The effect of fertilization and land use on soil organic matter

Ph.D. thesis

Thulfiqar Ali Jasim Al-Graiti
Supervisors
Dr. Gergely Jakab, Associate professor
Dr. Zoltán Szalai, Associate professor
Submitted to:

Faculty of Science

Doctoral School of Environmental Sciences

Prof. Dr. Tamás Turányi

Department of Environmental and Landscape Geography

Environmental Earth Sciences/Program of Environmental Geography

Eötvös Loránd University (ELTE)

HUN-REN Research Centre for Astronomy and Earth Sciences, Geographical Institute

Budapest, Hungary

2024

10.15476/ELTE.2024.074

1. Introduction and aims

Soil plays a vital role in the earth's carbon (C) cycle by having a substantial C reservoir. Cultivations are suggested to perturb the natural function of soil to store C, leading to soil degradation or soil organic matter (SOM) loss. SOM loss also can increase carbon dioxide (CO_2) emissions. It concerns climate change mitigation goals. Initiatives to reduce greenhouse gas (GHG) emissions from agricultural soil, such as 4 per 1000, are aimed at increasing soil organic carbon (SOC) concentration. A low SOC acquisition was expected in Eastern Europe's arable soils in 2050. It suggested improving soil management practices to increase C storage in Hungarian soils (Merante et al., 2017).

There are uncertainties about how C concentration and SOM compositions respond to soil management in arable lands. It is essential to understand if fertilization can increase SOC concentration and SOM stability in cropland to be almost comparable to intact soils in grassland. Furthermore, sampling time effects on SOM composition are not fully understood.

To help stakeholders decide on the best-balanced soil management practice to maintain C storage in arable soils, the present work aimed to understand the effects of fertilization, crops, and seasonality on the composition and concentration of three soil C pools and bulk soil. The objectives were: **1-** To study whether the concentration and composition of the separate soil C pools and the bulk soil are changed seasonally. **2-** To understand different long-term nutrient management effects (fertilization) on the concentration and composition of soil C pools and bulk soil in cropland. **3-** To study the effects of tillage on the concentration and composition of bulk soil and recalcitrant SOM pool, mobile SOM pool, and SOM within a soil stable aggregate pool. **4-** To study the effects of different crops on the concentration and composition of SOM within the stable aggregate pool, recalcitrant SOM pool, mobile SOM pool, and bulk soil. **5-** To determine the role of local weather conditions on mobile SOM pool composition and concentration in arable soil. **6-** To study the correlation between parameters characterizing solid-phase-related SOM pools and DOM parameters.

2. Methods

Cropland-tilled soil and nearby intact grassland soil at Martonvásár (47.331196 N, 18.789660 E), Hungary, were studied. They were characterized by the Chernozem reference soil group and part of a long-term experiment since 1958 comparing fertilization effects on soil quality under different plants. The field design consists of a two-factorial split plot, referring to plants (maize, wheat, and diculture), with the main plot (245 m^2) and the subplot (49 m^2) for fertilization. Fertilization was applied in cropland soil plots as follows: Unfertilized (control), NPK (110 kg ha^{-1} yr^{-1}) nitrogen, (45 kg ha^{-1} yr^{-1}) of phosphorus, and 50 (kg ha^{-1} yr^{-1}) of potassium, and NPK as in the former with manure. The applied amount of manure was 30 t/ha in October of each 4th year.

Soil samples were collected across 2018, 2019, and 2020, including twelve soil sampling dates covering each year's spring, summer, and fall seasons, to study SOC, total nitrogen concentration, and SOM composition in the dissolved organic matter (DOM) pool. Furthermore, bulk soil for soil samples from August 2018 (22/08/2018 or summer) and April 2019 (23/04/2019 or spring) was fractionated into the MPAOM (slow pool) and AAOM pools (fast pool) to study SOC concentration and SOM composition in these fractionated soil C pools. The wet fractionations method was used to separate the slow pool portion (<63 μm) from the fast pool (>63μm). The fractionation method started with 100 ml of distilled water mixed with 30 grams of the bulk soil. Then, the mixture was stirred under ultrasonic agitation for 10 seconds (22 J ml^{-1}). After that mixture was shaken and poured into the sieve (63 μm), 2 liters of distilled water was poured into the sieve. The slow pool liquid was filtered using a vacuum pump, with 0.45 μm glass fiber to separate the DOM pool. The aggregate fraction (>63μm) was separated from POM to obtain the AAOM pool using a density separation method. The fractionated soil was oven-dried, grounded finely (powdered to <50 μm), and saved in plastic bags until the instrumental analysis. An elementar vario MACRO cube CHNS elemental analyzer (Elementar Ltd., Germany) was used to measure total C and N concentrations. Fourier transform infrared (FTIR) spectroscopy (DRIFT mode) was used to estimate the following SOM compositions: Phenolic lignin, polysaccharides, amide nitrogen, aliphatic C, aromatic C, C/O ratio for functional groups and aromaticity (aromatic:aliphatic ratio). The total sample size for both sampling dates was (n=240, or n=120 per date). Cropland had a total sample size of n=108 (n=36 for each crop (maize, wheat, diculture), within each crop, n=12 for each treatment (control, NPK+manure, NPK), and within each treatment, n=4 in each pool and bulk soil. Grassland had a sample size of n=12 (n=4 for each pool and bulk soil).

For soil aggregate stability measurements, the AAOM pool with POM was collected in a glass container, and the weight of the container was labeled. After drying the container with soil in the oven, the container's weight with soil was measured and subtracted from the original container weight. The results were the soil weight of AAOM with POM. After calculating the POM weight, the aggregate stability ratio was found by dividing the weight of AAOM by the weight of the soil used for the fractionation procedure (30 grams) and multiplying the value by 100. Furthermore, the sample size for aggregate stability was (n=40) for both cropland (n=36) and grassland (n=4) per each sampling date.

DOM measurements include 4 g of soil suspended in 40 mL of distilled water. The solution was shaken for 2 hrs. After, the suspensions were centrifuged at 4800 rpm for 15 min, followed by filtration with 0.45 µm glass fiber. TOC/TN analyzer (Shimadzu, Japan) was used to determine DOC and DN concentrations. Biological, humification, and fluorescence indices (BIX, HIX, and FI) were estimated using an RF-6000 spectrofluorophotometer (Shimadzu, Japan). UV absorbance at 254 nm for $SUVA_{254}$ was estimated using a UV-ViS spectrophotometer (Shimadzu UV2600i). Three more replicates per sample were measured for the DOM pool. The total sample size for all dates was (n=1404).

3. Thesis results

1- Seasonality affected SOM composition in the mobile and the fast pools. SOM in the fast pool was not only affected by land use but also by sampling time. It suggested these soil C pools were sensitive to an instant change in a soil system, which might affect SOM values in arable Chernozem soil (Al-Graiti, under publication).

2- Both aliphatic and aromatic C ratios were potent indicators of tillage. For example, SOM compositions in cropland had a higher decomposition or lower SOM stability than in grassland. Furthermore, lower soil aggregate stability in cropland than grassland explained tillage's negative effects on SOC concentration.

3- Regardless of land uses and fertilization, the slow pool had higher SOC concentration and recalcitrant SOM than the fast pool. It shows the importance of the slow pool as the primary C protection route in Chernozem soil.

4- Plants and fertilization did not affect SOM compositions and SOC concentration in each soil C pool and bulk soil. It suggested that SOM patterns can be triggered by a spatially and temporally heterogeneous complex system in arable lands, as revealed by a high variance of some SOM variables.

5- The local weather parameters were significantly correlated with DOM variables but with a low correlation value. A low correlation value can be related to the soil's nature as a chaotic system. Hence, it proposed that including microbial data is necessary to understand DOM patterns in arable soil (Al-Graiti et al., 2022).

6- A considerable correlation was found between parameters related to the solid-phase SOM and the DOM. These phenomena suggest a biochemical link exists between the DOM and other SOM pools. It indicated that OM can be constantly exchanged between soil C pools, affecting SOM pattern in arable Chernozem soil.

4. Conclusion

SOM in slow, fast, and DOM pools and bulk soil were unaffected by fertilization or plants. A higher SOC and total N concentration were found in grassland than in cropland at all soil C pools and bulk soil. These results were more evident in solid-phase-related SOM pools than in the DOM pool. It explained varied tillage effects on soil C pools and showed the importance of soil aggregate stability in SOC concentration in solid-phase-related SOM pools. Aliphatic and aromatic C components were potent indicators of land use effects on SOM composition, showing that grassland had a more stable SOM composition than cropland. Furthermore, a higher SOC concentration and recalcitrant SOM in the slow pool than in the fast pool showed the importance of the slow pool as the primary C protection route. In contrast, all SOM compositions were changed seasonally in the fast pool. DOC concentration was proposed to increase SOC concentration in the fast pool during summer than in spring due to a seasonal variation in DOM composition. Specifically, labile DOM composition was found in summer rather than the following spring. A change in local soil conditions under potential climate change concerns would raise a question about how soil C pools would respond to a future climate. It suggested studying SOM composition seasonally for effective soil management to preserve C storage in arable soil.

5. List of Publications

Al-Graiti, T., Jakab, G., Ujházy, N., Vancsik, A., Fodor, N., Árendás, T., Madarász, B., Barcza, Z., Márialigeti, K., & Szalai, Z. (2022). The Composition of Dissolved Organic Matter in Arable Lands: Does Soil Management Practice Matter? Agronomy, 12(11), 2797. https://doi.org/10.3390/agronomy12112797

Jakab, G., Madarász, B., Masoudi, M., Karlik, M., Király, C., Zacháry, D., Filep, T., Dekemati, I., Centeri, C., Al-Graiti, T., &

Szalai, Z. (2023). Soil organic matter gain by reduced tillage intensity: Storage, pools, and chemical composition. Soil and Tillage Research, 226(November 2022), 105584. https://doi.org/10.1016/j.still.2022.105584

6- List of conferences

Studying Soil Organic Matter Composition in Arable Land: Can Soil Management Impact Carbon Pools? conference-presentation| https://doi.org/10.5194/egusphere-egu23-15258

Dissolved soil organic matter as a fertility indicator in arable soils: How local conditions control its properties and implications for climate change| conference-abstract. https://www.fao.org/fileadmin/user_upload/GSP/GSOIL4N/Presentations/27Jul/P2/005_Al_Graiti.pdf

Effects of Fertilization and Crops on Soil Organic Matter in Arable Soil| conference-poster. https://1778df732d.clvaw-cdnwnd.com/464163c6c58a7760d10c2dc0e217449b/200000484-c8066c8068/Thulfiqar.pdf?ph=1778df732d

Dissolved organic carbon and soil porosity: how cultivation systems impact concentration and implication for land use | conference-poster. E-Book_Abstracts_PD_2021-3.pdf (d6scj24zvfbbo.cloudfront.net)

Dissolved organic matter differences in the soil as affected by the extraction method | conference-abstract.http://kti.rkk.uni-obuda.hu/files/csatolmany/2021_12-iceee_proceedings_book.pdf

References

Merante, P., Dibari, C., Ferrise, R., Sánchez, B., Iglesias, A., Lesschen, J. P., Kuikman, P., Yeluripati, J., Smith, P., & Bindi, M. (2017). Adopting soil organic carbon management practices in soils of varying quality: Implications and perspectives in Europe. *Soil and Tillage Research*, *165*, 95–106. https://doi.org/10.1016/j.still.2016.08.001