DOI: 10.26177/VRF.2020.7.3.005

THE FERTILITY OF CHERNOZEMIC SOILS ON THE MORAINE DEPOSITS

S.P. Lomov[1], Doctor of Geographic Sciences, Professor;
V.S. Lomov[2], Student

[1] Federal State Budgetary Educational Institution of Higher Education "Penza State University of Architecture and Construction", e-mail: stas_lomov@mail.ru;
[2] Federal State Budgetary Educational Institution of Higher Education "Moscow Pedagogical State University", e-mail: vyacheslavlomov@rambler.ru

Moraine deposits in the Penza oblast were formed as a result of the destruction of the Oka-Don glacier of the lower boundary of the neo-Pleistocene during warming [6, 15, 16]. The thickness of the main moraine can be ≈ 30.0 m [8, 10]. In terms of spacing, glacial deposits of the Don horizon predominate in the western part of the oblast. In current physical-geographical conditions, they are placed as the cover on watersheds and used in the agro-ecosystem. The composition and properties of soils on morainic deposits are special due to their structural state, peculiar distribution of physical clay fractions, low humus content and low fertility.

Keywords: moraine complex, soil properties, soil recovery stage, virgin land.

Introduction

Problems of rational use of the Penza oblast's land resources in modern conditions determine the need to study the "untouched" area when speaking about the soil cover up to the present time. This may indicate the complexity of the soil cover structure of the Penza oblast, the insufficiently represented variety of soil-forming material, in particular, soils on moraine deposits. The Penza oblast in its western part underwent the glaciation in the lower boundary of the neo-Pleistocene. A part of the Oka-Don glacier covered a significant area of the oblast, dividing it into glacial and non-glacial zones. The Oksko-Don glacier recession was associated with climate warming and accompanied by the deposition and transformation of various moraines, which caused a variety of soil-forming materials, mainly in the glacial zone of the Penza oblast [6, 15, 16]. The thickness of the main moraine part can be 30.0 m [8, 10]. Current absolute levels of moraine deposits record at 200-240 m above the sea level [3, 7]. The outlines of the primary relief forms of moraine deposits has not been preserved [13]. In the current physics and geographical conditions, the moraines place as well in watershed levels as slope positions.

Present landscapes on moraine deposits are mostly located at sublatitudinal placing. The coniferous-broad leaved forest dominates on the moraines in the Northern part. In the Central part and in the South, the forest-steppe landscapes dominate on the morainic plains of the Volga Upland [14].

In the Penza oblast the soils on moraine deposits have not been observed by the study until recently; there are corresponding gaps in information about the soil cover structure [2, 9, 11]. According to this fact, the goals of the research were determined. They are the need to study the features of the soils' morphological structure on moraine deposits, and physical and chemical properties, as well as to compare the data obtained with the fertility of chernozems on loess loams.

After reconnaissance exploration of the moraine complexes in the area of Lipyagi (a village in the western part of the Penza Oblast), a section was laid to study the morphological features of soils. In addition, a collection of particular minerals and bone remains within the moraine complex was carried out [12]. Diagnostics of the collected stony material fragments from the surface of the soil cover, especially on the slopes, allowed determining various resources: limonite, quartzite, granite, phosphorite, siliceous fragments, quartzite with calcite, geyserite, chert with calcite, corals, jasper, olivine, silicified corals of organic origin. According to expert evaluation, almost all the geological species and bone fragments were brought by the glacier from the deposits of the northern seas, that is, the original area of glaciation. Therefore, following V.V. Dobrovolsky [5], it can be considered that glacial moraines are re-appeared products of nival weathering (nival-tundra crust), including not only large boulders but also small-scale material.

Methods and materials

The main used research method was comparative-geographical, which consisted of the combined study of the soils' morphological structure on the moraine deposits and loess loams. Analytical parameters of soils were determined

in the laboratory of the State Center of Agrochemical Service "Penzenskiy".

Grade analysis was carried out in accordance with N.A. Kachinskiy. In addition, the clay deposition coefficient was calculated as a quotient of the ratio of silt to physical clay in the soil and the corresponding value in the rock (according to I.A. Krupennikov). The aggregate composition was determined by the classification of S.A. Zakharov. Calculations of the structural and waterproofness coefficients were carried out according to N.I. Savvinov. Among the physical and chemical properties, acidity (pH_{KCl}) and the total exchangeable bases were studied. The content of humus, as well as mobile and total forms of nitrogen, potassium and phosphorus were determined by E.V. Arinushkina [1].

Thus, the presented set of research methods allows implementing a comprehensive approach to substantiating the features of soil formation and assessing fertility on moraine deposits in comparison with soils on loess loams.

Results

On the moraines that currently stand out on the mild slopes on both banks of the Penzyatka river, leached chernozems are formed. Previously, the mild slopes were plowed up. Currently, the soil is subject to the processes of virgin land's creation under the planting of pine and birch (Pinus silvestris, Betula pendula).

An example of the morphological structure of soils can be a meter section set on the top of a slope. Speaking about flora, only the feather-grass groups can be seen; the others are the wormwood ones. Micro-relief is in the form of bumps up to 15-20 cm high. There are dried stems of chiccory, tansy, etc. There are shrubs of sweet briar and willow (Salex alba) somewhere.

Ad (0-11 cm). Humid, dark-grey, slightly grass-lined. Some infrequent markers of lessivage can be noticed. Huge root system; the granulometric texture is loam with unclear structure and gradual transition.

A1 (11-31 cm). Humid, dark-gray; light "dots" can be noticed (the lessivage markers). Grassy root system; loam with unclear structure. Transition is gradual.

AB (31-46 cm). Grey with a yellowish tinge, slight lessivage markers. Loam with unclear structure. Transition is noticeable.

C (46-90 cm). Ochre-coloured, the granulometric texture is inhomogeneous with the layers of the grey sand lens. Humid, heavy loam. Fragments of granite, sandstone and other minerals can be noticed.

Leached chernozems on moraines are currently being restored under pine plantations, the density of which varies. Spaced plantings are dominated by feather-grass groups (Stipa pennata) and wormwood-tansy forbs (Artemisia santonica). The weeds' stage seems to be ended, but the sod soil has not fully recovered. According to the morphological structure of the 1 m section, the thickness of leached chernozems on loamy moraines is small, only 46 cm. This may indicate that the studied soils were eroded during plowing and their usage in agrocenosis. This can be indirectly indicated by data on the structural state of chernozems on moraines, compared with chernozems on loess loams (Table 1).

From the data in Table 1, it can be seen that moraine loams have an unsatisfactory structural state, lumpy fractions (> 10.0 mm) predominate in the rock up to 70 %. As a result, the structural coefficient was only 0.4. In the sub-humus horizons A1 and AB, the lumpy fraction decreased to 57.8 % and 55.2 %. Thus, the structural state increased to a satisfactory assessment. In the sod horizon Ad, the lumpy fraction decreased to 32.0 %, the structural coefficient increased to 1.4. It might be due to the processes of virgin land's creation and restoration of natural fertility.

The waterproofness properties of the structure were determined in the same samples (Table 1). The data obtained indicate satisfactory waterproofness throughout the soil profile and even in the soil-forming rock. Besides, the waterproofness coefficient increased down the profile from 0.8 to 1.19, i.e. in the rock, waterproofness increased, compared to the humus horizon Ad. Such extraordinary data predetermined viewing of small fractions of the structure under a microscope. The results of the examination showed that all small fractions from 1.0 to 0.25 mm, which increased the waterproofness coefficient in the lower layers, are fragments of primary minerals of siliceous and other previously noted rocks and are not structural fine-grained granules. This is confirmed by data on the distribution of 1.0-0.5 mm fraction values over the soil profile – 9.8 % in the Ad horizon and 21.8 % in the rock.

The low number of values of the marked fraction in the Ad horizon indicates the activity of weathering and soil formation processes in the upper layer of the soil profile, which together determine the increased rate of destruction of primary minerals, in comparison with the data of soil-forming rocks (Table 1, section 14). As a result, data on the waterproofness of the structure in the lower part of the soil profile from a depth of 31 cm can be considered erroneous. Chernozems on loess loams differ significantly in their structural state (Table 1, section 79). It is characteristic that even arable options on loess loams have a good structural state of the upper horizon. For the sub-arable horizon, the structural coefficient increased to 10.1, which may indicate, firstly, the structure of an excellent level,

Table 1. Structural state of soils on moraines and loess loams

Layers and depth, cm	Fractions, mm; content, %								Fractions 10-0.25 % (dry sieving); >0.25 mm (wet sieving)	Cs and Cw	Evaluation of structure and waterproof-ness
	>10	10-5	5-3	3-2	2-1	1-0.5	0.5-0.25	< 0.25			
Leached chernozems on moraines, 1 m section (dry sieving)											
Ad, 0-11	32.0	19.0	12.4	8.2	8.6	5.4	7.4	9.0	59.0	1.43	Satisfactory
A1, 11-31	55.2	21.6	6.4	5.6	3.4	1.6	1.2	1.8	43.0	0.72	Satisfactory
A1B, 31-45	57.8	20.2	8.0	4.4	3.8	1.6	1.4	1.0	41.0	0.70	Satisfactory
C, 70-90	70.2	15.0	5.4	3.3	2.8	2.6	3.6	4.2	25.6	0.34	Unsatisfac-tory
Leached chernozems on moraines, 1 m section (wet sieving)											
Ad, 0-11	-	-	2.22	0.96	5.3	9.8	25.1	56.6	43.4	0.8	Satisfactory
A1, 11-31	-	-	0.2	1.36	10.1	15.3	22.5	50.56	49.4	0.98	Satisfactory
A1B, 31-45	-	-	0.16	13.2	4.0	20.9	16.58	45.2	54.8	1.21	Satisfactory
C 70-90	-	-	0.4	2.0	7.8	21.8	22.4	45.6	54.4	1.19	Satisfactory
Leached chernozems on loess loams, section 79 [10] (dry sieving)											
A_{ah}, 0-30	21.2	18.6	12.0	6.7	15.1	10.1	8.8	7.6	71.2	2.4	Good
A_{sah}, 40-50	4.7	18.7	28.4	15.0	18.1	6.4	4.6	4.1	91.2	10.4	Excellent
A1, 70-90	24.1	22.3	18.1	3.8	13.3	1.9	3.8	2.7	73.2	2.7	Good

and secondly, the heredity of a good structural state from the stage of virgin development of chernozems, as evidenced by the data from section 79.

The granulometric texture of chernozems on moraine deposits is characterized by a predominance of fine sand fraction > 40-50. 0 % in the upper horizons, low content of large fines (8.9-11.0 %) over the entire soil profile, and relatively uniform distribution of fine dust from 3.0 to 6.6%. (Table 2, section 1 m). The distribution of the silt fraction is accompanied by an increase in its indicators with a depth from 12.5 % in the upper horizon to 28.1% in the rock, thus reflecting the development of lessivage processes. The clay deposition coefficient was less than one within the underhumus horizons Ad, A1 and AB of the soil profile – 0,81-0,73 (Table 2).

As a result, the granulometric texture changed along the profile from light loam in the Ad and A1 horizons to medium-textured loam in the lower part of the soil profile (Table 2).

Table 2. Grade analysis of leached chernozems on moraine deposits, % (1 m section)

Index of hori-zons and depth, cm	Sand, mm		Fines, mm			Silt < 0.001 mm	Sum of fractions < 0.01 mm	Argilliza-tion coef-ficient	Grade analysis
	Large (1.0-0.25)	Small (0.25-0.05)	Large (0.05-0.01)	Average (0.01-0.005)	Small (0.005-0.001)				
Ad 0-11	13.4	55.4	8.9	4.5	5.3	12.5	22.3	0.81	Light loam
A1 11-31	11.1	49.1	10.9	4.7	6.6	17.6	28.9	0.86	Light loam
AB 31-46	8.4	42.5	11.0	15.2	3.0	19.9	38.1	0.73	Medium-textured loam
C 46-90	21.5	33.2	8.7	4.2	4.3	28.1	36.6	1.0	Medium-textured loam
Leached chernozems on loess loams (Kamensky district; section 90 [10])									
An 0-10	0.4	7.1	28.5	9.9	7.4	36.7	54.0	1.0	Heavy loam
A1 60-70	0.5	8.3	24.2	9.0	14.6	43.4	67.0	0.96	Light clay
Cca 140-150	2.3	10.7	22.4	7.2	13.3	43.5	64.0	1.0	Light clay

Table 3. Physico-chemical and chemical properties of leached chernozems on moraine deposits (section 1 m)

Index of horizons and depth, cm	Humus, %	pH_{KCl}	Amount of absorbed bases, cmole (EQ)/kg	Alkaline-hydrolyzable nitrogen	Exchangeable potassium	Mobile phosphorus,
				mg/kg		
Ad 0-11	3.44	5.1	14.1	60.2	300	360
A1 11-31	3.10	4.8	15.2	45.5	127.5	370
AB 31-46	1.55	4.2	23.7	-	142.5	521.5
C 46-90	0.7	4.0	20.2	-	120.0	260
Leached chernozem on loess loams, section 80						
A_{ah} 0-30	7.60	5.4	38.0	106[1]	100	89.0
A_{sah} 30-40	7.29	5.4	35.5	102	80	79.0
A 50-60	5.30	5.6	32.5	89	70	35.0
A1 70-80	2.80	6.0	31.0	48	70	30.0
AB 80-90	1.80	6.6	31.5	38	60	24.0
B 90-100	0.80	7.0	30.0	10	70	19.0

[1] Data on easy hydrolysable nitrogen are given.

By granulometric texture, chernozems on loess loams are distinguished by increased values of the large dust fraction – 28.5 %, as well as average and small dust, with the predominance of the silty fraction of 36.7-43.4 %. As a result, the granulometric texture of the studied soils is characterized by heavy loam in the A_{ah} horizon and light clay in the middle and lower parts of the profile (Table 2, section 90). Moreover, the clay deposition coefficient was close to 1.0 for the entire soil profile.

Such differences in the granulometric texture are related to the loess rocks' carbonate content. Soil formation on these rocks was accompanied by processes of leaching of carbonates and weak clay deposition of the upper part of the soil layer. The acidity of morainic rocks caused the development of lessivage processes and changes in the granulometric texture from light to medium loams down the soil profile.

Chemical and physico-chemical data of the considered soils are presented in Table 3. It should be noted that the low humus content in the upper sub-humus horizons Ad and A1 is low – 3.44 % in the sod horizon and 3.10% in the lower one (Table 3 section 1 m). In the AB transition horizon, the humus content decreased to 1.55 %. It should be noted that the humus content, gradually decreasing along the profile, is typical for chernozemic soils. The values pH_{KCl} – 5,1 in the Ad horizon determine a weak acid reaction. With depth, these values decrease to 4.8, 4.2, 4 and characterize a strong acid reaction in the lower horizons and in the soil-forming rock. The amount of absorbed bases is low, in the upper sub-humus horizons – 14.1 cmole (EQ)/kg, in the Ad horizon – 15.2 cmole (EQ)/kg, significantly increases in the transitional horizon AB – 23.7 cmole (EQ)/kg and in the soil-forming rock – 20.2 cmole (EQ)/kg (Table 3, section 1 m). This fact is consistent with the distribution of physical clay fractions (Table 2).

There is a low content of mobile nitrogen in the upper humus horizons of chernozems on moraine deposits. At the same time, the studied soils are rich in exchangeable potassium – 300 mg/kg in the Ad horizon (Table 3). Also, the soils are rich in mobile phosphorus 360 mg/kg in the Ad horizon and 521.5 mg/kg in the AB horizon. The high content of potassium and phosphorus is associated with the presence of phosphorite and shale rocks in moraine deposits, the destruction and weathering of which ensures the entry of mobile forms of phosphorus and exchangeable forms of potassium into the soil solution.

Leached chernozems on loess loams differ significantly in their morphological structure. The thickness of the A+B horizons is twice as large, up to 100 cm, compared to the soils on moraines. Besides, the chemical properties are characterized by a high humus content almost twice as high as 7.60 % and 7.29 % in A_{ah} and A_{sah} horizons than in soils on moraines.

The reaction of chernozems on loess loams: pH is 5.4-5.6; close to neutral. It was determined using the KCl salt. The amount of absorbed bases is high in the upper horizons – 38,0- 35,5 cmole (EQ)/kg, in the A_{ah} and A_{sah} horizons with a gradual decrease to 30.0 cmole (EQ)/kg, in the B horizon (Table 3, section 80). Leached chernozems are poorly provided with mobile nitrogen, exchangeable potassium, and mobile phosphorus (Table 3, section 80).

Conclusion

The area of the studied chernozems on moraine loams is confined to the mild slopes of the Penzyatka river. Currently, the studied soils are included in the zone of riverside afforestation, mainly pine and birch planting.

The study of the morphological structure of soils confined to the top of the slope showed a small thickness (AB horizon) of only 46 cm, which may indicate that they were eroded during ploughing and use in agrocenosis. This is emphasized by the unsatisfactory assessment of the aggregate composition of the entire profile, with the exception of the Ad sod horizon.

Chernozems on loess loams are distinguished by a much greater thickness (AB horizon) up to 90-120 cm and good aggregation even of arable horizons.

The granulometric texture of chernozems on morainic rocks is light-loamy in the upper subhumus horizons Ad and A1, and medium-loamy in the lower part of the soil profile, which reflects the development of lessivage processes in the conditions of acidic reaction of soil formation.

The granulometric texture of leached chernozems on loess loams is characterized by a high content of large dust fractions (0.05-0.01 mm) up to 28.5 % and maximum content of silty fraction (less than 0.001 mm) up to 36.7-43.5 %, which in total provides heavy loam and light clay.

Chernozems on moraine deposits are characterized by a low humus content of 3.44 % and strong acidity, a small number of absorbed bases, and high provision of exchangeable potassium and mobile phosphorus.

Chernozems leached on loess loams, on the contrary, are characterized by a high humus content of 7.60 %, an almost neutral reaction, a big number of absorbed bases, and low provision of mobile nitrogen, exchangeable potassium, and mobile phosphorus.

Comparison of chernozems formed on morainic and loess loams highlights the low fertility of leached chernozems on morainic deposits.

References

1. Arinushkina E.V. Guidelines for chemical analysis of soils. Moscow: Mysl, 1975, 288 p.
2. Vikhreva V.A., Grishin G.E., Nadezhkina E.S., Arefyev A.N., Erkaev V.N., Bocharov S.S. Chemical elements in the soils of the southern forest-steppe of the middle Volga region (on the example of the Penza Oblast): monograph. Penza: RIO PGSKHA, 2015, 178 p.
3. Geographical Atlas of the Penza Oblast. Penza: Oblizdat, 2005, 60 p.
4. State geological map of the Russian Federation: map of Quaternary formations, M. 1: 1000000. Saint Petersburg: VSEGEI, 1997.
5. Dobrovolsky V.V. Geography and paleogeography of the weathering crust of the USSR. Moscow: Mysl, 1975, 288 p.
6. Zolnikov I.D. Genetic and facies analysis of glacial deposits. Novosibirsk: IGiG SO AN USSR, 1986, 78 p.
7. Zozyrev Yu.N., Saltykov V.F. Geological atlas of the Penza Oblast. Saratov, 2001, 52 p.
8. Kaplyanskaya F.A., Tarnogradsky V.D. Glacial Geology: a methodological guide to the study of glacial formations in large-scale geological survey. Saint Petersburg: Nedra, 1993, 328 p.
9. Kuznetsov K.P., Galdin G.B., Nikolaeva N.I. Palamozhnykh E.A. Soils of the Penza Oblast. Saratov: Privolzhskoe knizhnoe izdatelstvo, 1966, 125 p.
10. Lavrushin Yu.A. Proceedings of the geological Institute. Issue 288. Structure and formation of the main moraines of continental glaciations. Moscow: Nauka, 1976, 244 p.
11. Lomov S.P. Soil and climate of the Penza oblast. Penza: PGUAS, 2012, 260 p.
12. Rukhina E.V. Lithology of glacial deposits. Leningrad: Nedra, 1973, 176 p.
13. Problems of exogenous relief formation. Book 1. The terrain is glacial, cryogenic, aeolian, carstic and of sea-coasts. Moscow: Nauka, 1976, 435 p.
14. Spiridonova I.N., Lomov S.P., Artemova S.N. Forest-steppe geosystems of the Penza oblast and their agro-soil development in the Holocene: materials of the regional scientific and practical conference. Penza: PGUAS, 2016, pp. 109-118.
15. Benn D.I., Evans D.J.A. Glaciers and glaciation. London: ARNOLD, 1998, 734 p.
16. Hambrey M.J. Glacial environments. UCL: London, 1994, 293 p.