Changes in the Agrophysical Properties of the Chernozem Leached with the Use of Defecate and Fertilizers for the Cultivation of Winter Wheat

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Abstract. The intensive use of chernozems has led to an imbalance between their effective and potential fertility, as evidenced by the worsening of their agrophysical and agrochemical properties. A necessary condition to solve the complex of agroecological problems is the study and development of scientifically based methods of reproduction and increasing soil fertility. It is also necessary to effectively use fertilizers in combination with other chemical ameliorants for various technologies for the cultivation of agricultural crops in crop rotation aimed at improving the agrophysical properties of these crops and ensuring an increase in their yield and quality while meeting environmental requirements.

1. Introduction
The flat part of Krasnodar Krai is located in the Azov-Kuban Lowland in the Western Ciscaucasia. The soil covering of this territory is characterized by low diversity and domination of fertile super-deep and deep Kuban chernozems.

A number of works shows that due to long-term agricultural use, use of mineral and organic fertilizers, and liming there is, in some cases, a regular change in the physical properties of soils in the form of a heavier grain-size composition, changes in the structural state, porosity of soils and aggregates [1]. According to many scientists, there is a relationship between the indicators of soil structure and water resistance of aggregates with humus content in it [2–4].

In Krasnodar Krai, the negative impact of intensive technologies was most pronounced in the case of leached chernozem with its low buffer capacity, a tendency to acidification and compaction in comparison with other subtypes of chernozem. The chemical degradation of leached chernozem, caused by the intensification of agriculture, turned into physical degradation in the course of time, accompanied by compaction, merging, formation of numerous closed depressions with a highly compacted waterproof layer, overwetting, inflow, and other negative signs. This process has led to a decrease in crop productivity. E. g. the yield of winter wheat in grain-row crop rotation of a stationary experiment for 5 predecessors (at the average) during 25 years decreased by 32–36% at different levels of saturation of the crop rotation with fertilizers.
The aim of the research is to study the changes in the agrophysical properties of chernozem in the leached experimental field, depending on the use of defecate, mineral fertilizers, and various technologies in the cultivation of winter wheat.

2. Statement of the problem
In Russia, large areas are occupied by soils with high acidity. They are characterized by poor physical, physicochemical, and biological properties. Their properties can be improved only by land amelioration, more specifically, by liming of acidic soils (elimination of high acidity by applying neutralizing substances) [5].

The need for liming is increasing due to the fact that the application of mineral fertilizers acidifies the soil, and a significant amount of magnesium and calcium is washed out of it. Under the influence of atmospheric precipitation and the use of fertilizers, the annual loss of bases from arable soils in terms of CaCO₃ is 350–450 kg/ha. The precise amount of losses depends on the soil and climatic conditions.

Most cultivated plants and soil microorganisms develop better under subacid and neutral reactions (pH 6–7). Under increased acidity, root growth slows down; it is difficult for plants to use soil nutrients and fertilizers; the physical properties and structure deteriorate, microbiological activity is suppressed; the chemical absorption of phosphates is strongly manifested; mobile forms of aluminum, iron, and manganese have a negative effect [6].

At a certain historical stage and under past conditions, chernozem soils, due to the high saturation of the soil absorbing complex with calcium and magnesium, buffering capacity, and high humus content, slowly and imperceptibly worsened their fertility indicators as a result of agricultural use, and did not require liming.

Intensification of agriculture has sharply increased the direction of soil processes in chernozems towards acidification, alination of calcium from the arable layer [7]. Therefore, it is now important to apply lime fertilizers (in calculated doses) on leached chernozems as well.

The scientifically substantiated use of defecate (waste from the sugar industry, filter cake, on which dyes contained in the raw material are sorbed) as a fertilizer for agricultural crops has been developed by a number of researchers based on a fairly large number of field experiments [7].

Defecate consists of non-sugars in beet juice and a mass of lime which is used in sugar production technology. It contains all micro- and ultramicroelements, nitrogen (up to 0.5%), phosphorus (up to 1.0%), potassium (up to 1.0%). Defecate also contains a significant amount of nitrogen-free organic substances—sugars. After washing, the defecate turns into a very valuable raw material for liming acidic soils [8].

The comparative effect of defecate on reducing soil acidity, performed in a number of republics of the former USSR and abroad, showed that in amounts comparable in terms of the active substance (CaCO₃), defecate is not inferior to industrial lime fertilizers, and is even better in some cases. The applying of defecate in order to increase the fertility of meadow-brown bleached soil and the yield of alfalfa (the increase in green mass was 15% and that in hay was 19.9%) is organizationally and economically justified. In addition, liming of soils with defecate is one of the methods to reduce the concentration of heavy metals in it and the negative impact on the environment [9].

3. Materials and methods
All studies were carried out in field and laboratory conditions. Field research was carried out on the experimental field of the agrotechnological department of Lukyanenko Krasnodar Research Institute of Agriculture in 2018. The object of research was leached, compacted, low-humus, super-deep, light-clayey chernozem formed on loess-like light clay. In the allotments showed in the scheme (Nos. 7, 8, 11, 12, 25, 26, 31, 32), 16 wells were drilled, including 8 wells each by Negovelov and Rozanov drills to a depth of 300 and 100 cm respectively. Soil samples were taken in allotments after harvesting winter wheat included in the grain-herb-row crop rotation every 20 cm (0–20, 20–40 cm etc.). The total area of the plot is 66 m² (6x11 m).
Soil number, colour key | Soil name |
--- | --- |
1 | Chernozem leached packed low-humus super-deep soil |
2 | Meadowish-chernozem leached packed low-humus super-deep soil |
3 | Meadow-chernozem leached packed low-humus super-deep soil |

Figure 1. Soil sketch-map of the experimental field.

On the experimental allotments, the calculated dose of defecate was applied (based on the neutralization of complete hydrolytic acidity—7.35 t/ha of CaCO₃ once every 5 years).

Thus, the research was carried out on two field experiments with different soil cultivation systems: traditional one (experiment 1) and surface-mulching one (experiment 2) with the following variations: without fertilizers and defecate (for control purpose), with fertilizers (without defecate), with defecate (without fertilizers), with fertilizers and defecate.

In the samples, we measured pH H₂O and hydrolytic acidity, Ca²⁺ and Mg²⁺ content, total humus, nitrogen of easily hydrolyzable compounds and exchange potassium parameters according to [11–12].

After a detailed morphological description of the genetic horizons of the studied soil in the research laboratory of the Department of Soil Science, the following types of analyzes were performed twice: mechanical analysis by the pipette method according to Kachinsky; structural composition and water resistance according to Savvinov; soil density with a Negovelov drill; solid phase density by the pycnometric method; general porosity by the calculation method; full moisture capacity by the calculation method [10].

4. Discussion of the results

Since 2000, Lukyanenko Krasnodar Research Institute of Agriculture has carried out extensive researches of the effectiveness of applying defecate on leached degraded Kuban chernozem in order to restore its fertility, increase its productivity and product quality, as well as other indicators (Table 1).

Table 1. Effect of the Degree of Neutralization of the Hydrolytic Acidity of Leached Chernozem on Some of Its Indicators.

| Degree of neutralization of the hydrolytic acidity | Ca²⁺ % to control | Hh (hydrolytic acidity) % to control | N-NO₃ % to control |
|---|---|---|---|
| NPK (control) | 17.5 | 5.3 | 4.3 |
| NPK+ Ca₀.25 Hh | 18.3 | 105 | 4.7 | 87 | 6.6 | 153 |
| NPK+ Ca₀.5 Hh | 18.6 | 106 | 4.4 | 83 | 6.8 | 158 |
| NPK+ Ca₁.0 Hh | 19.4 | 111 | 2.7 | 51 | 6.9 | 160 |

The defecate was applied at the following rates of neutralization of hydrolytic acidity (Hh): 0.25, 0.5, and 1.0. As a result, the content of calcium in the soil increased from 17.5 in the control to 19.4
mg-Eq. In this case, the hydrolytic acidity decreased from 5.3 to 2.7 mg-Eq per 100 g of soil, or 51%. Studies have shown that calcium, as an amendment, contributes to an increase in the share of the most valuable agronomic structures (more than 10 mm) due to the small structures (0.25 mm or less). As a result, the soil density decreases.

**Table 2.** The Yield of the *Tanya* Winter Wheat Cultivar Depending on the Soil Cultivation System and the Use of Defecate and Fertilizers (2017–2018), t/ha.

| Tillage                          | Application of CaCO₃ | Control fertilizers | (without | With fertilizers and defecate |
|----------------------------------|----------------------|---------------------|----------|-------------------------------|
|                                  |                      | 2017    | 2018    | 2017    | 2018                           |
| Traditional (20–27 cm ploughing for row crops + 6–8 cm surface plowing for spiked crops) | –                    | 3.41    | 3.64    | 6.02    | 6.64                           |
|                                  | CaCO₃                | 3.68    | 3.84    | 6.21    | 6.95                           |
| Average yield, t/ha              |                      | 3.64    | 3.64    | 6.46    | 6.46                           |
| Surface mulching (6–8 cm)        | –                    | 3.20    | 3.32    | 5.43    | 6.36                           |
|                                  | CaCO₃                | 3.31    | 3.50    | 5.65    | 6.62                           |
| Average yield, t/ha              |                      | 3.33    | 3.33    | 6.02    | 6.02                           |
| Least significant difference ₀⁹⁵ |                      | 2017: 0.23, 2018: 0.18 |

In Krasnodar Krai, the sown area of grain crops averages about 2 million ha, and more than half of this area is occupied by winter grain crops, since their productivity is higher than that of spring crops. The main winter crop produced in Krasnodar Krai is winter wheat. Its sown area in 2014–2018 grew by 233 thousand ha, or 21.6%. Over 5 years, the sown area of winter wheat averaged to 1203 thousand ha.

Agricultural machines play an important role in increasing the yield of winter wheat. But the yield itself is largely determined by the hereditary economic and biological properties of the varieties, and only 30% depends on the properties of the soil. The soil is the most important means of agricultural production. The combination of water and physical, physical and chemical, agrochemical, biological, and other properties of the soil determines (against the background of specific environmental conditions) the level of its fertility.

**Table 3.** Grain Quality of the *Tanya* Winter Wheat Cultivar Depending on the Soil Cultivation System and the Use of Defecate and Fertilizers (2017–2018), t/ha.

| Tillage                          | Application of CaCO₃ | Control (without fertilizers) | Gluten, % | Gluten deformation measurement | With fertilizers and defecate |
|----------------------------------|----------------------|-----------------------------|-----------|--------------------------------|-----------------------------|
|                                  |                      |                             | Gluten, % | Gluten deformation measurement |                             |
|                                  |                      |                             |           |                               |                             |
| Traditional (20–27 cm ploughing for row crops + 6–8 cm surface plowing for spiked crops) | –                    | 20.0                         | 76        | 26.0                           | 75                           |
|                                  | CaCO₃                | 22.1                         | 78        | 26.8                           | 74                           |
| Surface mulching (6–8 cm)        | –                    | 20.2                         | 75        | 22.5                           | 74                           |
|                                  | CaCO₃                | 20.4                         | 73        | 23.0                           | 72                           |

Based on the obtained yield data, it should be noted that a higher yield for all the studied technologies was observed in 2018. The highest rate of winter wheat was noted in 2018 with
traditional plowing on the option with fertilizers and defecation—6.95 t/ha, and without the application of defecate—6.64 t/ha, or by 4.6% less (Table 2).

Raw grain gluten is a hydrated protein and consists of water-insoluble protein fractions, as well as small amounts of starch, fats, and other substances firmly held by proteins. Since gluten consists mainly of proteins, its yield and quality depend on the quantity and quality of grain proteins (Table 3).

In terms of the gluten content in flour, wheat grain is divided into four groups: with a high gluten content (over 30%), with an average gluten content (from 26 to 30%), with a gluten content below average (from 20 to 25%), and with a low gluten content (below 20%) [7].

5. Conclusions
The use of defecate as an ameliorant helped to form a better structure of the studied soil, to increase the content of agronomically valuable and water-resistant aggregates in it, and to improve the soil adsorption complex. The traditional system of soil cultivation had a more favorable effect of defecate on the structural composition of leached packed chernozem.

The traditional tillage system improves the agrophysical properties of the leached packed chernozem in comparison with the surface tillage. After harvesting the winter wheat, the density of the arable layer of the studied chernozem in all variants of experiments with the traditional system of soil cultivation was 1.35–1.39 g/cm³, and with the surface one—1.40–1.41 g/cm³. Accordingly, the total porosity and full moisture capacity change as well.

In order to obtain higher yields, improve agrophysical and physicochemical properties when growing winter wheat on leached compacted chernozem, the agricultural enterprises in the central part of Krasnodar Krai should use the traditional mouldboard tillage (20–27 cm ploughing for row crops + 6–8 cm surface plowing for spiked crops) with the use of defecate (7.5 t/ha) and a zonal dose of mineral fertilizers.

6. References
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