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ECONOMICS OF SOIL CARBON SEQUESTRATION AND DEVELOPMENT OF LOW-CARBON LAND USE

Anatolii KUCHER[1,2]

[1]V. N. Karazin Kharkiv National University, 6 Svobody Sq., Kharkiv, 61022, Ukraine, Phone: +38 (057) 70-75-636; E-mail: kucher@karazin.ua
[2]NSC «Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky», 4 Chaikovska st., Kharkiv, 61024, Ukraine

Corresponding author: kucher@karazin.ua

Abstract

This paper studied the economic assessment of soil carbon sequestration and financial support for development of low-carbon land use in Ukrainian agriculture in the context of climate change. Results of evaluation show that Ukraine plays a strategic role in the soil carbon sequestration in Europe. Ukrainian soils contribution is equal to one third of SOC sequestered in agricultural soils of the European Union. Economic assessment of stocks of SOC in Ukrainian soils indicates that its value is in the range from 14.4 thousand USD/ha (Gray forest soils) to 103.7 thousand USD/ha (Chernozem-meadow soils). The results of analysis revealed that for agricultural production and the formation of the economic fertility of soils in Ukraine, the effects of climate change on warming will be both positive and negative. Taking into account the international experience of adaptation of land use processes to climate change, the basis of strategy of adaptation of agriculture in the enterprises of Ukraine to warming is proposed to put the concept of low carbon land use. As a result of the study it was determined the macroeconomic assessment of the need of financial resource for development potential of low carbon land use in Ukraine for the period until 2030.

Key words: *soil organic carbon, climate change, low-carbon land use, Ukraine*

INTRODUCTION

In the world, the problem of the economics of soil carbon sequestration is an urgent one. This is evidenced by the fact that this issue is in the center of attention of the international scientific community. We agree that «Given the background of global warming, carbon emission reduction has become a topic of global importance. Land use change not only influences carbon storage in terrestrial ecosystems directly, but it also indirectly affects anthropogenic carbon emissions...» [6].

The study of the relationship between the dynamics of soil organic carbon (Hereinafter – SOC) and agricultural productivity, as well as the evolution of carbon prices has been investigated in many studies worldwide and at EU level. So, for example, in a recent book it is indicated that «almost all Chernozem will remain as arable land, but CO_2 emissions can cut, or reversed, by reducing energy consumption processes: biological nitrogen fixation instead of mineral fertilizers, crop rotation to reduce pesticide, use and zero tillage. Long-term field experiments on Chernozem in Canada comparing perennial cropping with wheat yielded a mean increase of SOC stocks in the 0–30 cm layer of 0.6 t C/ha per year; eschewing alternate years of black fallow in favour of continuous cropping increased stocks by 0.23 t C/ha per year; the increase from zero tillage was 0.14 t C/ha per year for the top 15 cm of the soil» [5].

In the paper by Ligthart and van Harmelen, the following shadow prices were found for SOC depletion: (i) abatement-based shadow prices (Pa) – 100 EUR/t of SOC and (ii) damage-based shadow price (Pd) – 28.6 EUR/t of SOC [13]. According to Berazneva et al., the steady-state shadow price for soil carbon ranges from 95 USD/t to 168 USD/t, indicating a significant opportunity cost for soil mismanagement [4]. The value of soil carbon substantially depends on the discount rate. The income provided by carbon payments could partially counteract the effects of high discount rates [3].

The High-Level Commission on Carbon Prices, led by J. Stiglitz and N. Stern, concluded based on an extensive review that a range of 40–80 USD/t of CO_2e in 2020, rising to 50–100 USD/t of CO_2e by 2030, is consistent with achieving the core objective of the Paris Agreement of keeping temperature rise below 2 degrees, provided a supportive policy environment is in place [18]. The low and high values on carbon prices are extrapolated from 2030 to 2050 using the same growth rate of 2.25 % per year that is implicit between the 2020 and 2030, leading to values of 78 USD and 156 USD by 2050 [7].

Ukrainian scientists focus their attention mainly on the issues of perspectives of development of the land-rental relations development in agriculture of Ukraine [20] and methodological foundations of the organization and protection of lands in the context of the balanced nature use [19].

In Ukraine, environmental and economic issues of carbon dioxide emission and sequestration of organic carbon in the soil are investigated by scientists of the NSC «Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovsky» (Hereinafter – NSC «ISSAR»), in particular, S. A. Baliuk et al. [2; 1], A. V. Kucher [11; 10], M. M. Miroshnychenko, O. P. Siabruk [15] et al. For example, according to M. M. Miroshnychenko, O. P. Siabruk, «the hydrothermal conditions of the warm period of the year are decisive in the formation of the CO_2 emission from chernozems. Due to the improvement of agricultural practices, emissions might be reduced but not more that by 15 % of natural factor contribution». In our previous studies, it is proposed author's scientific-and-methodical approach to quantitative economic (monetary) evaluation of the environmental effect from preventing carbon dioxide emissions from the soil of agricultural lands under different levels of anthropogenic pressure [12] and substantiates the ecological and economic aspects of development of low-carbon agricultural land use [11]. This article is a logical continuation of the author's systematic scientific research.

MATERIALS AND METHODS

The methodological basis of the study is a system-structural and interdisciplinary approaches. The database of the average content of humus in the soils of arable land in the regions of Ukraine, was used as the empirical basis. Humus contains on average 58 % of the organic carbon, therefore for their mutual conversion, we used a coefficient of 1,724 (Humus = 1.724 * SOC). The study used the following methods: economic-statistical and monographic (depth analysis of the issue under study); expert and calculation-constructive (economic assessment of stocks of humus and SOC in Ukrainian soils, determination of the main parameters of the need of financial resource for development potential of low carbon land use); grapho-analytic (for the visual representation of the obtained results); abstract-and-logical (theoretical generalization and formulation of conclusions); analysis and synthesis (justification and analysis of project indicators of potential of low carbon land use).

RESULTS AND DISCUSSIONS

Expert assessment of contribution of Ukrainian soils into global carbon sequestration

As known, 5 December 2017 (Marking World Soil Day), FAO has launched the most comprehensive global map to date showing the amount of carbon stocks in the soil. The map shows that globally, the first 30 cm of soil contains around 680 bln t of carbon – almost double the amount present in our atmosphere. This is a significant amount compared with the carbon stored in the whole vegetation (560 bln t). More than 60 % of the 680 bln t of carbon is found in ten countries (Russia, Canada, USA, China, Brazil, Indonesia, Australia, Argentine, Kazakhstan and Democratic Republic of Congo) [23].

In this context, it should be noted that for the first time a National digital map of soil organic carbon stocks in the 0–30 cm layer

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with a resolution of 1 x 1 km was created at the NSC «ISSAR» (with FAO support) (Fig. 1). The National map was developed in accordance with GSP specifications and integrated into the FAO Global Soil Organic Carbon Map. The main sources of information on the content of SOC and humus on agricultural lands used for the preparation of the National map of Ukraine on SOC were as follows: database «Soil Properties of Ukraine», developed by the NSC «ISSAR»; materials of large-scale soil survey 1957–1961 years; materials of agrochemical certification of agricultural lands; database of ecological and agro-reclamation state of ameliorated soils, developed by the NSC «ISSAR»; data of research institutions of various ministries, departments and universities; data of stationary field experiments listed in State Register of Ukraine.

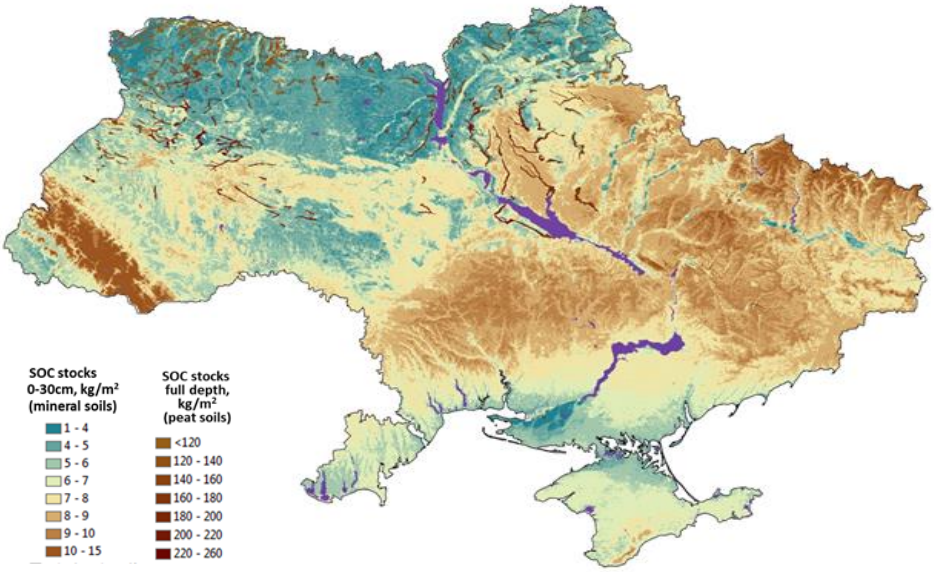

Fig. 1. National map of soil organic carbon in layer 0–30 cm of Ukrainian soils
Source*:* built by scientists of the NSC «ISSAR» [17], [22].

This map is the basis: firstly, to control the content and stocks of organic carbon in soils; secondly, for the sustainable management of soil organic carbon.

Soils of Ukraine are characterized, in general, by average (2–3 %) and high (3–4 %) humus content in arable layer. Soil area with this content is 16.4 mln ha, or about half of the arable land. Soils with low (1–2 %) and very low (<1 %) content of humus are distributed in the Polissya area, where soils of sandy and sandy granulometric soils are concentrated. The depth of the profiles of Ukrainian soils varies in very wide limits and for chernozem soils, depending on geographical, climatic and other factors, ranges from 50 to 150 cm [2].

Stocks of humus (SOC) in the main Ukrainian soils also vary widely: humus 100–720 t/ha, SOC – 58–418 t/ha (Table 1). Economic assessment of stocks of SOC in Ukrainian soils indicates that its value is in the range of 14.4–103.7 thousand USD/ha.

Table 1. Economic assessment of stocks of humus and SOC in Ukrainian soils

Type of soil	Humus content in arable layer, %	Stocks of humus in profile, t/ha	Stocks of SOC in profile, t/ha	Economic assessment of stocks of SOC in profile, thsd. USD/ha	
				min	max
Chernozems ordinary	3.5–5.7	200–550	116–319	28.8	79.2
Chernozems typical	2.5–6.0	300–600	174–348	43.2	86.4
Chernozems southern	3.0–3.5	200–250	116–145	28.8	36.0
Chernozems podzolized	2.6–4.5	220–350	128–203	31.7	50.4
Chernozem-meadow soils	3.0–7.2	360–720	209–418	51.8	103.7
Gray forest soils	1.3–3.5	100–230	58–133	14.4	33.1
Sod-podzolic soils	2.0–3.7	150–280	87–162	21.6	40.3

Source: [2], author's calculations.

According to preliminary expert estimates of NSC «ISSAR» researchers, the total SOC stocks in Ukrainian soils are about 7 Gt. This compares with 1/3 of SOC in agricultural soils of the EU, which are estimated about 18 Gt in 0–30 cm layer [16]. There are estimates according to which organic carbon stocks in arable soils in Ukraine reach 5.12 Gt, including 2.47 Gt in the layer 0–30 cm. This is equivalent to 157 t per hectare, including 75 t/ha in the layer 0–30 cm [14].

Table 2 presents the results of stocks of SOC in the arable layer of soil (0–30 cm) of agricultural land by the regions of Ukraine and by two variants of land area. According to these estimates, the total stocks of SOC in arable layer of the surveyed area of agricultural land are 1305.7 mln t. Based on the assumption that in other (unsurvey) agricultural lands, the content of organic carbon in the soil is at the same level, we can conclude that the total stocks of SOC in arable layer of the total area of agricultural land are 2738.7 mln t (about 2.7 Gt).

Table 2. Assessment of stocks of SOC in the arable layer of soil (0–30 cm) of agricultural land in the regions of Ukraine according to the results of the 10th round of an agrochemical survey

Names of regions*	SOC content in arable layer, %	Stocks of SOC in arable layer, t/ha	Area of agricultural land, thsd. ha	including the area of the surveyed agricultural land, thsd. ha	Stocks of SOC in arable layer of the total area of agricultural land, mln t	including stocks of SOC in arable layer of the surveyed area of agricultural land, mln t
Vinnytsia	1.566	56.4	2,014.2	1,040.7	113.6	58.7
Volyn	0.905	32.6	1,047.6	390.1	34.1	12.7
Dnipropetrovsk	2.187	78.7	2,512.09	1,432.5	197.8	112.8
Donetsk	2.204	79.4	2,044.2	776.0	162.2	61.6
Zhytomyr	1.166	42.0	1,510.2	845.8	63.4	35.5
Zakarpattia	1.485	53.5	451.48	238.6	24.1	12.8
Zaporizhzhia	1.972	71.0	2,241.7	1,326.1	159.2	94.2
Ivano-Frankivsk	1.903	68.5	630.5	290.6	43.2	19.9
Kyiv	1.729	62.2	1,658.8	765.0	103.2	47.6
Kirovohrad	2.384	85.8	2,031.6	1,103.2	174.4	94.7
Luhansk	2.268	81.6	1,908.62	772.4	155.8	63.1
Lviv	1.549	55.8	1,261.2	497.6	70.3	27.7
Mykolaiv	1.879	67.7	2,005.97	1,473.2	135.7	99.7
Odesa	2.187	78.7	2,591.66	1,155.0	204.0	90.9
Poltava	1.845	66.4	2,165.5	774.3	143.8	51.4
Rivne	1.317	47.4	925.4	496.6	43.9	23.5
Sumy	2.030	73.1	1,697.5	785.0	124.1	57.4
Ternopil	1.816	65.4	1,046.12	497.7	68.4	32.5
Kharkiv	2.378	85.6	2,411.3	1,178.8	206.4	100.9
Kherson	1.421	51.2	1,969.4	1,300.1	100.8	66.5
Khmelnytskyi	1.717	61.8	1,568.14	953.5	96.9	58.9
Cherkasy	1.775	63.9	1,451.00	805.3	92.7	51.5
Chernivtsi	1.508	54.3	468.7	236.0	25.4	12.8
Chernihiv	1.398	50.3	2,067.6	653.0	104.1	32.9
Ukraine	**1.833**	**66.0**	**41,504.88**	**19,787.1**	**2,738.7**	**1,305.7**

Note. * Excluding the temporarily occupied territories of the Autonomous Republic of Crimea.
Source: formed and calculated by the author on the basis of data of State Institution «Soils Protection Institute of Ukraine» [24].

Potential of SOC stock increasing by using the best agricultural technologies and balanced application of fertilizers is quite high and amounts according to expert estimates of 0.1–0.3 % for the layer 0–30 cm in medium term (5–10 years).

Assessment of development potential of low carbon land use in Ukrainian agriculture in the context of climate change

According to the data of the Ukrainian Hydrometeorological Center, «in Ukraine the increase in average annual temperature is ahead of the indicator observed in the world. If starting in 1961, the global temperature increased by 0.8 degrees, in Ukraine this indicator is about 1.1 degrees. In the next ten years, it is possible to increase it by a further 0.2–0.5 degrees. If earlier Ukraine was a moderately cold country with an average annual temperature of 7.8 degrees, now this

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indicator has grown to plus 9 degrees» [8]. Climate change, says M. Malkov, is largely anthropogenic – only up to 30 % are associated with natural changes, 70 % are dependent on human activity. According to him, agriculture also contributes to climate change due to the fact that emissions of greenhouse gases occur. In the total volume of emissions for agriculture, Ukraine accounts for 14 %. If soils are properly looked after, they absorb greenhouse gases, with incorrect management, on the contrary, they emit greenhouse gases [8].

Expected climate change will likely drive some part of Ukrainian agriculture to transformation in particular through substantial climate aridity strengthening over the vast majority of territories of Ukraine for 21st century, with a high probability of shift of bio-climatic zones at least for one gradation towards aridity (Fig. 2) [21].

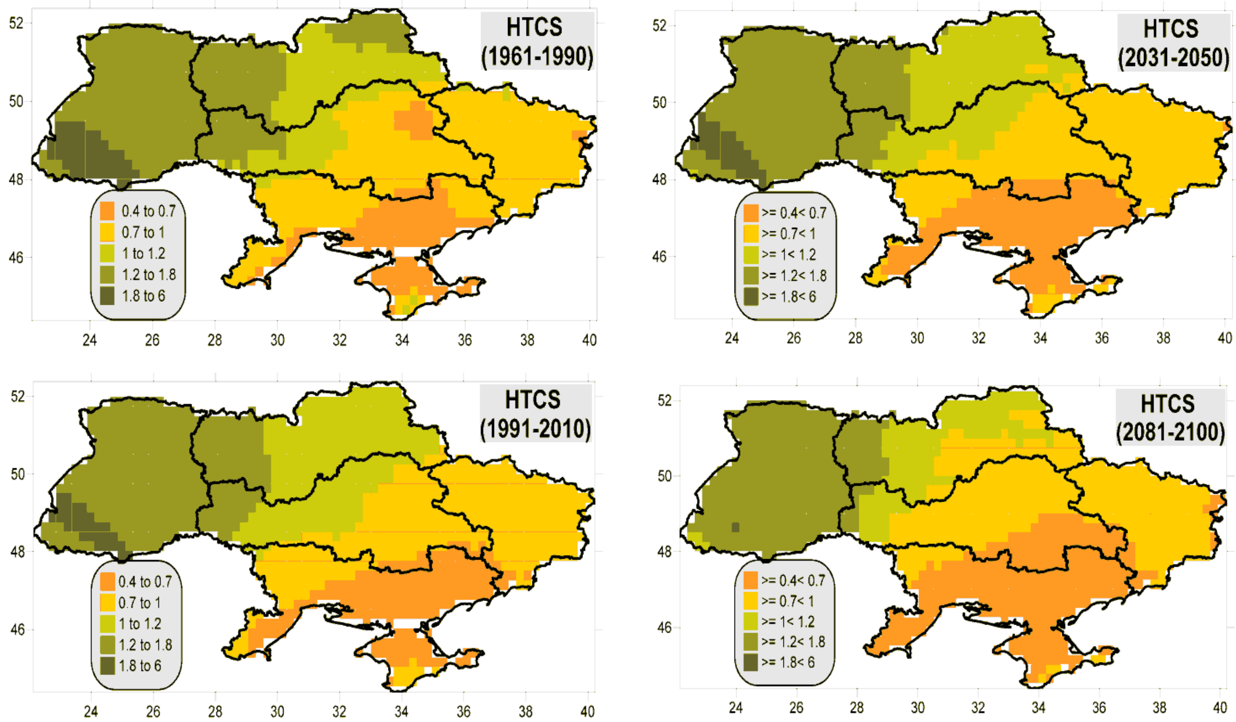

Fig. 2. Dynamics of Hydro-thermal coefficient by Selianinov (HTCS)
Source: [21].

For agricultural production and the formation of the economic fertility of soils in Ukraine, the effects of climate change on warming will be both positive and negative. A significant threat to agricultural production is climate variability, its increasing is expected, will accompany climate change. Taking into account the international experience of adaptation of land use processes to climate change, the basis of strategy of adaptation of agriculture in the enterprises of Ukraine to warming is proposed to put a number of strategic measures that would prevent the development of soil-degradation processes on the one hand, and on the other hand, – contributed to the reduction of greenhouse gas emissions during soil cultivation and increase carbon sequestration, and hence the humus in the soil, thus providing a rational land use (Table 2).

These measures should be considered not as self-sufficient, but as those that should be included in the general system of soil protection and low carbon development of the agrarian sector of the economy.

Strategic priorities for the development of low-carbon agricultural land use are proposed [9]:

-suspension of humus content reduction and achievement of its deficit-free balance through the use of traditional and non-traditional organic fertilizers (agrochemical

direction);
-reduction of anthropogenic load on soil cover by applying soil protective low carbon technologies, in particular, no-till (technological direction);
-optimization of the structure of land use by the removal of soil unproductive and degraded soil with their further afforestation or meadow (organizational direction);
-environmentalization of agrarian land use, in particular through the development of organic agriculture (ecological direction);
-development of agro-insurance and ecological insurance, in particular by developing and applying the mechanism of soil fertility insurance (economic direction).

Table 3. Macroeconomic assessment of the need of financial resource for development potential of low carbon land use in Ukraine for the period until 2030

Measures	Projected scope of measures			The estimated cost of the measures, mln USD		
	units	for year	all	USD/ha	for year	all
The annual measures – the running (current) costs						
Achieving a non-deficit balance of humus- content in the soil:	-	-		72.2	1,380.2	
- the use of traditional of organic fertilizers (2.0 t/ha)	mln t	38.8		20.1	388.0	
- the use of non-tradable part of crop (5.4 t/ha)	mln t	101.5		10.8	203.0	
- extraction and use of sapropel (2.4 t/ha)	mln t	46.0		40.8	782.0	
- extraction and use of peat (0.02 t/ha)	mln t	0.29		0.5	7.2	
Disposable measures – the investment costs						
Expanding the area of application of no-till technology	mln ha	0.5	5.0	64.0	32.0	320.0
Optimization of structure of land use:	-	-	-	55.5	7.25	72.5
- remove from cultivation of low productivity and degraded soils	mln ha	0.5	5.0	0.5	0.25	2.5
from them: for further use in pastures	mln ha	0.4	4.0	5.0	2.0	20.0
for further use in forestation	mln ha	0.1	1.0	50.0	5.0	50.0
Total investment costs	-	-	-	-	39.25	392.5
Transaction costs (30% of investment costs)	-	-	-	-	11.8	118.0
The total investment costs with transaction costs	-	-	-	-	51.05	510.5

Source: author's calculations.

It is clear that these strategic priorities for the development of low carbon agricultural land use do not exhaust the whole arsenal of low carbon measures, but only outline our strategic vision of priority ways to solve this problem.

CONCLUSIONS

The provision on the economic assessment of soil carbon sequestration and financial support for implementation of low-carbon land use in Ukrainian agriculture in the context of climate change was further developed. Results of evaluation of Ukrainian soils contribution into global carbon sequestration show that Ukraine plays a strategic role in the carbon sequestration in Europe. Her contribution is equal to one third of SOC sequestered in agricultural soils of the EU. According to our assessment, the total stocks of SOC in arable layer of the surveyed area of agricultural land (according to the results of the 10th round of an agrochemical survey) are 1,305.7 mln t. Based on the assumption that in other (unsurvey) agricultural lands, the content of organic carbon in the soil is at the same level, we can conclude that the total stocks of SOC in arable layer of the total area of agricultural land in Ukraine are 2,738.7 mln t. Economic assessment of stocks of SOC in Ukrainian soils indicates that its value is in the range from 14.4 thousand USD/ha (Gray forest soils) to 103.7 thousand USD/ha (Chernozem-meadow soils).
The results of analysis revealed that for agricultural production and the formation of the economic fertility of soils in Ukraine, the effects of climate change on warming will be both positive and negative. Taking into account the international experience of adaptation of land use processes to climate change, the basis of strategy of adaptation of agriculture in the enterprises of Ukraine to warming is proposed to put the concept of low carbon land use. As a result of the study it was determined the macroeconomic assessment of the need of financial resource for development

potential of low carbon land use in Ukraine for the period until 2030. The total average annual current costs for implementation of low-carbon land use in Ukrainian agriculture are equal to 1,380.2 million USD. The total investment costs with transaction costs for implementation of disposable measures of low-carbon land use in Ukraine for the period until 2030 are equal to 510.5 million USD.

The main results of the study can be used for (i) sustainable management of soil organic carbon and (ii) regulating the reproduction of organic carbon in the soil in the context of climate change.

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