SOIL ORGANIC CARBON: ASSESSMENT OF DYNAMICS AND SEQUESTRATION POTENTIAL ON THE EXAMPLE OF UKRAINE

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EOS DATA ANALYTICS

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Introduction

One of the biggest challenges of today is the global problem of climate warming. A number of international initiatives have emerged to reduce the negative anthropogenic impact, including the UN Framework Convention on Climate Change (1992), the Kyoto Protocol (1997), the Paris Climate Agreement (2015), and the Glasgow Climate Pact (2021). Among these agreements, the Paris Agreement stands out, where countries have committed themselves to taking steps to reduce carbon emissions and keep warming below the 1.5°C limit, which triggers climate apocalypse scenarios. Failure to fulfil the promises of the countries under the Paris Agreement will lead to a warming of the globe well above 1.5°C by the end of the 21st century, which means an inevitable catastrophe. There are often discussions about the ways and extent of emissions reductions, but no one has any additional questions about the sequestration of carbon dioxide from the atmosphere by soils through progressive land use.

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The main positive effect of increasing the volume of CO2 absorption by soils is the growth/restoration of their potential fertility, which is due to a significant increase in the amount of organic matter entering the soil. Sustainable soil management practices result in the almost complete elimination of agro-technical measures involving soil rotation and the transition to various options for minimal tillage. This dramatically reduces the mineralization of organic matter and the development of water and wind erosion processes. The combination of these beneficial effects ensures the restoration of soil fertility.

At the same time, the assessment of the real potential of sequestration on a scale up to and including countries is often limited by the lack of quality data for building an initiating map of organic carbon content in soils.

Problem statement

In Ukraine, which has 45 million hectares of agricultural land, the limiting factor for assessing carbon stocks, dynamics, and potential for carbon sequestration is the lack of input data. Currently, there are only a few potential sources or ways to obtain SOC content data:

I. 3931 soil samples collected during 1964-2016 pp. Holder: National Scientific Center "Institute for Soil Science and Agrochemistry Researchnamed after O.N.Sokolovsky" (NSC ISSAR). On this basis, the Ukrainian part of the Global Soil Organic Carbon Map was created with a resolution of 1 km/pixel.
The main problems of the dataset are: 1) inaccessibility for use due to the data holder's policy; 2) besides the fact that this number of samples is quite small for such a large area, their extended time frame makes a large part of them irrelevant.

II. Materials from a large-scale soil survey of Ukraine in 1957-1961 and their subsequent correction (conducted until the early 1990s). Result: soil maps at a scale of 1:10000 for an area of 40-45 million hectares. Holder: State Geodesy, Cartography and Cadaster Agency of Ukraine (StateGeoCadastre). The potential number of samples (including full-profile ones) is up to 1 million. Despite the time extension, full dense coverage of the territory would allow to build spatial and temporal series of changes not only in SOC content but also in other indicators.
The main problems of the dataset are: inaccessibility for use due to the data holder's policy and being in a non-digitized form.

III. A continuous agrochemical survey of Ukraine's agricultural landscapes every 5 years in the form of so-called rounds – currently, despite the war of the russian federation against Ukraine, the 12th round is being conducted. Holder: Ukrainian State Institute "Soil Protect Institute (SI SPI).
The main problems of the dataset are: 1) inaccessibility for use due to the data holder's policy; 2) being in a non-digitized form; 3) samples were not georeferenced until recently; 4) only in recent years data have been collected as average mixed samples of 4-5 hectares, most of the older information refers to the whole field. The holder disseminates statistical and mapping materials by administrative regions and districts *(Fig. 1a, b)*, which is in sharp contrast to current approaches *(Fig. 1c)*.

IV. The National Agriculture Land Degradation Neutrality (ALDN) monitoring platform was created with the support of FAO, GEF, Ukrainian Soil Partnership (USP) and a number of national institutions. Holder: USP (http://ismld.com.ua). This includes data for the 0-30 cm layer from NSC ISSAR – 1000 soil transects *(Fig. 2a)*, and SI SPI - data from 750 monitoring plots *(Fig. 2b)* – annually from 2015 to 2020, as well as 4030 fields - a total of 5780 soil samples.
The main problems of the dataset: difficulty in downloading (there are no tools for exporting the entire data set, access is provided separately for each data point).

V. There is one more type of data source - internal data of agroholdings, farmers and owners, but the lack of possibility to accumulate this data does not allow us to evaluate it as an acceptable method.
The analysis of potential data sources in Ukraine shows that the fourth option is the most realistic way to obtain data on a nationwide scale. Given adequate government policy in this area, as can be seen from the list of sources, there is great potential to expand this database to a significant volume. Of course, given the current political and military situation, this, unfortunately, cannot be a priority in the near future.

Methodology

The spatial modelling of soil organic carbon content was based on a framework similar to that proposed by Tomislav Hengl et al. in the creation of the SoilGrids series of maps and similar to the approaches used in the creation of the Global Soil Organic Carbon Map, but modified towards simplification, for instance, calculations are only conducted for the plow layer (as the training dataset is only available for the 0-30 cm layer).

The mapping models were created using the R-Statistic environment at a resolution of 250 m/pixel. There are 4 main steps in this process:
- overlaying observation points and covariates (derivatives of relief, including slope steepness and exposure, surface curvature, topographic humidity index, agroclimatic data, etc;)
- selection of the type of model for spatial forecasting (we used the implementation of the Random forest algorithm in the R-Statistic ranger package;
- SOC modelling for a specific year (2015-2020);
- creating difference maps to track the dynamics of SOC changes.

The sequestration potential was assessed using the modified EOSDA RothC model from FAO (Technical Manual Global Soil Organic Carbon Sequestration Potential Map GSOCseq, 2020), in particular with improvements in algorithmic acceleration of calculations, the ability to select an arbitrary resolution by implementing resampling of coarse-grained data to high resolutions, and automatic selection of refined biomass growth factors for different types of agricultural land within Ukraine.

Results and discussion

Spatial SOC content modelling *(Fig. 3a)* was conducted to visualise both spatial and temporal changes from 2015 to 2020. The map of differences in SOC content between 2020 and 2015 *(Fig. 3b)* shows moderate changes with a slight prevalence of areas where the content tends to decrease. Despite the rather short current time series, we see significant potential of this approach, especially given the progress made in recent years in this kind of modelling. Nevertheless, there are challenges that need to be addressed in the future:

- Lack of evenly distributed soil profile data for individual fields or monitoring plots, both current and historical. Data georeferencing is particularly problematic. The further we go back in time, the fewer observations are available, so the temporal gaps are potentially an order of magnitude more critical than the spatial data gaps;
- Outdated data on soil profiles tend to show significant variations (variety of methods, laboratories), so, for instance, for humus (soil organic carbon), with rather low temporal dynamics, it is difficult to detect actual changes over time in cases when the signal-to-noise ratio is low;
- It is virtually impossible to properly (instrumentally) verify spatio-temporal models created for previous years and predictive models, especially in occupied and combat zones.

The obtained model of the potential of carbon sequestration by soils of agricultural landscapes for various land use scenarios (Fig. 4) allows to establish territories in which sometimes even the best management practices will not ensure the neutralization of organic carbon emissions from soils. The scenario "Business as usual" - BAU (Fig. 4a) allows you to see what the content of organic carbon in the upper layer of the soil (0-30 cm) can be in 20 years with conservative approaches to land use. Other scenarios that predict Low (SSM1 - 5%), Medium (SSM2 - 10%) and High (SSM3 - 20%) increase in C input (Fig. 4b, c, d, respectively) show that the carbon absorption potential for the territory of Ukraine is quite high, and with the complex implementation of progressive soil management approaches, we can get a large positive effect.

Conclusions

In the course of our research and analysis, we have identified several potential sources of SOC data, some of which can be a powerful source of information for spatial and temporal modelling of soil organic carbon content. We traced the dynamics and created cartographic models of agricultural soil carbon content for the period between 2015 and 2020, and based on this, conducted an assessment of the soil carbon sequestration potential over a 20-year period using the RothC model and at a sufficiently high spatial resolution.

That said, certain allowances should be made for data accuracy and the inability to obtain model results in combat zones, where agricultural activities cannot be carried out a priori. Nevertheless, the general approaches remain the same and can be used as a basis for recalculating the results in the scenarios of Ukraine's post-war reconstruction and restoration of its agricultural potential after the end of the war.

Acknowledgement

The work was funded by EOSDA and written with the partial support of the grant program named Scholarships for Excellent Researchers Threatened by the Military Conflict in Ukraine from the Government of the Slovak Republic (09I03-03-V01-00049).

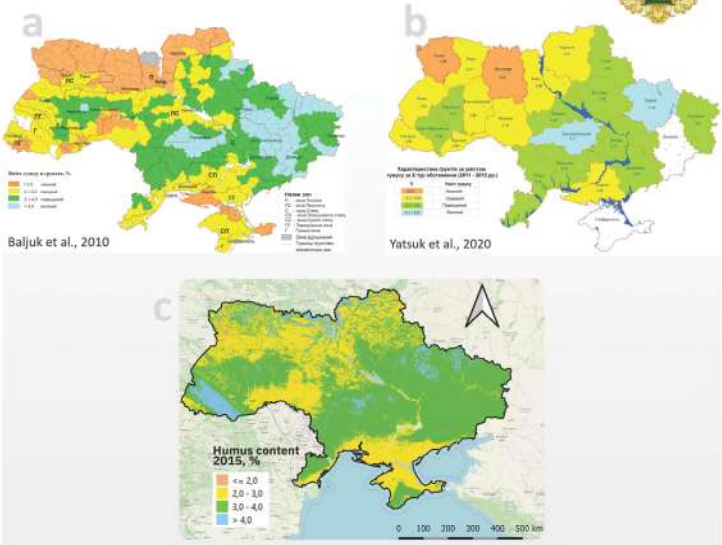

Fig. 1. Humus content in ukrainian soils according a SI SPI data for 2006-2010 (a), 2011-2015 (b) and our model data (c)

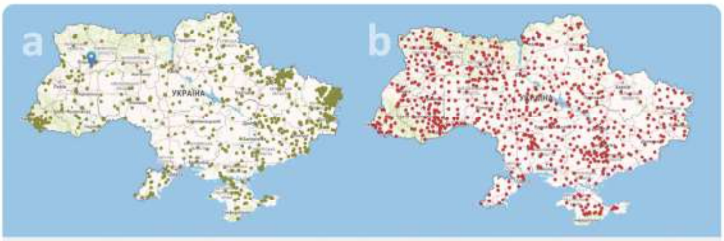

Fig. 2. Data of ukrainian ALDN monitoring platform: a) soils profiles; b) monitoring sites

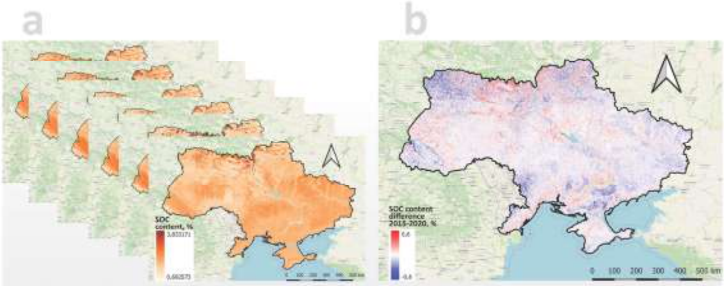

Fig. 3. Spatio-temporal SOC model for 2015-2020 (a) and difference map 2015-2020 (b)

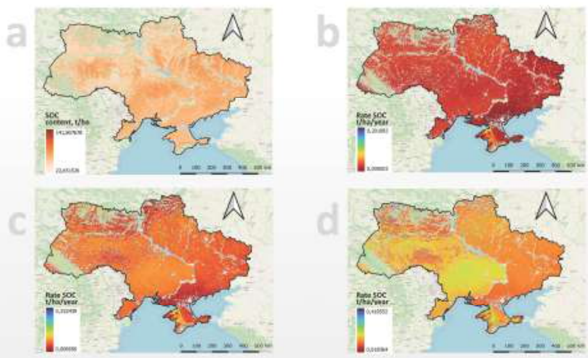

Fig. 4. Predicted carbon content in the soils of Ukraine in 20 years under the BAU scenario (a) and relative rates with an increase in the supply of carbon to the soil: SSM1 (b), SSM2 (c) and SSM3 (d)