the formation of preferential water flows. Under these conditions, the participation of intraped pores in the water migration is negligibly small. Preferential water flows are concentrated along fissures separating prismatic aggregates, which has been confirmed in the experiments with starch label. The study of the spatial pattern of soil water flows made it possible to detect the horizontal spreading of water above the contact with the underlying sandy layer. As a result, the stagnation of water and the development of anaerobic conditions take place. Gleyzation is developed, particularly in the inner zone of peds. Iron compounds are concentrated on ped faces.

3. Soil biota distribution contributes to movement of iron ions to ped surface because the alkaline conditions this ions is chemically immobile. Our investigations showed the the inner part of the ped contains the anaerobe association of microorganisms, but the external – the aerobe ones. This microbiological composition favored the Fe-ions migration to the surface, transformation to Fe-oxides films on the ped surface and columnar rigid blocks formation. Results of the study assume that the preferential flows create favorable conditions for the soil gleization inside the ped, anaerobic microbiota formation, but during following dry periods aerobic microbiota on the surface ped layers transform $Fe^{2+}$ to $Fe^{3+}$ and lead to aggregate transformation from granular structure to the columnar blocks.

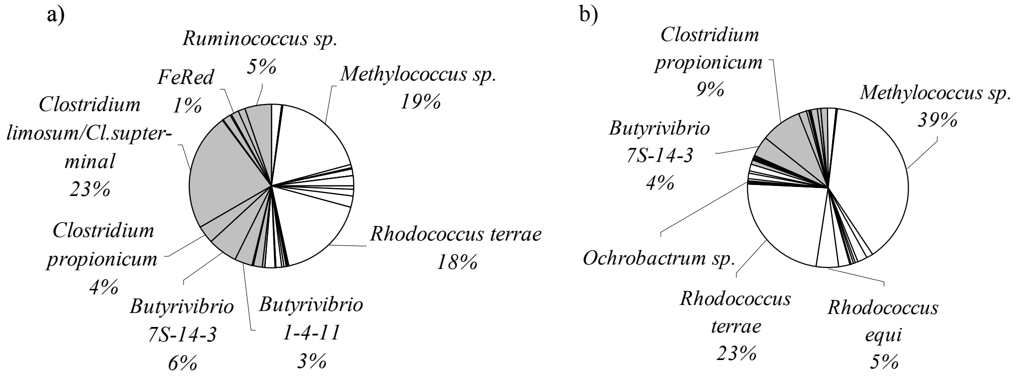

Figure 3. Microbiological composition in the inner part (a) and on the ped surface (b) from the depth 40-60 cm of the chernozemic layer of the soil construction

## 5. ACKNOWLEDGEMENT

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