Environmental Impact Assessment of Technogenesis on Genetic Features, Composition and Properties of Light Gray Forest Soils

L P Stepanova¹, A V Pisareva², T N Bolmat³

¹Doctor of Agricultural Sciences, Professor of the Department of Agriculture, Agrochemistry and Agronomic Soil Science of Federal State Budgetary Educational Institution of Higher Education Orel State Agrarian University named after N.V. Parakhin, 302019, Orel, Generala Rodina St., 69, Russia
²Assistant Professor, Candidate of Biological Sciences of Federal State Budgetary Educational Institution of Higher Education Bauman Moscow State Technical University (national research university), 105005 Moscow, Russia, ul. Baumanskaya 2-ya, 5/1
³Ph.D. student of the Department of Agriculture, Agrochemistry and Agronomic Soil Science of Federal State Budgetary Educational Institution of Higher Education Orel State Agrarian University named after N.V. Parakhin, 302019, Orel, Generala Rodina St., 69, Russia

E-mail: step.lp@yandex.ru, pavpav.06@mail.ru

Abstract. The paper presents an environmental impact assessment of technogenesis (waste slag from metallurgical production) on the genetic characteristics of light gray forest soils. To study the degree of technogenic impact of the slag dump on the degradation changes in the morphological characteristics and composition of light gray forest soils in the area of action of the slag dump of fines of aluminum casting on the example of a slag dump in the village of Bolshoye Dumchino, Mtsensk district of the Oryol region, field and laboratory studies of soil samples taken at different distances from the slag dump - 20 m, 150 m, 300 m, 450 m. The soil cover of the territory in the area of the slag dump is represented by light gray forest soils, which are characterized by the following typical diagnostic horizons with characteristic morphological features at different distances from the dump. This research aims to establish the degree of anthropogenic transformation of light gray forest soils of agricultural areas, disturbed by the technogenic impact of metallurgical waste. The tasks were solved, as a result of which the influence of the slag dump on the typical diagnostic features of the genetic horizons of light gray forest soils was established. The nature of the change in the aggregate and granulometric composition in the profile of light gray forest soils in the area of influence of the slag dump was studied. An assessment of the degree of degradation changes in the physicochemical properties of light gray forest soils at different distances from the pollution source is given.
1. Introduction

Environmental problems currently cover all spheres of nature and urgently require detailed research and practical solutions [5]. To date, in the industrial and densely populated regions of the Russian Federation and the Commonwealth of Independent States, anthropogenic pollution of the soil cover reaches a high level [2], [6]. This is known to pose a serious public health hazard. The reclamation of forest areas for agricultural use is accompanied by the removal of forest biomass, while the flow of plant residues into the humus layer is reduced [20], [21]. The production potentials due to the intensification of production exceed the possibilities due to the reclamation of contaminated soils [7]. An increase in the mineralization of the humus layer occurs due to a sharp change in aeration conditions in arable soils compared to virgin soils [17]. Such soils are devoid of the so-called "natural barrier", which slows down the mineralization of plant residues. Thus, up to 80% of the total litter mass is lost in two years. It should be noted that the rate of decomposition of stubble-root residues (SRR) of field crops is approximately the same as in the forest-steppe area [18]. In arable soils, due to the regular loosening of the soil mass, the decomposition of SRR occurs completely without local accumulation in the upper soil layer [21]. Studies have shown that the humus content in the arable horizons of all subtypes of gray forest soils is 1.5 times less than in the A1 horizon of similar virgin soils [21]. Today, measures to determine the ecological stability of the soil cover to various anthropogenic and technogenic loads under various external influences are relevant. For this purpose, scientists are developing certain measures. For example, one of the activities the authors of [10] in their works consider the engineering treatment of sewage sludge using a flotation combine [1], [8], [9], [13]. The scheme proposed by the authors of [11] excludes the ingress of toxic substances of sludge into the environment. The authors of [3] presented a methodology and a mathematical model for assessing environmental damage using the example of agricultural equipment.

The authors [12] consider the problem of the toxicity of ash and slag wastes that are generated during the combustion of coal at various enterprises, which are subjected to additional processing during soil leaching [12], [13].

The purpose of this research is to establish the degree of anthropogenic transformation of light gray forest soils of agricultural areas, disturbed by the technogenic impact of metallurgical waste (slag dump).

Tasks:
1. To establish the influence of the slag dump on the typical diagnostic features of the genetic horizons of light gray forest soils.
2. To study the nature of changes in the aggregate and fractions of the granulometric composition in the profile of light gray forest soils in the area of influence of the slag dump.
3. To assess the degree of degradation changes in the physicochemical properties of light gray forest soils at different distances from the source of anthropogenic impact.

2. Objects and methods

The studies were carried out in agricultural areas using soils that are characteristic of the study area - light gray forest soils. The objects of study are located in areas with a distance from the source of influence at 20 m, 150 m, 300 m, and 450 m from the slag dump in the village of Bolshoye Dumchino, Mtsensk district, Oryol region [10]. The light gray forest soil of the investigated site was used as a control (background) sample [6], [7]. The slag dump that formed is currently a mountain with a height of more than 40 m, consisting of bulk material, which is located near the settlement of the village of Bolshoye Dumchino (the distance from the borders of the settlement to the slag mountain is 1 km).

Soil sample No.1 in the section (distance from the pollution source is 20 m): A0 - organogenic bedding horizon, 0 - 3 cm; A1 - humus-accumulative horizon, gray, pale-gray, dense, platy-lumpy, inclusions of roots, 3 - 17 cm; A1/A2 - transitional, eluvial-illuvial, textured, with ochreous-gray gleying spots, dense, lumpy-platy, the presence of a whitish powder of gray and dark fulvous gleying spots, wet, single roots,
inclusions of slag grains, 17 - 25 cm; \( B_g \) - gley, textured, heavily loamy, brown-fulvous, finely dispersed input, enriched with sludge and bulk forms of iron and aluminum with signs of gley; \( B_{Cg} \) - transitional to the parent rock, gley, pale-fulvous, clay-illuviated, presence of gray and ochreous gleying spots, single roots, from 70 cm to 105 cm.

Soil sample No.2 in the section (distance from the pollution source is 150 m) \( A_0 \) - arable, gray, platy, lumpy. Root inclusions, compacted, whitish powder of \( \text{SiO}_2 \) when dries up, gradual transition, in color, 0 - 17 cm; \( A_1 \) - humus, gray, lumpy-platy, compacted, the presence of a whitish powder of \( \text{SiO}_2 \), gradual transition in color, 17-20 cm; \( A_1A_2 \) - humus-eluvial fulvous-pale, platy, compacted, abundant whitish of \( \text{SiO}_2 \) signs of gleying in the lower part, the transition is gradual, 20 - 30 cm; \( A_2B \) - transitional, pale-fulvous, platy-hazelly, compacted, the presence of whitish powder of \( \text{SiO}_2 \) and gray gleying spots, gradual transition, 30 - 50 cm; \( B \) - illuvial, reddish-fulvous, hazelly-prismatic, dense, the presence of ochreous iron spots, 50 - 80 cm; \( B_{Cg} \) - transitional to the parent rock, pale-fulvous, lumpy, lumpy-prismatic, dense, the presence of gray and ochreous gleying spots, 80 - 110 cm.

Soil sample No.3 in the section (distance from the pollution source 300 m) \( A \) - arable gray, humus-accumulative, lumpy, inclusions of roots, slightly compacted, gradual transition in density, 0 - 17 cm; \( A_1 \) - humus or humus-accumulative, lumpy, including roots, when dries up, a weak whitish powder of \( \text{SiO}_2 \). The transition is gradual, 17 - 39 cm; \( A_1A_2 \) - eluvial-illuvial or transitional, pale-whitish, platy, compacted. The presence of a whitish powder of \( \text{SiO}_2 \), 39 - 49 cm; \( A_2B \) - transitional, fulvous, with a whitish powder, hazelly, transitional, compacted, 46 - 62 cm; \( B \) - illuvial or textural horizon, fulvous, hazelly-prismatic, the presence of dark gray humus-clay films when the whitish powder of \( \text{SiO}_2 \) dries up. The transition is gradual, 62 - 90 cm; \( B_{Cg} \) - transitional to the parent rock, light fulvous, pale-fulvous, prismatic, dense, 90 - 100 cm.

Soil sample No.3 in the section (distance from the pollution source is 450 m) \( A_0 \) - dense turf, coherent, intertwined with roots, 0-3 cm; \( A_1 \) - humus, gray, lumpy-hazelly, compacted, when dries up, a weak whitish powder of \( \text{SiO}_2 \), the inclusion of roots. The transition is gradual, 3-5 cm; \( A_1A_2 \) - humus-eluvial light gray, whitish-gray, platy, compacted, the presence of whitish silica powder, 25-38 cm; \( A_2B \) - eluvial-illuvial fulvous-pale, hazelly-prismatic, dense, single roots, constant transition, 38-50 cm; \( B \) - illuvial, pale-fulvous, yellow-fulvous, prismatic, dense, whitish powder of \( \text{SiO}_2 \) along the cracks, presence of humus smears, 58-80 cm.

The soil is light-gray forest, meddle, low-humus, middle loamy on podzolized loess-like loams.

It was found that the value of the structural coefficient of the upper soil horizons varied significantly depending on the remoteness of the slag dump and the nature of soil use. Thus, the lowest value of the structural coefficient was established in the immediate vicinity of the slag dump, and its value was 0.5 units. It should be noted that this characterizes the soil structure as unsatisfactory. With a distance of 150 m and 300 m from the pollution source, the structural state of the soil cover improves, since the value of the structural coefficient increases from 1.8 units. up to 2.3 units respectively. It was also found that a favorable water-air regime develops in the soils since the samples differ in terms of water permeability and moisture capacity. Sufficient aeration in soil samples from sections No.2,3,4 contributes to the creation of favorable conditions for the mobilization of nutrients and the course of microbiological processes. It has been established that a rather high density and an unsatisfactory structural state of the soil sample from section No.1 close to the pollution source contribute to the stagnation of surface waters and the development of gleying processes, which is ultimately reflected in the characteristics of diagnostic and morphological characteristics of soil samples.

Changes in the granulometric composition of soil samples and the nature of the distribution of fractions of mechanical elements in the samples under study were established [4]. In all soil sections at a depth of 0-20 cm, the composition of the fractions is characterized as medium loamy with a predominance of particles of coarse dust (0,05 mm) and particles of fine sand (0,25 mm), which leads to reduced water
resistance, a tendency to crust formation, soil overcrusting, as well as a decrease in the mechanical strength of the aggregate structure [16]. It was found that the soil under study is also characterized by an increase in the granulometric composition of the soil near the source of anthropogenic impact as a result of technogenic degradation, destruction of the upper fertile soil layer and with the emergence of a weighted illuvial soil horizon on the surface. It has been proven that in the illuvial horizons, the content of the sludge fraction (particles less than 0.001 mm) increases with the depth of the soil section. This phenomenon makes the granulometric composition heavier to light clay and heavy loamy composition. In this regard, such soils are characterized by low water permeability, and with heavy rainfall, there is a danger of moisture stagnation, waterlogging, and the development of the gleying process. It should be added that scientists have proven that surplus activated sludge can be directly used in biological treatment plants, pre-thickening it by pressure flotation with preliminary acidification [6], [10], [14]. At the same time, the authors of [13] found that the age of activated sludge practically does not affect the sorption of rare earth metals [13], [15]. It has been shown that the toxic load of pollution sources not only does not decrease but even increases [20].

It is known that the specific surface area of soil particles plays a key role in the formation of soil fertility since the soil surface is the place of interaction of the humus layer with plant roots and soil microbiota. The research results of the authors [20] showed a manifested dependence of the specific surface area on the granulometric composition and the content of organic matter in soil samples in the sections. In soils located at different distances from the pollution source, the specific surface area varies from 84 m²/g near the slag dump to 163 m²/g with the greatest distance from the pollution source at a distance of 450 m. In all the studied soil samples, the specific surface area changes. If its value in the upper humus horizons ranged from 57-62-84-163 m²/g, then in the illuvial horizons of the studied soils, where their granulometric composition becomes heavier, the specific surface area of soil particles steadily increases in the range from 124-177 m²/g.

It is known that organic substances significantly affect the agronomic properties of soils [19]. The content of organic matter in the soils of the study area adjacent to the pollution source indicates a low humus content of the contaminated soils. It was found that the humus content in the upper soil horizon close to the pollution source is 2%, and in the arable soil horizons, 150 m and 300 m away from the pollution source, the amount of humus is 2.2% and 2.1%. In the soils adjacent to the field of the forest protective belt (at a distance of 450 m from the pollution source), the humus content under the herbaceous vegetation increases to 2.7%.

Studies have established the dynamics of the value of the cation exchange capacity in the humus horizons of soils from 34 mg-equiv/100g in the closest location of the soil to the pollution source (20 m) to 48 mg-equiv/100g with the greatest distance (450 m) from the slag dump.

The most important in assessing the composition of exchangeable cations are ions Al³, Ca²; Mg²; Na, H. The cations Mg², Ca², and Na are exchangeable bases, and the cations Al³ and H cause hydrolytic acidity. It was found that the lowest value of hydrolytic acidity was found in soils located 150 m and 300 m away from the dump (samples No.2 and No.3), the value of acidity was 2.4 – 2.0 mg-equiv/100 g of soil, and with the depth of the soil profile, the value of hydrolytic acidity increases in the range of 9.4-13.1 mg-equiv/100g. The degree of saturation with soil bases also changes, its highest value was established for arable soils - 91-96% (samples No.2 and No.3).

The degree of contamination of soil samples was estimated using the value of the concentration factor of pollutants in the soil according to the formula:

\[ K_f = \frac{C_{\text{ime}}}{C_{\text{MPCme}}} \]  

where \( C_{\text{ime}} \) - is the average concentration of heavy metal in the soil, mg/kg;

\( C_{\text{MPCme}} \) - is the maximum permissible concentration of polluting heavy metals following Hygienic Norms 2.1.7.2014-06.
The total indicator of chemical contamination of the humus horizon of the light gray forest soil with heavy metals was calculated using the formula:

\[ Z_c = K_1 + K_2 + \ldots + K_n - (n-1) \tag{2} \]

where \( n \) - is the number of heavy metals taken into account.

The total indicator of chemical soil pollution varies within 1.3-11.3, which proves the acceptable or moderate degree of soil pollution. It was found that chemical elements in terms of the excess of their content over the MPC values in the soil form the following series: Zn > Pb > Cu > Ni > Cd. A significant excess of MPC for lead (Pb) was noted, the content of which exceeds MPC by 1.2-3.8 times. The excess of the MPC was found for zinc (Zn) in soil samples No.2 and No.3, the value of the concentration factor of this element ranges from 2.2 (sample No.2) and 5.6 units (sample No.3). The excess of MPC was also noted for copper (Cu), the content of which in sample No.1 was 1.2 times higher than its permissible concentration, and in soil sample No.3 it exceeded the limiting concentration by 2.6 times. The content of mobile manganese (Mn) is found to be significantly lower than the maximum permissible level of accumulation in soils. For mobile forms of cadmium (Cd) and nickel (Ni), their maximum permissible level is shown to be 2.2 times higher for cadmium (sample No.2) and 2.3 times for nickel (sample No.3).

The technogenic impact of the pollution source on the studied soils of agricultural lands leads to regular dynamics in the concentration of heavy metals and a significant excess of the MPC for cadmium, lead, zinc, nickel, and copper.

3. Conclusion

Studies have shown that all samples of the studied soils contain an excess of heavy metals. The influence of metallurgical production wastes on the agroecological state of light gray forest soils has been established. The change in the aggregate composition and degree of aggregateness of the humus horizons of light gray forest soils has been proved depending on the degree of remoteness of the slag dump: the lowest value of the structural coefficient was established for the humus layer of light gray forest soil in the immediate vicinity of the pollution source, its value is 0.49 units and characterizes the unsatisfactory structural condition of the soil. At the greatest distance from the pollution source, the value of the structural coefficient increases to 2.3 and is estimated as "the proper aggregative state."

The homogeneity of the granulometric composition of soils is shown, which is assessed as medium loamy with a predominance of the fraction of particles of coarse dust and particles of fine sand, which causes low water-resistance of structural aggregates, a tendency to float, crust formation and a decrease in the mechanical strength of structural aggregates.

Light gray forest soils adjacent to the storage of slag waste are characterized by low humus content. The impact of slag waste on the composition and properties of soils is manifested in a change in the physicochemical properties of soils. The lowest value of hydrolytic acidity was found (2.44 mg-equiv/100g) in soils with a high degree of saturation with bases (96%); with increasing depth, the value of hydrolytic acidity increases to 13.13 mg-equiv/100g.

For the humus horizons of light gray forest soils, the specific surface area of soil particles varies from 84 m²/g in the immediate vicinity of the slag dump to 163 m²/g with an increase in the distance between the soil and the slag dump.

4. References

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