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Peculiarities of Leached Black Soil Absorption Capacity in the Pre-Kuban Lowland in the conditions of the Field Agrocoenosis

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ABSTRACT: The effect of intensification-alternative technologies of cultivating maize and winter wheat on the physicochemical properties of leached black soil of the pre-Kuban lowland has been studied. The studies were performed in the system of agroecological monitoring of the Kuban State Agrarian University in the 11-field grain-and-grass crop rotation. The soil cover of the experimental plot was represented by leached extra-thick slightly humic black soil. Two factors were studied in the experiment: the complex ABC factor (A — conditional soil fertility level, B — a system of fertilizers, and C — plant protection) in four gradations (000, 111, 222, and 333); and factor D — the system of primary tillage — was studied in three gradations: D_1 – nonmold board (soil-protective), D_2 – recommended (used in the agricultural zone of the experiment), and D_3 — moldboard with periodic deep loosening to the depth of 70 cm twice per crop rotation. It has been found that the intensification of agronomic technologies in the conditions of 2016 – 2017 contributed to the stabilization of the state of the soil-absorbing complex. The main way of improving the fertility of leached black soil is the reasonable intensification of the agronomic technology that combines the use of mineral and organic fertilizers on the background of recommended and moldboard primary tillage system, with the mandatory science-based scheme of field crops alternation in the crop rotation.

Keywords: Leached black soil, physicochemical properties, soil absorption complex, winter wheat, maize, yield rate, grain, intensification, agronomic technologies.

I. INTRODUCTION

The absorption capacity of the soil is its ability to absorb with or without exchange solid, liquid, and gaseous substances, or increase their concentration on the surface of soil colloids. The absorption capacity of the soil has a significant effect on all soil processes and is closely related to its fertility. The main role in the absorption of various elements and compounds is played by the soil absorption complex (SAC) — a set of water-insoluble finely dispersed mineral, organic, and organomineral compounds formed during soil formation and partially inherited from the parent rock. The state of SAC determines many soil properties that determine the level of soil fertility [1-6]. It is characterized by physicochemical properties, such as the cation exchange capacity, the sum of absorbed bases, the degree of saturation with bases, and types of soil acidity. The Cation Exchange Capacity (CEC) is the maximum amount of cations absorbed from the soil that are capable of exchange. For assessing the ratio in the SAC of bases ($Ca^{2+,}$ Mg^{2+}, Na^+, K^+, NH^{4+}, and absorbed hydrogen (H+) and aluminum (Al3+)), the percentage content of the sum of exchange bases in the total amount of absorbed ions (CEC), that is, the degree of saturation with bases (DSB) is used. The share of exchange cations H^+ and Al^{3+} in SAC characterizes insufficient soil saturation with bases. Such soils have low buffering capacity, i.e., the ability to neutralize acids or alkali and to withstand changes in the reaction of the soil solution.

Depending on where cations H^+ and Al^{3+} are present (in the solution or SAS), the active and the potential types of soil acidity are distinguished, respectively. Potential acidity is manifested depending on the chemistry of mineral fertilizers introduced into the soil. In the case where hydrolytic alkaline salts are used, hydrolytic potential acidity is formed in the soil. Active acidity is characterized by the pH value, and hydrolytic acidity is determined by titration. Acidic soil reaction is unfavorable for most cultivated plants and beneficial microorganisms [7-10]. Due to the lack of bases, especially calcium, organic matter does not accumulate in these soils, and they lose their main energy resource, humus. Many researchers note the strengthening of such processes in leached black soil, which is heavily used in agricultural production. It is known that, despite the use of organic fertilizers, the use of large dosages of traditional mineral fertilizers containing monovalent ions (ammonium nitrate, sylvin — potassium chloride, etc.) can increase hydrolytic acidity and cause the loss of calcium from SAC [11-16]. This is explained by the low efficiency of using manure for humus accumulation due to the poor formation of calcium humates. Ammonium nitrate and sylvin, which are still used in the agricultural production of Kuban, contain monovalent cations ($NH\ 4^+$, K^+), which contribute to the peptization of soil colloids, and anions (NO^{3-} and Cl^-), which, leaching from the soil, carry out the equivalent amount of calcium [17- 22].

Studying the problem of regulating the state of the SAC and the changes in the physicochemical properties of the soil under the action of agronomic technologies with various degree of intensification is quite important in the modern world, as it is required for developing methods of maintaining fertility of the soil, particularly, Kuban black soil, and the yield of field crops.

II. METHODS

The studies were performed in the system of agroecological monitoring of the Kuban State Agrarian University in the 11-field grain-and-grass crop rotation. By the amount of precipitation (643 mm), the territory of the experimental plot was moderately warm, the moisture coefficient was 0.3 – 0.4. The sum of temperatures for the period of active vegetation was 3,567ºC. The weather conditions in the years of research varied: in 2016, the amount of annual precipitation exceeded the long-term average value by 141 mm, and in 2017 — by 41 mm. The average annual air temperature exceeded the long-term indicator (10.8ºC) by 2.1 – 2.5ºC.

The soil cover of the experimental plot was represented by leached extra-thick slightly humic black soil. The amount of sustainable wilting humidity was 11 – 12.7 %, the humus content was 3.1 %. The type of humus in the arable layer was humate or fulvate-humate, the amount of humic acids exceeded 1.5 – 5 times the content of fulvic acids, which was typical for the formation of black soils. The content of gross nitrogen reserves was 0.16 – 0.18 % and decreased with the depth to 0.07 – 0.1 %. The amount of mobile forms of nitrogen, phosphorus, and potassium varied in the relevant range: 2.9 – 5.9, 17.2 – 35.7, and 10.2 – 37.0 mg per 100 g of soil. Due to leaching of carbon salts ($CaCO_3$) down beyond the humus horizons, the reaction of leached black soils was neutral or slightly acidic, pH was 6.5 – 7.3 [17, 23-27].

Two factors were studied in the experiment. The complex ABC factor (A — the conditional soil fertility level, B — a system of fertilizers, and C — plant protection) was studied in four gradations (000, 111, 222, and 333). Fertility levels (A) were created by a single introduction of increasing dosages of organic fertilizers and phosphorus into the soil during the crop rotation (11 years): A0 – without fertilizers, A1 — 200 kg of P2O5/ha, and 200 t of litter/ha, A2 and A3 stood for double and triple dosages of the fertilizers. The fertilizer dosages range (B) on average per 1 ha was as follows: B0 — without fertilizer; B1 — N91P91K91; B2 and B3 stood for a corresponding increase two and four times of the dosage of the mineral fertilizers. The system of plant protection (C) from weeds, pests, and diseases was built with consideration of the ecological threshold of their harmfulness: C – without the use of protective products, C1 — the biological protection system, C2 — chemical weed control, and C3 – chemical protection from diseases, pests, and weeds [17, 28-33].

Factor D – the main tillage system – was studied in three gradations: D1 — nonmoldboard (soil protection), D2 — recommended (used in the agricultural zone of the experiment), and D3 – moldboard with periodic deep loosening to 70 cm twice per crop rotation.

Plot area was as follows: total 105 m^2, accounting area for winter wheat (the Bezostaya 100 cultivar) — 34.0 m^2, and for maize (the Krasnodar 292 AMB hybrid) — 47.6 m^2.

The experiment was repeated three times, the plots with the variants were placed systematically.

Soil analyses were made in the arable and the subsurface layers: the sum of absorbed bases — using the method of Kappen-Gilkovits, the hydrolytic acidity – using the method of Kappen; the pH value — using the potentiometric method, the CEC and the DSB — through calculations. In describing the results of the study, conventional names of the technologies were used: 000 — extensive, 111 — nonpesticidal, 222 — environmentally acceptable, and 333 — intensive. The obtained experimental materials were subjected to statistical processing according to the full factorial scheme of the field experiment 4 × 3 × 3.

III. RESULTS

In 2016, maize was grown after winter wheat as a predecessor. As a result of the studies, it was found that in that year, there had been a significant increase in the amount of exchange bases in the variant with the use of the environmentally acceptable technology (222) and a decrease in the level of hydrolytic acidity by 8 %, compared to the variant with the use of extensive technology (000). The level of active acidity in the variants with the use of environmentally acceptable and intensive technologies significantly decreased (by 3 %) (Table 1).

With the intensification of the technologies of growing field crops in a link of the crop rotation, a tendency to increase the amount of exchange bases regardless of the methods of tillage was identified. However, a significant increase in this indicator was confirmed by analysis of variance only in the variant with the use of ecologically acceptable technology of growing maize (3.3 % relative to reference — St(ABC)).

Note: S was the sum of exchange bases, Hh was the hydrolytic acidity, CEC was the cation exchange capacity, DSB was the degree of saturation with bases, and St was the reference variant for factors ABC and D.

In 2017, only a tendency to increase the amount of exchangeable bases was noted, when the amount of precipitation was 100 mm less than in 2016. In less humid years, the dissolution and availability of fertilizers for the plants were lower, and the metabolic reactions slowed down (Table 2).

Table 1: The physicochemical properties of leached black soil depending on the intensification of the cultivation technology and maize yield, 2016.

Factor (ABC) and factor (D)	S	Hh	CEC	DSB, %	pH	Grain yield, t/ha
	mEq. per 100 g of soil					
Extensive (000) –$St_{(ABC)}$	36.3	3.35	39.6	91.6	6.62	3.55
Nonpesticidal (111)	36.9	2.83	39.7	92.8	6.76	4.81
Environmentally acceptable (222)	37.4	2.82	40.2	93.0	6.74	5.89
Intensive (333)	36.5	2.96	39.5	92.5	6.75	6.85
Nonmoldboard (D_1)	36.4	3.07	39.5	92.2	6.79	5.24
Recommended (D_2) – $St_{(D)}$	37.0	3.30	40.3	92.0	6.75	5.22
Moldboard (D_3)	36.9	3.00	39.9	92.5	6.74	5.36
LSD_{05} for ABC	1.1	0.48	—	—	0.10	0.09
LSD_{05} for D	0.8	0.41	—	—	0.09	0.08

Table 2: The physicochemical properties of leached black soil depending on the intensification of the cultivation technology and winter wheat yield, 2017.

Factor (ABC) and factor (D)	S	Hh	CEC	DSB, %	pH	Grain yield, t/ha
	mEq. per 100 g of soil					
Extensive (000) –$St_{(ABC)}$	36.8	3.38	40.2	91.6	6.46	5.77
Nonpesticidal (111)	36.6	3.21	39.8	92.0	6.53	8.19
Environmentally acceptable (222)	37.0	3.27	40.3	92.0	6.46	8.35
Intensive (333)	37.1	2.91	40.0	93.0	6.61	8.30
Nonmoldboard (D_1)	37.4	2.80	40.2	93.0	6.65	7.52
Recommended (D_2) – $St_{(D)}$	36.8	3.19	40.0	92.0	6.54	7.77
Moldboard (D_3)	36.5	3.58	40.1	91.2	6.50	7.67
LSD_{05} for ABC	1.0	0.43	—	—	0.14	0.11
LSD_{05} for D	0.9	0.30	—	—	0.11	0.09

A significant decrease in the level of hydrolytic acidity was found in the variants with the use of intensive technology (by 13.9 %). Hydrolytic acidity is the initial form of acidity in the soil that occurs at the beginning of soil depletion of bases; therefore, a decrease in its level is a positive factor in stabilizing soil fertility.

In 2017, the level of active acidity significantly decreased only in the variant with the use of intensive technology (by 2.32 % compared to the variant with extensive technology). The use of mineral fertilizers in combination with high norms of manure introduction in this variant reduced soil acidity by increasing the buffering capacity of leached black soil against acidification. Manure is known to increase the amount of bases. The carbonic acid released during its decomposition promotes calcium carbonate transition to bicarbonate, coagulation of soil colloids, and improvement of the structural strength [34].

Active acidity was more likely to occur when the soil solution contained water-soluble compounds, such as mineral and organic acids or physiologically acidic fertilizers. The use of ammonium nitrate in spring fertilization of winter wheat contributed to decreasing the pH of the soil solution, i.e., increasing the active acidity in the variants of the experiment, compared to the same variants in maize cultivation in 2016. Soil acidification in agrocoenoses occurred faster than in natural conditions. The reasons thereto were a more powerful root system of plants in arable lands, the lack of circulation of fresh organic matter with postharvest remainders, as well as the lack of macro- and microelements in plant nutrition. They were alienated along with the harvest, but were replaced only by NPK, and were not [1] forced to destroy the mineral base of soils with protons that saturated the root exchange capacity [35].

In the climatic conditions of 2017, a positive effect of using no moldboard tillage (D_1) was identified, which contributed to reducing the hydrolytic acidity by 12.2 %, compared to variant D_2 – $St_{(D)}$. However, the use of moldboard tillage (D_3) contributed to a substantial increase in this type of soil acidity.

In general, intensification of crop cultivation technologies contributed to increasing the amount of exchange bases. However, this tendency was not always statistically veracious. The unstable manifestation of the regularities of improving the state of SAC in dynamics was explained by both weather and technological conditions.

IV. DISCUSSION

The state of SAC of leached black soil largely determines its fertility and influences the formation of physicochemical properties. Studying the effect of alternative agronomic technologies on these properties showed that with increasing the intensification of the methods of cultivating the winter wheat variety Bezostaya 100 and the maize hybrid Krasnodarsky 292 AMB, the status of SAC was stabilized. A significant reduction of active and hydrolytic acidity was noted, and a tendency to increase the amount of exchange bases was identified.

SAC stabilization was indicated by CEC and the DSB, which remained virtually unchanged in the variants of the field experiment. Their values varied within the corresponding limits between 39.8 – 40.3 mEq. per 100 g of soil and 91.6 – 93.0 % (2016), as well as 39.8 – 40.3 per mEq. per 100 g of soil and 91.6 – 93.0 % (2017).

The intensification of the technologies of cultivating maize and winter wheat mainly influenced the grain yield. With the intensification of technologies, maize grain yield increased by 35.5 – 93.0 %, and winter wheat grain yield — by 41.9 – 44.7 %, compared to the variant with the use of extensive technology.

The effect of various types of tillage on the yield of experimental field crops was not unambiguous. When growing maize, the largest grain yield increase was noted in the variant with the use of moldboard tillage (26.8 % compared to the reference ($St_{(D)}$)). Deep soil loosening contributed to creating more favorable conditions for the development of the deeply penetrating root system of maize.

Winter wheat cultivation was more efficient with the recommended tillage, which contributed to increasing the grain yield by 1.29 – 3.2 % compared to no moldboard (D_1) and moldboard (D_3) tillage.

V. CONCLUSION

Thus, the performed set of studies has shown that intensifying the technologies of field crops cultivation in the conditions of 2016 – 2017 contributed to optimizing the physicochemical properties of leached black soils and stabilizing the state of the soil-absorbing complex. The main areas of improving leached black soil fertility in the pre-Kuban lowland and increasing the yield of maize and winter wheat are moderate intensification of the agronomic technologies, combination of mineral and organic fertilizers on the background of recommended and moldboard systems of primary tillage, and the mantadory use of a scientifically substantiated scheme of field alternation in crop rotation.

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