СІЛЬСЬКЕ ГОСПОДАРСТВО. ЕКОЛОГІЯ

Agriculture. Ecology

BULLETIN OF POLTAVA STATE AGRARIAN ACADEMY

ISSN: 2415-3354 (Print)
2415-3362 (Online)

https://journals.pdaa.edu.ua/visnyk

original article | UDC 631.4:311| **doi: 10.31210/visnyk2022.04.06**

SPATIO-TEMPORAL VARIABILITY OF THE CHORNOZEM SOILS HUMUS

A. Pol'ovyi[1]* ORCID 0000-0001-8395-0068
A. Mykytyuk[2] ORCID 0000-0002-0141-8586
L. Bozhko[1] ORCID 0000-0002-8712-2099
E. Barsukova[1] ORCID 0000-0002-9054-142X
V. Pylypyuk[1] ORCID 0000-0002-0365-4275

[1] Odessa State Environmental University, 15 Lvivska St., Odesa, 65016, Ukraine
[2] Institute for the Development of Territorial Communities, 21/12 Liuteranska St., Kyiv, Ukraine
**Corresponding author*
E-mail: apolevoy@te.net.ua

How to Cite

Polevoy, A., Mikityuk, A., Bozhko, L., Barsukova, E., & Pylypiuk, V. (2022). Spatio-temporal variability of the chornozem soils humus. Bulletin of Poltava State Agrarian Academy, (4), 49–58. doi: 10.31210/visnyk2022.04.06

An assessment of the spatio-temporal variability of the humus content in the soil is presented, and a tendency of its decreasing in the agro-climatic regions of the Luhansk region is established. The cartograms of the humus content spatial distribution and the tendencies of changing its content in the soils of the Luhansk region for 20 years have been obtained. A very high humus content in the soil (from 4 to 6.5 %) is observed in the northern, central, and, partially, in the southern and eastern parts of the first agroclimatic region, where mainly thick and ordinary medium-humus chornozems are located in the loess rocks. In the rest of the territory, the humus content varies mainly from 2 to 4 %. In most of the territory of the second agroclimatic region, except for the southern strip, which stretches from the northwest to the southeast, the humus content in the soil is 3–4%, interspersed with those areas with high (up to 4–6 %) humus content. The soil covers of the third agroclimatic region are characterized by a great variety of soil types. In most of the region, there are ordinary crushed chernozems on the eluvium of the dense bedrocks with a predominant humus content of 2.5–4 %, and here, in a narrow strip (along the Anthracite – Sverdlovske line), there are powerful medium-humus chernozems on the loess rocks with a high content humus up to 4–6 %, a small part of them is also in the south of the region. In the eastern part of the district (to the east of the Lutugino – Krasnodon line), there are ordinary medium-thick medium-humus chernozems and ordinary low-power low-humus chernozems, where the humus content is mainly 2–3.5 %. Over the years of surveys between 1987–1991 and 2007–2011 against the background of sufficiently high humus content in the soil compared to the other regions of the Steppe zone of Ukraine, the decrease in the humus content in the first agroclimatic region was 0.49 % in absolute terms (89.62 % of the results of the first survey), in the second agroclimatic region – 0.29 % (92.45 % in relative values), in the third agroclimatic region – 0.1 % (97.48 % in relative values). The variation in the humus content in the soil is the smallest in the first agroclimatic region (the coefficient of variation is 15.37 %), where the soil cover is more uniform, it is somewhat larger in the second and third regions (the coefficient of variation is 20.0 and 20.67 %), where the soil cover is more variegated. The number of fields (cases) with a high humus content decreased, and the number with an average content, on the contrary, increased.

Keywords: *chernozem, humus, agroclimatic region, variation, asymmetry, excess.*

ПРОСТОРОВО-ЧАСОВА МІНЛИВІСТЬ ГУМУСУ ЧОРНОЗЕМНИХ ҐРУНТІВ

А. М. Польовий[1]***, О. Ю. Микитюк***[2]***, Л. Ю. Божко***[1]***, О. А. Барсукова***[1]***, В. В. Пилипюк***[1]
[1] Одеський державний екологічний університет, м. Одеса, Україна
[2] Інститут розвитку територіальних громад, м. Київ, Україна

Представлено оцінку просторово-часової мінливості вмісту гумусу у ґрунті, встановлено тенденцію його до зменшення по агрокліматичних районах Луганської області. Отримано картограми просторового розподілу вмісту гумусу та тенденції до зміни його вмісту у ґрунтах Луганської області за 20 років. Дуже високий вміст гумусу у ґрунті (від 4 до 6,5 %) спостерігається у північній, центральній і, частково, у південній та східній частинах першого агрокліматичного району, де розташовані переважно чорноземи потужні та звичайні середньогумусні на лесових породах. На решті території вміст гумусу змінюється переважно від 2 до 4 %. На більшій частині території другого агрокліматичного району, за винятком південної смуги, що тягнеться з північного заходу на південний схід, вміст гумусу у ґрунті становить 3–4 % із вкрапленнями територій із підвищеним (до 4–6 %) вмістом гумусу. Для ґрунтового покриву третього агрокліматичного району характерна велика строкатість типів ґрунтів. На більшій частині району розташовуються чорноземи звичайні щебенюваті на елювії щільних корінних порід із переважним вмістом гумусу 2,5–4 %, тут же вузькою смугою (по лінії Антрацит – Свердловське) розміщуються чорноземи потужні середньогумусні на лесових породах з високим вмістом гумусу до 4–6 %, невелика їхня частина знаходиться також на півдні району. У східній частині району (на схід лінії Лутугино – Краснодон) розташовуються чорноземи звичайні середньогумусні і чорноземи звичайні малопотужні малогумусні, де вміст гумусу становить переважно 2–3,5 %. За роки обстежень між 1987–1991 та 2007–2011 рр. на тлі досить високого вмісту гумусу у ґрунті порівняно з іншими областями Степової зони України зниження вмісту гумусу становило у першому агрокліматичному районі 0,49 % в абсолютних величинах (89,62 % від результатів першого обстеження), у другому агрокліматичному районі 0,29 % (92,45 % у відносних величинах), у третьому агрокліматичному районі 0,1 % (97,48 % у відносних величинах). Варіація вмісту гумусу у ґрунті – найменша в першому агрокліматичному районі (коефіцієнт варіації 15,37 %), де більш однорідний ґрунтовий покрив, дещо більший у другому і третьому районах (коефіцієнт варіації 20,0 і 20,67 %), що відрізняється більш строкатим ґрунтовим покривом. Кількість полів (випадків) з високим вмістом гумусу зменшилося, а із середнім вмістом – навпаки, збільшилося.

Ключові слова: *чорнозем, гумус, агрокліматичний район, варіація, асиметрія, ексцес.*

Introduction

Developing and implementing the new farming technologies, especially precision farming, managing the agricultural crops production process seems problematic without assessing the spatio-temporal variability of the indicators characterizing the soil fertility [16].

Assessing the agroecosystems soil fertility and its spatial and temporal variations are important for predicting its possible future changes in the face of climate changes. Understanding the spatial distribution of soil organic carbon (SOC) and predicting its future state is essential for future estimating the CO_2 emissions and the management options for carbon storing. Taking into account the spatial heterogeneity of the specific fields fertility, intra-field variability is the basis of the precision farming modern technology.

There are several lines of researching the spatial and temporal variability of the soil fertility. Conditionally, the first of them should include the works devoted to assessing the soil carbon stocks and these stocks spatial distribution [22, 25, 26].

Soil organic carbon (SOC) is the largest carbon storage in the Earth. Understanding its dynamics and the environmental factors that influence its behavior as an absorber or a source of atmospheric CO_2 is critical to quantifying the carbon balance globally.

The second direction represents a wide range of works, where the spatio-temporal variability of agrochemical and physical soils characteristics is considered [21, 23, 27].

The third area of researching the soil fertility dynamics should include studying the influence of the climatic factors on the dynamics of the soil fertility indicators and predicting the soil carbon reserves in connection with climate changes [17, 18, 20].

The fourth line of the research is characterized by the works devoted to the problem of the carbon sequestration in the soils, the so-called "carbon sequestration", aimed at the possibly slowing climate change and mitigating the consequences of these changes [19, 24].

An analytical review of the opinions on the methodology for applying the geostatistical approach using to characterize the soil cover heterogeneity and the soil properties variability is presented [11]. In the works [4, 6], the modern ideas about the geostatistics the ory and methods and their application in soil science and ecology.

Using the geostatistics methods provides a quantitative description of the soil spatial variability, increases the accuracy of estimating the soil properties during interpolating the data and making the cartograms, and also serves as a basis for planning the rational soil sampling [7, 28].

One of the important fertility indicators is a humus content in the soil and the change in its content is influenced by both natural and anthropogenic factors.

The aim of this work was to study the humus spatio-temporal variability in the Luhansk region chernozem soils.

Materials and methods

The object of the research was the chernozem soils of the Luhansk region, located in the southeastern part of Ukraine (between 47°49′and 50°05′north latitude and 37°52′and 40°13′east longitude). The region is located on the territory of two Donbass soil provinces: the zadonetsk northern steppe and the Donetsk northern steppe.

The climate of the Luhansk region is moderately continental, with pronounced dry-dry wind phenomena.

Winters are little snowy, unstable, summers are warm with unstable moisture and dry periods. According to the heat and moisture conditions, three agroclimatic regions are distinguished on the territory of the region (fig. 1).

The research was based on the results obtained in [10]. Determining the humus content in the soil was carried out according to the approved methodology [5]. We examined the humus spatio-temporal variability in the chernozem soils in three agroclimatic regions of the Luhansk region.

Calculations and statistical processing were performed in the STATISTICA 8.0 program. The geostatistical analysis was performed using the Surfer 11 package.

Agroclimatic region	Indicators of the agroclimatic resources during the crops active vegetation period		
	Sum of positive temperatures above 10 °C	Quantity precipitation, mm	Hydrothermal coefficient (HTC)
I. Sufficient heat supply, sufficient and unstable moisture	2870 – 2900	310 – 315	1,0
II. Adequate heat supply, unstable moisture	2900 – 2970	280 – 305	0,9 – 1,0
III. A high level of heat supply, unstable humidification	3000 – 3103	300 – 305	0,8 – 1,0

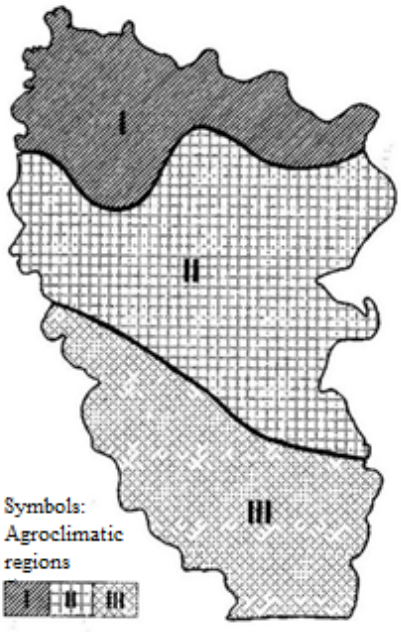

Fig. 1. Agroclimatic zoning of the Luhansk region [2].

Research results and their discussion

The main reason in declining the soil fertility is violating the laws of agriculture. Nowadays, extremely small amounts of organic fertilizers are being applied. Mineral fertilizers are also applied insufficiently. As a result, there is a decrease in the soil fertility, first of all, this refers to decreasing the content of humus in the soil - an integral indicator of the soil fertility [8].

The spatial pattern of the humus content distribution in the Luhansk region soils is shown in fig. 2. In the figure, a light shading represents the lowest values, and a darker shading is associated with the highest humus content in the soil. Let us consider the humus spatio-temporal variability in the chernozem soils in three agroclimatic regions of the Luhansk region.

The first agroclimatic region. The soil cover, of the first agroclimatic region is characterized mainly by ordinary medium-thick medium-humus chernozems on the loess and loess-like rocks and partly by ordinary low-thick low-humus chernozems on the loess-like rocks. A very high humus content in the soil (from 4 to 6.5 %) is observed in the northern, central and, partially, in the southern and eastern parts of the first agroclimatic region (figure 2a), where mainly thick and ordinary medium-humus chernozems are located on the loess rocks. In the rest of the territory, the humus content varies mainly from 2 to 4 %. During the study period there was a decrease in the humus content in the soil (table 1). It was especially significant in the late 1990 – early 2000 years, when using the organic fertilizers sharply decreased. In total, compared with 1986–1989, the humus content in the soil in 2007–2009 years decreased by 0.49 %in an absolute value, which amounted to 10.38 % of the initial values.

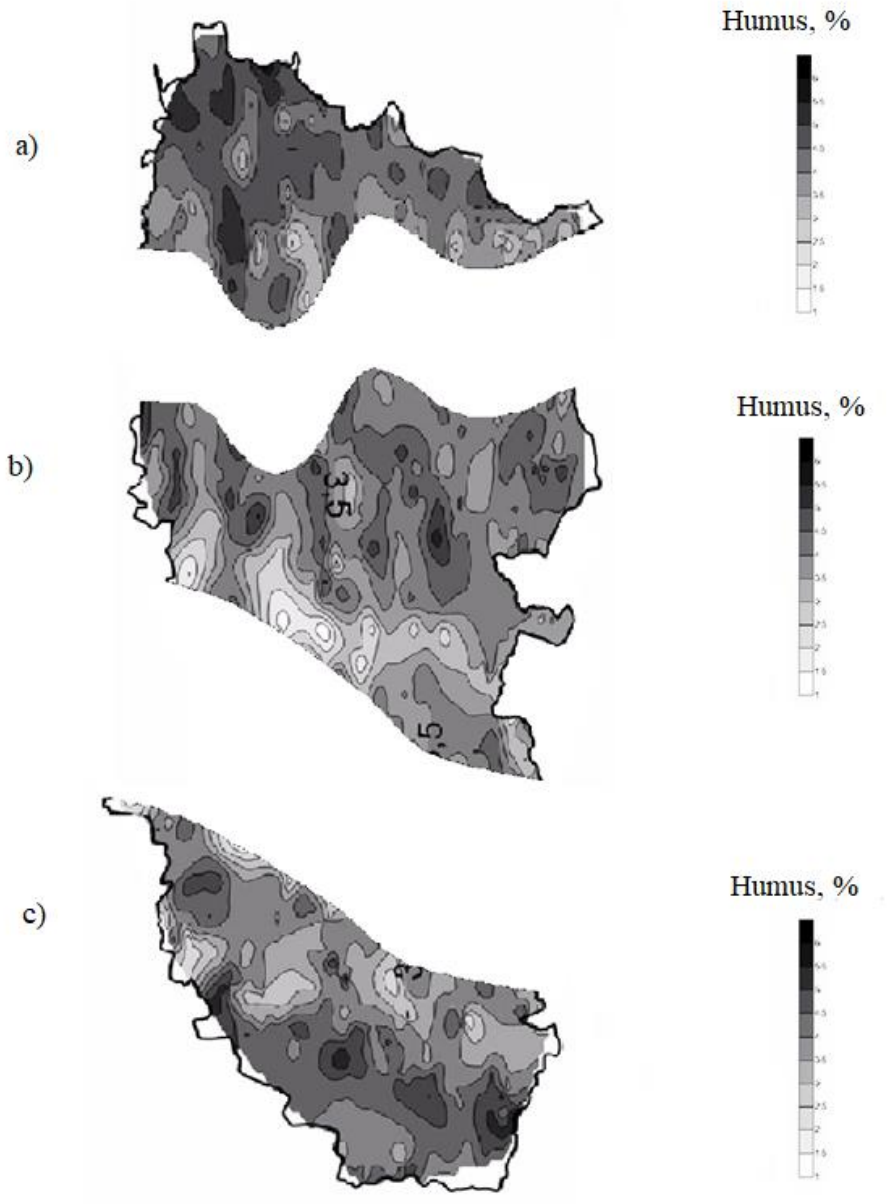

Fig. 2. The cartogram of the spatial distribution of the humus content in the Lugansk region soils, agroclimatic regions: a) I, b) II, c) III.

1. Statistical parameters of the humus content in the soil (the I agroclimatic region)

No	Indicators	Years of surveys					Ratio of the last survey results to the first survey results, %
		1986–1989	1991–1994	1997–1999	2002–2004	2007–2009	
1	Number of cases	306	306	306	306	306	
2	Average	4.72	4.70	4.64	4.46	4.23	89.62
3	Standard mean error	0.04	0.04	0.04	0.04	0.04	
4	Median	4.78	4.73	4.66	4.54	4.28	89.54
5	Mode	4.90	5.0	4.91	4.60	4.17	85.10
6	Standard deviation	0.75	0.70	0.67	0.64	0.65	86.67
7	The coefficient of variation,%	15.89	14.89	14.44	14.35	15.37	97.00
8	Asymmetry	-0.21	-0.01	-0.13	-0.60	-0.43	
9	Excess	-0.46	0.42	-0.22	0.28	0.11	
10	Range	3.82	4.78	3.76	3.67	3.64	95.29
11	Minimum	2.55	2.96	2.78	2.31	2.23	87.45
12	Maximum	6.37	7.73	6.54	5.96	5.67	89.01

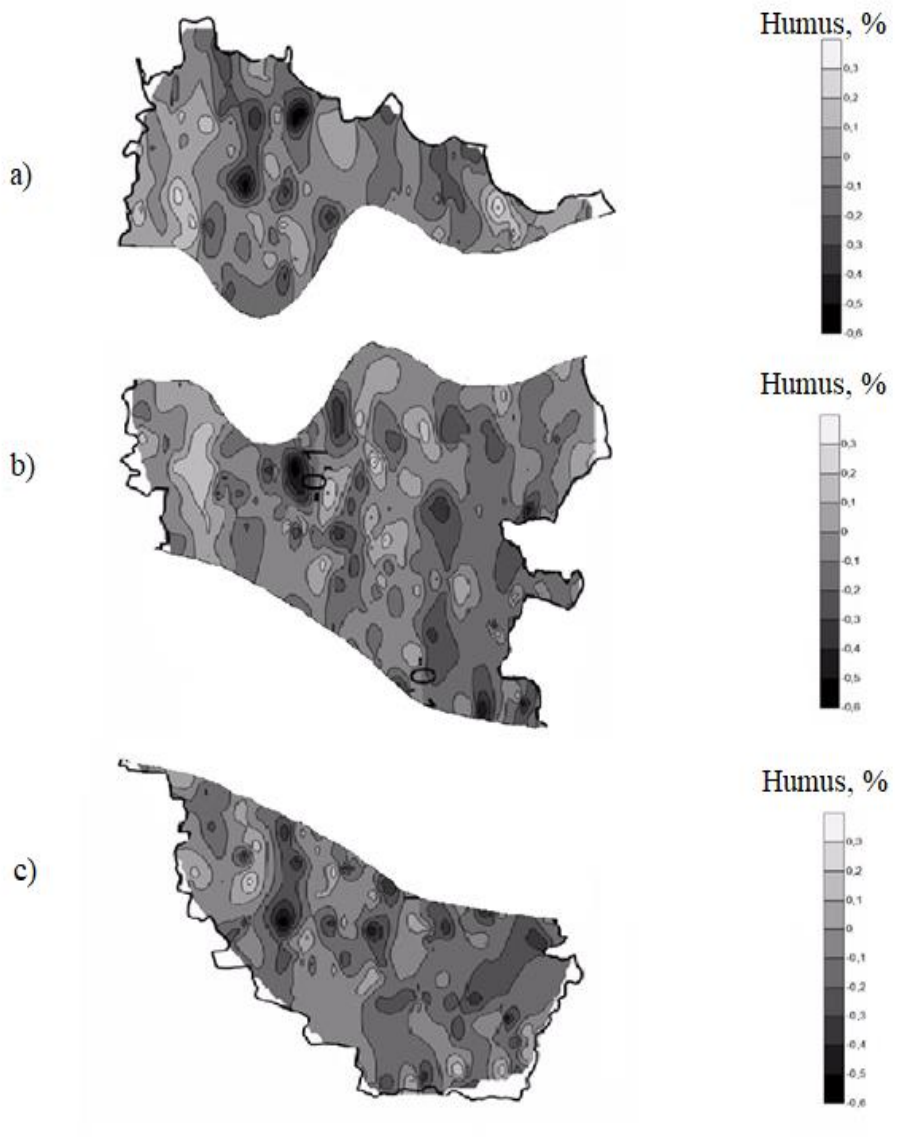

Fig. 3. The cartogram of the tendency of changing the humus content in the Lugansk region soils by five year periods, agroclimatic regions: a) I, b) II, c) III

Decreasing the indicators of the humus content in soil (average, mode, median, maximum, minimum) shows that there is a redistribution of fields (cases) with a high humus content. In particular, the number of fields (cases) with a high humus content decreased, while those with an average content, on the contrary, increased. Figure 3 shows the tendencies of these changes for five years. They differ in color saturation, which characterizes both positive and negative tendencies in changing the humus content. As can be seen from the data in figure 3a, on the territory of the first agroclimatic region, the following can be distinguished rather conditionally by the tendencies values: the relatively narrow western subregion, which will be characterized by the lighter spots inclusion, showing that some of the fields have a positive tendency to humus changing; the central subregion, which is characterized by a predominantly negative tendency to changing the humus content; the eastern subregion located to the east of the central subregion and characterized by a positive tendencies.

A positive tendency for humus changing is observed in the low and flat relief elements. This is due to less soil erosion and greater adherence to agricultural practices and crop rotation in these fields. For the first agroclimatic region, the changing tendency is very variegated and varies across the territory from +0.2 to –0.6 %.

*The second agroclimatic region***.** The soil covers of the second agroclimatic region is dominated by ordinary medium-thick medium-humus chernozems and ordinary low-humus chernozems, in the eastern part of the region there are southern low-humus chernozems on the loess-like rocks, and there are ordinary low-humus chernozems, soddy-podzolic soils and and soddy-sandy soils in the southern part of the region.

In most of the territory of the second agroclimatic region (figure 2b), with the exception of the southern strip, which stretches from the northwest to the southeast, the humus content in the soil is 3–4 %, interspersed with those areas with a high (up to 4–6 %) humus content. The analysis of the table 2 statistical data shows that the interval of the average humus content values in soil varies from 3.84 to 3.55 %. In total, from the first to the last round of the survey, the average humus content value in absolute terms decreased by 0.29 %. This change was not uniform.

2. Statistical parameters of the humus content in soil (II agroclimatic region)

No	Indicators	Years of surveys					Ratio of the last survey results to the first survey results, %
		1987–1991	1991–1996	1997–2001	2002–2006	2007–2011	
1	Number of cases	310	311	311	311	311	
2	Average	3.84	3.83	3.82	3.65	3.55	92.45
3	Standard mean error	0.04	0.04	0.04	0.04	0.04	
4	Median	3.84	3.90	3.86	3.71	3,61	94.01
5	Mode	4.50	3.60	3.59	3.37	3.42	76.0
6	Standard deviation	0.79	0.74	0.71	0.78	0.71	89.87
7	The coefficient of variation,%	20.57	19.32	18.59	21.37	20.0	97.23
8	Asymmetry	-0.56	-0.94	-0.74	-1.04	-0.52	
9	Excess	1.13	1.90	0.88	3.28	1.03	
10	Range	5.39	4.68	4.12	5.44	4.37	81.08
11	Minimum	0.78	0.80	1.30	0.0	1.10	141.02
12	Maximum	6.17	5.48	5.42	5.44	5.47	88.65

The most significant changes in the humus content occurred between the third and the fourth periods of the surveys. During the survey period from 1997–2001 to 2002–2006 the average humus content in relative terms decreased by 19.0 %.

The second agroclimatic region is also characterized by the variegated tendency of changing the humus content in the soil. Over the five-year period, it changes from +0.3 to –0.6 %. The western subregion with positive tendencies is distinguished (Figure 3b), the central subregion is characterized by the presence of both positive and negative tendencies, and to the east the negative change tendencies in the humus content in the soil prevail.

The third agroclimatic region. The soil covers of the third agroclimatic region is characterized by a great variety of soil types. In most of the region, there are ordinary crushed chernozems on the eluvium of the dense bedrocks with a predominant humus content of 2.5–4 % (figure 2c), and here, in a narrow strip (along

the Anthracite – Sverdlovskoe line), there are powerful medium-humus chernozems on the loess rocks with a high content humus up to 4–6 %, a small part of them is also in the south of the region. In the eastern part of the district (to the east of the Lutugino – Krasnodon line) there are ordinary medium-thick medium-humus chernozems and ordinary low-power low-humus chernozems, where the humus content is mainly 2–3.5 %.

With a positive (by 0.18 % absolute values) dynamics of the average value of the humus content in the soil in the period from the first (1984–1991) to the second (1992–1996) survey, in the future – the third, fourth and fifth periods – there was a decrease of the humus content in the soil. It amounted to 0.20 % of absolute values. The mode values varied from 4.70 to 3.30 % of absolute values; it decreased by almost 30.0 % (table 3).

The spatial distribution of the tendency for changing the humus content in the soil (figure 3c) shows a significant variation in the tendency values from positive to negative. For the third agroclimatic region, a predominantly high negative value of tendency changing (up to –0.3; –0.6 %) will be characteristic. It should be noted that for powerful medium-humus chernozems, the loss of humus will be more significant.

Being the main base of agriculture, chernozem soils change under the influence of natural factors and an ever-increasing anthropogenic loading. Many studies have been devoted to knowing the trend of changes in the chernozems properties, which allows us to compare our results with the materials related to the dynamics of changes in the chernozems humus state in the different climatic conditions.

3. Statistical parameters of the humus content in soil (III agroclimatic region)

№	Indicators	Years of surveys					Ratio of the last survey results to the first survey results, %
		1987–1991	1992–1996	1997–2001	2002–2006	2007–2011	
1	Number of cases	243	294	294	294	294	
2	Average	3.97	4.15	4.07	3.95	3.87	97.48
3	Standard mean error	0.06	0.05	0.05	0.05	0.05	
4	Median	4.0	4.18	4.15	4,02	3.89	97.25
5	Mode	4.70	4.69	4.24	4.15	3.30	70.21
6	Standard deviation	0.92	0.88	0.85	0.81	0.80	86.96
7	The coefficient of variation,%	23.17	21.20	20.88	20.51	20.67	89.21
8	Asymmetry	-0.08	-0.09	-0.20	-0.32	-0.21	
9	Excess	-0.42	-0.12	0.13	0.16	0.10	
10	Range	5.18	5.66	5.49	4.90	5.08	98.07
11	Minimum	1.05	1.08	0.81	0.88	1.12	106.67
12	Maximum	6.23	6.74	6.30	5.78	6.20	99.52

Changing the forms of management and land ownership, which have become the main content of the reforms in the agricultural sector in Ukraine in recent years, unfortunately, affected the soil fertility negatively. They have lost a significant part of humus, the world fertile chernozems have turned into the soils with an average level of fertility and continue to deteriorate [8]. Comparing the humus content of the soils at the time of Dokuchaev [3] with the present state indicates that the relative losses of humus over this, almost 120-year period, reached 22 % in the forest-steppe, 19.5 % in the steppe and 19 % in the Polesie zones of Ukraine. The dehumification processes have not stopped over the past 20 years, but continue to proceed with a fairly high intensity. According to the results of the agrochemical certification of the agricultural lands during the last 4 rounds (1986–2005), the humus content in Ukraine decreased by 0.5 % in absolute terms. This is comparable to the obtained results of the land certification in the Luhansk region in the period 1986–2011. Thus, the calculations show that for the first agroclimatic region, the humus content decreased by 0.49 %, for the second region – by 0.29 %, and for the third – by 0.10 % in absolute terms. The average humus content in the soil in the Luhansk region is 3.85 %, which is significantly higher compared to the Kherson region chernozems located in the same soil-climatic zone [9], which regional average equals to 2.4 %.

The maximum humus content in the soil in these areas is 9.0 and 3.8 %, respectively. The spatial heterogeneity of the humus content in the soil cover is large in the soils of the Kherson region (the coefficient of humus variation is 28.75 %) compared to the Luhansk region (the coefficient of variation is

17.30 %). It should be noted that the smallest variations are observed in the soils of the first agroclimatic region (14,35–15.89 % over the years of surveys), the variability of the humus content in the soil in the second agroclimatic region is slightly higher (18.59–21.37 %) and it is higher in the third agroclimatic region (21.20–23.17 %) It is also necessary to point out one peculiarity: from the first to the last survey date, the variability is decreasing.

The state of the soils in Ukraine at the present stage is reflected in the works [12, 14], which indicates that the main reason for decreasing the soil fertility is a violation of the laws of agriculture. Sharp decreasing the volumes of the applied organic fertilizers and insufficient applying the mineral fertilizers are the reasons for decreasing the soil fertility over the past two decades. First of all, this concerns a decrease in the content of humus - an integral indicator of fertility. In the fundamental work [15], the current state and the direction of the chernozems evolution in the Central regions of Russia is considered. It is noted that the plowing of the virgin chernozems leads to a significant decrease in the humus content in the arable chernozems.

In the conditions of the Central chernozem region of Russia (Belgorod region), it was established [13] that the humus content in the arable layer of the leached and typical chernozems decreased by 0.4–0.6 %, and in the ordinary chernozems decreased to 1.0 %. And in the conditions of the Kursk region for a 47-year observation period [1], a significant decrease in the humus content of the chernozems, which are typical at the experimental plots, was revealed: 6.22; 5.60; 5.07 % on the Kursk region arable chernozems. At the same time, the total loss of humus reached 18.5 % of its initial content, and the annual losses amounted to 0.02–0.03 %. These humus losses are comparable to the humus content losses in the first agroclimatic region of the Luhansk region (0.49 %) and exceed them.

Conclusions

As a result of the assessment of the humus content spatio-temporal variability in the soil, a tendency for its decrease in the agroclimatic regions of the Luhansk region was established. A cartogram of the spatial distribution of the humus content in the soils of the Luhansk region was obtained. Over the years of surveys between 1987–1991 and 2007–2011 against the background of a fairly high humus content in the soil compared to the other regions of the steppe zone of Ukraine, the decrease in the humus content in the first agroclimatic region was 0.49 % in absolute terms, in the second agroclimatic region it was 0.29 %, in the third agroclimatic region it was 0.1 %. The variation in the humus content in the soil is the smallest in the first agroclimatic region (the coefficient of variation is 15.37 %), where the soil cover is more uniform, it is somewhat larger in the second and third regions (the coefficient of variation is 20.0–20.67 %), which are characterized by a more variegated soil cover. Cartogram of the tendency for changing the humus content in the soils of the Luhansk region for five years has been built. On the territory of the region according to the values of the tendencies in changing the humus content, the western and eastern subregions can be distinguished quite conditionally. A positive tendency for changing the humus is observed in the low and flat relief elements. This is due to less soil erosion, greater adherence to agricultural practices and rotating the crops in these fields.

Prospects for further research – the obtained results of the research provide a basis for determining the areas in which a significant change in agricultural techniques for growing agricultural crops is needed in order to overcome the negative trend of reducing the content of humus in the soil.

References

1. Avdeeva, T. N., & Markina, L. G. (2017). Evolution of the arable chernozems in the Kursk region. *In collection: Chernozems of Central Russia: Genesis, Evolution and Problems of Rational Using.* Voronezh: Publishing and Printing Center “Scientific Book”: 72–76.

2. Agroclimaticguideto the Luhansk region (1986–2005). (2011). Lugansk: LLC “Virtual reality”

3. Dokuchaev, V. V. (1883). *Russian black earth.* Saint Petersburg.

4. Giniyatullin, K. G., Ryazanov, S. S., Grigoryan, B. R., Shakirzyanov, I. V., & Shakirzyanov, R. V. (2016). Using the geostatistical methods to characterize the agrochemical properties variability (on the example of studying the arable land in Northern Kazakhstan). *Kazan University Scientific Notes. Series “Natural Sciences*”, 2, 259–276.

5. Soil quality. Methods for determining the organic matter. (2005). *GOST 4289: 2004.* Kyev.

6. Klebanovich, N. V., & Kindeev, A. L. (2018). The geostatistical assessment of the soil properties variability. *Bulletin of the Udmurt University. Series “Biology. Earth Sciences“,* 28 (1), 91–102.

7. Kuzyakova, I. F., Romanenkov, V. A., & Kuzyakov, Y. I. (2001). The geostatistics method in the soil-agrochemical research. *Pochvovedenie*, 9, 1132–1139.

8. Balyuk, S. A., Medvedev, V. V., Tarariko, O. G., Grekov, V. O., & Balaev, A. D. (2010). *National Report on the State of the Soil Fertility in Ukraine*. Kyev.

9. Pichura, V. I., & Beznitska, N. V. (2017). The spatio-temporal transformation of the soil agrochemical statein the dry steppe zone. *Science Reportsof the National University of Bioresources and Natural Using of Ukraine*, 3, 5–20.

10. Project "Strengthening the economic and legal instruments for saving the steppe biodiversity, adapting to climate change and its mitigation (Steppe biodiversity)". Topic "Conducting a study on the dynamics of the humus content in the arable agricultural lands of the Luhansk region for preparing a carbon project on changing the land use in the degraded agricultural lands of the Luhansk region". (2013). *International charity organization "Institute for the Development of Territorial Communities"*. Kyev.

11. Sakhabiev, I. A., & Ryazanov, S. S. (2015). Studying the soil properties spatial variability using the geostatistical approach. *Russian Journal of Applied Ecology. Area of Sciences: Mathematics*, 32–37.

12. Semenchuk, I. M., & Shkriobka, M. I. (2018). The problems of saving and improving the soils efficiency in Ukraine. *AGROSVIT*, 5, 49–52.

13. Solovichenko, V. D., & Azarov, V. B. (2002). Changing the typical chernozem properties under the influence of anthropogenic loading. *Agrochemical Bulletin*, 5, 23–28.

14. Trus, O. M., Gospodarchuk, G. M., & Prokopchuk, I. V. (2016). *Humus of thepodzolic chernozemand its reproduction*. Uman.

15. Shcheglov, D. I. (2017). Chernozems of the central regions of Russia: a current state and the direction of evolution. *In collection: Central Russia Chernozems: Genesis, Evolution and Problems of Rational Using.* Voronezh: Publishing and Printing Center "Scientific Book".

16. Yakushev, V. P., & Yakushev, V. V. (2018). Prospects for "Smart Agriculture" in Russia. *Bulletin of the Russian Academy of Sciences*, 88 (9), 773–794. doi: 10.31857 / S086958730001690-7

17. Adamat, R. A., Rawajfih, Z., Easter, M., Paustian, K., Coleman, K., Milne, E., Falloon, P., Powlson, D. S., & Batjes, N. H. (2007). Predicted soil organic carbon stocks and changes in Jordan between 2000 and 2030 made using the GEFSOC (Modelling System). *Agriculture, Ecosystems & Environment*, 122 (1), 35–45. doi: 10.1016/j.agee.2007.01.006

18. Adhikari, K., Owens, P., Libohova, Z., Miller, D., Wills, S., & Nemecek, J. (2019). Assessing soil organic carbon stock of Wisconsin, USA and its fate under future land use and climate change. *Science Total Environment*, 667, 833–845. doi: 10.1016/j.scitotenv.2019.02.420

19. Baveye, P. C., Schnee, L. S., Boivin, P., Laba, M., & Radulovich, R. (2020). Soil Organic Matter Research and Climate Change: MerelyRe-storing Carbon Versus Restoring Soil Functions. *Frontiers Environment Science*, 10. doi: 10.3389/fenvs.2020.579904

20. Conant, R. T., Ryan, M. G., Agren, G. I., Birge, H. E., Davidson, E. A., Eliasson, P. E., Evans, S. E., Frey, S. D., Giardina, C. P., & Hopkins, F. M. (2011).Temperature and soil organic matter decomposition rates – synthesis of current knowledge and a way forward. *Global Change Biology. Review*. doi: 10.1111/j.1365-2486.2011.02496.x

21. Deng, X., Ma, W., Ren, Z., Zhang, M., Grieneisen, M., Chen, X., Fei, X., Qin, F., Zhan, Y., & Lv, X. (2019). Spatial and temporal trends of soil total nitrogen and C/N ratio for croplands of East China. *Geoderma*, 361, 114035. doi: 10.1016/j.geoderma.2019.114035

22. Funes, I., Savé, R., Rovira, P., Molowny-Horas, R., Alcañiz Ignasi, E., Carmen Herrero, H., Boixadera, J., & Vayreda, J. (2019). Agricultural soil organic carbon stocks in the north-eastern Iberian Peninsula: Drivers and spatial variability. *Science Total Environment*, 668, 283–294. doi: 10.1016/j.scitotenv.2019.02.317

23. Moinet, G. Y. K., Moinet, M., Hunt, J. E., Rumpel, C., Chabbi, A., & Millard, P. (2019).Temperature sensitivity of decomposition decreases with increasing soil organic matter stability. *Science of The Total Environment*, 704, 135460. doi: 10.1016/j.scitotenv.2019.135460

24. Pärn, J., Verhoeven, J. T. A., Butterbach-Bahl, K., Dise, N. B., Ullah, S., & Aasa, A. (2018). Nitrogen-rich organic soils under warm well-drained conditions are global nitrous oxide emission hotspots. *Nature Communications*, 9, 1135. doi: 10.1038/s41467-018-03540-1

25. Rial, M., Martínez, A., & Rodríguez-Lado, L. (2017). Understanding the spatial distribution of factors controlling topsoil organic carbon content in European *Soils Science Total Environment*, 609, 1411–1422. doi: 10.1016/j.scitotenv.2017.08.012

26. Stumpf, F., Keller, A., Schmidt, K., Mayr, A., Gubler, A., & Schaepman, M. (2018). Spatio-temporal land use dynamics and soil organic carbon in Swiss agroecosystems. *Agriculture, Ecosystems & Environment*, 258, 129–142. doi: 10.1016/j.agee.2018.02.012

27. Wang, C., Li, H., Cai, T., & Sun, X. (2021). Variation of soil carbon and nitrogen storage in a natural restoration chronosequence of reclaimed temperate marshes. *Global Ecology and Conservation*, 27, e01589. doi: 10.1016/j.gecco.2021.e01589

28. Webster, R., &Burgess, T. M. (1980). Optimal interpolation andisarithmic mapping of soil properties'. Ill: Changing drift and universal kriging. *Journal Soil Science*, 31 (3), 505–524. doi: 10.1111/j.1365-2389.1980.tb02084.x

Стаття надійшла до редакції: 17.10.2022 р.

Бібліографічний опис для цитування:

Польовий А. М., Микитюк О. Ю., Божко Л. Ю., Барсукова О. А., Пилипюк В. В. Просторово-часова мінливість гумусу чорноземних ґрунтів. *Вісник ПДАА*. 2022. № 4. С. 49–58.