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EFFECT OF IRRIGATION AND FERTILIZATION ON THE CONTENT AND COMPOSITION OF HUMUS OF CHERNOZEM IN THE VEGETABLE-FODDER CROP ROTATION

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Abstract

Study was conducted in long-term field experiment (47 years) in irrigated vegetables cropping system on chernozem heavy loamy in Forest-Steppe zone of Ukraine. Different types of fertilization regimes were compared: mineral (NPK); organic (manure) and organo-mineral (manure + NPK). Humus content decreased by 10-12% after two 9-crops rotations compared to initial data (before irrigation) on all variants of experiment. Since the end of third 9 years cropping system humus has been increased up to 4.35% at the end of fifth crop rotation in organo-mineral fertilization regime. Mineral fertilization systems did not increase humus content compared to the control (without any fertilization). The highest humic compounds content in chernozem was observed on organic fertilization system. Long-term regular manure application led to significant increase of the content of humic complexes with calcium in comparison with mineral and organo-mineral fertilization regimes. Fulvic acids content was higher on variant with NPK application.

Key words*: chernozem, composition of humus, different types of fertilization.*

INTRODUCTION

Climate change adaptation, mitigation and food security may be addressed at the same time by enhancing soil organic carbon sequestration through environmentally sound land management practices (Rumpel et al., 2020). Soils are the largest terrestrial reservoir of organic carbon (C) and thus play a significant role in the global C cycle. The loss of organic matter from agricultural lands constrains our ability to sustainably feed a growing population and mitigate the impacts of climate change (Machmuller et al., 2015). Also, soil organic matter (SOM) has traditionally been viewed as the main yield determining factor in agriculture. Addressing these challenges development and implementation of practices that accumulate soil C are extremely important. Increase in agricultural production and productivity depends, to a large extent, on the availability of water. In arid and semi-arid regions, irrigation improves economic returns, but on the other hand irrigation can produce unwanted environmental consequences (Cirelli et al., 2009).

A meta-analysis (Zhou et al., 2016) showed that, on average across all biomes, drought and irrigation similarly induced minor increases in soil C pool by 1.45% and 1.27%, respectively. However, drought and irrigation oppositely affected both C fluxes and plant C pools as well as in agroecosystems (e.g., croplands and grasslands). Active management of agricultural soils may reduce the losses of soil organic matter, but full life cycle analyses for fertilized and irrigated soils seldom show net carbon sequestration (McGill et al., 2018). Positive effects of irrigation on soil organic carbon become less pronounced at higher initial soil organic carbon contents and higher precipitation (Trost et al., 2013). Soils with higher initial carbon contents and higher soil moisture offer better living conditions for microorganisms. Inputs of carbon by the cultivation of crops exceed the microbial decomposition. In addition to increased input of carbon by improved plant growth, irrigation shows direct effects on soil aggregate building and thus on the ability of soil to fix organic carbon long-term (Trost et al., 2013).

Many researchers, as a general trend, note a slight decrease in humus stocks in the initial periods of irrigation and their gradual restoration over time, as well as a decrease of its content in the arable layer and an increase with depth (Komissarov, 2015).

The reduced soil organic carbon (SOC) content in irrigation treatment was attributed to drainage associated with greater stocking, together with accelerated decomposition of organic C resulting from elevated soil moisture maintained throughout the growing season (Condron et al., 2014).

During the growing season, there was a fluctuation in the humus content in the layer of 0-40 cm with an increase at the end of the irrigation season from 7 to 23% and a subsequent decrease of 9-10% compared to the initial values at the beginning of the next irrigation season (Voevodina, 2017).

Compared to non-irrigated areas, by irrigation with fresh water, the humus content is less than by irrigation with weakly mineralized water (Shedrin et al., 2017).

The combination of irrigation with other agronomic management factors also influences the development of soil organic carbon content. Authors (Stoner et al., 2019) observed that frequent irrigation decreases the amount of long-term stable C in pastures. Despite no difference in soil C accumulation, fertilized pastures store C longer than unfertilized pastures.

The application of organic fertilizers has an important influence on the carbon exchange of agro-ecosystems, especially in irrigated agriculture. The joint application of organic fertilizers in irrigated areas can maintain a high crop yield and increase the soil organic carbon content and CO_2 net absorption of paddy soil ecosystems (Shihong et al., 2018).

MATERIALS AND METHODS

Long-term field experiment was conducted on chernozem typical at Institute of Vegetables and Melons NAAS of Ukraine (Kharkiv oblast, Ukraine). Experimental field is located in Forest-Steppe zone of Ukraine (49°.45' N, 35°.51' E and 110 m above mean sea level). The territory of experimental fields is characterized by a temperate continental climate. The sum of positive temperatures is about 2850°C. The vegetation period (days with an average daily temperature above 5°C) 195-220 days. The average annual precipitation is 560 mm.

Soil - chernozem typical heavy loamy with pH = 5.7, bulk density = 1.30 g cm^{-3}, the amount of absorbed bases = 26.0 meq per 100 g of soil, hydrolytic acidity = 2.8 meq per 100 g of soil, humus content = 4.3%. At the beginning of field experiment soil contained 15.2 mg kg^{-1} available nitrogen (NH_4-N + NO_3-N), 106-119 mg kg^{-1} available phosphorus (P_2O_5) and 173 mg kg^{-1} potassium (K_2O).

Experimental plot were irrigated by sprinkler irrigation system during 47 years (2-4 times per year with the norm of 350-500 m^3 ha^{-1}). An each experimental plot was 58.3 m^2 with 4 replicates. In all variant of experiment plow tillage was applied.

The chernozem samples were taken from the depth of 0-25 cm. Sampling locations varied in terms of fertilization: 1) Without fertilizer (control); 2) Mineral fertilization system ($N_{60}P_{57}K_{50}$); 3) Organic fertilization system (manure 21 t ha^{-1}); 4) Organo-mineral fertilization system (14 t ha^{-1} of manure + $N_{60}P_{57}K_{50}$).

Crop rotation: barley - cucumber - winter wheat - onion - tomato - cabbage - beetroot. $N_{540}P_{510}K_{450}$ (mineral fertilization system), manure 189 t ha^{-1} (organic fertilization system), 126 t ha^{-1} of manure + $N_{330}P_{330}K_{450}$ (organo-mineral fertilization system) were applied for rotation.

Organic carbon content was determined by Tyurin method based on dichromate oxidation. Organic carbon content was re-calculated into humus using the mean coefficient (1.724). Humus composition was determined by Tyurin method according to Ponomareva-Plotnikova procedure (Ponomareva & Plotnikova, 1980). Different organic matter fractions were isolated: humic acid (HA), fulvic acid (FA), and humin. For humus fractional composition, the solutions of different NaOH concentrations were used for extraction: 0.1 M NaOH (room temperature); 0.02 M NaOH (hot extraction) also 0.05 M H_2SO_4 (for decalcitation, room temperature) at a soil solution ratio at 1:20. The extracted humic substances were then separated into humic and fulvic acid fractions by acidifying the extract to pH = 1.3-1.5 using 0.5 M H_2SO_4 at 68-70°C and humic acids were separated by filtering. Separated humic acids were re-dissolved in 0.1 M NaOH solution. Some humic and fulvic acid solutions of each fraction were evaporated and oxidized. Carbon content in the fractions of humic and a fulvic acid was determined by the dichromate oxidation procedure.

HA extracts were transferred to cuvettes. A solution of 0.02 M of NaOH was used as the blank. The absorbance of solutions at wavelengths of 465 and 665 nm was measured. The color indexes (E4:E6) were calculated as the ratio of E465:E665 nm. Spectral properties of solutions were measured using an UV-Vis spectrometer (SF-26).

All measurements were performed in triplicate. Statistical analysis of variance was performed using Statistica 10 software.

Initial soil test information collected in 1967 from 0-25 cm (Table 1).

Table 1. Fractional composition of humus in chernozem typical before the experiment

Corg, %	HA-1, %	HA-2, %	HA-3, %	FA-1, %	FA-2, %	FA-3, %	% to Corg			HA:FA
							HA	FA	Humin	
2.85	0.18	0.58	0.73	0.09	0.32	0.21	52.3	21.8	25.9	2.41

RESULTS AND DISCUSSIONS

Continuous irrigation (47 years) resulted in considerable changes of organic C in the topsoil (0-25 cm) in chernozem typical. Soil organic carbon content was by 10% less than in initial soil before irrigation.

An improved water supply leads, on the one hand, to an increased yeild therefore to a higher input of carbon into the soil in the form of roots and plant material. On the other hand, consequently higher soil moisture results in an increased microbial decomposition of soil organic matter (Trost et al., 2013).

Analysis by Condron with coathors revealed that amounts of SOC were significantly greater between the dry land (125.5 Mg ha^{-1}) and irrigation treatment (93.0 Mg ha^{-1}).

Nitrogen fertilisation promotes plant growth but may lead to a change in the Carbon:Nitrogen ratio and hence to a higher decomposability of SOC.

In present study fertilization promoted to less carbon loss and in organo-mineral fertilization system to C accumulation (by 9%) compered to plots without fertilization.

An increase in organic carbon stocks in response to organic fertilization by irrigation was not limited to the surface soil, but it continued down the soil profile to a depth of 160 cm (Bughio et al., 2016).

The fractional composition of humus of chernozem heavy loamy after long agricultural use (47 years) was determined that under the conditions of irrigation and application of mineral and organic fertilizers. A tendency to increase the content of mobile fulvic acids of fraction I from 3.5 to 5.1% of Corg (Table 2) was observed. The content HA-1 remained at 1.2% of Corg.

Table 2. Fractional composition of humus in chernozem typical under irrigation and fertilization

Treatment	Corg, %	HA-1, %	HA-2, %	HA-3, %	FA-1, %	FA-2, %	FA-3, %	% to Corg			HA:FA
								HA	FA	Humin	
Without fertilizer (control)	2.57	0.03	0.86	0.41	0.16	0.09	0.26	50.6	19.8	29.6	2.6
Mineral fertilization system	2.44	0.03	0.86	0.38	0.20	0.11	0.40	52.0	29.1	18.9	1.8
Organic fertilization system	2.41	0.03	1.23	0.41	0.17	0.07	0.26	69.3	20.7	10.0	3.3
Organo-mineral fertilization system	2.82	0.03	0.98	0.35	0.17	0.1	0.25	48.2	18.4	33.3	2.6
LSD$_{0.05}$[1]	0.41	0.01	0.11	0.10	0.03	0.03	0.08	-	-	-	-

[1]LSD 0.05 - Least Significant Difference at p=0.05

The results of long-term investigations show that during irrigation the humus state of chernozems of the Steppe zone is met with significant transformation in the direction of decreasing the total humus content and its fulvization (Shedrin et al., 2017).

The systematic application of mineral fertilizer separately and in combination with manure under the organo-mineral fertilization system increased the content of the most mobile groups of humic substances. The use of manure twice per rotation resulted in a reduction of the content of the active components in the soil organic matter by 11% of Corg compared to the control. This indicates that mobile organic matter is rapidly mineralized and is a source of nutrients for crops.

The content HA-2 bound with calcium under the effect of mineral and organo-mineral fertilization systems was not changed significantly. By the organic fertilizer system it was observed an accumulation HA bound with calcium of up to 51% of C org. With the increasing HA the content FA-2 decreases accordingly.

It was found that under the conditions of application of only organic fertilizers the content HA-3 increased from 16% of Corg in the control variant to 17% of Corg by the organic fertilization system.

The mineral fertilization system tends to increase the content FA bound with the mineral part of the soil.

With a slight variation in the relative content of mobile HA the influence of an agrogenic factor of different intensity on the indicator HA-1:FA-1 which reflects the direction of the first stage of the humification process was observed (Ovchinnikova, 2019). By the indicator of the ratio HA-1:FA-1 which according to the variants of the experiment was from 0.24 to 0.35 the low intensity of the process of humification at the stage of formation HA was observed.

The ratio of HA-1:FA-1 which characterized the polymerization of humus structures in the second stage of humification. Under organo-mineral fertilization system increased from 9.6 (on control) to 9.9 under the mineral fertilization system decreased to 7.8 which indicated a decrease in the intensity of formation of high-molecular compounds from low molecular ones.

The application of single organic fertilizers increased the expansion of the HA-2:FA-2 ratio to 17.6 due to the supply of fresh organic matter which is a source for the synthesis of young HA. Soil before the setting of the experiment in the arable layer of soil was characterized by a ratio of the amount of HA:FA at the level of 2.4 despite the anthropogenic influence (application of organo-mineral and organic fertilization systems in irrigated vegetable-fodder crop rotation) type of humus remained humate.

With long-term use of mineral fertilizers there was a narrowing of the HA:FA ratio to 1.8 in which the type of humus changed to fulvate-humate which was a sign of the negative orientation of the humification process.

Under conditions of long-term agricultural use of chernozem heavy loamy in irrigated vegetable-fodder crop rotation (9 crops) under different agrochemical loading signs of degradation transformation of humus with unequal degree of expression at different levels of its organization were revealed.

Although the humus content remained at a high level (at least 4%) in the arable soil layer. The losses were recorded ranging from 1.2 to 15.7% of Corg of the baseline to the experiment (Figure 1). Such losses are estimated to be relatively low.

Differences of humus state of chernozem heavy loamy in the layer of 0-20 cm under different agrochemical load were diagnosed by the complex of characteristics. Changes in the variants of the experiment in the form of a trend were observed at the maximum values of the fertility parameters. The degree of humification of organic matter was characterized as very high by the investigated variants among which was notable the organic fertilization system. With the high degree of humification of organic matter a very low content of "free" HA was observed. During the long agricultural use of chernozem heavy loamy the content of "free" HA in the arable layer of soil decreased by 5 times compared to 1967.

The content HA bound with calcium from low level (soil before setting of the experiment) was changed to high according to the investigated variants among which were notable organic and organic-mineral fertilization systems.

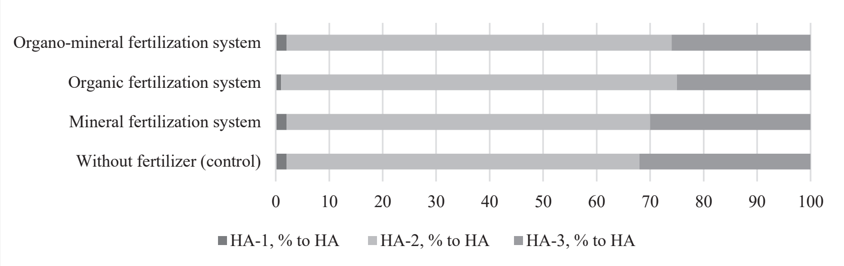

Figure 1. Content of different fractions of humic acids in chernozem typical under irrigation and fertilization

The content of strongly bound HA in the organic matter of chernozem heavy loamy remained high although changes in the direction of the conditions of humification were detected.

The primary information on the elements of humic substances was given by the values of E4:E6 ratio (ratio of the absorbances at 465 nm and at 665 nm). The E4:E6 ratio is considered to be inversely related to the degree of condensation and aromaticity of the humic substances and to their degree of humification (Senesi et al., 2003). The electronic absorption spectra of mobile fraction HA-1 at 465 nm and 650 nm are preferably lower than those of the other humus fraction Ca-bound fraction of humic acids (HA-2) and the fraction strongly bound with soil clay minerals (HA-3). Long-term agricultural use of chernozem heavy loamy without application of fertilizers resulted in a decrease in the E_4:E_6 ratio in labile humus compounds compared with soil before the experiment setting indicating that the aromatic nucleus with a condensed carbon atom network is predominant in the structure of HA-1 molecules.

The obtained data show that the organic matter of chernozem heavy loamy by different agrochemical loads has different degree of humification (Figure 2).

The decrease in molecular weight and carbon content the increase in the number of acidic functional groups and the oxidation of humic acids are observed under mineral and organo-mineral fertilization systems as evidenced by an increase of E_4:E_6 ratio by 38 and 67% compared to the control.

The E4:E6 ratio was higher in organo-mineral fertilization system compared with the control and initial soil test mainly due to the higher proportion of fresh SOM. Mineral fertilization increases the content of aliphatic compounds in the humic substances while in organic fertilization system the E4:E6 ratio is lower which means a predomination of molecules with a high degree of aromaticy and condensation.

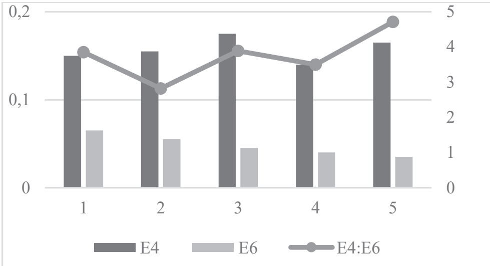

Figure 2. The ratio of the absorbances at 465 nm and at 665 nm of humic acids in chernozem typical under irrigation and fertilization:
1 - initial soil (before the experiment); 2 - without fertilizer (control); 3 - mineral fertilization system; 4 - organic fertilization system; 5 - organo-mineral fertilization system

CONCLUSIONS

During 47 years of irrigation (≈2000 m^3 ha^{-1} $year^{-1}$) without fertilization a content of organic C in 0-25 cm of chernozem typical heavy loamy in a vegetable-fodder crop rotation have been decreased by 9.8% compared to initial data. There were no statistically significant differences in soil organic C from mineral and organic fertilization systems and control (without fertilization). Only organo-mineral system (126 t ha^{-1} of manure + $N_{330}P_{330}K_{450}$ per 9-course rotation) contributed to stabilization organic C content in chernozem typical under irrigation.

The topsoil highest humic acids (HA) content was observed under organic fertilization. Application of mineral fertilizers only led to increasing of the content of fulvic acids (FA) by 45% compared to other fertilization systems.

Fractional composition of humus showed that 47 years of irrigation led to decrease of content of mobile humic acids (HA-1) in 6 times due to leaching while fraction of HA-2 increased by 50-112% compared to soil before irrigation that could be explain by intensive bounding with calcium from irrigation waters. The intensity of the process of formation of humic acids and the process of polymerization of humus structures was evaluated according to the ratios HA-1:FA-1 and HA-2:FA-2, respectively. It was found that in organic fertilization humus structure is more compensated that in other fertilization systems. On comparing E4:E6 ratios among different fertilization systems the lower ratio was in organic fertilization system which correspond with higher degree of aromaticity of organic substances in soil. Mineral fertilization increased the content of aliphatic compounds in the humic substances.

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