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Mineralogical Soil Complex Indicates an Effectiveness of Fertilizers in Agriculture

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Abstract

The mineralogical composition of clay loamy agro-gray soil and the content of nutrient elements in the soil and its fractions were determined. This allowed estimating the nutrient supply and natural productivity of the soil. The long-term use of soils with the application of mineral and organic fertilizers affected the soil mineralogy: both aggradation and degradation processes were observed. The fertilizing system recommended for application to the agro-gray soil did not affect the crystal-chemical parameters of soil minerals. However, soil acidification and changes in the humus fractional composition towards increasing the content of fulvic acids show intensive degradation of soil minerals, which can lead to adverse consequences for soil fertility.

Keywords

Fertilizers, Soil Mineralogical Complex, Soil Degradation

1. Introduction

In agrocenosies, a significant number of plant nutrients are alienated from the crop, which they absorb from the products of the destruction of minerals or natural sources of nutrition. It was established earlier that the processes of the destruction of minerals are significantly influenced by a sharp change in the reaction of the medium to the acidic or alkaline side, the processes of the soil mass dispersing [1, 2, 3, 4, 5].

The purpose of this work is to analyze the mineralogical composition of fractions of different dimensions, the crystal-chemical state of minerals, the content and reserves of nutrients in soils in long-term field tests with mineral and organic fertilizers.

2. Materials and Methods

The objects of the study were fractions of silt, fine and medium dust, and also the residue after these fractions separation of agro-gray loamy soils in long-term field tests.

Investigations were carried out on the basis of long-term field tests at the agrotechnological station of Ryazan State Agrotechnological University, the Department of Agriculture (Experiment 1) and the Department of Agrochemistry and Soil Science (Experiment 2).

Experiment 1 with an organic-mineral fertilizer system was laid down by L.V. Ilyina in 1970 [6]. The following crop rotation was selected for the study: annual grasses ($N_{30}P_{110}K_{70}$)—winter wheat ($N_{60}P_{40}K_{40}$)—potatoes ($N_{140}P_{110}K_{110}$+manure 40 t/ha)—barley ($N_{90}P_{100}K_{80}$).

Experiment 2 with different forms of mineral fertilizers was laid by E. A. Zhorikov in 1962 [7]. For the study, we used a variant involving the use of P_c, K_x and Na_x in the following doses: for annual grasses—$N_{30}P_{60}K_{60}$, potatoes—$N_{100}P_{100}K_{100}$, winter wheat and barley—$N_{60}P_{60}K_{60}$. No organic fertilizers were added. There were no significant differences between the control options for agrochemical properties and the granulometric composition of the soil, which indicated the homogeneity of the field in these parameters. The repetition of the experiment was threefold. Humus was determined in the experiment according to Tyurin, the quality composition of humus was determined according to Tyurin's scheme in modification of Ponomareva-Plotnikova, pHKCl was determined by potentiometric method with LPU-0.1 instrument and labile phosphorus and exchange potassium—according to Kirsanov.

Separation of silt, fine and medium dust fractions to determine the mineralogical composition was carried out according to Gorbunov's method [8]. Oriented fractions preparations were examined by X-ray diffractometry. X-ray diffraction patterns were obtained for air-dry samples saturated with ethylene glycol and heat-treated at 550 °C for 2 hours.

3. Results and Discussion

The increase of soil acidity (Table 1), fulvic acids proportion in the topsoil (Table 2), and silicon content (Table 3) in variants with long-term use of fertilizers indicated that processes of minerals carrying nutrients destruction processes.

The silt component was most susceptible to anthropogenic factors. A comparison of this parameter (Table 4) in the arable horizons of agro-gray soils for different variants of the fertilizer system indicated higher silt content (25.4%) in the soil in the variant where ammonium chloride (NaX) was added. The increase of the silt fraction content is quite natural when adding such a strong dispersant as an ammonium radical. In the variant with an organic-mineral fertilizer system, the amount of silt was minimal (19.1%), which can also be explained by the coagulating effect of the organic matter formed as a result of manure application. The fine dust fraction in the top and sub-surface horizons varied from 8% to 11%. The nature of this fraction distribution in these horizons changed. The variants without fertilizers and with the organic-mineral system had the greatest amount of the fraction in the arable horizons equal to 9.7% and 10.6%, respectively. The variant with mineral fertilizers had the minimal amount of the fraction equal to 8.3%.

Table 1. Agrochemical properties of agro-gray soil (0-20 cm)

Fertilizer system	Humus, %	Labile phosphorus	Labile potassium	pH_{KCl}	Combined Kappen acidity	Adsorbed base
		mg/100 g of soil			mg-equiv/100 g of soil	
Without fertilizers	2.1±0.2	12.3±0.9	14.4±0.9	5.7±0.1	2.6±0.1	24.1±0.3
Organic-mineral system of fertilizers	3.0±0.2	32.0±0.4	24.1±0.4	5.9±0.2	1.9±0.01	26.0±0.4
Mineral system of fertilizers	2.3±0.1	26.1±0.3	23.3±0.5	4.4±0.2	6.1±0.0	14.5±0.5

Table 2. Carbon content of humus fractions, % to total carbon of soil

Fertilizer system	Layer, cm	C_{HA}				C_{FA}					C_{HA} + C_{FA}	C_{HA} : C_{FA}
		HA-1	HA-2	HA-3	Total	FA-1a	FA-1	FA-2	FA-3	Total		
Without fertilizers	0-20	3.25	32.1	8.4	43.7	3.3	4.8	7.8	4.3	20.2	63.9	2.2
	20-30	2.75	32.3	9.9	44.9	2.9	5.4	6.7	6.8	21.8	66.7	2.0
Organic-mineral system of fertilizers	0-20	6.1	28.9	12.5	47.5	2.6	5.1	4.1	8.0	19.7	67.3	2.4
	20-30	6.35	20.2	11.7	48.3	2.4	5.3	5.9	6.8	20.5	68.8	2.4
Mineral system of fertilizers	0-20	14.0	24.3	8.6	46.9	3.0	10.8	3.4	4.7	21.9	68.9	2.1
	20-30	11.5	28.1	7.9	47.5	3.1	10.1	3.5	5.0	21.8	69.3	2.2
HCP_{05}	0-20	1.0	1.1	0.8	–	1.0	1.3	0.8	1.2	-	-	-
	20-30	0.65	1.1	1.3	–	0.34	1.3	1.0	1.2	-	-	-

The organic-mineral fertilizer system had 2.8%-4.5% increase of medium dust in the arable and sub-surface layers as compared with other variants of the experiment. In a case of the long-term effect of fertilizers, the increase of the lithosolic portion in the arable layer of soil was expected 60% against 56.3% in the control variant.

Table 3. Total chemical composition of agro-gray soil (%)

Fertilizer system	Layer, cm	SiO_2		Al_2O_3		Fe_2O_3		CaO		MgO		P_2O_5		K_2O	
		1	2	1	2	1	2	1	2	1	2	1	2	1	2
Without fertilizers	0-20	53.3	77.6	17.8	11.3	10.4	3.9	0.7	1.0	3.2	1.0	0.3	0.2	2.8	2.4
	20-30	54.7	76.8	17.0	11.5	10.1	4.0	0.8	1.0	3.2	1.2	0.2	0.2	2.7	2.3
Organic-mineral system of fertilizers	0-20	53.0	78.3	17.3	10.1	9.9	3.4	0.9	1.1	3.0	0.9	0.4	0.4	2.8	2.4
	20-30	52.3	78.7	16.9	10.1	10.0	3.4	0.8	1.1	3.1	1.0	0.3	0.3	2.7	2.3
Mineral system of fertilizers	0-20	53.6	78.4	16.8	10.7	10.3	3.8	0.5	0.9	3.2	1.0	0.4	0.4	2.9	2.4
	20-30	52.9	78.1	17.5	11.0	10.3	3.8	0.6	0.9	2.8	1.0	0.4	0.4	2.8	2.4
HCP_{05}	0-20	0.6	0.8	0.5	0.5	0.6	0.5	0.2	0.10	0.1	0.1	0.1	0.1	0.2	0.2
	20-30	0.6	0.6	0.6	0.6	0.6	0.1	0.1	0.1	0.2	0.1	0.1	0.1	0.2	0.1

Note: Column 1—in silt, column 2—in soil as a whole.

The mineralogical composition of the fraction <1 um extracted from the top and sub-surface horizons of gray forest soil was represented by hydro micas of di/trioctahedral type (53%-63.0%), kaolinite (12%-15%) and complex disordered mixed layers formations with low smectite packet content (23%-35%). A number of horizons marked the presence of chlorite. The ratio of these mineral phases varied in two directions: the amount of mixed-layer minerals with the smectite package in sub-surface horizons was somewhat larger than in the silt component of the arable horizons. The content of the mixed layer formation in the arable horizons was the smallest in the variant where mineral fertilizers were applied. The same variant had the greatest amount of hydro mica (Table 5).

Table 4. Content of finely dispersed fractions (%)

Fertilizer system	Layer, cm	Lithosolic part (>10 um)	Medium dust (5–10 um)	Fine dust (1-5 um)	Silt (<1 um)
Without fertilizers	0-20	56.3	7.4	9.7	24.5
	20-30	59.6	7.4	8.4	26.8
Organic-mineral system of fertilizers	0-20	60.2	10.2	10.6	19.1
	20-30	59.0	9.9	9.9	21.3
Mineral system of fertilizers	0-20	59.7	6.6	8.3	25.4
	20-30	60.1	5.7	10.7	23.5

Table 5. Fertilizers influence on silt mineralogical composition

Fertilizer system	Layer, cm	Kaolinite + chlorite	Hydro mica	Mixed-layers formations	Kaolinite + chlorite	Hydro mica	Mixed-layers formations
		in silt fractions (%)			on conversion to soil as a whole (%)		
Without fertilizers	0-20	14.7	60.4	24.4	3.3	14.7	5.9
	20-30	12.9	53.0	34.5	3.5	14.2	9.0
Organic-mineral system of fertilizers	0-20	13.9	62.6	23.5	2.6	12.0	4.5
	20-30	12.1	56.9	31.1	2.6	12.1	6.6
Mineral system of fertilizers	0-20	13.5	63.8	22.8	3.4	16.3	5.8
	20-30	12.2	62.2	25.7	2.9	14.6	6.0

This regularity can be explained by the non-fixed fixation of potassium and ammonium cations of mixed layers formations. As a result of potassium and ammonium contractions, some compression of the mineral trellis and transition to a mica-like structure were noted.

Tendencies of changes in such important parameters as the content of the silt fraction, and the smectite phase and hydro micas in it, proved the acid hydrolysis of minerals with a change in the reaction of the medium to the acidic side, which activated minerals transformation processes. The appearance of an increased quantity of potassium and ammonium cations in the soil activated the processes of aggradational transformation of smectite packets with the non-exchangeable fixation of these elements. The process of mechanical disintegration of minerals in the arable horizons, first, where dispersants were introduced, became more active. Therefore, the number of minerals of micron dimension, such as quartz and feldspars, increased in arable horizons. The mineralogical composition of finely dispersed dust fractions (1-5 um) was multicomponent and differed significantly from that of the silt (Table 6). They completely lacked mixed layers, and quartz (30%-33%), potassium feldspars (15%-18%), plagioclases (9%-15%) and micas (27%-36%), mostly of trioctahedral type, were diagnosed. Kaolinite was detected as a small admixture (5%-7%), in a number of samples chlorite was found.

The content of these minerals and their crystal chemistry varied somewhat in the arable and sub-surface layers, as well as in the arable layers, depending on the type of action. In variants without and with fertilizers the smallest amount of micas in the arable horizons was noted. It is possible to assume that micas, as a source of potassium, were destroyed in these variants first of all. This assumption is true, because the mechanism for micas entry into the silt fraction during the mechanical disintegration of particles in all variants was the same, since it was activated under man-made loads.

In the silt fraction, extracted from the gray forest soil under the forest, the amount of micas also exceeded their content in the indicated variants. It is necessary to point out one more regularity: a change in the ratio of di- and trioctahedral mica differences in various variants. The variant without fertilizers had this parameter <2, the variant with fertilizers had the index varying within 2 and the variant with the organic-mineral system had the parameter >2.

The content of chlorite declined in variants with an organic-mineral system and with mineral fertilizers. Probably, acidification when using fertilizers led to the destruction of chlorites. It is also necessary to pay attention to the behavior of fine-dust quartz. The amount of quartz in arable horizons of all variants was greater than in the sub-surface ones, except for the variant with an organic-mineral system, where this parameter was the same within the studied layers. The greatest differences in the content of quartz were noted in arable and sub-surface layers of variants with fertilizers. The character of the distribution of minerals of finely dust fractions considered above has made it possible to reveal the following processes: the destruction of minerals of chlorite and trioctahedral micas that are less resistant to weathering and soil formation, which are sources of plant nutrients, and the activation of the process of mechanical disintegration of potassium feldspars and plagioclases, the relative accumulation of finely silt quartz in the arable layers.

The arable layer of the variant with the organic-mineral fertilizer system had the least amount of quartz (40.1%) in the medium silt minerals, which was 4.3%-4.6% less than in the control variant and in the variant with the mineral system, where its content decreased with the depth, while in other cases it increased. The reverse trend was observed for mica, kaolinite and chlorites.

When considering the behavior of potassium feldspars in the arable layer, their higher content in the variant with mineral fertilizers (18.8%) and the smallest one (16.5%) in the variant with the organic-mineral system were observed. In the mineralogical composition of the fractions of medium dust, a decrease in the content of quartz in the arable layer was established in a case of using mineral and organic fertilizers and mica, and chlorites decrease was observed when using ammonium chloride at the background of phosphorus and potassium fertilizers.

A differentiated evaluation of the reserve of nutrients for plants was proposed by N.I. Gorbunov in 1970s-1980s. During this period, some considerable material on the evaluation of the reserve of nutrients for different types of soils in different countries was accumulated. However, calculations of the change in the stock of elements, depending on the type of anthropogenic impact and farming systems, were carried out in single cases, mainly at the oldest experimental stations (for example, Shatilovskaya). The scheme proposed by N. I. Gorbunov [9] for dividing the elements by the size and quality of reserves on the basis of minerals dispersion was detailed with the help of experimental materials on the stability of soil minerals to weathering processes, which is determined by the structural features of the minerals [10]. To some extent, these predicted reserves are proved by analysis of the gross amounts of elements in fractions of different dimensions: <1, 1-5 and 5-10 um and in the residue after the separation of finely dispersed fractions.

Below are the calculations of the reserves of nutrients in arable and sub-surface horizons (Table 6). The data of the gross chemical analysis of the agro-gray soil of the experimental variants showed the high content of potassium, and the mineralogical investigations revealed the forms in which this element was located. The comparison of the distribution of potassium forms in the arable and sub-surface layers showed that the largest reserve of potassium was achieved in the arable layer of the agro-gray soil in the variants with mineral and organic-mineral fertilizer systems—2430 mg/100 g of soil.

Potassium content in the potential reserve has changed significantly depending on the type of action. The highest values (1770-1860 mg/100 g) were found in the arable layer, where fertilizers were used [11, 12]. The potassium amount in the sub-surface layer decreased.

Table 6. Mineralogical composition of fractions 1-5, 5-10 um extracted from agro-gray loamy soil (%)

Fertilizer system	Layer, cm	Quartz	Mica	Kaolinite	Chlorites	K-field spars	Plagioclases
				1-5 um			
Without fertilizers	0-20	32	30	5	3	16	13
	20-30	28	35	7	3	15	12
Organic-mineral system of fertilizers	0-20	31	34	5	0	17	15
	20-30	31	32	5	0	18	14
Mineral system of fertilizers	0-20	33	27	5	0	17	15
	20-30	30	36	5	3	16	9
				5-10 um			
Without fertilizers	0-20	44.7	16.8	2.6	4.4	17.1	14.5
	20-30	46.4	15.7	2.1	3.6	16.9	15.4
Organic-mineral system of fertilizers	0-20	40.1	15.6	4.8	3.8	16.5	17.9
	20-30	42.7	11.1	2.6	3.0	19.3	15.7
Mineral system of fertilizers	0-20	44.4	15.5	2.5	3.3	18.8	15.7
	20-30	36.8	17.5	2.6	6.2	18.9	18.0

The smallest amount of potassium in the near reserve was recorded in the arable horizon of the soil with an organic-mineral fertilizer system. Distinctive features can probably be explained by the following fact: potassium in agro-gray soil without fertilizers is taken from hydro micas and alumina-silicate mica-smectites with a low content of smectite packets. In the agro-gray soil with fertilizers, the potassium of the introduced fertilizers is fixed, that is an aggradational transformation causing potassium increase. In soils with an organic-mineral fertilizer system, the presence of organic matter introduced with manure interferes with the interlayer fixation of potassium, on the one hand, and potassium is actively removed by higher yields, on the other hand.

Thus, it has been established that the mineralogical composition of the arable and sub-surface layers of the agro-gray loamy soil is represented by components typical for soils developed on loess loams. Hydro micas predominated in silt fractions of arable and sub-surface layers. In addition to hydro micas, mixed-layer formations, kaolinite and chlorites have been established in the sub-surface layer. Quartz dominated in fine and medium-dust fractions [13, 14]. There were feldspars, micas and plagioclases, kaolinite and chlorites in a subordinate amount.

Long-term use of various fertilizer systems led to small changes in the structural and mineralogical characteristics of fine-dispersed fractions (silt, fine and medium-dust). The greatest changes were recorded in the mineral part of the soil in the variant where nitrogen fertilizers were applied at the background of phosphorus and potash fertilizers. In this case, the processes of interlayer fixation of the ammonium radical with mica-smectites in silt fractions have been established.

4. Conclusion

The evaluation of the behavior of the structural and mineralogical parameters of the soil showed that the long-term (more than 40 years) application of fertilizers at established doses did not lead to significant negative consequences for the mineral complex of the agro-gray loamy soil. At the same time, some weak tendencies of degradation processes were noted, especially if acidification of the soil solution takes place. Therefore, considering that soil minerals represent an irreplaceable source of natural plant nutrition, in order to prevent negative transformations of structural and mineralogical parameters, constant monitoring of the acid state of soils and structural changes in finely dispersed fractions is necessary.

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