Changes in some properties of agro-gray soil fertility under the influence of biofertilizer

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Abstract. In the field experiment with the agro-gray soil of the Krasnoyarsk forest-steppe, the improvement of the agro-physical properties was established with the use of organic fertilizers, regardless of their type and application rate. Under the influence of bio-fertilizer and chicken manure introduced into the agro-gray soil, there is a tendency to increase the amount of humus and nitrate nitrogen, mobile phosphorus and the yield of wheat grain. The correlation between the yield of wheat grain and mobile forms of humus is estimated at the average level. Using the method of multiple regression, a model of wheat yield was calculated, according to which it depends on the content of mobile humus substances.

1. Introduction
To restore the fertility of agro-gray soils, the main efforts should be aimed at improving the agrochemical and agro-physical properties. A significant role is given to various organic fertilizers. The decrease in the use of fertilizers has led to a decrease in the effective fertility of the soil, therefore; recently, much attention has been paid to the search and study of the methods of using new types of local fertilizers. One of the promising areas in this area is the use of organic fertilizers in crop rotations, prepared on the basis of local sources of raw materials: chicken manure and hydrolytic lignin, processed by the method of vermiculiture into bio-fertilizer. The aim of the work is to assess the effect of increasing doses of bio-fertilizers on the agrochemical and agro-physical properties of soil agro-gray.

2. Research methods
The study was conducted in a grain-crop rotation in the conditions of “Dawn” field stationary in the Krasnoyarsk forest-steppe, located on the south-western border of Central Siberia. In this area, 350-450 mm of precipitation falls annually. The average annual temperature in the region varies from 0.5 to 1.3 °C, sometimes dropping to -1.2 °C. The duration of the period of biological activity varies from 90 to 115 days. The sum of active temperatures is 1550 – 1800 °C, soils are frozen to a depth of 1.5–3.0 m.

The object of the study is agro-gray medium-power light clayey soil, which was affected by water erosion and was characterized by a low content of humus (2.2–3.3%) in the arable layer, a high amount of exchange bases (24.0–24.3 mg-eq/100 g), slightly acidic reaction of the medium (pH Cl5.4-5.5). In the arable layer of soil agro-gray contained 162.0 mg P₂O₅/kg and 125.0 mg K₂O / kg. The bio-fertilizer tested in the experiment had the following parameters: pH 7.2, organic matter - 36%, N - 1.3%, P₂O₅ - 2.28%, K₂O - 0.82%. Sanitary-bacteriological and helmintological analysis showed the absence of pathogenic microflora of the intestinal group in bio-fertilizers, as well as helminth larvae and eggs,
which confirmed the safety of its use. Chicken dung used in the experiment contained in %: N — 2.9, P2O5 - 2.94, K2O — 1.08, Ca — 2.40, Mg — 0.70, S — 0.40.

The evaluation of the effect of the above organic fertilizers was carried out in the field experiment according to the following scheme: 1. Control (without fertilizers); 2. Chicken dung, 1 t/ha; 3. Bio-fertilizer, 2 t/ha; 4. Chicken dung, 2 t/ha; 5. Bio-fertilizer, 4 t/ha. The experiment is repeated three times, the size of the experimental plots is 100 m², their placement is systematic. Organic fertilizers were applied in spring under pre-sowing cultivation with embedding to a depth of 14–20 cm. In the years of the experiment, spring wheat of the Novosibirskaya-15 was cultivated. Soil samples were taken from the arable layer in the phase of waxy ripeness of wheat grain to determine the humus according to Tyurin [1] and mobile humus (Cmob): humic substances were removed from one sample sequentially. Water-soluble carbon (Ca2o) - by the method of bichromate oxidizability and carbon extracted by 0.1N. NaOH (C0.1NaOH) and in its composition carbon of humic acids (Cph) - with acidification of the obtained alkaline extract with a solution of sulfuric acid of 1% concentration. The content of fulvic acids (Ca) was determined by the difference in the total amount of humic substances in 0.1 n. NaOH-extract and carbon humic acids is in the same extract. Determination of pH, total nitrogen, phosphorus, potassium content was carried out using the method of NIR spectroscopy (analytical system based on the NIR-4250 scanner). Mobile compounds of phosphorus and potassium were determined by the Kirsanov method in the modification of TsINAO (GOST 26207-91. Soils). Nitrate nitrogen was determined by the disulfophenol method in the modification of S.L. Iodko and I.N. Sharkov [2], ammonium nitrogen - with Nessler's reagent (GOST 26489-85). To study the agrophysical properties, soil samples were taken in the tillering-out phase and wax ripeness of wheat grain from a 0-20 cm layer. The density of addition was determined according to Kaczynski, moisture - by thermo-weight method [3]. The structural composition is according to Savinov, the water strength of the structure is on the Bakshiyev device [4].

Harvesting of plants was carried out in the phase of wax ripeness by cutting the plants at the soil level. The results of the study were processed by methods of dispersive and correlation-regression analyses [5].

3. Research results and discussion

The morphological peculiarity of the studied agro-gray soils was the compaction of the arable horizon and its heterogeneity in structure: the upper 0-10 cm was granular-lumpy, the lower part was walnut. The morphologically marked compaction of arable horizons is confirmed by the results of the determination of agrophysical properties. The density of the soil in the control variant at the beginning of the observations corresponded to 1.4 g/cm², which made it possible to consider it highly compacted (table 1). The organic fertilizers used in the field experiment reduced the density of the soil by 0.1-0.2 g/cm² in the agroecosystem of the first wheat at the time of its tillering. The maximum decompaction effect during this period was found in the variant with the use of 4 t/ha of bio-fertilizer, due to its direct loosening effect when mixed with the soil.

The few works on the effect of bio-fertilizers on the structural and functional properties of soils [6, 7] showed that the use of bio-fertilizers is important in agroecosystems that have lost important biogeoecological links as a result of agricultural use. It was established that during the operation of the experimental plots of agro-gray soils, a decrease in the density of soil composition, lumpiness and soil fracture occurred. By the time of wheat harvest, the soil of the control variant still corresponded to the highly compacted. During this period, the chicken droppings had a weakening effect on the soil. In the aftereffect, a strong compaction of the soil by agro-gray was maintained in the unsuccessful control (1.3-1.4 g/cm³). A significant decrease in the soil density of the arable layer in the crops of the 2nd wheat was noted in the variants with chicken manure introduced in doses of 1 and 2 t/ha and in the variant with bio-fertilizer introduced in the amount of 2 tons / ha. In the period of tillering-out in the tube, the addition of soil in these variants corresponded to 1.2 g/cm³. In general, the average seasonal density of addition of the arable layer of agro-gray soil per year of fertilization was 0.1 g/cm³ less compared to the control variant.
The strongly compacted agro-gray soil had an unsatisfactory structure of the arable layer. The content of agronomically valuable fractions with a size of 10-0.25 mm (AVF) in the soil of the control variant in the year of fertilizer application was 40% (table 1). The soil in the period of tillering-release into the tube was very high blocky (60%) and low content of dust fractions (<1%).

**Table 1.** The dynamics of the density of the composition, the content of agronomically valuable fractions and water-resistant aggregates in agro-gray soil, %.

| Variant | Action | Consequence |
|---------|--------|-------------|
|         | tillering- | wax | tillering- | wax |
|         | out | ripeness | out | ripeness |
| Addition density, g/sm³ |
| 1. Control (without fertilizer) | 1.4 | 1.3 | 1.3 | 1.4 |
| 2. Chicken dung, 1 t / ha | 1.3 | 1.2 | 1.2 | 1.4 |
| 3. Bio-fertilizer, 2 t / ha | 1.3 | 1.3 | 1.2 | 1.3 |
| 4. Chicken dung, 2 t / ha | 1.3 | 1.2 | 1.2 | 1.4 |
| 5. Bio-fertilizer, 4 t / ha | 1.2 | 1.3 | 1.3 | 1.4 |
| HCP⁰⁵ | 0.1 | 0.04 | 0.1 | 0.1 |

Agronomically valuable fractions, %

| Variant | Action |
|---------|--------|
|         | tillering-out wax ripeness |
| 1. Control (without fertilizer) | - |
| 2. Chicken dung, 1 t / ha | 41.4 11.4 70.5 51.2 |
| 3. Bio-fertilizer, 2 t / ha | 36.6 23.5 52.9 55.1 |
| 4. Chicken dung, 2 t / ha | 51.3 40.2 56.6 55.1 |
| 5. Bio-fertilizer, 4 t / ha | 40.6 17.2 48.1 58.6 |
| HCP⁰⁵ | 7.6 9.3 5.9 |

Water resistant units, %

| Variant | Action |
|---------|--------|
|         | Fₜₚ<Fₘ |
| 1. Control (without fertilizer) | 87.1 90.7 66.3 66.0 |
| 2. Chicken dung, 1 t / ha | 92.8 89.5 69.6 68.8 |
| 3. Bio-fertilizer, 2 t / ha | 86.6 91.3 62.1 73.3 |
| 4. Chicken dung, 2 t / ha | 89.0 94.1 72.0 74.0 |
| 5. Bio-fertilizer, 4 t / ha | 85.9 92.4 73.3 68.9 |
| HCP⁰⁵ | Fₜₚ<Fₘ Fₜₚ<Fₘ 2.9 2.8 |

Significant improvement in the structural state of the soil was not found in all variants of the experiment. The satisfactory and good structure of the arable layer is achieved when the chicken manure is introduced into the soil. It was established that the structural composition of the soil agro-gray significantly changed during the season. By harvesting wheat, the arable layer was lumpy. In the soil of the control variant, the share of agronomically valuable fractions accounted for only 7%. This structural condition is rated as bad. It was critical and indicated the degradation of the structure at the level of the arable horizon. The dynamics of AVF content was associated with changes in soil moisture. Correlating the content of aggregates of valuable sizes with the field humidity level during the growing season of the first year of research, a strong inverse relationship was established between the studied traits in all variants of the experiment (r = -0.77- -0.95). Abundant rainfall in August contributed to the strengthening of cobblestone formation in the agro-gray soil.

The structuring effect of the applied fertilizers before wheat harvest manifested itself ambiguously. Against their background, the content of fractions of valuable size increased, but this increase was not always statistically significant. Significant improvement was found when using both doses of bio-fertilizer and 2 t/ha of chicken manure. The maximum net effect during the growing season to improve the structural condition of the soil was found when 2 t/ha of chicken manure were introduced. In the aftermath, the soil structure of the control soil with agro-gray was satisfactory (49-56%). A satisfactory and good structure of the arable layer was noted at the beginning of the growing season of wheat in all variants of the experiment. A statistically significant increase in the share of AVF was observed in the
variants of using chicken manure, but the ostructuring effect of fertilizers was weakening by harvesting. The structural composition of the soil agro-gray of the experimental variants had close quantitative estimates (51-59%) and remained at a satisfactory level.

The dynamics of the structural state of the arable layer of soil agro-gray that developed during two growing seasons was in medium and strong dependence on the value of field moisture ($r = -0.30 - 0.83$). Negative dependency indicated the formation of large particles $> 10$ mm in wet periods. In general, the data of structural composition indicated the predominance of lumpy fractions in the arable layer. Their share in the variants of experience accounted for 45-61%. The content of structural units $< 0.25$ mm was $< 1%$. The data of the structural composition obtained during the two growing seasons allowed us to establish the positive effect of fertilizers on the change in the fractions of the structural composition. Under the influence of fertilizers, there was a slight increase in structural units of all fractions of agronomically valuable size and a decrease in blocky aggregates by an average of 2-16%. Chicken droppings introduced into the soil in the amount of 2 t/ha provided the greatest reduction in the arable layer.

Agro-gray soil had a high water content of the structure in the first growing season, which was associated with its lumpiness. Such water resistance is agronomically harmful, since due to the dense packing of soil particles and non-washable structural aggregates in the analysis. Studies have established the absence of significant differences between the variants of the experiment on the aggregate composition. The amount of water-resistant units (WU) during this period was high and amounted to 86-95%. In the aftermath, the excellent structure of the arable layer changed to a good one with a small variation in the water resistance of the aggregates ($V = 12-17\%$). The aggregating efficiency of organic fertilizers was manifested in the 2nd year after their introduction into the soil. Against the background of the use of 4 t/ha of bio-fertilizers and chicken manure in doses of 1-2 t/ha, the water resistance of aggregates $> 0.25$ mm in size reached 70-73% during the tillering of wheat. By wheat harvesting, statistically significant changes in the water structure of the structure were already noted in all variants of the experiment (69-76%). Aggregate composition of soil agro-gray was mainly formed by aggregates $< 3$ mm. The fertilizers used in the experiment had different effects on the aggregate composition fractions. The fractional composition of the aggregates indicated a significant increase in waterproof units 3–1 mm ($25–26\%$) with 2 t/ha of bio-fertilizers and 5–3 mm ($15–17\%$) when adding 4 t/ha of bio-fertilizers and 1 t to the soil / ha chicken droppings.

Fertilizers had an impact on the agrochemical (humus, general and mobile NPK) and physicochemical (pH) properties of the soil studied. According to the properties of the humus state [8], the soil of the control version of the experiment was characterized by a low content of humus (table 2). and bio-fertilizers in amounts from 1 to 4 t/ha determined the tendency of increasing the content of humus in agro-gray soil, but not reliably. Apparently, low doses of fertilizer applied did not affect the change in the humus state of the soil. In all the fertilized variants of the experiment, a significant increase in the soil content of total nitrogen and potassium was found.

A statistically significant increase in the amount of total phosphorus in the soil was observed only with the introduction of bio-fertilizer in the amount of 4 t/ha. The use of fertilizers contributed to a significant change in pH from weakly acid in the control to close to neutral in the fertilized variants of the experiment. The soil of the control variant is characterized by a very low supply of nitrate and ammonium nitrogen, an average supply of exchangeable potassium, and a low content of mobile phosphorus.

This is typical of these soils. The increase in the nitrate form of nitrogen to the average level of security occurs only with the use of 4 t/ha of bio-fertilizer. The increase in mobile phosphorus to the middle class of security occurs in all fertilized variants, and only the use of 4 t/ha of bio-fertilizer has increased this indicator to an elevated level. Under the action of fertilizers, there is a tendency to increase exchange potassium in agro-gray soil.
In the structure of the organic matter of the soil agro-gray, the compounds constituting the fund of stable humus prevail, 73% of the reserves of Shum. Mobile organic compounds (Cmob), passing into the liquid phase of the soil, have a low proportion of Chum (27%). Young humus acids, extracted by alkaline hydrolyzate (92%), dominate in the composition of the substrate. The share of water-soluble fractions is small (8%). Fertilizers used in the experiment show differences in quantitative estimates of the intensity of the humification process. The inclusion of modern carbon-containing compounds in the previously formed humus is a slow process; therefore fertilizers introduced into the agro-gray affect mainly the labile part of humus and have little effect on the main stable foundation. Organic fertilizers, being direct sources of organic matter, enrich agro-gray soil with moving components. The increase in sprod on fertilized variants of experience ranges from 12 to 20% for wheat harvesting, the content of mobile humic acids also increases by 13-44% and up to 23% fulvic acids.

The introduction of various types of fertilizers into the soil has a positive effect on the formation of wheat grain yield. But the effect of fertilizers was different depending on the year of study, the composition and dose of their introduction into the soil. The minimum grain yield of wheat (1.4 t/ha) was formed in the first year of the study on the unsuccessful variant of the experiment, due to the special hydrothermal conditions and low natural fertility of the soil agro-gray. With a single dose of organic fertilizer there is only a tendency to increase the yield of wheat. Significant increases in grain were obtained only with a double dose of all the fertilizers under study. It should be noted that in the second year of the study, the yield of wheat grain is higher compared to the previous one and was associated with other hydrothermal conditions. A sufficient amount of precipitation in the second year of research contributed to the formation of wheat grain yield of 2.0-2.3 t/ha, depending on the type of experience. Estimating the average for 2 years grain yield of wheat, it should be said that it decreases in the series: chicken dung 2 t/ha > bio-fertilizer 4 t/ha > bio-fertilizer 2 t/ha > chicken dung 1 t/ha > Control (w/f) (table 3).

Table 2. The effect of fertilizers on the agrochemical and physicochemical properties of soil agro-gray.

| Variant | Humus, % | pH<sub>KCl</sub> | Mobile, mg/kg | General, % |
|---------|----------|----------------|---------------|-------------|
|         |          |                | N-NO<sub>3</sub> | N-NH<sub>4</sub> | P<sub>2</sub>O<sub>5</sub> | K<sub>2</sub>O | N | P<sub>2</sub>O<sub>5</sub> | K<sub>2</sub>O |
| 1. Control (without fertilizer) | 3.53 | 5.1 | 3.1 | 3.5 | 162 | 125 | 0.14 | 0.15 | 0.86 |
| 2. Chicken dung, 1 t/ha | 3.38 | 5.7 | 6.9 | 3.8 | 226 | 128 | 0.27 | 0.15 | 1.03 |
| 3. Bio-fertilizer, 2 t/ha | 3.20 | 5.6 | 4.4 | 5.7 | 232 | 133 | 0.27 | 0.12 | 1.03 |
| 4. Chicken dung, 2 t/ha | 3.60 | 5.7 | 7.1 | 5.0 | 234 | 126 | 0.27 | 0.15 | 1.03 |
| 5. Bio-fertilizer, 4 t/ha | 3.73 | 5.6 | 8.3 | 6.4 | 258 | 133 | 0.28 | 0.16 | 1.03 |
| HCP<sub>05</sub> | 0.44 | 0.1 | 1.1 | 0.5 | n/a | n/a | 0.05 | 0.07 | 0.06 |

Table 3. The effect of fertilizers on the yield of spring wheat of the Novosibirskaya-15.

| Variant | Wheat yield, t/ha | The increase in wheat grain to the control, t/ha |
|---------|------------------|-----------------------------------------------|
| 1. Control (w/f) | 1.8 |                                 |
| 2. Chicken dung, 1 t/ha | 1.9 | 0.1 |
| 3. Bio-fertilizer, 2 t/ha | 2.0 | 0.2 |
| 4. Chicken dung, 2 t/ha | 2.3 | 0.5 |
| 5. Bio-fertilizer, 4 t/ha | 2.2 | 0.4 |

The correlation analysis performed made it possible to establish the dependence of wheat yield on the content of humus substances in the soil. The obtained results show the average dependence of grain yield on the content of humus substances in the agricultural soil, extracted with 0.1 n. NaOH and generally mobile humus (C<sub>mob</sub>), the correlation coefficients are 0.64 and 0.65, respectively (table 4).
Relationships of the yield of wheat grain with the content of humus and its water-soluble form are assessed as weak ($r = 0.07$).

**Table 4.** Correlation dependencies of wheat grain yield with humus content and its mobile forms in agro-gray soil.

| Properties          | $C_{\text{hum}}$ | $C_{\text{mob}}$ | $C_{0.1 \text{ n. NaOH}}$ | $C_{\text{n2o}}$ |
|---------------------|------------------|------------------|--------------------------|-----------------|
| Wheat crop yield    | 0.07±0.36        | 0.65±0.22        | 0.64±0.23                | 0.07±0.36       |

The analysis of the obtained data made it possible to calculate by the method of multiple regression a model of wheat yield on agro-gray soil, according to which it depends on the content of mobile humus substances and the equation has the following form:

$$\text{Yield} = 7.65 + 0.0005(C_{\text{hum}}) + 0.01(C_{\text{n2o}}) + 0.0007(C_{0.1 \text{ n. NaOH}}), \text{ when } r=0.78 \text{ and } r^2=0.61.$$

4. **Conclusions**

Agro-gray soil of the Krasnoyarsk forest-steppe, developed on brown-brown carbonate clays, is characterized by strong compaction (1.4 g/cm$^3$), poor or satisfactory structure of the arable layer (24-53%). An improvement in agrophysical properties was noted with the use of organic fertilizers, regardless of their type and dose.

A stable optimizing effect on the addition and structural-aggregative state of the arable layer of soil agro-gray was revealed when using 2 t/ha of chicken manure. The use of this fertilizer provided the addition of the arable layer at a level of 1.2-1.3 g/cm$^3$ with a satisfactory structure (51%) and excellent water content of the structural aggregates (82%) during two growing seasons.

Under the influence of bio-fertilizer and chicken manure introduced into the agro-gray soil, there is a tendency to increase the amount of humus, an increase in nitrate nitrogen, mobile phosphorus and an increase in wheat grain. The dependence of wheat grain yield on mobile forms of humus is estimated at the average level. Based on the multiple regression method, a model of wheat yield on agro-gray soil is calculated, according to which it depends on the content of mobile humus substances.

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