Regulation of agrophysical indicators of degraded sod-podzolic soil fertility using a system of fertilizers and predecessors

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Abstract. Experimental data on the dynamics of the most important agrophysical indicators of soil fertility which were obtained against the background of various fertilizer systems and predecessors in the development of degraded reclaimed lands that were withdrawn from circulation are presented. It has been shown that the rate of formation of a macrostructure that is valuable in production (0.25–10 mm) strongly depends on the amount of organic matter entering the soil in the form of high doses of all types of organic fertilizers, green manure and crop-root residues, upon decomposition of which an active humus is formed, which, when interacting with calcium, impregnates and cements the soil lumps, transforming them into a water-insoluble form. The greatest positive influence on the structural coefficient is exerted by cultivation of barley according to the organic background with the introduction of manure (40...80 t / ha) or liquid runoff of livestock complexes (120 t / ha) in combination with sowing application 10 kg a.v. P2O5 and 30 kg a.m. nitrogen as a top dressing per 1 ha. It has been established that in order to improve agrophysical parameters when degraded lands are involved in agricultural production, along with the introduction of high doses of organic fertilizers, crops with a deeply penetrating, powerfully developed root system that can not only condense the arable and plow layers, reduce acidity should be sown soil, but also at the same time improve its structure.

1. Introduction
Agrophysical indicators of soil fertility are represented by particle size distribution and mineralogical composition, structure, density, porosity, air intensity and thickness of the arable layer. Management of agrophysical indicators can be carried out by various methods, however, all of them should ensure the creation of optimal conditions for water-air, thermal and nutritional conditions for plant growth and development [1].

The most important technological measures that positively affect the parameters of agrophysical indicators include the use of high doses of mineral and organic fertilizers, as well as the use of effective natural phytomeliorants in the structure of sown areas, which positively affect the stabilization of agrophysical indicators of soil fertility. The developed root system of such plants contributes to the accelerated restoration of the soil structure, softening of the soil, migration of nutrients to a depth of more than 20 cm (with the decomposition of root residues). The cultivation of phytomeliorant plants is especially justified in the development and restoration of the fertility of unproductive degraded lands [2].
The aim of our research was to study the possibility of regulating agrophysical indicators of the fertility of degraded lands of the North-West region of the Russian Federation when involving them in agricultural circulation using a system of fertilizers and predecessors.

2. Research ideologies
The studies were carried out in OOO Ruchevskoye-1, Rzhevsky district, Tver region in 2012 ... 2018. The soil of the experimental plots is sod-podzolic, light loamy in granulometric composition, the thickness of the arable horizon is 16 ... 18 cm, and drained by open drainage. Initial content in the soil (2012): humus - 1.76 ... 1.78 mg/kg - very low; P_2O_5 - 106. ...109 mg/kg - increased; K_2O - 90 ... 100 mg/kg - average; pH_KCl - 4.88 ... 5.00 units.

The meteorological conditions during the years of the experimental work significantly differed both in temperature and in the amount of precipitation and their distribution by decades and months, but they were not a limiting reason for the growth of programmed yields of barley grain of the Sanshit variety, recommended for use in Non-chernozem zone of Russia.

A pig-breeding complex with 109 thousand heads is located on the farm’s territory; therefore, liquid wastewater and solid manure fraction extracted from wastewater using a screw separator were used as organic fertilizers. Organic and calculated doses of mineral fertilizers were used as the main fertilizer before sowing. The liquid runoff of livestock complexes was introduced using the technology of hose systems, which allows not only to evenly distribute them along the surface of the field, but also to close it into the soil, which eliminates the loss of gaseous forms of nitrogen [3].

Placement of experiment variants (presented in Table 2) - by the method of randomized repetitions; repetition - 4 times. Sowing was carried out in optimal time by seeds of the 1st class of the sowing standard, the depth of seeding is 4...5 cm.

During the development period, all lands involved in agricultural turnover were found to be at the physiological optimum level of the acid state, taking into account the granulometric composition, the thickness of the arable layer and the initial pH [4].

All studies evaluating the agrophysical indicators of agricultural land were carried out in accordance with modern standards used in agricultural research institutions.

3. Research results and their analysis
Before starting to study the dynamics of agrophysical indicators under the influence of various technological methods when degraded lands were introduced into the agricultural sector, they were grouped by granulometric composition, arable layer thickness, humus content and soil solution acidity (table 1). It was found that 93.8% of the lands of the Rzhevsky district, Tver region belong to light-loamy, have a low humus content (1.8 ... 1.9%), slightly acidic soil solution (pH 5.1 units) and power the arable layer of 15 ... 16 cm. Insignificant areas (4.9%) are occupied by sandy loam soils, the proportion of medium loamy soils by granulometric composition in the land fund of the region is extremely insignificant and amounts to only 1.3%.

| № | Granulometric composition of soils | Area, ha | % | Arable layer power, cm | Humus content,% | pH_KCl |
|---|----------------------------------|----------|---|------------------------|----------------|--------|
| 1 | Sandy loam                       | 257      | 4.9 | 13...14                | 1.8            | 4.8    |
| 2 | Light loamy                      | 4970     | 93.8| 15...16                | 1.9            | 5.1    |
| 3 | Medium loamy                     | 70       | 1.3 | 17...19                | 2.1            | 5.2    |
| Total |                                     | 5297     | 100 | 15...16                | 1.9            | 5.0    |

The granulometric composition of the soil has a direct impact on the formation of the structure of degraded lands involved in the circulation, since soil aggregates of various sizes and shapes are formed
from primary mechanical elements: sand, clay, gravel, stones, dust and other material particles. When involving lands in circulation, it is very important to quickly create an arable layer that differs in structural soil, since structural aggregates are highly resistant to the erosive action of water, have good aeration, quickly absorb rainfall, evaporate moisture slowly, do not swim, are well processed and are characterized by juice microbiological activity. In terms of production, the macrostructure with the size of water-resistant lumps from 0.25 to 10 mm is considered the most valuable. Soils with a predominance of such structural units, with timely processing, easily disintegrate into lumpy or grainy-lumpy particles, the field is rather smooth and uniform.

Since the structure of the arable layer is one of the determining indicators of the physical state of fertility, the search for ways to regulate it is important in the development of degraded reclaimed lands that are no longer in use.

The results of studies on the effect of various fertilizer systems and predecessors on the aggregate composition of the arable and subsurface layers of the soil are presented in table. 2.

It has been established that over an 8-year observation period in all experimental variants, when cultivating barley according to different predecessors, a change in the ratio of structural units occurred, however, the degree of variation of soil aggregates had different intensities. Thus, in the control variant without the use of fertilizers, as well as on the mineral fertilizer system, an unreliable improvement in the size of soil aggregates relative to the initial state (2012) was observed for all the predecessors and soil layers for the interaction of AB factors. In this case, the share of the coarse microstructure (<0.25 mm) for all predecessors decreased in the arable layer from 6.1 ... 7.2% to 5.0 ... 7.1%, and in the arable layer - from 4.2 ... 5.7 to 3.8 ... 5.4%. Due to a decrease in the share of coarse microstructure and lumpy part (> 10 mm), an insignificant increase in the agronomically valuable macrostructure in the rooting layer was noted, the content of which varies from 34.1 ... 50.3% in 2012 to 35.5 ... 52.3% in 2019 year.

When high doses of solid fraction of manure and liquid effluents of livestock complexes are used as the main fertilizer, the process of structuring soil aggregates proceeds more intensively towards the formation of a macrostructure, however, in such a short period of time, the structural state of the arable and arable layers in the degraded layers is significantly improved soil did not happen. Nevertheless, it should be noted that the amount of organic matter entering the soil in the form of crop-root residues, green manure, and all types of organic fertilizers, during the decomposition of which active humus and organo-mineral colloids. Periodic moistening and drying (dehydration) of soil colloids during their interaction with constant enrichment of the upper layers with active humus, as well as in combination with the systematic mixing of arable land with agricultural tools, earthworms and the influence of the root systems of cultivated plants, grasses and weeds, accelerates the process of structure formation and promotes the creation of water-resistant units [5].

According to our observations, the improvement of the structure of degraded reclaimed land occurs against the background of liming. This is due to the fact that the organo-mineral soil colloids interact with the calcium cation, as a result of which the colloids undergo coagulation and transform into a difficultly soluble form, as a result of which individual soil lumps stick together into larger units and transform are in larger units. However, the soil structure, like any dynamic system, although it is one of the most important factors in the fertility of agricultural land, cannot be a constant indicator of field quality. When arid lands are cultivated by plowing, disking, or harrowing, the lumpy structure inevitably collapses, as a result of which the soil becomes structureless and dispersed. At the same time, the formation of a large number of clumpy aggregates is observed, which leads to the formation of irregularities on the surface of the plowed field. To exclude these negative phenomena, the cultivation of reclaimed land should be carried out upon the occurrence of physical ripeness of the soil, with arable layer moisture of 60 ... 70% of the WSP.

The most important indicator for assessing the structural state of degraded reclaimed lands is the structural coefficient, which is the ratio of the number of meso-aggregates (0.25 ... 10 mm),% to the total percentage of structural units less than 0.25 mm and more than 10 mm. Moreover, the greater the structural coefficient, the better the structure of the soil is expressed. When using the dry sieving method, it is believed that with a content of meso-aggregates of about 40%, the structural state of the soil is
considered satisfactory, and less than 40% - unsatisfactory. Consequently, the structural coefficient, being an aggregate criterion for changing the state of aggregation of the soil, allows us to evaluate the dynamics of this process during the development of degraded lands that are out of circulation, depending on the studied agricultural practices. In our studies, a significant influence of predecessors on this indicator was not established, however, its greatest increase in the arable layer of 0–20 cm relative to the initial value was noted when barley was cultivated after spring and winter crops (+0.09), and the smallest (+0.08) - after spring rape (Table 3). This is due to the fact that the powerfully developed root system of crops is formed mainly in the arable layer of the soil, penetrating with numerous roots the entire volume of the sprayed soil, turning it into aggregates. After dying off, the root residues decompose to a freshly precipitated humus, which is absorbed by lumps, coagulates, and with the help of a divalent calcium cation, turns into a cementitious substance, cementing soil separately into water-resistant aggregates.

Of the studied fertilizer systems, the greatest positive effect on the structural factor is the cultivation of barley according to the organic background with the introduction of manure (40 ... 80 t/ha) or liquid runoff from livestock complexes (120 t/ha) in combination with sowing 10 kg a.v. P2O5 and 30 kg a.m. nitrogen as a top dressing per 1 ha. In these variants, the structural coefficient increased by 0.2 units, however, this excess was within the experimental error and was insignificant. A minimal increase in the structural coefficient (+0.09 units) is noted on the mineral system.

**Table 2.** The structure of soil aggregates in barley crops, depending on the fertilizer system and predecessors in the development of reclaimed land reclaimed from circulation in the layer of 0–20 cm (numerator) and 20–40 cm (denominator), %.

| №   | Experience Options (Factor A) | Years | Precursors (factor B) | spring rape on seeds | spring cereals |
|-----|-------------------------------|-------|-----------------------|----------------------|---------------|
|     |                               |       |                       | <0.25 mm 0.25-10 mm 10 mm | <0.25 mm 0.25-10 mm >10 mm |
| 1   | Control (without fertilizer).  | 2012  | 6.1/4.2               | 50.4/34.1 43.5/61.7 | 6.2/4.8 50.2/35.9 43.6/59.3 |
|     |                               | 2019  | 6.0/3.8               | 52.3/35.5 41.7/60.7 | 5.0/4.7 51.1/36.6 43.9/58.7 |
| 2   | Mineral system                 | 2012  | 7.2/4.3               | 50.3/36.0 42.5/59.7 | 6.6/5.1 50.2/36.1 43.2/58.8 |
|     | N10P6K8 + P10 – when sowing; N30 – when feeding. | 2019  | 7.1/4.1               | 51.6/36.4 41.3/59.5 | 5.6/4.9 51.0/37.0 43.4/58.1 |
| 3   | Manure (t.p.) 40 t/ha + P10 – when sowing; N30 – when feeding. | 2012  | 7.2/5.1               | 53.5/36.8 39.3/58.1 | 6.9/5.3 52.4/36.9 40.7/57.8 |
|     |                               | 2019  | 7.0/4.9               | 55.2/37.9 37.8/57.2 | 6.1/5.0 54.5/38.0 39.4/57.0 |
| 4   | Manure (t.p.) 60 t/ha + P10 – when sowing; N30 – when feeding. | 2012  | 6.9/5.3               | 54.3/35.8 38.8/58.9 | 6.8/5.4 53.6/36.9 39.6/57.7 |
|     |                               | 2019  | 6.5/5.0               | 56.6/36.7 36.9/58.3 | 5.9/5.0 55.8/37.9 38.3/57.1 |
| 5   | Manure (t.p.) 80 t/ha + P10 – when sowing; N30 – when feeding. | 2012  | 7.1/5.1               | 54.4/36.8 38.5/58.1 | 6.9/5.2 54.1/36.8 39.0/58.0 |
|     |                               | 2019  | 6.2/5.0               | 56.8/38.2 37.0/56.8 | 5.8/4.8 55.4/37.9 38.8/57.3 |
| 6   | Liquid drains 100 t/ha + P10 – when sowing; N30 – when feeding. | 2012  | 5.9/4.8               | 54.5/37.1 39.6/58.1 | 5.9/4.7 53.7/36.4 40.4/58.9 |
|     |                               | 2019  | 5.3/4.4               | 56.7/38.0 38.0/57.6 | 4.7/4.5 55.9/37.5 39.4/58.0 |
| 7   | Liquid drains 120 t/ha + P10 – when sowing; N30 – when feeding. | 2012  | 5.1/4.8               | 54.8/37.7 40.1/57.5 | 5.2/4.6 54.1/38.1 40.7/57.3 |
|     |                               | 2019  | 4.3/4.2               | 56.9/38.9 38.8/56.9 | 4.0/4.3 56.0/39.2 40.0/56.5 |

HCP<sub>05</sub> for interaction AB

0.4/0.3 3.2/2.4 3.1/3.5

0.3/0.2 2.4/2.2 2.6/2.8

0.5/0.4 3.7/2.5 3.8/4.0

IOP Conf. Series: Earth and Environmental Science 548 (2020) 062032 doi:10.1088/1755-1315/548/6/062032
Table 3. Structural coefficient and content of water-resistant aggregates (%) on barley crops depending on fertilizer systems and predecessors during the development of degraded land turnover that left them in a layer of 0 - 20 cm.

| №  | Experience Options (Factor A) | Years | Precursors (factor B) | Coeff. structure | Water strength of aggregates | Coeff. structure | Water strength of aggregates | Coeff. structure | Water strength of aggregates |
|----|-----------------------------|-------|-----------------------|-----------------|-----------------------------|-----------------|-----------------------------|-----------------|-----------------------------|
| 1  | Control (without fertilizer). Mineral system | 2012 | spring rape on seeds | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 3.9 | 38.8 | 4.0 | 39.5 | 4.0 | 39.5 |
| 2  | Mineral system N55P30K90 + P10 – when sowing; N30 – when feeding. Manure (t.p.) 40 t/ha + P10 – when sowing; N30 – when feeding. | 2012 | spring cereals | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 3.9 | 38.6 | 3.9 | 39.2 | 3.9 | 39.2 |
| 3  | Manure (t.p.) 60 t/ha + P10 – when sowing; N30 – when feeding. | 2012 | winter cereals | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 4.0 | 39.4 | 4.0 | 39.8 | 4.0 | 39.8 |
| 4  | Manure (t.p.) 80 t/ha + P10 – when sowing; N30 – when feeding. | 2012 |                      | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 4.0 | 39.2 | 4.0 | 39.9 | 4.0 | 39.9 |
| 5  | Liquid drains 100 t/ha + P10 – when sowing; N30 – when feeding. | 2012 |                      | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 4.0 | 39.5 | 4.0 | 39.8 | 4.0 | 39.8 |
| 6  | Liquid drains 120 t/ha + P10 – when sowing; N30 – when feeding. | 2012 |                      | 3.8 | 37.4 | 3.8 | 38.0 | 3.8 | 38.1 |
|    |                              | 2019 |                      | 4.0 | 39.5 | 4.0 | 39.8 | 4.0 | 39.8 |
| 7  | factor A | 0.2 | 2.3 | 0.3 | 2.4 | 0.4 | 2.6 |
| HCP<sub>05</sub> factor B | | |

Thus, the use of spring and winter crops as a precursor in combination with the introduction of high doses of organic fertilizers increases the structural coefficient of the arable layer of degraded lands involved in agricultural circulation.

Studies by a number of authors have found that the addition of sod-podzolic soils of medium grain size distribution is resistant to erosion processes in the presence of at least 40% water-resistant aggregates more than 0.25 mm in diameter [1, 5]. In our experiments, the largest increase in the content of water-resistant aggregates in the arable soil layer over an 8-year observation period relative to the initial amount was noted in the variants where high doses of manure (+1.7 ... 2.1%) and liquid effluents of livestock complexes (+1.5 ... 2.1%). The minimum tendency to increase this fraction of aggregates is characteristic of the mineral system (+1.1 ... 1.2%), while in the control variant the proportion of water-resistant aggregates increased by 1.4 ... 1.5% relative to the initial amount.

4. Conclusions
Thus, the content of water-resistant aggregates in the arable layer of degraded reclaimed lands of light loam granulometric composition is in close correlation with the structural coefficient ($r = 0.73 ... 0.86$),
therefore, all technological measures aimed at improving the structural condition will increase the number of water-resistant aggregates. It should also be noted that the precursors studied by us when cultivating barley do not significantly affect the structural coefficient and content of water-resistant aggregates, although a more pronounced positive trend is characteristic of spring and winter breads. After these precursors, an increase in the arable 0–20 cm layer of the agronomically valuable fraction of 0.25 ... 10 mm is observed by an average of 1.4 ... 2.0%. Of the studied fertilizer systems, the greatest positive effect on the structural factor is the cultivation of barley according to the organic background with the introduction of manure (40 ... 80 t / ha) or liquid effluent from livestock complexes (120 t / ha) in combination with sowing application of 10 kg d .at. P2O5 and 30 kg a.m. nitrogen as a top dressing per 1 ha.

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