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The Influence of Prolonged Cultivation of Agricultural Crops with Various Technologies on the Properties of Leached Chernozem of Western Ciscaucasia

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Abstract

The studies were conducted in a long multifactor field experiment in a typical lowland agrolandscape in the southern part of the Azov-Kuban lowland. The introduction of high doses of organic fertilizers during the second rotation (10 years) contributed to the improvement of its agrophysical and physical and chemical properties, in comparison with extensive technology. The intensification of technologies in crop rotation with the use of a boardless soil treatment system contributed to an increase in the content of general humus in leached chernozem while cultivating field crops. Limiting factors in increasing the content and reserves of humus in chernozem were the intensification of the main tillage system and the plant protection system.

Keywords: agroecological monitoring, agrotechnology, content and balance of humus, crop rotation, leached chernozem, properties, Western Ciscaucasia.

Introduction

In the southern part of the Azov-Kuban lowland of the Krasnodar Krai, mainly leached chernozems were formed. Their total area is 240.7 thous. ha, including arable land – 160.2 thous. ha. The prolonged intensive agricultural use of chernozems, as well as other soils, led to an imbalance between potential and effective fertility [1-7]. The loss of humus in the chernozems of the region over the last 30-40 years was over 30% of its original content, which significantly deteriorated their properties [3, 8, 9]. Therefore, at present, the studies on the changes in the properties of chernozems and, especially, their humus state, are quite relevant, given various technologies for cultivating agricultural crops to increase the productivity of land in the region [10, 11].

Materials And Methods

Long-term studies were conducted in the agroecological monitoring system in a typical lowland agrolandscape in the southern part of the Azov-Kuban lowland. The object of the research was leached chernozem, occupied by crops of 11-field grain-grass tillage rotation. Field crops were cultivated by various technologies during 2 rotations; the second rotation took place from 2003 to 2013. Alternation of crops in the field crop rotation was as follows: sunflower – winter wheat – maize for grain – winter wheat – sugar beet – winter wheat – lucerne of the first year with undersowing of spring barley – lucerne of the second year – lucerne of the third year – winter wheat – winter barley.

In the long-term multifactor field experiment, the following factors were studied: the fertility level (A), the fertilizer application system (B), the plant protection system (C) and the main tillage system (D).

In the field experiment, the factor A included 4 levels of fertility of leached chernozem: initial and natural background (A_0), medium one (A_1), elevated one (A_2) and high one (A_3) by adding in it for A_1 – 200 kg/ha of P_2O_5 and 200 ton/ha of manure, for A_2 – the fertilizer dose doubled, and for the A_3 - the fertilizer dose tripled.

The range of fertilizer doses in the factor B - the fertilizer system – was determined on the basis of the balance method taking into account the planned yield, the required product quality, the specified rates of soil fertility improvement, a favorable state/environment: B_0 – without fertilizers, B_1 – the minimum dose of fertilizers (91 kg/ha of the active ingredient NPK and 4.5 ton/ha of semi-decomposed manure), B_2 – average dose (doubled), and B_3 – high dose (increased 4-fold to B_1).

In the third factor, the following plant protection systems were applied: C_0 – without protection, C_1 – biological pest and disease protection system, C_2 – integrated plant protection system from weeds, C_3 – integrated plant protection system from pests, diseases and weeds.

The studies were conducted against the background of the fourth factor – the main tillage system: D_1 – boardless one (soil protection), D_2 – zonal one (recommended), and D_3 – moldboard one with deep soil loosening up to 70 cm twice in rotation (for 11 years).

The scheme of the experiment was presented as part of a sample from the complete scheme of a long-term multifactor field experiment (4×4×4) ×3 and included 12 options out of 48 with the conventional name of agrotechnology: 000 (extensive technology), 111 (nonpesticidal), 222 (ecologically permissible), 333 (intensive) on 3 studied main tillage systems (D_1 D_2, D_3). Plot area was as follows: total - 105 m, accounting area – from 34.0 to 47.6 m, depending on the culture of a crop in the rotation. The repetition of the experiment was 3-fold; the arrangement of the plots was systematic.

Sampling of soil samples was conducted by the method of a continuous column in layers 0-20 cm, 20-40 cm and 40-60 cm under all crops of a crop rotation in the summer period (July-August). The following parameters were determined and calculated in soil samples: general humus according to the method of I.V. Tyurin in the modification of V.N. Simakov, accelerated determination of the humus composition of mineral soils according to the method of M.M. Kononova and N.P. Belchikova, as well as humus balance calculation.

Results

Granulometric composition is the most important characteristic of the soil. Agrophysical, agrochemical, physical and chemical and other soil properties depend on it, as well as fertility on the whole.

It was established that during the second rotation of agricultural crops in the system of agroecological monitoring, regardless of the degree of intensity of agricultural technologies, the level of fertility, the system of fertilizer application and plant protection and the soil treatment system, the granulometric composition of leached chernozem remained practically unchanged, confirming that it was the most conservative characteristic feature of its properties (Slyusarev *et al.*, 2013). According to the granulometric composition, leached chernozem belongs to a light silty clay containing 60-63.9% of physical clay (less than 0.01 mm) and 36.2-41.0% of silt (less than 0.001 mm) in the 0-100 cm layer. The distribution of mechanical fractions along the profile of this layer is relatively uniform.

With agricultural use of soils, especially the long-term one, their agrophysical properties change: density, density of the solid phase, total porosity and moisture capacity.

It has been established that, with the intensification of agrotechnologies, and primarily with the application of high doses of organic fertilizers, the agrophysical properties of soil improve (Table 1).

The density of leached chernozem in the 0-100 cm layer when using the zonal soil cultivation system after the second rotation of field crops cultivated by alternative technologies was as follows: 1.28-1.45 g/cm on the extensive one (0002), 1.24-1.38 g/cm on the nonpesticidal one (1112), 1.20-1.37 g/cm on the ecologically permissible one (2222), and 1.17-1.39 g/cm on the intensive one (3332). The total porosity was 46.7-52.3%, 49.1-53.4%, 48.9-54.6% and 48.2-55.0%, respectively, which contributed to an increase in the total moisture capacity and moisture reserves.

Consequently, the prolonged use of alternative technologies for the cultivation of crops during the second rotation of the 11-field crop rotation affects the agrophysical indicators of leached chernozem of the Azov-Kuban lowland in different ways. The introduction of high doses of organic fertilizers in the cultivation of crops using alternative technologies contributed to the improvement of its agrophysical properties, in comparison with extensive technology.

Table 1. Influence of various agrotechnologies on agrophysical properties of leached chernozem while cultivating field crops (2003-2013)

Technology (index*)	Depth, cm	Density, g/cm^3		Porosity general, %	Full moisture storage capacity, %
		bulk	solid phase		
Extensive (0002)	0-20	1.28	2.68	52.3	40.8
	20-40	1.36	2.70	49.7	36.5
	40-60	1.39	2.70	48.6	35.0
	60-80	1.42	2.72	47.8	33.7
	80-100	1.45	2.72	46.7	32.2
Nonpesticidal (1112)	0-20	1.24	2.66	53.4	43.1
	20-40	1.28	2.66	51.9	40.5
	40-60	1.34	2.68	50.0	37.3
	60-80	1.38	2.69	48.7	35.3
	80-100	1.38	2.71	49.1	35.6
Ecological (2222)	0-20	1.20	2.64	54.6	45.5
	20-40	1.29	2.64	51.2	39.7
	40-60	1.35	2.66	49.3	36.5
	60-80	1.37	2.68	48.9	35.7
	80-100	1.37	2.68	48.9	35.7
Intensive (3332)	0-20	1.17	2.60	55.0	47.0
	20-40	1.27	2.64	51.9	40.9
	40-60	1.33	2.64	49.7	37.4
	60-80	1.36	2.66	48.9	35.9
	80-100	1.39	2.68	48.2	34.7

Table 2. The influence of various agricultural technologies on the physical and chemical parameters of leached chernozem after the second rotation of cultivating field crops (2003-2013)

Technology (index*)	Depth, cm	The sum of absorbed cations, mg –eq./100 g of soil	Hydrolytic acidity, mg –eq./100 g of soil	Capacity of cation exchange, mg –eq./100 g of soil	Degree of saturation with bases, %	pH_{H2O}	pH_{KCl}
0002	0-20	28.4	4.6	33.0	86.1	6.6	5.7
	20-40	30.5	4.6	35.1	86.9	6.7	5.4
	40-60	30.5	3.2	33.7	90.5	7.0	5.6
	60-80	30.5	3.2	33.7	90.5	6.8	5.6
	80-100	30.5	2.8	33.3	91.6	7.0	5.8
1112	0-20	29.9	4.6	34.5	86.7	6.8	5.6
	20-40	32.4	4.1	36.5	88.8	6.8	5.4
	40-60	35.6	3.0	38.6	92.2	6.9	5.7
	60-80	35.0	2.8	37.8	92.6	6.9	5.9
	80-100	35.0	2.3	37.3	93.8	6.9	6.0
2222	0-20	33.4	3.6	37.0	90.3	6.9	6.1
	20-40	33.4	3.6	37.0	90.3	7.0	5.7
	40-60	33.7	2.9	36.6	92.1	7.0	5.8
	60-80	34.3	2.3	36.6	93.7	7.0	5.9
	80-100	34.4	1.8	36.2	95.0	7.1	6.0
3332	0-20	33.4	3.9	37.3	89.5	6.8	5.9
	20-40	32.1	3.9	36.0	89.2	6.8	5.8
	40-60	34.6	3.4	38.0	91.1	6.8	5.7
	60-80	35.9	3.0	38.9	92.3	6.7	5.8
	80-100	37.5	2.3	39.8	94.2	6.9	5.9

Table 3. Influence of various agricultural technologies on the change in humus content and balance in the 0-20 cm layer of leached chernozem for the second rotation of cultivating field crops (2003-2013)

Index of technology	Year/crop, t/ha											Humus content on average for 2003-2013,%
	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	
	sunflower	winter wheat Krasnodarskaya 99	maize	winter wheat Nota	sugar beet	winter wheat Fortuna	lucerne + barley	lucerne 2 years	lucerne 3 years	winter wheat Yuka	winter barley	
0001	3.26 -0.31	2.89 -0.01	3.04 +0.23	2.99 -0.02	2.90 -1.05	3.35 -0.12	3.30 +1.51	3.61 +2.14	3.87 +1.87	3.31 -0.28	3.22 -0.28	3.25
0002	3.26 -0.33	2.84 -0.02	2.72 +0.25	2.77 -0.01	2.87 -1.07	3.35 -0.12	3.15 +1.25	3.46 +1.89	3.56 +1.87	3.24 -0.27	3.20 -0.27	3.13
0003	3.21 -0.32	2.78 -0.02	2.52 +0.26	2.73 -0.01	2.80 -1.08	3.00 -0.22	3.10 +1.26	3.10 +1.72	3.25 +1.85	3.11 -0.28	3.03 -0.13	2.97
1111	3.34 -0.55	3.14 -0.02	3.11 +0.31	3.73 +0.01	2.96 -1.12	3.60 -0.35	3.24 +1.59	3.86 +2.09	3.93 +1.72	3.47 -0.27	3.38 -0.33	3.43
1112	3.29 -0.55	3.10 -0.02	3.08 +0.32	3.30 +0.01	3.04 -1.14	3.55 -0.35	3.25 +1.59	3.65 +2.06	3.68 +1.76	3.40 -0.29	3.38 -0.29	3.34
1113	3.26 -0.59	2.95 -0.01	2.77 +0.32	3.12 +0.01	2.96 -1.14	3.35 -0.35	3.26 +1.51	3.11 +1.91	3.46 +1.94	3.26 -0.29	3.36 -0.13	3.17
2221	3.40 -0.61	3.37 +0.01	3.24 +0.39	3.95 +0.01	3.10 -1.02	3.40 -0.18	3.55 +1.76	3.91 +2.23	3.81 +1.73	3.55 -0.13	3.48 -0.44	3.52
2222	3.42 -0.62	3.23 +0.09	2.54 +0.39	3.30 +0.01	2.97 -1.09	3.00 -0.18	3.08 +1.66	3.41 +2.15	3.31 +1.97	3.49 -0.14	3.44 -0.12	3.20
2223	3.45 -0.63	3.02 -0.02	2.92 +0.39	3.51 +0.02	3.05 -1.11	4.00 -0.18	3.52 +1.65	3.25 +2.04	3.50 +1.77	3.42 -0.13	3.48 -0.13	3.37
3331	3.49 -0.62	3.40 +0.02	2.90 +0.45	3.17 +0.02	3.36 -1.02	4.05 +0.02	3.74 +1.82	4.08 +2.26	4.17 +1.79	3.80 +0.01	3.72 -0.26	3.63
3332	3.45 -0.66	3.32 +0.02	2.61 +0.45	3.59 -0.01	3.26 -1.09	3.60 +0.02	4.03 +1.87	4.15 +2.32	4.18 +1.84	3.72 +0.01	3.64 -0.12	3.60
3333	3.47 -0.65	3.11 +0.01	3.02 +0.47	3.48 +0.02	3.59 -1.07	4.05 +0.01	4.03 +1.94	4.02 +2.16	4.06 +1.74	3.56 +0.01	3.60 -0.13	3.64
HCP_{05}	0.04	0.08	0.10	0.17	0.12	0.15	0.13	0.14	0.10	0.08	0.08	

The conducted studies (Table 2) show tendencies of stabilization of the soil-absorbing complex in leached chernozem according to the studied indicators on the options with a set high fertility level and, first of all, high doses of organic fertilizers in the zonal soil cultivation system. At the end of the second crop rotation, the amount of exchangeable bases, hydrolytic and active acidity in the investigated chernozem on options with extensive (0002) and nonpesticidal (1112) technologies were insignificantly different.

Options with environmentally permissible (2222) and intensive technologies (3332) were characterized by a tendency to improve these properties, and a decrease in hydrolytic acidity (8.5-11.0%) in reference to extensive technology (0002) was established.

The long-term studies established that at the end of the second rotation, the content of general humus in the upper layer of leached chernozem after harvesting winter barley was 3.03-3.72% (Table 3). The minimum values of these indicators were noted using the technology 0003 (the extensive one with moldboard deep soil loosening), and the maximum values – when using the technology 3331 (the intensive one with boardless soil tillage). The greatest content of general humus in the arable layer of leached chernozem (4.17-4.18%) was observed under the lucerne of the 3rd year of life when using intensive agrotechnology against the background of boardless and zonal soil cultivation systems (3331, 3332), which was explained by the entry into the soil of a large number of organic residues and weak humus mineralization in comparison with the deep moldboard loosening. Winter crops leave behind fewer stubbles and root residues, so the reserves of humus under winter wheat (2012) and winter barley (2013) are significantly lower than under lucerne. A one-time application of high doses of organic fertilizers to the soil, 400 and 600 t/ha of manure, did not contribute to the increase in the humus content in the upper layer of leached chernozem up to the calculated figures for the 2 rotations. However, the actual content of humus in the soil under study at the initial fertility level (0002) was higher than the planned level on average by 1.1-1.2 times.

All changes that occur in the soil during its agricultural use are related to the state of humus, which is caused by varying degrees of decomposition of organic substances and the nature of their changes, as well as links of humic compounds between themselves and the mineral part of the soil [2, 5].

The calculation of the humus balance in leached chernozem for the second rotation of 11-field crop rotation from 2003 to 2013 is presented in Table 3. The humus balance was calculated as the difference between its receipts due to stubbles and root residues, application of organic fertilizers, and expenses caused by mineralization.

It follows from the obtained materials that while cultivating crops (sunflower, sugar beet) by various technologies, regardless of the soil treatment system, a negative humus balance is observed in the upper layer of leached chernozem. With the intensification of agricultural technologies and the main tillage intensification system while cultivating technical tilled crops, the rate of humus mineralization of leached chernozem significantly increases, which leads to a deficiency in the humus balance in its upper layer. Therefore, when cultivating the above-mentioned crops, organic fertilizers should necessarily be used based on the calculated data on the humus balance of the leached chernozem. A deficit-free humus balance in the examined soil was noted in the cultivation of lucerne of 3 years of vegetation and maize for grain, regardless of technology and soil treatment system.

When cultivating lucerne for 3 years with different technologies, the humus balance in the upper layer of leached chernozem was positive. This is because the roots of lucerne are actively involved in the creation of soil fertility. They involve a large mass of organic matter in the soil-forming process after their decay, especially nitrogen, synthesized by nodule bacteria. The maximum accumulation of humus in leached chernozem was established under the lucerne of the second year of vegetation and was from +1.72 (0003) to +2.32 t/ha (3332), which was explained by its highest yield and the considerable mass of stubbles and root residues left in the soil.

CONCLUSIONS

Consequently, long-term use of alternative technologies for cultivating agricultural crops during the second rotation in the 11-field crop rotation affects the agrophysical and physical and chemical parameters of the leached chernozem of the Azov-Kuban lowland in different ways. The introduction of high doses of organic fertilizers contributed to the improvement of its agrophysical and physical and chemical properties, in comparison with extensive technology. Regardless of agrotechnology, the granulometric composition of leached chernozem did not change and referred to a light silty clay. The intensification of technologies in crop rotation with the use of a boardless soil treatment system contributed to an increase in the content of general humus in leached chernozem while cultivating field crops in the Azov-Kuban lowland. The maximum positive effect on this indicator was made by the fertility level factor (A) of the soil. The limiting factors in increasing the content and reserves of humus in chernozem were the intensification of the main tillage system (factor D) and plant protection system (factor C).

In the second rotation of the 11-field grain-grass tillage rotation, the positive balance of humus in the upper layer of the leached chernozem was noted under lucerne of 3 years of vegetation and maize, regardless of the technology of their cultivation. Under winter crops of continuous planting, depending on the predecessor, a deficit-free balance of humus in the investigated soil was observed only when using intensive technologies. The negative balance of humus in leached chernozem was established when cultivating various technical tilled crops, especially sugar beet, by different technologies.

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