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Challenges and opportunities of modelling carbon dioxide sequestration potential in Ukrainian soils

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ABSTRACT

The article examines approaches to modelling carbon dioxide sequestration by soils at different scale levels and describes a number of problems encountered in this process. The main problems in the modelling of organic carbon reserves for the territory of Ukraine have been identified, among which: lack of high-resolution data (hard to access), including types of land use; need for harmonization of existing data; the need for predicative modelling of indicators (clay and organic carbon content) for areas where data are not available; significant amounts of machine time for actual modelling. The need for open access to archived data (technical reports) from large-scale soil surveys 1957-1990 is highlighted. Also, the need to access large-scale topographic data as in the form of scanned topographic maps M 1:10000 and vectorized isolines are substantiated. It is shown that calculations of areas based on rasters in the geographical coordinate system to ensure the same pixel size, regardless of the location within Ukraine, it is proposed to use the “Ukraine Albers conic equal area” projection based on the Datum Pulkovo 1942 for which the error in the lengths of the lines is only 0.1%. Within areas can be used as a proposed projection, as well as precise Gauss-Kruger projections (EPSG 28404-28407, 5565-5583). In this case, it is necessary to take into account the likelihood of finding individual areas in several of the listed zones. It is demonstrated that simulation allows to establish territories in which even the best practices of management do not provide neutralization of emission of organic carbon from soils. However, it is necessary to introduce a priority introduction of adaptive management of the soil resources of agro-landscapes that will contribute to carbon sequestration or minimization of its emission.

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1. Introduction

Taking into account the globality of the climate warming and all the negative consequences that it entails, there was a number of international initiatives to correct this situation. Thus, in 1992, United Nations Framework Convention on Climate Change (UNFCCC) was signed, which was designed to prevent dangerous anthropogenic influence on the climatic Earth system [1]. Annual Climate Summits of the United Nations (Conference of the Parties, COP) raise topical current issues on reducing greenhouse gas emissions and prevention of possible effects of global warming. The Kyoto Protocol was signed on COP 3 [2], COP21 – Paris Climatic Agreement [3], and in Glasgow - COP26: a new climatic agreement, more efficient, compared to the Paris Agreement [4]. According to the latter, the country assumed to make steps that will reduce carbon emissions and to keep warming at 1.5°C. This is the limit for which the implementation of the scenarios of the climatic apocalypse begins. Failure to fulfill the promises of countries within the framework of the Paris Agreement will lead to heating the globe until the end of the 21st century significantly more than 1.5°C, which means an inevitable disaster [5]. This failed to full extent, although it was necessary to reduce global carbon dioxide emissions by 45% to 2030 compared to 2010, and to zero in 2050 [4]. Although at the methods and volumes of emission reductions are still discussions, the path of sequestration of carbon dioxide from the atmosphere of soils in the proceeding of progressive ways of land use is a prospective not causing doubts. It is better to fight with CO2 emissions into the atmosphere by developing stable agricultural systems in which carbon is sequenced and stored in soils. The binding of carbon at the same time solves three problems: soil degradation, sustainable development and climate change [6]. Lal [7] says that the Carbon Sink Capacity of The World's Agricultural and Degraded Soils Is 50 to 66% of the Historic Carbon Loss (from 42 to 78 Gigatons of Carbon). The absorption of organic carbon using the recommended technologies depends on the soil structure and texture, climate (precipitation, temperature), agricultural systems. Among the strategies of increasing carbon reserves in soils - changes in land use, the very best increase in the forestry, growing energy crops on marginal lands, effective irrigation, optimal organization of pastures, but primarily – agrotechnology’s that include minimal cultures, covering cultures, nutrients management, organic fertilizers. Carbon sequestration with soils simultaneously contributes to increasing their quality, increasing their fertility, solving problems of providing food, compensate for fossil emissions by 0.4–1.2 carbon gigaton per year. Organic carbon soil is an extremely valuable natural resource. Regardless of climatic debates, its reserves should be restored.

Within the framework of the Kyoto Protocol, a carbon loan mechanism (the right to emission of one tone-equivalent of carbon dioxide) is proposed. It provides for the possibility of acquiring certain values on the right to emit greenhouse gases. And those manufacturers, primarily agrarians, which reduces emissions, can obtain carbon loans with the right to further resale. Therefore, the estimation of a potential level of carbon dioxide sequestration at the local level has not only scientific, but also quite obvious interest.

So, enormous attention to the potential of sequestration of soil organic carbon to soils of agricultural landscapes, as one of the most cost-effective in the environmental point of view decisions for mitigating the effects of climate change and adaptation to it is fully substantiated [8, 9]. However, the implementation of this potential depends on the creation of effective mechanisms for monitoring, reporting and verification (MRV) of changes in the reserves of organic carbon soils [10]. In any case, the first step is initiated under the auspices of the FAO program to create a global map of the potential of organic carbon sequestration [11] on the basis of the network of national maps [12]. Methods of sustainable soil management, which are considered within this approach, are directly transferred to three levels of carbon receipt. They are defined as a percentage increase in carbon occurring relative to the usual land use scenario. The use of predefined interest indicators with an increase in the volume of carbon receipt (Low / SSM1 – 5%, Medium / SSM2 – 10%, High / SSM3 – 20%) provides the use of the ROTHC model [13–15] on a global scale.

It is assumed that the model GSOCseq will serve as a starting point for creating a database for coordinating actions and strengthening international cooperation in order to mitigate the effects of climate change and food security. In this case, the approach from below to the top will be used, and member countries are proposed to prepare national maps of potential capabilities of binding of carbon dioxide by simulating its reserves for the 20-year period in agricultural land within the limited three different scenarios specified above. However, in the implementation of the process of modeling the sequestration of carbon dioxide, with soils of Ukraine, there is a number of problems that are often a non-trivial task. The purpose of this article is to provide proposals for solving these problems, as well as an analysis of possible ways to overcome barriers, which is definitely an actual and important task significantly, not only for its own soil science and land management, but also environmentalists, economists, managers of different levels, etc.

2. Materials and methods

According to the set task, we have identified stages [12], which would have a process of modeling sequestration of carbon dioxide, by soils [16, 17] and simultaneously highlighted problem issues of this process, in particular:

1. Preparing data (collection, harmonization).
2. Modelling (sub-steps Spin Up, Warm Up, Forward).
3. Generation of maps (total 28 variations for BAU, SSM1, SSM2, SSM3):
   3.1. Products (7 map): Final SOC stocks (tC/ha) & Uncertainties (%).
   3.2. SOC Absolute differences (4 map): SSM 1-3–T0 (tC/ha).
   3.2. Absolute sequestration rates (8 map): Abs. Diff/20 years (tC/ha/year).
   3.4. SOC Relative Differences (3 map): SSM1-3 – BAU (tC/ha/year).
   3.5. Relative sequestration rates (6 map): Rel. Diff./20 years (tC/ha/year) & Uncertainties (%).

From the listed steps, the first stage characterized by most frequent complexity and accuracy (Tab. 1), a detailed analysis of which will be conducted in the section.

The interpolation of climatic data to a higher resolution was carried out by the algorithm of regulated splines with tension [18] in GIS GRASS [19], and the modelling of carbon and clay content, map of agro-production groups of soils - in R-Statistic [20] by Random Forests algorithm [21].

The studies were conducted within the Chernivtsi region (Fig. 1a) parts of the Dniester administrative district (Fig. 1b). Output data for modeling (content of humus, Fig. 1c) obtained by the results of agrochemical certification of soils (Chernivtsi branch of the State Institution "Soils Protection Institute of Ukraine"), and agro-production groups of soils (Fig. 1d) - in accordance with the maps of the DP "Chernivtsi Research and Project Institute of Land Management". To simulate the spread of agro-production groups of soils within the range of studies, the SRTM data fragment [22] was loaded and resampled to a resolution (ρ) 25 m.

Table 1
Input data requirements and their source (modification on base [12])

Input data requirements					Resolution	
Data	Variables	Time series	Units	Type	GSOCseq map	Ukraine SOCseq map
Climatic data	Monthly air temperature	1980-2000; 2001-2020 (or until last year available)	°C	Raster	50x50 km or finer	50x50 km, 9x9 km or finer (interpolated)
	Monthly evapotranspiration (Penman-Monteith)	1980-2000; 2001-2020 (or until last year available)	mm	Raster	50x50 km or finer	50x50 km, 9x9 km or finer (interpolated)
	Monthly precipitation + irrigation	1980-2000; 2001-2020 (or until last year available)	mm	Raster	50x50 km or finer	50x50 km, 9x9 km or finer (interpolated)
Soil data	Topsoil clay content (0-30 cm)	-	%	Raster	1x1 km	1x1 km or finer
	Current Soil organic carbon stocks (0-30 cm)	Latest version of national FAO-GSOC map	tC ha-1	Raster	1x1 km	1x1 km or finer
Land use/cover	Predominant land use/cover, re-classified into 12 classes defined in the FAO Global Land Cover - SHARE (GLC-SHARE)	Minimum: representative 2000-2020 (or last year available) Optimum: annual land use 2000 to 2020	1-11	Raster	1x1 km	1x1 km or finer
	Monthly vegetation cover. Obtained from national statistics/local expert knowledge; or derived from NDVI or spectral indexes	Minimum: average 2015- 2020 (or last year available period) Optimum: monthly soil cover 2000 to 2020	0-1	Raster	1x1 km	1x1 km or finer

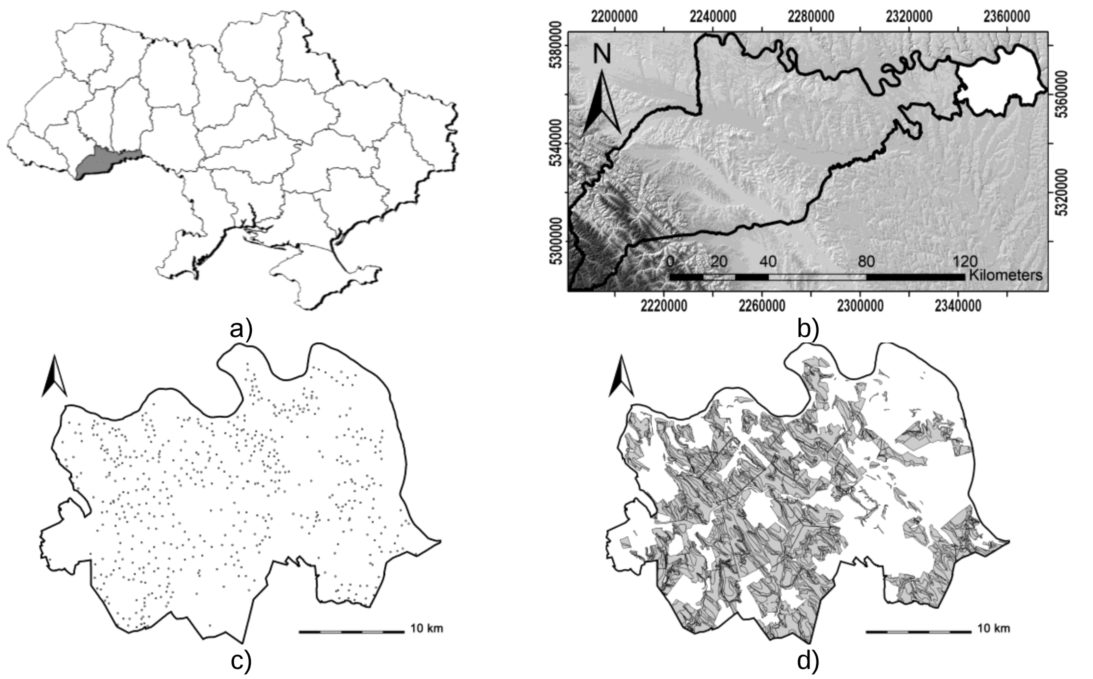

Fig. 1. *Geographical location of the region of research within Ukraine (a) and Chernivtsi region (b); distribution of dataset points (c) and the availability of data large-scale soil surveys (d) *SRTM data was used for the background*

Analysis of the nomenclature list of soils and the coordination of their contours, allowed to obtain preliminary data on the percentage of the territory with soil surveying. It is worth noting that the measurement of vector objects and their raster analogues shows some different results. If for large continuous areas, they are often identical, such as, for example, for the area of the district (67644.5 ha), the area of small contours – differs (Tab. 2). Which is lower spatial resolution, the greater it will be this difference. Characterizing the structure of the soil cover, we find that dominant soils of soils are gray forest soils, dark gray forest soils and podzolized Chernozems. The structure of the soil cover is quite complicated and field studies are really covered with 51.4 % of the area of the district (Tab. 2, Fig. 1d). Such a picture is characteristic of the rest of Ukraine [23, 24]. At the same time, there are many locations where large-scale soil studies were not carried out in general, but there are intensively used in agricultural production, which is also characteristic of the study area (Fig. 1c, d).

Table 2

List of agro-production groups of soils of studies area

№	Cipher	Area of agro-production groups of soils, ha (ρ=25 м)			№	Cipher	Area of agro-production groups of soils, ha (ρ=25 м)		
		vector map	raster map	predictive raster map			vector map	raster map	predictive raster map
1	25e	11,68	11,50	12,44	28	103ezh	71,80	71,19	286,50
2	35d	11688,76	11389,06	26172,37	29	104dz	131,96	132,94	965,45
3	35e	24,64	24,50	425,57	30	104dk	87,35	87,88	559,74
4	37v	19,88	19,94	80,75	31	133e	22,51	22,25	39,83
5	37d	5021,22	4927,50	9962,84	32	133l	14,97	15,38	26,42
6	37e	15,75	15,69	50,47	33	139e	3,86	3,81	15,26
7	38e	1211,60	1207,25	2467,24	34	139l	57,54	57,06	336,36
8	38ezh	28,65	28,75	92,14	35	141e	1028,52	945,81	1729,50
9	39e	310,25	307,38	941,88	36	142e	395,29	394,56	422,38
10	40e	2792,37	2775,25	3331,38	37	149e	3,23	3,13	313,81
11	41e	783,14	781,13	957,13	38	175d	14,07	14,06	1,66
12	44e	20,35	20,38	20,38	39	175zl	6,02	6,13	53,34
13	45e	232,25	231,19	321,94	40	176g	6,32	6,19	37,50
14	49d	0,33	0,31	199,69	41	176e	16,17	16,19	437,19
15	49e	3705,33	3635,44	5350,61	42	208d	13,30	13,44	16,63
16	49l	16,25	16,19	237,89	43	208e	9,47	9,31	9,50
17	50e	554,56	520,06	896,81	44	210e	21,53	21,50	138,13
18	51e	66,74	63,94	80,63	45	215e	77,45	77,56	185,57
19	53e	63,61	63,88	288,06	46	215zh	1,81	1,88	8,18
20	55e	89,57	89,63	77,88	47	216e	0,63	0,56	1,12
21	75d	6,10	6,13	4,44	48	216l	22,42	22,94	23,26
22	82l	176,53	175,50	185,25	49	217ek	225,49	218,94	2033,82
23	85l	1128,94	1125,44	1381,31	50	217zh	155,03	154,31	1155,49
24	86l	1881,65	1868,25	2632,94	51	218e	0,62	0,63	0,13
25	87e	41,35	41,19	81,52	52	221e	5,74	5,88	15,87
26	87l	1129,35	1124,56	2041,48	53	221l	67,42	58,75	123,26
27	101d	88,48	88,56	334,56		**Total:**	**33569,85**	**32920,88**	**67565,50**

3. Results

Analysis of problems regarding the most important goal – modeling of organic carbon reserves in soils and evaluation of their temporal dynamics is carried out in accordance with the main stages we are recommended. First, if necessary to receive not indicative data (GSOCseq map, resolution 1 km), but more precise, for example, with ρ=25 m, which will provide solutions to the real tasks of calculating carbon credits on a scale of a separate field, it is difficult to access or absent this data in Ukraine (even the source data with ρ=1 km is a big problem).

Second, if the data is already collected, then the further process of harmonization is impossible without a number of improvements. After bringing heterogeneous data to a single coordinate system and cut for AOI (area of interest), it is necessary to evaluate their current ρ and do not simply resampling, but interpolation to the required resolution. The current version of the methodology uses the simplest option, that is, a mechanical increase in the resolution, which is a resampling by the algorithm of the nearest neighbor. In this case, smooth data gradients are not achieved and the same, for example, average temperatures on the boundaries of the former 50 km pixels will have a sharp change. Obviously, at the local level, this may be a significant difference in the final results.

We propose a tested algorithm [25], which adequately reproduces climatic and other indicators when resampling from low resolution data and provides a smooth, not discrete gradients. Actually, all climatic data (Tab. 1) were obtained by such an approach.

The third stage is modeling of soil data, in particular the content of clay (0-30 cm) and organic carbon reserves (0-30 cm) based on the map of agro-production groups of soils. As already shown, existing maps do not cover the entire territory of surveys, and therefore predicative modeling was carried out for filling these gaps (Tab. 2, Fig. 2a) and obtained good level of Cohen's Kappa coefficient 89.5% (based on previous research [23-24, 26- 30]). Such a predictive map became the basis for model of clay content (Fig. 2b) and organic carbon (Fig. 2c). If the Random Forest algorithm used for the latter, the modeling of the clay content was non-trivial. Since measured values with a sufficient density of points are practically absent, then for obtaining information about the soil texture we used the ciphers of agro-production groups of soils obtained by the results of large-scale soil surveys on a scale of 1:10,000 (1957-1990). Each cipher corresponds to a certain group according to the soil texture and from each group were elected median the content of clay in two-fraction classification. In the future, we switched to three--fraction classification using Shein's methodology [31]. This was obtained by quantitative values of the clay content for all the polygons of each of the agrogroups, including and predicted for the study area (Fig. 2b).

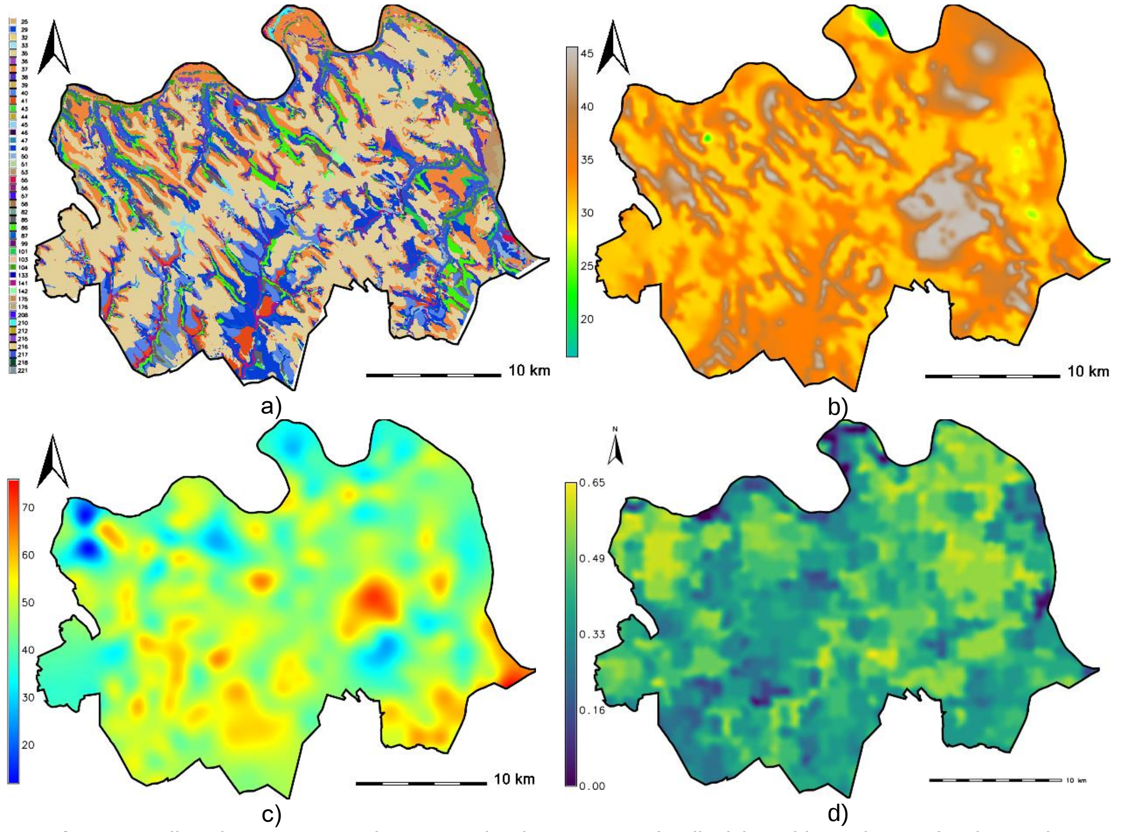

Fig. 2. *Predicted cartograms of agro-production groups of soils (a) and input layers for the RothC model: clay content map (%) by classification FAO/USDA (b), organic carbon content (c), t/ha and NDVI index at ρ=25 m*

The fourth stage provided for a choice of data on the type of land use (land use/cover, re-classified into 12 classes defined in the FAO Global Land Cover) and the degree of coverage of vegetation ((Monthly vegetation cover) are also needed to build a model. For vegetation, we used the NDVI index (Fig. 2d). In the absence of national data (maps) on the type of land use, we were forced to use open public sources, where the pixel size is approximated by 300 m. Since the interpolation here is incorrect (the limits of the settlement or land are discrete), then the type of land use contributes the most uncertainty in results.

The last stage is an actual modeling of the planned indicators, which allowed getting all the results in the form of a vector point file with intermediate and final data located in the corresponding fields of its attribute table. Here were consistently attracted supplemented and changed to work on local levels of scripts (generally 15) in the language R [20]. This stage requires the largest cost of machine time: at an average compute for 1 point (pixel center) about 2 seconds, field of 100 hectares for ρ=25 m is calculated about 1 hour. So, with the current implementation of the algorithm for building a potential sequestration map of carbon for the entire territory of Ukraine with ρ=1 km, only this stage will continuous about 25-30 days, and in resolution of 25 m in order more.

After completing the last script, we get results – full series of maps (see the section Materials and Methods). All of them have a significant value, but their characteristic requires a large volume of material, and therefore we demonstrate the results on the example of the relative difference in organic carbon (SOC Relative Differences), which is defined as the difference between the practices of sustainable land use and traditional agriculture (SSM1–3 – BAU). As can be seen from the data (Fig. 3), there are quite significant areas where even modern sustainable land use practices is not enough to neutralize the emission of carbon dioxide. Accordingly, it is in these areas that it is advisable to pay the most attention to the type of agrotechnics, which will contribute to the sequestration of carbon or minimize its emission.

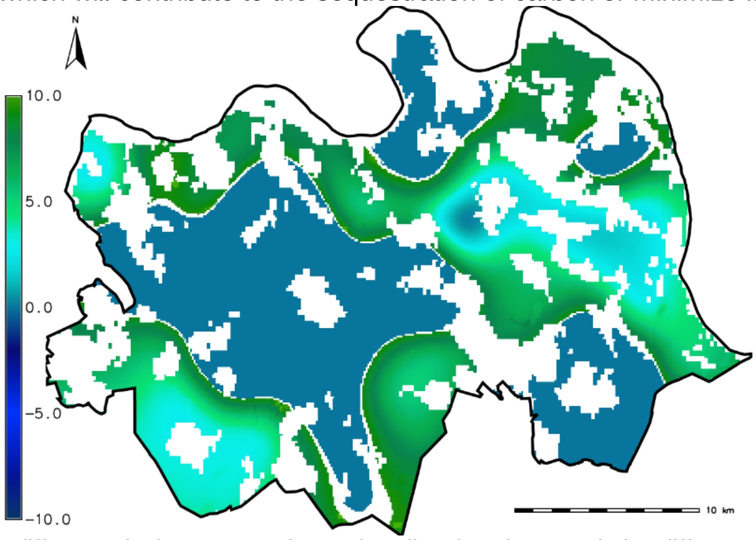

Fig. 3. *Relative difference in the content of organic soil carbon (SOC Relative differences as SSM3– BAU, in tC/ha); white spots are territories of settlements and other areas for which the simulation is impossible*

4. Discussion

The obtained results indicate that the RothC model in FAO implementation variant using a number of adaptations can be used at all levels: a state, regional or local (farm). For estimated judgments at different levels, it is necessary to choose the corresponding resolution parameter. For the state level, it is quite enough ρ=1 km, on the regional (oblast), in our opinion – 100 m, separate districts – 50, and farms – 25 m. Even such values ρ in modeling are currently prolonged in time and therefore one of the following directions of our research will be optimize the code and its implementation with all improvements in the faster programming languages then R.

It should be borne in mind that calculations on the basis of rasters stored in the geographic coordinate system have certain features. Technically, this is possible, however, measurements are not entirely correctly, since the area of the raster (pixel) will depend on latitude, because degrees are not linear units, but angular. In particular, the linear dimensions that are declared for GSOCseq map 1x1 km resolution grid (30 arcseconds), at the latitude of the equator make up 1x1 km; but at the latitude of the southern coast of Crimea ~1360x1420 m, in the area of the most northern point of Ukraine ~1500x1780 m. In the area of surveys, 30 arcseconds will be 1440x1590 m. Consequently, calculations on the scale of the whole state based on the geographical coordinate system will be too generalized, and therefore it is advisable to use projections that will provide single results for the entire territory of Ukraine. These include, in particular, used by us "Ukraine Albers conic equal area" projection based on the Datum Pulkovo 1942 with an extent of 22.00, 44.30, 40.20, 52.40, which in terms of Proj4 will have the appearance:

+proj=aea +lat_0=48 +lon_0=32 +lat_1=46 +lat_2=51 +x_0=796902 +y_0=0 +ellps=krass +towgs84=23.57,-140.95,-79.8,0,0.35,0.79,-0.22 +units=m +no_defs +type=crs

The proposed option makes it possible to provide the same pixel size regardless of the location within Ukraine, while the error in the lengths of the lines is only 0.1%. Of course, within the oblasts you can use as a proposed projection, and more precise Gauss-Kruger projections (EPSG 28404-28407, 5565-5583). It is necessary to only take into account the likelihood of finding some areas in several of the listed zones.

A separate place is a problem with the insufficient accuracy map of the high-resolution content of the organic carbon content and the inaccessibility of data on its content in the surface (0–30 cm) of the soil layer (or any other). According to the conclusion of the authors of the organic carbon stock map of Ukraine with ρ=1 km [32], the spatial evaluation is based on a set of data, 30% of which are obtained in the period up to 1991 and therefore it is necessary to complement it with newer studies. These include the data of Soils Protection Institute of Ukraine, which every 5 years conduct agrochemical examination of fields and, accordingly, may have a solid array of data. Deserves attention base of the properties of Ukraine soils [33] with a large amount of data on soil profiles. Integration of these and other databases into system for monitoring the soils of Ukraine and the national infrastructure of geospatial data and subsequent cooperation with WOSIS will be even a step towards close international cooperation between Ukraine in this area.

As indicated, there is a problem with data on granulometric structure of soils both global and local scales. The path of its solution shown to a certain extent is blocked by the inaccessibility of cartograms of agro-production groups of soils in open access. With them, it was possible to be acquainted with the website of the normative monetary assessment of agricultural land of Ukraine, but currently these data became unavailable. Their use and predictive algorithms would allow the corresponding card to the entire territory of Ukraine in a detailed scale. In addition to this possible future model, it would be possible to add data of Laktionova et al. [33] to obtain results that are more correct.

Potentially there is another way that can create prerequisites for the development of Ukrainian soil science - it is the use of the results of large-scale soil surveys of 1957-1990. Technical reports about surveys for 40 million hectares with schemes of soil profiles and pits, the results of laboratory surveys are practically stored in archives Land management institutes without working on the interests of the state, although great funds were spent on the state budget for these surveys. For political will, these materials could get to monitoring services in full volume, and their number, according to rough estimates, exceeds hundreds of thousands. Such results would be able to significantly expand the possibilities of any modeling both in soil science and in related sciences, providing managers of different levels with the most necessary information.

In addition to purely soil-based data, there is an urgent need to access large-scale topographic data, or in the form of scanned topographic maps M1:10000, or vectorized isolines. In the leading world states, these data are in free access, and are quite ready to use in the form of high-resolution digital elevation models. Of great importance for modeling carbon sequestration have maps of land types (land use), which are constantly updated and are publicly available, for example, in Europe.

Solving the complex of the above-described problems will develop maps of carbon sequestration potential by soils and to obtain more precise results than similar studies, which included the territory of Ukraine [34]. Such maps, despite the assessment of changes in the content of organic carbon, will allow specific measures to offer, if simulated practices of agriculture (traditional plowing, minimum or zero cultivation etc.) will not provide the necessary results. These include attribute such as the change in land use types: forest -> arable land, arable land -> pasture, forest -> pasture or any other combinations. To this, you can also add a carbon balance tool. For example, an EX-ANTE system (EX-ACT) has been FAO developed, which provides an assessment of projects, management programs of soil resources (lands) and agricultural development policies on carbon balance [35]. Integration of all mentioned tools and approaches creates a methodology for obtaining actual spatial information about emissions-sequestration of soil carbon. This will become the basis for making decisions by managers of all levels, providing the necessary data to mitigate climate change, supporting the necessary soil fertility, reduction of their degradation, providing international cooperation and trade and, as a result, state's food security.

5. Conclusion

The main problems in modeling organic carbon stocks for the territory of Ukraine are determined, among which: absence (difficult to access) high resolution data, including land use types; the need to harmonize existing data; the need for predictive modeling of indicators (clay and organic carbon content) for the areas where the necessary data is absent; significant volumes of machine time for computation.

There is a need for open access to archival data (soil essays) of the results of large-scale soil surveys of 1957–1990 and access to large-scale topographic data as in the form of scanned topographic cards M 1:10000 and vectorized isolines.

To ensure the same pixel size, regardless of the location within Ukraine, it is proposed to use the Ukraine Albers conic equal area projection based on the Datum Pulkovo 1942 for which the error in the lengths of the lines is only 0.1%. Within areas can be used as a proposed projection, as well as precise Gauss-Kruger projections (EPSG 28404-28407, 5565-5583). In this case, it is necessary to take into account the likelihood of finding individual areas in several of the listed zones.

Modeling allows you to establish territories in which even the best practices of management will not provide neutralization of the emission of organic carbon from soils. However, it is necessary to introduce a priority introduction of adaptive management of the soil resources of agro-landscapes that will contribute to carbon sequestration or minimization of its emission.

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Проблеми та можливості моделювання потенціалу секвестрації діоксиду карбону грунтами України

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У статті розглянуто підходи до моделювання секвестрації діоксиду вуглецю ґрунтами України на різних масштабних рівнях та охарактеризовано ряд проблем, які виникають в ході цього процесу. Визначено основні проблеми в моделюванні запасів органічного вуглецю для території України, серед яких: відсутність (важкодоступність) даних високої роздільної здатності, у тому числі, про типи землекористування; необхідність гармонізації наявних даних; потреба в предикативному моделюванні показників (гранулометричний склад, вміст органічного вуглецю) для ареалів, де необхідні дані відсутні; істотні об'єми машинного часу для власне моделювання. Вказано на потребу відкритого доступу до архівних даних — ґрунтових нарисів, результатів великомасштабних ґрунтових обстежень 1957-1990 рр. та у доступі до великомасштабних топографічних даних, як у вигляді сканованих топографічних карт М 1:10000, так і векторизованих горизонталей. Для забезпечення однакового розміру пікселя, незалежно від місцерозташування в межах України, запропоновано використання проєкції Ukraine Albers Conic Equal Area на основі датума Pulkovo 1942, за якого похибка у довжинах ліній становить всього 0,1 % і показано, що в межах адміністративних областей можна використовувати як пропоновану проєкцію, так і більш точніші проєкції Гаусса-Крюгера із відповідними засторогами. Продемонстровано, що моделювання дозволяє встановити території, в яких навіть найкращі практики господарювання не забезпечують нейтралізацію емісії органічного вуглецю з ґрунтів. Саме в таких ареалах є необхідним першочергове запровадження адаптивного управління ґрунтовими ресурсами агроландшафтів, яке сприятиме секвестрації вуглецю чи мінімізації його емісії.

Ключові слова: *GSOCseq; секвестрація діоксиду карбону; предикативні алгоритми; моделювання*

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