Determination of Ecologically Acceptable Technology for Cultivation of Agricultural Crops on Leached Chernozem in the Western Ciscaucasia

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Abstract. The Western Ciscaucasia, which occupies the flat part of the Krasnodar Territory, is a unique natural site of the Southern Federal District of the Russian Federation. The soil covering this region is characterized by domination of fertile super-deep and deep Kuban Chernozems. However, their intensive use has led to an imbalance between their effective and potential fertility, as evidenced by a decrease in humus reserves and a worsening of its qualitative composition; depletion in nitrogen, phosphorus, potassium, calcium; acidification; heavy metal pollution; and, consequently, an ecological imbalance in the soil–plant system.

1. Introduction
The leached chernozem is the most common subtype of chernozems on the experimental field of agroecological monitoring in the southern part of the Azov-Kuban lowland of the Western Ciscaucasia. These soils occupy 240.7 thousand ha in Krasnodar Krai (3.2% of the total area), and 213.5 thousand ha of them are occupied by agricultural land, including 160.2 thousand ha of arable land. They are developed on the flat land. Loess-like heavy loams served as soil-forming rocks for chernozems.

A necessary condition to solve the complex of ecological problems is the study and development of scientifically based methods of reproduction and increasing soil fertility, the effective use of fertilizers in combination with other means of chemicalization of agriculture for various technologies for the cultivation of agricultural crops in crop rotation, ensuring an increase in their yield and quality while meeting environmental requirements [1-3].

2. Statement of the problem
In terms of the thickness of the humus layer, the leached chernozem belongs to the super-deep species with an average thickness (A + AB) of 150 cm; the thickness of the humus accumulation layer (A) is 50 cm.

In terms of granulometric composition, the leached chernozem is light-clayey. The physical clay content is 59.1–63.9%, there is a high silt content (33.5–39.9%) and a small amount of sand (2.8–6.3).
The dust fraction (0.05–0.001 mm) clearly predominates over the silt one in leached chernozems, i. e. they belong to the silty-dusty light clays [4].

The distribution of fractions and, especially, of silt along the profile is relatively uniform. Leached chernozems have favourable water-physical properties [5]. The density of the upper meter stratum does not exceed 1.41 g/cm³, and the porosity does not fall below 48.2%, which indicates a weak and medium compaction and favourable conditions for water permeability [6]. The maximum hygroscopicity (MH) of leached chernozems is low—9.5% in the Ap horizon. The data of the chemical analysis of leached chernozems indicate a relatively low humus content in them. Its amount in the arable layer is 3.2%.

At the same time, humus penetrates to a significant depth with a gradual decrease down the profile. At the depth of 1.5 m, its content is more than 1%, which indicates high gross reserves of humus in the entire soil thickness. The calculation of the gross reserves of humus showed that its content is 458.46 t/ha in the horizons A + AB and is 497.68 t/ha in a two-meter layer.

The humus in the arable layer of leached chernozems belongs to the humic type. The amount of humic acids exceeds the content of fulvic acids by 2.74 times, which is characteristic of chernozem formation.

The enrichment of humus with nitrogen in leached chernozems is average and amounts to 9.2–9.8. The low content of humus in these chernozems predetermined the low content of gross nitrogen reserves. In the arable layer, it amounts to 0.17% and it gradually decreases to 0.10% with the depth of the soil; nitrogen mobility is also low (2.9–5.9 mg per 100 g of soil).

The cation exchange capacity is one of the integral agronomic and ecological characteristics of soils. The cation exchange capacity is connected with the buffering capacity and resistance of soils to anthropogenic influences, in particular, to chemical pollution. The higher this indicator, the higher is the degree of soil resistance to anthropogenic impact [7].

Leached chernozems have a high cation exchange capacity [8]. The amount of absorbed bases reaches 37.0 mEq. per 100 g of soil. Among the absorbed bases, 74.8–81.3% are calcium. The reaction of the soil environment (pH H₂O) changes down the profile of the leached chernozem from weakly acidic to slightly alkaline due to the leaching of calcium carbonates.

Thus, the leached chernozems of the area under study are characterized by favourable water-physical, chemical, and physicochemical properties for the growth of zonal agricultural plants.

Human intervention in natural processes during agricultural production inevitably leads to an increase in chemical and physical stress on the soil. As a result, the ecological situation in the agricultural landscape deteriorates, which leads to an increase in the concentration of heavy metals, and the stability of the ecosystem as a whole is disrupted.

Heavy metals in high concentrations are a dangerous pollutant of soils, which reduces their productivity and biological activity and deteriorates the quality of agricultural crops.

3. Materials and methods

The studies were carried out in field and laboratory conditions. The field studies were carried out under the conditions of a long-term multifactorial experience in agroecological monitoring on the experimental field of the Kuban instructional farm of Kuban State Agrarian University, the laboratory studies—in the research laboratory of the Department of Soil Science. The scientific research was carried out in accordance with the plan of research work on agroecological monitoring in an 11-field grain-grass-row crop rotation typical for the central zone of Krasnodar Krai. The alternation of crops in the crop rotation is as follows: sunflower, winter wheat, corn for grain, winter wheat, sugar beet, winter wheat, spring barley underseeded with alfalfa, alfalfa, alfalfa, winter wheat, winter barley. The field experiment has been carried out since 1992 on three fields with the gradual introduction of one crop rotation into each field. On field No. 1, the second crop rotation has been carried out from 2003 to 2018. The crops comprising the research object are winter wheat of the Fortuna cultivar (the predecessor is sugar beet) and the Kreta hybrid sugar beet.
Special symbols are used for the coding of the cultivars. According to this system, in conventional units, the first number indicates the level of fertility, the second one indicates the fertilization rate, the third number is the plant protection system, and the fourth one is the system of primary tillage.

Table 1. Experience scheme in years of research.

| Technology index | Factor index | A—level of fertility | B—fertilization rate | C—plant protection system | D—system of primary tillage |
|------------------|--------------|----------------------|----------------------|---------------------------|-----------------------------|
| 0001, 0002       | 0003         | A0—initial level     | B0—no fertilizers    | C0—no protection means    | D1—mouldboardless           |
| (control)        |              | A1—average level     | B1—minimum rate      | C1—biological plant       | Daging repeated             |
| 0003             |              | 1111                 | N45P45K45 + 30 t/ha of manure | protection system        | 2–3 times.                 |
|                  |              | 1112                 | 200 t/ha of          | (against plant pests      | Mouldboardless              |
|                  |              | 1113                 | 200 t/ha of          | and diseases)             | cultivation for 30–32 cm    |
|                  |              |                     | manure + 200 kg/ha of P₂O₅ |                          |                             |
| 2221             |              | A2—higher level      | B2—average rate      | C2—integrated plant       | D2—mouldboard              |
|                  |              | 400 t/ha of          | N90P90K90 + 60 t/ha of manure | protection system        | zonal (recommended)       |
|                  |              | manure + 400 kg/ha of P₂O₅ |                          | (against weeds)           | Disking repeated           |
|                  |              | 1132                 | 200 t/ha of          | C3—chemical plant         | 2–3 times.                 |
|                  |              |                     | manure + 200 kg/ha of P₂O₅ | protection system        | Mouldboardless             |
|                  |              |                      | 1111                 | (against plant pests,     | cultivation for 30–32 cm    |
|                  |              |                      | A1—average level     | diseases, and weeds)      |                             |
|                  |              |                      | 1112                 | C1—biological plant       | D3—mouldboard              |
|                  |              |                      | 1113                 | protection system        | deep cultivation           |
|                  |              |                      | 2002                 | (against plant pests,     | Disking repeated           |
|                  |              |                      | A2—higher level      | diseases, and weeds)      | 2–3 times.                 |
|                  |              |                      | 3331                 | C3—chemical plant         | Mouldboardless             |
|                  |              |                      | A3—high level        | protection system        | cultivation for 30–32 cm    |
|                  |              |                      | 3332                 | (against plant pests,     |                             |
|                  |              |                      |                      | diseases, and weeds)      | Mouldboard              |
|                  |              |                      | 3333                 | C3—chemical plant         | cultivation for 18–22 cm    |

The selection of soil samples was carried out at all the allotments of the experimental field in the middle of the plant growing season: winter wheat—in layers of 0–20, 20–40, and 40–60 cm, sugar beet—in layers of 0–30 and 30–60 cm.

Types and methods of soil analyses performed: total humus—I. V. Tyurin’s method, modified by V. N. Simakov, GOST 26213-91; the sum of exchange bases—the Kappen–Gilkowitz method, GOST 27821-88; soil acidity (pH H₂O, pH KS1)—the potentiometric method; mobile forms of heavy metals in ammonium acetate extraction—the atomic absorption method [9, 10, 11].

4. Discussion of the results

Comparing the research results obtained by us and the staff of the Department of Inorganic and Analytical Chemistry of Kuban State Agrarian University in 2016–2018, we can conclude that the application of mineral and organic fertilizers in various doses does not cause a significant accumulation of gross and mobile forms of manganese, copper, zinc, cobalt, lead, and cadmium in the arable layer of
0–20 cm of the chernozem leached during the cultivation of winter wheat using various agricultural technologies.

Table 2. Gross (numerator) and mobile (denominator) content of heavy metals in the chernozem leached during the cultivation of winter wheat, mg/kg of soil in a layer of 0–20 cm, 2018.

| Technology index | Mn    | Cu    | Zn    | Co    | Pb    | Cd    |
|------------------|-------|-------|-------|-------|-------|-------|
| 0001             | 506.3 | 25.5  | 54.3  | 10.8  | 5.65  | 0.311 |
| 1111             | 502.5 | 25.2  | 52.7  | 10.4  | 6.41  | 0.326 |
| 2222             | 512.7 | 26.3  | 56.7  | 10.9  | 4.95  | 0.367 |
| 3331             | 516.1 | 25.8  | 55.0  | 10.6  | 6.95  | 0.340 |
| 0002 (control)   | 515.2 | 25.9  | 55.5  | 10.8  | 4.98  | 0.362 |
| 1112             | 507.2 | 23.1  | 48.3  | 10.4  | 7.39  | 0.331 |
| 2222             | 507.8 | 24.4  | 53.4  | 10.4  | 6.12  | 0.325 |
| 3332             | 502.9 | 25.8  | 56.1  | 10.3  | 6.98  | 0.394 |
| 0003             | 503.1 | 22.2  | 45.4  | 10.4  | 7.67  | 0.295 |
| 1113             | 508.4 | 24.6  | 54.2  | 10.6  | 5.82  | 0.378 |
| 2223             | 512.4 | 24.7  | 56.6  | 10.6  | 5.10  | 0.392 |
| 3333             | 511.8 | 24.5  | 52.2  | 10.4  | 6.89  | 0.271 |
| ПДК              | 1500  | 50    | 50    | 32    | 3    |

The obtained data indicates that the content of gross and mobile forms of heavy metals in the studied soil is two times less than the maximum permissible concentration (MPC) in this soil. The exception is the gross zinc content, which exceeds the MPC by 4.4–13.4%. However, the number of its mobile forms is much less than the MPC.

Similar data was obtained in terms of the content of these elements in leached chernozem (in a layer of 0–30 cm) sowed with sugar beet. An excess of the maximum permissible concentration of gross forms of zinc was also observed, but the mobile forms of this element did not exceed the MPC.

The largest amount of heavy metals enters the soil with manure [12]. The amount of heavy metals which had entered the soil during the three-year growing season of this crop was calculated taking into account the content of heavy metals in fertilizers and the application dose according to various technologies of winter wheat cultivation.

Table 3. Heavy metals which have entered the soil with fertilizers during the three-year growing season of winter wheat, kg/ha (2017–2018).

| Technology index | Mn    | Cu    | Zn    | Co    | Pb    | Cd    |
|------------------|-------|-------|-------|-------|-------|-------|
| 000              | –     | –     | –     | –     | –     | –     |
| 111              | 16.3  | 1.67  | 3.90  | 0.38  | 0.14  | 0.002 |
| 222              | 32.6  | 3.34  | 7.81  | 0.76  | 0.28  | 0.005 |
| 333              | 52.2  | 5.36  | 12.50 | 1.22  | 0.44  | 0.008 |

The accumulation coefficient of heavy metals was calculated as the ratio of the element in the variety to its content in the control.

The accumulation coefficients of the gross content ranged from 0.98 to 1.0 for manganese, 0.86–1.02 for copper, 0.82–1.02 for zinc, 0.95–1.01 for cobalt, 0.99–1.54 for lead, and 0.81–1.09 for cadmium, depending on the technology of winter wheat cultivation.

The low mobility of copper and zinc compounds leads to the fact that the content of these elements in leached chernozem is below average, which indicates the formation of poorly soluble compounds of these metals (phosphates, organomineral complexes). The content of mobile forms of cobalt approaches
the critical limit of cobalt deficiency as a microelement. The gross content of heavy metals on average has increased slightly over three years of research, with the exception of zinc.

5. Conclusions
Long-term agricultural use of the leached chernozem located on the flat agricultural landscape of the Western Ciscaucasia caused the changes in its fertility. The intensification of technologies for the cultivation of winter wheat and sugar beets under conditions of agro-ecological monitoring contributed to an increase in the content and reserves of humus in leached chernozem, especially when the mouldboardless system of the primary tillage is used. The factor of the level of soil fertility had the greatest positive influence on these indicators.

Long-term use of organic and mineral fertilizers in combination with various systems of soil cultivation and plant protection during the cultivation of winter wheat did not significantly affect the content of gross and mobile forms of heavy metals in the arable layer of leached chernozem, with the exception of the gross zinc content. However, the number of their mobile forms is much less than the maximum permissible concentration.

The environmentally acceptable technology proved to be the most effective in the cultivation of winter wheat and sugar beet: for winter wheat—when using mouldboardless (2221) and moldboard zonal (2222) soil cultivation, for sugar beet—only when using mouldboard soil cultivation (2222, 2223). In these agricultural technologies, the average rate of organic and mineral fertilizers was used in combination with chemical means of protecting crops from weeds against the background of increased soil fertility. A high yield of the studied link of crop rotation was also ensured, and it helped to reproduce the fertility of leached chernozem. The pesticide-free technology (1112, 1113) is also effective in terms of its ecological and bioenergy indicators when used with the same systems of primary tillage.

6. References
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