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Assessment of the Agroecological State of Long-Term Irrigated Meadow-Chernozem Soil

Yulia Aksenova
Department of Agrochemistry and Soil Science
Omsk State Agrarian University named after P. A. Stolypin
Omsk, Russia
yuv.aksenova@omgau.org

Natalia Nevenchannaya
Department of Agrochemistry and Soil Science
Omsk State Agrarian University named after P. A. Stolypin
Omsk, Russia
nm.nevenchannaya@omgau.org

Vasiliy Boiko
administrative office
Omsk Agrarian Scientific Center
Omsk, Russia
boicko.vasily2011@yandex.ru

Artem Timokhin
Laboratory of Field Feed Production
Omsk Agrarian Scientific Center
Omsk, Russia
timoxin514@mail.ru

***Abstract*—We examined the effect of long-term irrigation on the fertility of meadow-chernozem soil and evaluated its current agroecological state. The humus content stabilized at the average level and varied over the years of the research in the range from 4.95-5.18% in the 0-20 cm layer to 4.88-5.21% in the 20-40 cm layer. The humification degree of organic matter in irrigated soil was high, the ratio of humic and fulvic acids did not change and amounted to 1.5-1.7, the type of humus remained stably fulvate-humate. Humic acids occupy more than 50.0% of the humus and their amount did not change under the influence of irrigation. Soils are characterized by a very low content of the free fraction of humic acids, a medium content of acids linked to calcium and a high content of acids, bound to the mineral part of the soil. A redistribution of fractions was observed within the groups of humic acids. The amount of humic and fulvic acids bound to the mineral part of the soil increased by 1.2-2.0% with simultaneous reduction of humic acids linked to calcium. The content of the fraction of free fulvic acids increased. The energy potential of organic matter is at the critical level. The part of the most accessible energy is accumulated in mobile humic acids. They concentrate from 79 to 192 GJ/ha of potentially active energy. Under the influence of irrigation in the soil, a tendency for the development of secondary alkalinization was noted, as evidenced by an increase in the composition of exchange magnesium cations and an increased sodium content reaching 7%. The structural aggregation testified to the development of physical degradation. The content of aggregates with agronomic value did not exceed 45.2-59.9% and was below the optimal level. Soil aggregates were not resistant to the destructive effects of water.**

Keywords*—*irrigation, humus, humic acids, structural and aggregate composition, labile organic matter.

I. INTRODUCTION

Soils under the influence of systematic treatment, fertilizing, land reclamation, irrigation and drainage and other anthropogenic influences change either in the direction of cultivation or in the direction of degradation [1,2]. Large-scale irrigation of soils formed in areas with unstable and insufficient moisture was started in the 70-80s of the last century and ended by 2000. The main reason for land users refusing irrigation was the rise of groundwater above the critical level and the secondary salinization of soils. Under conditions of lowered, poorly drained plains with a pronounced microrelief, irrigation changes soil formation processes in the direction of increasing hydromorphism due to an increase in the level of groundwater, the development of secondary salinization and alkalinization, the processes of physical, chemical and biological degradation occur in soils [3-7]. In most cases, the degree of degradation development is irreversible. Previously long-term irrigated soils, which were removed from arable land to a deposit for the desalinization, have remained degraded to date and require large capital investments to restore lost fertility. The problem of the agroecological state of soils is relevant for agricultural production in the Omsk region, as it is dictated by the limited distribution of thick chernozem soils with high humus content there and a clear tendency to reduce energy reserves in them.

The agroecological state and soil fertility level of irrigated agrolandscapes depends on the quantity and quality of the organic matter entering them, its available reserves, the content of the labile group of humic substances, the composition of the exchange cations, the provision of the soil with mineral nutrients, and indicators of their physical condition. Productivity and soil resistance to anthropogenic loads and degradation processes is also determined by the nature and direction of the processes of influx and outflow of energy resources. To ensure ecological balance and soil resistance to various changes under the influence of human activity, it is necessary to take into account the influence of the farming system, type of crop rotation, applied fertilizers not only on the transformation of soil organic matter but also on its energy potential. The amount of energy reserves is determined by the amount of plant residues entering the soil, as they accumulate the energy of the sun. After the decomposition of plant material, a part of the energy is retained by the soil. Considering that the volumes of plant residues in agrocenoses are much smaller than in biocenoses, under irrigation conditions and accelerated processes of their transformation, energy losses and changes in the energy state of the soil will occur in an unfavourable direction. This indicator allows you to assess the intensity and direction of matter and energy flows in the agrolandscape. In soils, the energy balance constantly changes due to energy consumption for the formation of crops, evaporation, migration of substances, heat transfer. The rate and direction of energy flow depend on the quality and quantity of the organic matter of the soil since it is the accumulator of solar energy. This indicator is responsible for soil fertility, sustainability and the level of their productive ability [8].

In the existing unfavourable soil reclamation situation, the need arose to regularly monitor the fertility level and the agroecological and energy state of arable soils under long-term irrigation. Since the main production load in arable land falls on chernozems and meadow chernozem soils, which are

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the main components of the base of crop production [9], special attention is paid to the fertility of these soils.

II. Objects and Methods

The object of the research is irrigated meadow-chernozem medium-thick low-humus heavy loamy soil in the territory of the Novoomsk irrigation system (IS) of the Omsk region. The soil formed on saline and carbonate loams, underlain by water-resistant clays, has a predisposition to secondary salinization, alkalinization, and waterlogging. Novoomsk IS was built in 1968. According to Omskgiprovodkhoz reports, ordinary chernozems and meadow-chernozem soils were the most widespread there. They contained readily soluble salts at a depth of two meters, within the first meter their amount varied about 0.1%. Irrigated lands had a different exploitation period. Groundwater with a salinity of 1.9–4.3 g/L occurred at the depth of 5–6 m. It was groundwater and parent rocks that served as sources of salts and caused secondary salinization of the soils. Watering the rocks contributed to the involvement of previously conserved readily soluble salts in the middle, and later on, in the upper part of the soil profile. Already in 1982, in areas with the longest irrigation time, a widespread rise in groundwater was established and their salinity increased to 3.5–6.6 g/L. In parent rocks, the sodium content ranged from 5% to 23.4%, indicating that they were solonetz-like. In 1985, soils evolved into meadow-chernozem solonchak soils and were saline throughout the profile.

Currently, irrigation is carried out by the waters of the Irtysh River with a calcium-carbonate composition. The soil, irrigated for more than 30 years, is used for vegetable crops: beet, potato, tomato, carrot.

Soil fertility monitoring was carried out from 2011 to 2017 in the arable layer (0–20 cm and 20–40 cm) according to the following indicators:

humus content – according to Tyurin's method in Simakov's modification;

the qualitative composition of humus – according to Tyurin's method in Ponomoreva's and Plotnikova's modification;

structural and aggregate composition – by dry screening;

exchange cations of calcium and magnesium – by complexometric method, sodium cations – by flame photometric method;

soil pH – by potentiometric method;

the content of labile humic acids – by the extraction with 0.1 N NaOH;

the energy potential of organic matter and labile humic compounds – according to the method developed by the All-Russian Research Institute of Agriculture and Soil Protection from Erosion.

III. Results and Discussion

The inclusion of soils into irrigated agriculture is accompanied by a change in their water, air and thermal regimes, which affects the transformation of their organic matter. The most intense decrease in the value of this indicator is observed in the first years of irrigation, due to the decomposition of mobile humus compounds. Subsequently, this process slows down as a result of the approach of organic matter to a new equilibrium state and its stabilization at a new level. The change in the conditions of humus formation is associated not only with additional irrigation but also with a change in the volume, quality and nature of the supply of organic residues into the soils of agrocenoses. When growing vegetables, the major part of the plant biomass is taken away with the yield and a small amount of plant residues enters the soil. Under conditions of their accelerated decomposition against the background of irrigation in the absence of the organic fertilizer application and grass sowing, such volumes of biomass are not enough to increase the humus content.

The soil of the study area was characterized by an average provision with humus, the content of which varied over the years (2011, 2013, 2017) in the range from 4.95–5.18% in the 0–20 cm layer to 4.88–5.21% in the 20–40 cm layer, depending on hydrothermal conditions of the year and cultivated crops.

The degree of humification of organic matter is high; humic acids predominate in the composition of humic compounds (Figure 1).

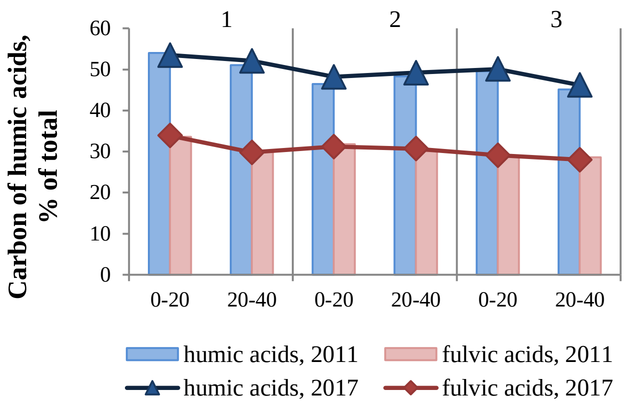

Fig. 1. Group composition of humus of irrigated meadow-chernozem soil: 1 – potato, 2011; beet, 2017; 2 – potato, 2011; beet, 2017; 3 – tomato, 2011; potato, 2017.

Labile organic substances are of the greatest agronomic importance; they include the fraction of humic acids (HA 1) and fulvic acids (FA 1) that are free or loosely bound to the mineral part of the soil. This group of substances performs a protective function in respect of conservative stable organic compounds, serves as a source of nutrition and energy for plants. Their accumulation in soils depends on the cultivation system, cultures in a crop rotation, the amount of plant residues left in the fields after harvesting, and application of organic fertilizers [10, 11, 12]. According to the results of the analysis, the content of mobile humic acids changed irregularly over the years. The amount of HA 1 fraction in the soils of the surveyed sites in 2011 varied within 7.3–9.8% in the 0–20 cm layer and within 5.8–9.0% in the 20–40 cm layer. In 2017, its value was between 9.0% and 9.9%, and 7.8% and 9.6%, respectively.

Fulvic acids have high solubility and mobility, they are most accessible to microorganisms as a source of nutrition and are susceptible to washing-out by irrigation waters to the lower horizons of the soil. For these reasons, their content in the soil is slightly lower than that of humic acids. The size of FA 1 fraction in 2011 was 4.9–6.2% in the 0–20 cm layer and 4.2–6.4% in the 20–40 cm layer; in 2013, 6.1–8.2 and 5.6–6.1%, respectively.

In 2017, we assessed the provision of soils with labile organic matter. Arable soils have a low and very low content of an easily transformed part of humus due to the extensive use or a deficit of new organic material [10, 13]. In three surveyed plots, its amount in the arable layer was at the average level (3455–3906 mg/kg), which is typical for soils with stabilized humus state while observing the usual zonal agrotechnical measures.

At high saturation of the soil-absorbing complex and the soil solution with calcium, the newly formed and free humic acids are fixed in the form of calcium salts – humates, forming a fraction of humic acids linked to calcium in the humus (HA 2). This fraction gives the soil aggregates resistance to the damaging effects of water and mechanical processing by machinery. The content of calcium humates in the soil humus of the study area in 2011 was 24.9–27.3% in the 0–20 cm layer and 27.0–25.6% in the 20–40 cm layer. In 2017, their average value was lower by 1.3–2.0% but remained at the average level.

Mobile humic compounds not bound to exchange calcium in calcium humates are fixed by the mineral part of the soil. Since the soils of the region have a heavy texture, the content of the fraction of humic acids associated with clay minerals (HA 3) is high. Over the years of the research, significant changes regarding this fraction have not been established. In 2011, it was from 13.2% to 16.9% in the 0–20 and 20–40 cm layers, and in 2017, from 14.0% to 19.7%, respectively.

An analysis of the qualitative composition of the humus of the irrigated soil showed that the group composition did change significantly; redistribution of the fractions of humic acids within the groups was observed. The type of humus remained stable, with a fulvate-humate composition.

The organic matter of the soil is an open heterogeneous multi-component system that constantly exchanges various compounds and energy with the environment. The calculation of energy reserves in soil organic matter showed its critical content level. Since for the soils of Western Siberia, gradations of the provision of organic matter with energy reserves have not been developed and these studies are not carried out by research institutes, the assessment was performed on the gradations proposed by the All-Russian Research Institute of Agriculture and Soil Protection from Erosion.

The energy reserves in the organic matter of the soil and their changes in time reflect the energy state of the soil. The energy potential of the soil organic matter was determined for the layer of 0–20 cm, and it did not change over the years of the study and plots. The value of this indicator in plot 1 (potato in 2011, beet in 2017) was 2169–2239 GJ/ha.

The energy reserves in the organic matter of the soil in plot 2 (potato in 2013, beet in 2017) were at the level of 2143–2187 GJ/ha, in plot 3 (tomato in 2011, potato in 2017) – 2178–2243 GJ/ha.

Energy reserves contained in labile humic acids are most accessible to living organisms. Fractions of humic acids, which are parts of the labile group of organic matter, accumulate 2 times more energy than fulvic acids. In 2011, the energy reserves in mobile humic acids in the soil of plot 1 were 192 GJ/ha; by 2017, their value decreased to 138 GJ/ha. In plots 2 and 3, the energy potential of mobile humic acids did not change and varied from 137–147 GJ/ha to 141–159 GJ/ha. The fraction of mobile fulvic acids contains up to 78–106 GJ/ha.

An analysis of the cationic composition of the soil-absorbing complex showed the predominance of calcium (75–77%) among the exchange cations, magnesium accounted for up to 16–19%. The amount of sodium varied from 5 to 7% of the total exchange cations, which testified to the development of secondary alkalinization of the soil under the influence of long-term irrigation (Figure 2).

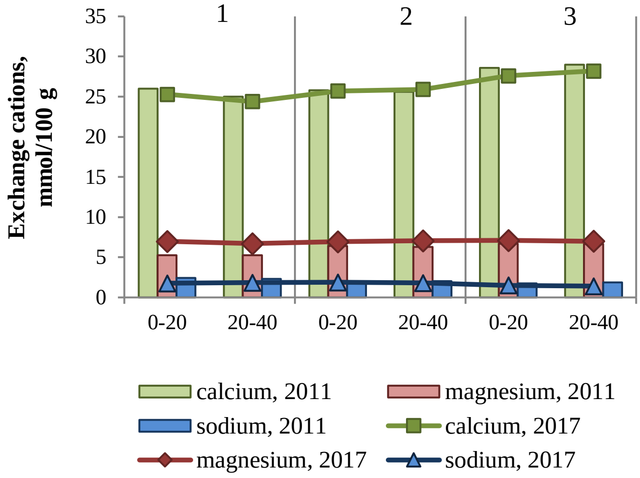

Fig. 2. The content of exchange cations in irrigated meadow-chernozem soil: 1 – potato, 2011; beet, 2017; 2 - potato, 2011; beet, 2017; 3- tomato, 2011; potato, 2017.

The increased content of absorbed magnesium and sodium is a peculiarity of Omsk meadow-chernozem soils and is considered as a relict sign of the previous process of soil formation. The weak solonetzic degree of soil did not change the response of the medium, which was close to neutral.

When freshly formed organic matter enters the soil under conditions of high content of exchange calcium in the soil-absorbing complex and close contact with the mineral part of the soil, clay-humus and organic-mineral complexes are formed. These complexes determine the formation of an agronomically valuable structure. With an increase in the proportion of sodium in the cations, the effect of humic compounds on the structure weakens due to an increase in dispersion and bond strength with the mineral part of the soil. At the same time, the formed sodium humates can have a peptizing effect on soil aggregates, as a result of which they lose their resistance to anthropogenic effects.

According to analyzes, the structural condition of irrigated soil in the surveyed areas was satisfactory. The fractions, the most valuable from an agronomic point of view (10.0–0.25 mm), dominated in the aggregate composition; their amount reached 45.2–59.9% in the 0–20 cm layer and 49.0–58.6% in the 20–40 layer, but it was below the optimum. The amount of blocky fraction (> 10 mm) varied over the plots within a wide range from 19.2–36.4% in the 0–20 cm layer to 23.4–34.1% in the 20–40 cm layer and was at the optimal and acceptable level (Table 1).

The value of these fractions over the years of the research varied irregularly and was largely determined by the quality and physiological ripeness of the soils during the period of its mechanical treatment. With a satisfactory structural state, the aggregates were not resistant to the destructive effects of water.

TABLE I. AGGREGATE COMPOSITION OF THE IRRIGATED MEADOW-CHERNOZEM SOIL

Year	Layer, cm	Fraction size, mm			Structure coefficient
		more than 10	10-0.25	less than 0.25	
Plot 1					
2011, potato	0-20	36.4	45.2	18.4	0.8
	20-40	29.4	51.1	19.5	1.0
2013, potato	0-20	34.4	56.4	9.2	1.3
	20-40	33.4	58.6	8.1	1.4
2017, beet	0-20	28.3	54.2	17.5	1.2
	20-40	34.1	49.0	17.1	1.0
Plot 2					
2013, potato	0-20	34.0	56.1	9.9	1.4
	20-40	32.3	57.2	10.5	1.3
2017, beet	0-20	29.3	51.9	19.0	1.1
	20-40	33.4	50.0	16.2	1.0
Plot 3					
2011, tomato	0-20	29.6	58.6	11.8	1.4
	20-40	32.2	55.7	12.0	1.3
2013, potato	0-20	19.2	59.9	20.9	1.5
	20-40	23.4	55.8	20.6	1.3
2017, potato	0-20	25.8	57.8	16.5	1.4
	20-40	29.3	55.1	15.6	1.2

The number of waterproof aggregates in both the 0–20 and 20–40 cm layer did not exceed 2–6%.

An assessment of the physical, physicochemical, and chemical properties showed that with the constant use of the row crop system, the soil quickly loses its fertility. For comparison, we give a description of the agroecological state and the fertility level of long-term irrigated soil but used in a grain-grass crop rotation. Crops were cultivated without the use of fertilizers. The soil had a high provision with humus (6.95–7.45%) when the crop rotation was saturated with perennial and annual grasses to 50–60%. The total amount of humic acids in the humus was approximately the same. But when cultivating grasses, the proportion of humic acids linked to calcium was higher by an average of 10%, and to the mineral part of the soil – by 3–5% lower. This indicates that humic acids are more strongly fixed by exchange calcium since it is present in a greater amount than in the soil under vegetable crops. Grasses contribute to the accumulation of labile humic substances (in particular in the withdrawn fields of perennial grasses), their amount is higher by 1000–2000 mg/kg and reaches a high level. The soils of such an agrocenosis are stable and relatively resistant to anthropogenic loads. The energy potential of soil organic matter is estimated as low and medium. Under the influence of grasses, energy reserves are higher by 1000–2000 GJ/ha and depending on a crop reach 3758–4195 GJ/ha. However, with a favourable regime of organic matter, soil compaction and signs of compactness strengthening were observed. With heavy particle size distribution and high magnesium content, the soil is prone to compaction, in particular with long-term cultivation of perennial grasses in one place. In the aggregate composition, the amount of blocky fraction was higher than the optimum. The content of valuable aggregates (10.0–0.25 mm) was at optimal and acceptable levels. The mechanical particles were firmly bound by calcium humates to the aggregates, giving the soil excellent and good water resistance. Studies of the fertility parameters of irrigated soils used in different farming systems showed that the introduction of environmentally stabilizing elements, which include grasses, is necessary for the stability of agrocenosis to anthropogenic loads.

IV. CONCLUSIONS

Under modern conditions of agricultural production, farming should be based on an adaptive-landscape system and ensure the formation of an ecologically balanced agrolandscape [14]. In vegetable crop rotations, up to 70% (or more) of biomass can be taken away with the yield, which makes agrocenosis unstable to anthropogenic loads. The degree of the anthropogenic load is limited permissible and unacceptable. Under regular irrigation, without the use of organic and mineral fertilizers, the soil was characterized by a low level of fertility.

The content of humus and labile humic substances stabilized at the average level. The value of these indicators over the years of the research did not change. We can say that the processes of mineralization of organic matter were replenished with the volume of the non-commodity part of the product that was left in the fields. Humic acids prevailed in the soil humus, but the content of the most valuable fraction linked to calcium was average. It is possible to increase the availability of organic matter in the soil and improve its quality by applying organic fertilizers (manure, compost, straw) and sowing legumes with their subsequent ploughing in the soil. This type of measure aimed at increasing energy reserves in soil organic matter and its labile components.

The development of secondary alkalinization is associated with a high content of exchange sodium and magnesium in the parent rocks, on which the soils of the region form. Under conditions of irrigation and rising flows of soil moisture in dry hot periods, they became involved in the root layers of the soil. This indicator requires regular monitoring to timely conduct chemical reclamation in the form of soil gypsuming.

The insufficient amount of valuable aggregates (10.0–0.25 mm) and the weak bond strength of mechanical elements with calcium salts of humic acids indicate the development of physical degradation of the soil. The structure was not resistant to mechanical effect and water, which led to an increase in the dust fraction, the formation of a crust on the soil surface and the deterioration of the water-air regime. These changes were reversible. To achieve the optimal level of blocky fraction and valuable aggregates, the application of organic fertilizers, the introduction of legumes into the crop rotation and soil tillage in the state of physical ripeness are recommended.

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