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THESIS OF THE DOCTORAL (PHD) DISSERTATION

The impact of land use/land cover change on soil organic matter content/variation and composition

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1. Introduction

1-1. Background

➢ **Soil Organic Matter: Dynamics, Importance, and Influencing Factors**

Soil organic matter (SOM) is a complex mix of decomposed plant, fungal, and animal residues. It is essential for preserving soil health, supporting the growth of plants, influencing CO_2 emissions from the soil, and enhancing microbial diversity (Feng and Simpson, 2011). SOM stores almost twice as much carbon as the atmosphere, making it essential for ecosystems. This carbon reservoir supports vital functions like water retention, erosion control, nutrient cycling, and sustainable food production (Loveland and Webb, 2003; Grandy and Robertson, 2007). Rising food demand and limited arable land exacerbate this issue (Turalija *et al*., 2022).

➢ **Depletion and Restoration of Soil Organic Carbon Stocks (SOCS)**

Soil organic carbon (SOC) in agricultural fields has been significantly reduced by human activities such as intensive farming, deforestation, and soil erosion (Oldfield *et al*., 2019**).** The balance between carbon inputs (e.g., crop residues) and losses from erosion and decomposition determines SOC levels (Zuo *et al*., 2023).

SOC stocks can be restored using sustainable methods such as afforestation, increased organic inputs, and decreased tillage (Lal, 2004b). These techniques enhance soil fertility and agricultural productivity in addition to reducing greenhouse gas emissions. Restoring SOC stocks also contributes to climate change mitigation by sequestering carbon and enhancing the land-based carbon sink, which absorbs about one-third of anthropogenic emissions (Lal *et al*., 2021).

➢ **Global and Regional Contexts**

The greatest terrestrial carbon reservoir is soils, which store between 1500 and 2400 PgC worldwide (Navarro-Pedreño *et al*., 2021). Nonetheless, these supplies are at risk from climate change, particularly in vulnerable locations like permafrost zones (Lal *et al*., 2021). Understanding land use patterns, soil interactions, and adaptive management techniques are necessary to address these issues (Chabbi *et al*., 2022).

In Hungary, diverse soil types and environmental factors such as topography and soil properties shape SOM dynamics. The key causes of SOM composition, whether land use, management, or climate, are still not fully understood, although agriculture and forests account for two-thirds of Hungary's land area (Szatmári *et al*., 2023).

1.2. Research Objectives

This study aims to explore the relationships between SOM composition and its influencing factors across four study areas in Hungary. The research focuses on seven land use/ management types. To achieve this aim, the following objectives were defined.

1. Assess how different land use/ management affects SOM composition and decomposition.
2. Identify tillage practices that enhance surface SOM content.
3. Compare SOM quality under afforestation, conservation tillage, and conventional tillage.
4. Investigate SOM composition in soil fractions (fine and aggregate fraction) under various tillage systems and tree line samples.
5. Explore relationships between SOM composition and its overall content.
6. Evaluate the influence of climate, topography, and soil properties on SOM

2. Materials and Methods

2.1. Study area

This research was carried out in four diverse areas in Hungary: Józsefmajor, a flat region with intensive crop farming; Szentendre Island, a mosaic of small farms with advanced techniques like agroforestry; and two steep areas in Zselic with high erosion, dense forests, and degraded agricultural land. These locations represent Hungary's varied landscapes.

Soil samples were collected from various land uses in each study area. In total 48 samples were collected from Józsefmajor (24 samples from cropland and 24 samples from tree line). In Szentendre Island, 45 soil samples were collected from five land uses (arable land, forest, conventional horticulture, organic horticulture, and permaculture), and in Zselic area, 41 samples were taken from arable land, intensive farming, orchards, forests, and grasslands.

Figure 1 shows 4 chosen study areas in Hungary. Also, table 1 shows the detail about sampling and land use in each of the study areas.

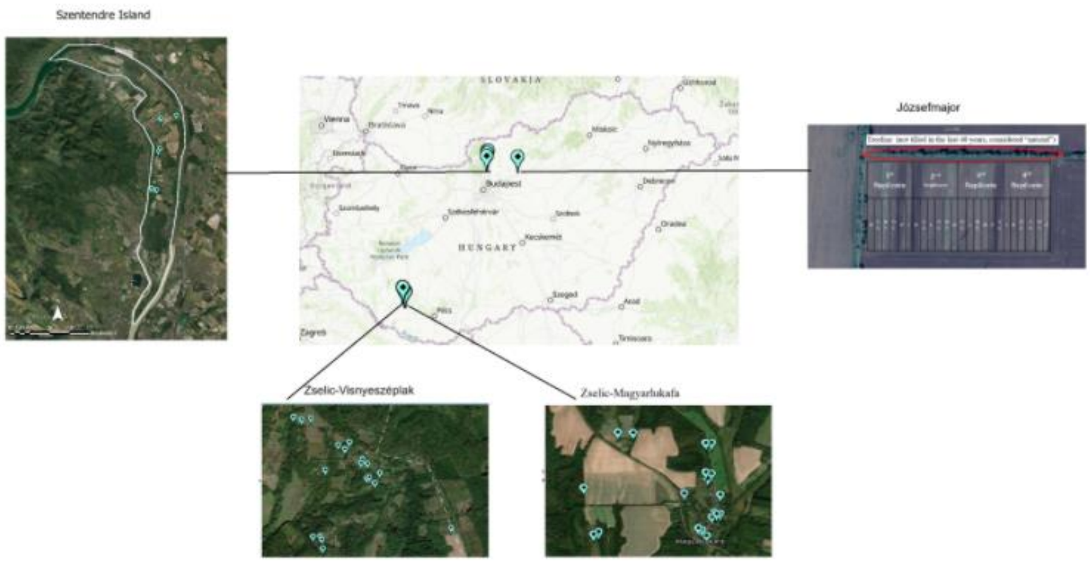

Figure 1. The locations of the study areas in Hungary

Table 1. Four study areas with sampling details

Study area		**Land management**		**Sampling points**	**Sampling depth (cm)**	**Soil**
Józsefmajor		Cropland	No-tillage	4	0-10	Chernozem soils
			Disking	4		
			Shallow cultivation	4		
			Deep cultivation	4		
			Loosening	4		
			Ploughing	4		
		Treeline		24		
		Total		48		
Zselic area	Magyarlukaf Visnyeszéplak	Arable land		11	0-30	Luvisol
		Orchard		10		
		Forest		10		
		Grassland		10		
		Total		41		
Szentendre Island		Permaculture horticulture		5	0-30	Fluvisol
		Arable land		15		
		Forest		15		
		Conventional horticulture		5		
		Organic horticulture		5		
		Total		45		

2.2. Measurement Methodology

2.2.1. SOM Characterization

The soil samples were ground into a fine powder (smaller than 200 microns) using an agate mortar and pestle and then dried overnight at 50 °C to remove any moisture. Mid-infrared spectra were collected using a Bruker Vertex 70 FTIR spectrometer in DRIFT mode. The spectra were recorded in the 4000-600 cm^{-1} range, with three scans for each sample to ensure accuracy. The data were processed to remove background interference from CO_2 and water vapor, and a baseline correction was applied using a rubber band method.

Five main organic bands were studied, including aliphatic C, aromatic C, aliphatic C-H bending, amide N, and polysaccharides. The areas of these bands were measured using OPUS software, and the relative band area (RBA) was calculated as the proportion of each band compared to the total of all bands (eq 1). Two other ratios, including aromaticity (the ratio of aromatic to aliphatic C and aliphatic C-H), and the ratio of C/O functional groups were calculated to understand the chemical composition of soil organic matter (SOM) and how it relates to decomposition and stability (eq 2 and 3) (Demyan *et al.*, 2012; Yeasmin *et al.*, 2020).

$$RBA = \frac{The\ area\ of\ a\ particular\ band}{Sum\ area\ of\ all\ bands} \times 100 \quad (1)$$

Aromaticity (Ratio Aromatic: Aliphatic C) = $\frac{RBA(1680-1580)}{RBA(2960-2840)+RBA(1465-1360)}$ (2)

The ratio of C to O functional groups =

$$\frac{RBA(2960-2840)+(1680-158)+(1547-1510)+(1465-1360)}{(1175-1148)} \quad (3)$$

The degree of decomposition and maturity of OM has been proven to increase aromaticity (Margenot et al., 2015; Veum et al., 2014). Also, an increase in the ratio of C-rich compounds (e.g., aliphatic, aromatic) to O-rich functional groups (e.g., carboxyl, polysaccharides) is likely to be associated with decreased biological reactivity, and recalcitrance of OM (Margenot et al., 2015; Veum et al., 2014; Yeasmin et al., 2020).

2.2.2 Soil OM pool fractionation

Soil organic matter pool fractionation was also conducted using the Zimmermann method, modified by Poeplau, to separate labile and stable C pools. This involved separating the aggregate fraction by wet sieving and density-based separation into mineral aggregates, particulate organic matter (POM), and mineral-associated stable organic matter. The fractionation procedure was applied to three tillage operations and tree lines in Józsefmajor due to time and financial constraints.

In addition to spectral analysis, other soil properties were measured in the lab. These included soil pH, texture (percentages of sand, silt, and clay), salinity, calcium carbonate content, and organic matter percentage. The Walkley-Black method was used to measure organic matter, and nutrients like nitrate, nitrite, and phosphorus were also analyzed.

Environmental factors like topography, precipitation, temperature, and evapotranspiration were also collected.

2.2.3. Data Analysis

The analyzed variables were summarized using the mean and standard deviation and visualized with box-and-whisker plots. Normality was assessed using different static like skewness, kurtosis, and the Shapiro-Wilk test. Several variables, including SOM content, pH, $CaCO_3$, Aliphatic C, Aliphatic C-H phenolic lignin, and aromaticity, exhibited non-normal distributions.

For non-normally distributed variables, the Kruskal–Wallis test was applied to compare SOM medians across seven land-use types. ANOVA was used for normally distributed variables, with Tukey's post hoc test ($p < 0.05$) for multiple comparisons. All analyses were conducted in R (version R4.0.3). Spearman's rank correlation coefficient was used to assess relationships between SOM composition, environmental variables, soil properties, and SOM content. Statistical significance was determined using the chi-square test ($\alpha = 0.05$).

2.2.4. Principal Components Analysis

Multivariate analysis procedure including Factor Analysis (FA) was used to determine discriminant variables. PCA analysis is useful in estimating a priori the number of homogenous groups in the data sets (Dossa *et al*., 2011). The ideal number of components was determined by applying both the Cronbach's alpha threshold and the eigenvalue rule (>1).

All soil, climatic, and other environmental properties that were investigated were standardized based on their standard deviations, and the resulting Z-scores were further subjected to analysis. To achieve dimensional reduction, principal component analysis (PCA) was conducted, followed by varimax rotation with Kaiser's normalization.

Before implementing PCA, relationships among soil properties and environmental covariates are tested and all dependent variables are represented by the most relevant factors. So, in the end, eight soil properties including Na (mg/kg), Cu (mg/kg), Humus %, Mg (mg/kg), NO_2 + NO_3 (KCl soluble) (mg/kg), P_2O_5 (mg/kg), pH-KCl, $CaCO_3$ % (m/m) and four environmental covariates including precipitation, slope, temperature, and TPI were selected. Then factors for soil characteristics were extracted using PCA and Varimax rotation with Kaiser Normalization. The eigenvalue threshold (>1), the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy (>0.5) and Bartlett's test of sphericity significance (<0.00001) were applied (Hair et al., 2010). Outliers in the data were examined and revised accordingly. Loadings that were greater or equal to 0.4 were considered for interpretation purposes (Samuels, 2017). Finally, to identify the most relevant and effective environmental covariates and soil properties on OM compound, spearman correlation analysis was applied among the environmental covariates and the OM-dependent varimax rotated principal components (rPCs) to discover the most relevant and effective environmental covariates on SOM composition.

4. Results and discussion

4.1. Soil Organic Matter content

In Józsefmajor, the study found that soil organic matter (SOM) was significantly higher in the tree line than in the tillage practices. Conservation tillage methods, such as disking and no-tillage, resulted in higher SOM content, while intensive tillage practices like plowing had lower SOM levels. Also, plowing increased Calcium Carbonate ($CaCO_3$) content in the soil, while the tree line had a significantly higher pH value than other management. These findings suggest that practices like disking and no-tillage, which reduce soil disturbance, help preserve organic matter in the soil. At the same time, intensive tillage accelerates SOM decomposition and reduces its levels.

In Szentendre Island, permaculture horticulture showed the highest SOM content, followed by forest, organic horticulture, arable land, and conventional horticulture. The pH in arable land was significantly lower compared to permaculture and forest areas, indicating that intensive agricultural practices may lower soil pH. $CaCO_3$ content did not show significant differences among land use types. Studies have shown that permaculture and similar sustainable farming practices can enhance SOM storage and improve soil properties, which is consistent with the findings of this study. Conventional horticulture, with its more intensive practices, had the lowest SOM, highlighting the benefits of less intensive, more sustainable land management.

In the Zselic area, grassland had significantly higher SOM compared to arable land and orchards. Interestingly, the forested areas had lower SOM than expected, which may be due to grazing animals that contribute organic carbon through their droppings in grassland. Arable land showed the highest pH values, followed by grassland and forest, suggesting that agricultural practices such as liming may increase soil pH. No significant differences were found in $CaCO_3$ levels between different land uses. These results contrast with some studies that show forests typically have higher SOM than grasslands (Evrendilek *et al*., 2004; Keen *et al.*, 2011). Forests in this area also showed a lower amount of SOM compared to cultivated areas (arable land and orchards). The higher SOM in the cropland as compared to the forest might be due to the C application of other organic manures (Keen *et al*., 2011).

land uses with conservation techniques or land uses that are more natural, such as forests and grasslands, showed greater SOM levels in all research locations compared to more intensively managed lands like arable land and conventional horticulture, this is consistent with the overall trend that more intense tillage techniques reduce SOM because they accelerate the decomposition of organic matter and increase soil aeration. The study indicates that conservation techniques, including reducing tillage could help enhance SOM content, improving soil health and carbon storage.

In summary, the study areas with less intensive land use and conservation tillage methods tend to preserve and increase SOM, while intensive tillage practices and conventional farming reduce SOM. Consequently, we recommend the implementation of land conservation practices that involve minimizing tillage and introducing crop rotation. Additionally, pH variations and $CaCO_3$ levels were influenced by land management practices, with more natural areas and sustainable farming showing better soil health indicators.

4.2. Soil organic matter composition

The DRIFT spectra results revealed relevant concentrations of aromatic C and aliphatic C-H in soil samples across various land use/management types.

The findings indicate that in cultivated lands (such as permaculture horticulture and arable land in Szentendre Island, and across six different tillage operations in Józsefmajor), the presence of aromatic C is significantly higher compared to other land uses. These results are consistence with Gonzales-Perez *et al*. (2007). However, the situation is different in the Zselic area, where a higher aromatic C ratio is observed in forests. A higher aromatic C ratio in the forest area might be due to the relative accumulation or the higher incidence of forest fires (which is not the case in Hungary) however, other factors like climate, topography, soil properties, and vegetation type can affect the concentration of soil organic matter composition. Additionally, in Józsefmajor and between different tillage systems, we noted higher aromatic C under conventional tillage compared to conservation tillage.

Regarding aliphatic C-H, it is more concentrated in natural ecosystems (such as the tree line in Józsefmajor and organic farming in Szentendre Island) compared to more intensive land management (e.g. all tillage operations in Józsefmajor and arable land in Szentendre Island). This finding is consistent and supported by Thai *et al*. (2021). However, in our other study areas (such as the Zselic area), arable land and orchards showed higher aliphatic C-H than the grassland and forest sites. Similarly, in Szentendre Island, conventional farming exhibited high values for aliphatic C-H. Aliphatic originates from plant waxes and suberin found in tree roots and bark (Lorenz *et al*., 2007). In forests, tree branches and bark contribute significantly, making up to 40% of the material above the ground because litter doesn't integrate much into the soil due to bioturbation, root material plays a substantial role (Vancampenhout *et al*., 2009).

Moreover, as we examine the connection between tillage operations and the aliphatic component, it appears that the latter likely decreases with increasing management intensity. These results are attributed to aliphatic predominance in biodegradation and aromatics' high biodegradation resistance (Schnitzer *et al*., 2006).

Changes in the SOM, such as decomposition and mineralization, involve alterations in functional group chemistry. For instance, the relative increase in aromatic to aliphatic groups during decomposition. In our case studies, particularly in more natural ecosystems like the tree line in Józsefmajor, SOM decomposition seems to be in an early stage, because of the higher proportion of aliphatic C-H compounds to aromatic C observed in forest, tree line, and other natural land use/management (except in the Zselic area). This could be the consequence of the much higher OC input than the reduced decomposition due to the lack of cultivation and soil turnover. Furthermore, the ratio of aromatics is assumed to increase as the degree of SOM humification increases. Land-use effects were particularly pronounced for the amides and polysaccharides in Józsefmajor, and in the Zselic area. Significantly higher amide N ratios in the tree line and conservation tillage (NT and D) in Józsefmajor, and forest in the Zselic area compared to more intensified tillage systems and agriculture may probably be the result of a slower turnover of the tree line and forest’s leave litter (and conservation farm cover residue). Also, significantly lower polysaccharide concentrations were observed in the soil of tree line compared to in the soil of arable land in Józsefmajor. However, in two other study areas, we observed different results, as forests in both provide results with the highest polysaccharide and lowest values in organic farming (in Szentendre

Island) and arable land (in Zselic area) respectively. The results of the two indices, i.e., aromaticity and ratio of C-containing to O-containing functional groups, are consistent with the concept of a relatively more advanced stage of decomposition of SOM in the cropland. The calculated aromaticity in Józsefmajor was much greater in the cropped land (27%) than in the tree line soil samples (15%). Also, in Szentendre Island, arable land, permaculture horticulture, and conventional horticulture showed higher aromaticity compared to other land management. However, the Zselic area shows different results, and arable land presents the lowest aromaticity compared to others (it suggests that other factors might affect SOM decomposing in this hilly slope landscape).

Aromaticity is estimated to be higher in microbial more processed OM. We suggest that afforestation might increase the SOM compound concentration (SOMcc) and even the aliphatic compounds due to both higher OM input and lower decomposition even in the investigated period. This causes a high content of easily available carbohydrates in the organic matter inputs. The highest ratio of the C to O functional group appears in the tree line (Józsefmajor) and Organic farm (Szentendre Island). It also shows less variation between different tillage operations in Józsefmajor. These results are consistent with Yeasmin *et al.* (2020).

For fractionated soils, differences were observed in the RBA of different compounds across fine and aggregate fractions. Aliphatic C-H had the highest RBA in the aggregate fraction of tree line soils, while aromatic C was highest in plowing's fine fraction. The C/O ratio was highest under the tree line and lowest under plowing.

In conclusion, the interaction between tillage methods and soil fractions can have intricate impacts on SOM composition. These factors play a significant role in the influence of fresh organic matter and the stability of SOM compounds, ultimately shaping the composition and alterations in soil organic matter in various agricultural settings and land use/management practices. Furthermore, in addition to the well-known benefits of conservation agriculture, such as reducing greenhouse gas emissions, preventing soil erosion, and boosting crop yields (as noted by (Lal et al., 2018). Our study reveals that employing long-term conservation tillage is more effective in preserving soil organic matter compared to traditional tillage methods.

4.3. Soil organic matter content and composition

In Józsefmajor, a strong positive correlation ($r=0.95$, $P<0.05$) was found between Aliphatic C-H (RBA) and SOC concentrations, while the increase in SOM content was linked to a decrease in aromatic C RBA ($r=-0.94$, $p<0.05$). Previous studies also supported a negative correlation between SOM content and aromatic C. Aliphatic C-H bands represent labile carbon, which is more accessible to microorganisms, while aromatic C groups, seen as recalcitrant, indicate stabilized SOM. Soils with higher SOC levels tend to have higher aliphatic C-H and lower aromatic C, suggesting greater decomposition of SOM. The degree of decomposition (aromaticity) was negatively correlated with SOM ($r=-0.9$, $p<0.05$), further confirming that higher SOM content is linked to less decomposed organic matter. The C/O ratio showed a strong positive relationship with SOM ($r=0.8$ $p<0.05$), indicating greater SOM recalcitrance and slower decomposition as SOC increases. Amides and polysaccharides showed negative relationships with SOM content in Józsefmajor, with environmental factors such as soil nitrogen influencing these compounds However, in the Zselic area and Szentendre and Szentendre Island, neither aliphatic components of the OM nor other functional groups showed strong correlations with SOM across fields. The correlation coefficients were relatively weak (e.g. $r=-0.35$, pp=0.024 in the Zselic area and $r=-0.25$, p= 0.08 in Szentendre Island for aliphatic C-H). One possible explanation for these different relationships between study areas is that SOM concentration is significantly lower in Szentendre Island (mean=2.23%) and Zselic area (mean= 2.48%) compared to Józsefmajor (mean=6.22%). The results suggest that soils with notably higher carbon contents also possess SOM with distinctly varied molecular compositions. It is irrespective of whether these molecular differences cause or result from its stability or resistance to decomposition.

Comparing forest and tree lines in our four case studies shows that the aliphatic components of the SOM are significantly lower in the Zselic forested area; whereas Szentendre Island forests showed the highest value compared to other study areas (Szentendre Island> Józsefmajor> Zselic-Visnyeszéplak> Magyarlukafa). We could see the same order for phenolic lignin accordingly. The ratio of aromatic C also showed a significantly highest value in Zselic-Magyarlukafa and Zselic-Visnyeszéplak and the lowest value was observed in Szentendre Island (Zselic-Visnyeszéplak> Zselic-Magyarlukafa> Józsefmajor> Szentendre

Island). For Polysaccharide, we could observe the lower values in Szentendre Island and Józsefmajor, which were different from the observed higher values in Zselic-Magyarlukafa and Zselic-Visnyeszéplak (Zselic-Magyarlukafa> Zselic-Visnyeszéplak> Józsefma-jor> Szentendre Island). However, aromaticity showed a significantly higher value in Zselic-Magyarlukafa and Zselic-Visnyeszéplak compared to two other areas of Szentendre Island and Józsefmajor. The C/O ratio however showed a higher value in Józsefmajor and Szentendre Island compared to two other study areas of Zselic-Magyarlukafa and Zselic-Visnyeszéplak.

When we compare arable land in our study areas, we could see fewer differences between Józsefmajor, Magyarlukafa, and Zselic-Visnyeszéplak for all soil organic matter compositions except for the amide N ratio, however, Szentendre Island showed a significantly lower value for all compounds except aliphatic C-H and C/O ratio compare other study areas. Based on these observations we can conclude land use can be effective on soil organic matter (SOM) composition but as it is clear there might be other factors that can affect soil organic matter composition and derive different compounds in different areas.

4.4. SOM composition and environmental variables

The results indicate that environmental variables, particularly climate-related factors and topographical features like slope and elevation, show the strongest and most consistent correlations with the composition of soil organic matter. This is particularly evident in specific molecular components such as aliphatic C-H, aromatic carbon, and polysaccharides. We found a negative correlation between Mean Annual Temperature (MAT) and aromatic C ($r = -0.8$, $p = 0$), polysaccharides ($r = -0.74$, $p < 0.005$), and the decomposition index of aromaticity ($r = -0.8$, $p < 0.005$). This association could be attributed to lower temperatures controlling soil respiration.

Our research also revealed strong positive correlations between precipitation and several components, including the ratios of aromatic carbon ($r = 0.86$, $p < 0.005$), polysaccharides ($r = 0.6$, $p < 0.005$), amide nitrogen ($r = 0.8$, $p < 0.005$), and aromaticity ($r = 0.84$, $p < 0.005$). In contrast, we found negative correlations for the aliphatic C-H ratio ($r = -0.76$, $p < 0.005$) and aliphatic phenolic lignin ($r = -0.5$, $p < 0.005$).

However, diverse findings have been presented in several studies. For instance, according to Lal (2004 b), increased precipitation or the existence of surface water might hinder the soil decomposition processes of SOM and result in the accumulation of SOM stock. In contrast, Lei et al. (2023) suggested that MAP could accelerate SOM decomposition by activating soil microbial processes. Precipitation affects soil moisture levels, which in turn regulate the decomposition of SOM. In areas with insufficient precipitation, low soil moisture and can elevate salinity which leads to reduce plant productivity and ultimately limits SOM accumulation. We observed a negative correlation between the C/O ratio and MAP ($r= -0.5$, $p < 0.005$) and a positive correlation with MAT ($r= 0.73$, $p < 0.005$). This correlation can potentially explain the higher microbial activity in areas with higher temperatures and lower precipitation, which is consistent with previous studies (Wu *et al*., 2022; Lei *et al*., 2023).
Moreover, our findings revealed a positive correlation between MAP and polysaccharide content ($C= 0.6$, $p<0.005$) and a negative correlation with MAT. Adequate moisture promotes the production of polysaccharides by both plants and microbes, aiding in their stabilization.
Topographical factors, such as elevation, slope, and related characteristics, also significantly influence SOM composition. The influence of topographical factors on soil organic matter relies on land use (because vegetation cover moderates the effects of soil erosion and deposition on slopes). They also can affect soil organic matter content and composition indirectly for example when elevation increases, temperature generally decreases, influencing microbial activity and decomposition rates. Higher elevations and slopes may experience greater precipitation, affecting leaching and nutrient cycling, and erosion which lead to an effect on soil organic carbon content and composition, especially topsoil (Wu *et al.*, 2022). In regions with steep slopes, erosion may lead to the removal of topsoil, while deeper soil minerals are incorporated into the surface layer through agricultural tillage practices. The subsoil generally contains lower levels of SOC, and the interaction between subsoil minerals and topsoil organic matter can form mineral-organic associations that reduce OM decomposition. This might be the reason that arable land in the Zselic area showed lower aromaticity and so lower decomposition compared to other land use, which was contrary to two other study areas. These arable lands are in eroded crop fields. Zselic area has a steeper slope (S= 4.92%), and higher altitude (E=196 m) compared to Józsefmajor (S= 0.91%,

E=102.82 m) and Szentendre Island (S=0.73%, E=102.82 m). Consequently, this hillslope landscape is affected by higher precipitation which according to some previous studies can increase SOM decomposition (Chen and Yu, 2021; Lei *et al*., 2023).

4.5. SOM composition and environmental variables

Our analysis revealed significant correlations between various soil properties and organic matter composition. Aliphatic C-H showed a strong positive correlation with $CaCO_3$, in contrast, aromatic C exhibited a weak correlation with pH and $CaCO_3$, while sodium (Na) displayed a strong negative correlation with aromatic C.

For amide-N, we observed negative correlations with zinc (Zn) and sodium (Na), with sodium exhibiting a stronger effect. Phenolic lignin also showed a weak positive correlation with both Zn and Na. Polysaccharides displayed strong negative correlations with pH and $CaCO_3$, while manganese (Mn) had a slight positive association. Aromaticity was weakly positively correlated with $CaCO_3$, while sodium and zinc showed negative correlations, with zinc having a stronger impact. The C/O ratio showed a strong positive correlation with pH and a weaker correlation with $CaCO_3$, while manganese presented a slight negative effect. These findings emphasize the role of pH and mineral composition, particularly $CaCO_3$, in influencing soil organic matter (SOM) composition.

Soil pH significantly affects SOM composition by regulating microbial activity, hydrolysis, and protonation processes, which, in turn, influence organic matter stability through sorption and desorption mechanisms. Our study identified $CaCO_3$ as a key factor, strongly correlated with the C/O ratio, aliphatic C-H, and aromaticity while showing negative associations with aromatic C and polysaccharides. These effects align with previous research suggesting that $CaCO_3$ alters soil biogeochemistry by increasing pH, extractable calcium, and soil organic carbon (SOC). Moreover, $CaCO_3$ contributes to SOC stability through aggregate formation, influencing the distribution of organic carbon fractions (Rowley *et al*., 2018).

4.6. Principal component analysis for environmental covariates and soil properties

A total of 13 environmental variables (climate and topography) and 10 soil properties were grouped into three principal components (PCs), capturing 63.45% of the total variance (KMO = 0.663). The first component (rPC1, 29%) represents slope steepness, precipitation, and temperature, and the second component (rPC2, 21.63%) is associated with soil properties, particularly pH and $CaCO_3$ content. Organic matter (OM) content moderately loads on both rPC1 and rPC2. The third component (rPC3, 12%) is also associated with P_2O_5 and NO_2 + NO_3, indicating its connection to nutrient availability. The PCA biplot highlights strong loading values for rPC1 and rPC2, showing that temperature and sodium (Na) drive rPC1 positively, while slope and precipitation have a negative influence, suggesting warmer, flatter areas with lower precipitation. In contrast, rPC2 is strongly linked to soil pH and $CaCO_3$, confirming the role of carbonate in regulating soil chemistry. rPC3 represents key nutrients (NO2 + NO3 and P2O5), which influence soil fertility. Spearman rank correlation analysis revealed that rPC1 is negatively correlated with aromaticity ($r = -0.73$, $p < 0.05$) and positively correlated with the C/O ratio ($r = 0.51$, $p < 0.05$), suggesting that humid, sloped environments reduce aromaticity due to lower microbial inputs. rPC2 (pH and $CaCO_3$) is positively correlated with amide ($r = 0.38$, $p < 0.05$) and the C/O ratio ($r = 0.46$, $p < 0.05$), indicating that higher pH and carbonate content favor amide-rich SOM. rPC3 (temperature) positively correlates with aliphatic C-H ($r = 0.64$, $p < 0.05$) and the C/O ratio ($r = 0.51$, $p < 0.05$), while negatively affecting polysaccharides ($r = -0.51$, $p < 0.05$) and aromaticity ($r = -0.73$, $p < 0.05$), suggesting higher temperatures accelerate SOM decomposition. while the PCA results provide valuable insights, they only explain two-thirds of the variance. It indicates that factors not included in our analysis, like the type of minerals present and the land use, may be important determinants of the composition of SOM. This highlights the need for further exploration of additional factors, particularly land use and mineralogy, to gain a more comprehensive understanding of SOM composition. Figure 2 illustrates how different land-use types and locations contribute to the distribution of SOM composition in the study areas, based on principal component analysis. Each point represents a sample, and the different shapes and colors show how the samples are grouped by land-use types (such as conventional, arable, forest, etc.), based on this scatter plot, tree line, and tillage operations differ significantly along rPC1, and also rPc2, as this area is almost flat and there is no significant difference in temperature we can conclude land use/land management along with soil properties (pH and $CaCO_3$) is the main driver of SOM composition in Jozsefmajor. Forest and arable land also show differences along PC2, but in opposite directions, which suggests there are no clear overall conclusions from this separation. This implies that other underlying environmental factors (possibly related to pH, precipitation, or microclimate) are contributing to the variability in these land uses, which aligns with the assumtion that land use alone does not fully explain SOM composition distribution. The Zselic area crop fields and the Szentendre Island crop fields also vary along PC1; however, both are arable land. This difference is likely due to location-specific factors (Zselic is a hilly and wet area and Szentendre Island is a flat and relatively dry area). Overall, these findings highlight the significant impact of local environmental conditions (such as climate and specific soil properties) on SOM composition distribution, often more so than general land-use types. This is a critical insight, suggesting that localized management practices and environmental variables must be considered when studying or attempting to manage SOM dynamics in different landscapes (fig 2).

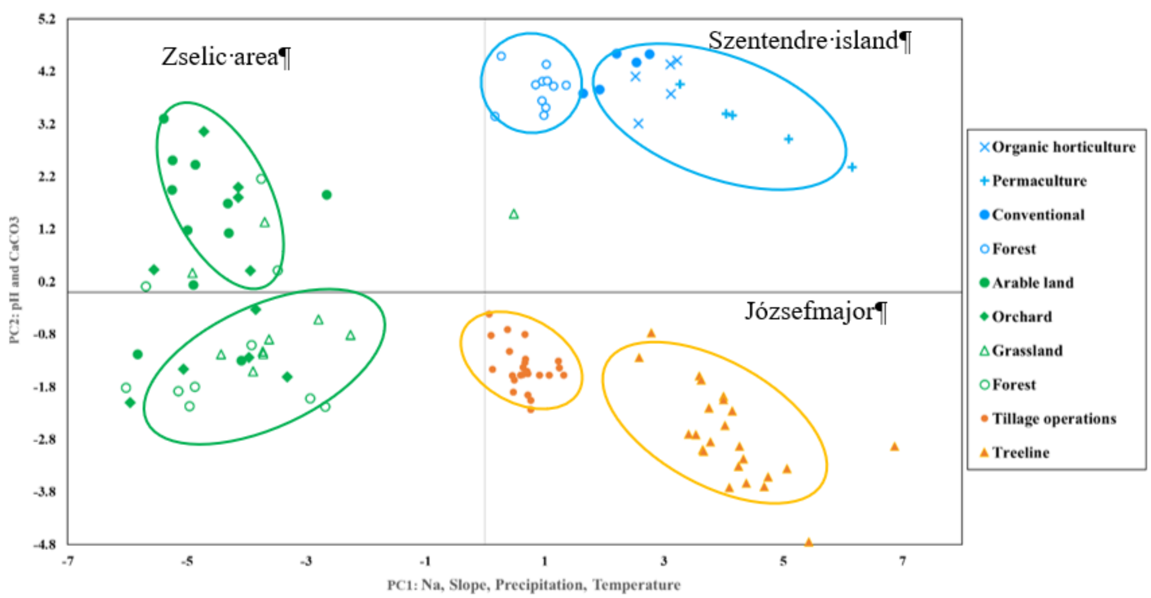

Figure 2. Principal Component Analysis (PCA) of different land-use Management based on soil and environmental parameters

5. Conclusion and Recommendations

(I) Assessing the impact of land use and land management practices on SOM composition and decomposition:

This objective was addressed in three study areas in Hungary, including eight land use types: tree line, arable land, permaculture horticulture, organic horticulture, conventional horticulture, forest, grassland, and orchard.

The examination of different land use/management practices showed higher concentrations of aromatic C and aliphatic C-H compounds across the soil samples compared to other OM compositions. The findings indicate that cultivated lands (such as permaculture horticulture, Conventional horticulture, and arable land) have significantly higher levels of aromatic C compared to other land use types. On the other hand, less intensively managed systems (such as the tree line and organic farming) exhibited higher concentrations of aliphatic C-H, except for the Conventional horticulture in Szentendre Island. Therefore, it can be inferred that cultivated areas have a more resistant composition of organic carbon than other land use types.

However, different results were observed in two other study areas. Comparing land use effects of SOM composition in three study areas revealed that land use can be one driver of OM compound but not the only one. In total natural land uses such as tree line, forest, and grassland, notably, different dynamics are observed in the study areas for polysaccharide and amide, these variations underscore the complexity of soil composition influenced by different land management practices across diverse environments. We discovered that forests lead to an increase in the polysaccharide ratio when compared to crop fields. However, a tree line aged 40 years does not seem sufficient to bring about a change in this soil organic matter compound

The results of two indices of aromaticity and the ratio of C/O functional groups support the concept of a relatively advanced stage of SOM decomposition in croplands. The calculated aromaticity in Józsefmajor was significantly higher in cropped land (27%) than in tree line soil samples (15%). Similarly, in Szentendre Island, arable land, permaculture horticulture, and conventional horticulture displayed higher aromaticity compared to other land use/management practices. However, in the Zselic area, different results were observed, with arable land exhibiting the lowest aromaticity compared to other land use types.

Overall, it is evident that different land uses can influence the composition of SOM. However, exceptions, such as the aromaticity in the Zselic area's arable land, suggest that it is not the sole determinant of SOM composition.

(II) Evaluate the effect of agrotechnical and various tillage operations on SOM content in surface soil to determine the most suitable tillage system.

The conclusion for this objective is based on Józsefmajor Experimental and Training Farm (JETF). We conclude conventional tillage (Plowing, loosening) has more resistance compounds of organic matter than conservation tillage (no-tillage, disking, shallow cultivation). This also leads to higher aromaticity under conventional tillage.

Because the entire field had been plowed for an extensive period (50 years) and the conservation tillage techniques had been applied since 2002, we can conclude that SOM increased owing to the less intensive tillage associated with the conservation practices. In addition, the greater decomposition under plowing and loosening was the result of tillage-induced oxygen abundance in the subsoil stimulating microbiological activity. These results suggest that decomposition increases with increasing tillage intensity, whereas SOM increases under conservation practices owing to less intensive tillage.

(III) Investigate the effect of afforestation on SOM quality and comparing it to conservation and conventional tillage

Here we compared the small woodland (tree line) in Józsefmajor to JETF. This study found that the natural ecosystem (tree line) and adapted conservation tillage, namely no-tillage and disking, produced similar results for most SOM compounds.

Moreover, the results of the two indices, aromaticity and C/O ratio, indicate that SOM has a higher degree of decomposition in cropland. The DRIFTS results revealed that tree line soil had the lowest aromaticity (15%) and, therefore, a lower decomposition rate and higher SOM recalcitrance compared to the cropland soil (27%). This study demonstrates that land use change and afforestation can alter the structure and stability of SOM compounds.

Finally, we conclude that afforestation is similar to conservation tillage, mostly no-tillage and disking, which is indicative of fast (<40 years) regeneration; accordingly, regeneration agriculture and the development of conservation tillage represent the superior solution for increasing SOM and food security in the present soil and climate conditions.

(IV) Varying OM composition in different soil fractions in three tillage systems and a tree line

Comparing three land use/management (Treeline, No-tillage, and plowing) revealed that plowing-based management leads to an increase in the content of aromatic C, while tree line (T) and no-tillage (Nt) land use/management practices promote higher levels of aliphatic C-H, particularly in the fine soil (S+C) fraction. Thus, it can be concluded that plowing-based management in the fine soil fraction may result in higher aromaticity and C/O ratio, indicating lower decomposition and higher stability of soil organic matter. Despite cultivation, the composition of the soil's aggregate fraction (S+A) is observed to be less aromatic and more labile which suggests that the process of cultivation seems to affect the soil making it less rich in aromatic substances and more susceptible to alteration.

The results from Józsefmajor demonstrate that changes in soil aggregation caused by tillage practices have the potential to influence soil organic matter dynamics. So, we conclude that the size of soil particles influenced by tillage primarily affects the molecular composition of soil organic matter, with specific components being retained in both mineral-associated organic matter and aggregate-associated organic matter. Aliphatic-containing compounds tend to be enriched in aggregate fractions, whereas aromatic compounds are more prevalent in fine fractions due to their ability to absorb soil minerals.

(V) The connection between OM composition and content

The findings indicate that soils with significantly higher organic carbon levels also contain SOM with noticeably diverse molecular compositions. It is important to note that these molecular differences do not necessarily cause or result in the stability or resistance of SOM to decomposition. This aspect is noteworthy because soils with a high content of SOC (soil organic carbon) do not necessarily guarantee that the SOC is more stable or resistant to decomposition. This observation is evident in the composition displayed in the Józsefmajor.

(VI) Assessing the effect of environmental covariates (climatic and topographic factors) and soil properties on SOM composition

The results indicate that certain environmental factors, particularly climatic conditions and topographical characteristics like slope and elevation, are significantly correlated with the composition of soil organic matter. Specifically, there is a notable correlation between these factors and the presence of aliphatic C-H, aromatic C, and polysaccharides in the soil. In our study, we observed a negative correlation between the Mean Annual Temperature (MAT) and aromatic C, polysaccharides, as well as aromaticity. However, since there was not a wide range of temperatures (ranging from 10.24°C to 11.47°C) among the study areas, we can conclude that temperature is not a significant driver of soil organic matter composition in these regions. On the other hand, other topographic factors, such as altitude/elevation (ranging from 102.82 to 235.43 meters) and slope steepness (ranging from 0.73% to 5.28%) varied more widely. This difference was particularly noticeable between two smaller areas within the Zselic area, and two other study areas of the Józsefmajor and Szentendre Island. Based on the correlation results, we can identify these topographic factors as influential factors that contribute to the different soil organic matter compositions, especially regarding aromaticity in cultivated land within the Zselic area compared to the Józsefmajor and Szentendre Islands. Additionally, according to the Principal Component Analysis (PCA), it is confirmed that factors related to slope steepness, represented as rotated Principal Component 1 (rPC1), affect soil organic matter composition in different areas. We also observed significant variation in precipitation values (ranging from 543.65 to 747.43 mm) between the Zselic area and the other two study areas (Józsefmajor and Szentendre Island). As precipitation is a known influential factor on soil organic matter composition, we can consider it as another reason for the differences in soil organic matter composition among the Zselic area, Józsefmajor, and Szentendre Island. The combination of steep slopes and higher precipitation in the Zselic area may intensify erosion, which can impact soil organic matter composition and decomposition. Among soil properties, we conclude that soil pH and calcium carbonate ($CaCO_3$) are the primary properties that might influence SOM composition. However, based on the PCA analysis, rPC1 (which represents slope, precipitation, and temperature) and rPC2 (which represents pH, and $CaCO_3$) showed correlations with soil organic matter composition, indicating that the interaction between pH and mineral content in the soil can affect soil organic matter composition. Comparing these results to the impact of land management on SOM composition emphasizes the importance of environmental variables (like soil properties, temperature, and pH) in determining SOM composition, which means local conditions have a stronger influence on SOM than land use alone.

Based on the findings of the study, the following recommendations are suggested:

❖ Promoting conservation tillage practices

Considering the research indicating that conservation tillage methods, such as no-tillage and disking, contribute to increased levels of aliphatic C-H and have the potential to improve the stability of soil organic matter (SOM), it is advisable to actively promote and advocate for these practices in agricultural environments. It is important to educate farmers and land managers about the advantages of conservation of tillage, emphasizing its positive influence on the composition of SOM and the rate at which it decomposes.

❖ Afforestation initiatives for soil health

It has been recognized that afforestation, like conservation tillage, has a beneficial impact on the quality of soil organic matter (SOM). Consequently, the promotion of afforestation initiatives, particularly in regions where soil degradation or low SOM levels are evident, is highly recommended. This suggestion aligns with the concept that afforestation is a rapid regeneration process, making it an applicable approach to enhance SOM and improve food security, especially considering the prevailing soil and climate conditions.

❖ Importance of monitoring soil aggregation

The study highlights the importance of monitoring soil aggregation induced by tillage practices, as it can potentially regulate changes in SOM dynamics. Understanding the relationship between soil aggregation and SOM composition is crucial for implementing effective land use/ management strategies.

❖ Monitoring and adjusting land use/management based on environmental factors and soil properties

The research highlights the strong relationship between environmental factors, particularly topographic elements and climate conditions, and the composition of soil organic matter (SOM). It shows these factors can be the main driver of SOM composition and affect its dynamic, especially in hilly and steep environments. As a result, it is advisable to monitor and adapt land use/management approaches according to the specific environmental characteristics of a given area. This may require considering factors such as the steepness of slopes, elevation, precipitation, and pH when designing land utilization and tillage strategies, to align them more effectively with the desired SOM composition.

❖ Considering sustainable agricultural practices

Considering the findings of the study, it is highly recommended that natural agricultural methods, such as permaculture horticulture, be implemented within the farming community. The research indicates that permaculture techniques have a similar effect on the dynamics and composition of SOM as those observed in natural ecosystems like forests. Embracing the principles of permaculture in agricultural practices can yield multiple advantages, supporting environmental sustainability and ensuring soil health.

6. NEW SCIENTIFIC RESULTS

1- Afforestation can affect SOM composition and dynamics due to higher organic matter input in a short period (40< years).

2- The study emphasizes the importance of soil particle size (two-size fraction of soil) in determining the molecular composition of SOM. It highlights that aliphatic compounds, tend to be enriched in aggregate-associated OM fractions, while aromatic compounds are more prevalent in fine fraction OM. This can be attributed to their respective abilities to be stabilized by soil minerals. Also, the higher ratio of aromaticity in the fine fraction compared to the aggregate fraction and the higher C/O ratio in the fine fraction compared to the aggerate fraction suggests that lower decomposition rate and biological reactivity in the fine fraction, which led to recalcitrant OM in the fine fraction of soil.

3- The findings highlight a similarity between the effects of organic farming and natural ecosystems on SOM decomposition rate (both help OM stability). This similarity suggests that organic farming practices can be considered sustainable land use, as they exhibit comparable impacts on soil composition and organic matter decomposition, similar to those seen in undisturbed natural ecosystems.

4- In the Zselic area, regional differences in SOM composition seem strongly influenced by local environmental factors, particularly topography and climate. Forests in Zselic show higher aromatic C ratios and increased aromaticity, suggesting slower SOM decomposition compared to arable lands, which exhibit lower aromatic C levels. This contrasts with the trends observed in other study areas. The hillslope landscape, with its higher precipitation, steeper slopes, and greater altitude, likely contributes to these differences by promoting reduced decomposition rates in arable lands due to the higher moisture and drainage conditions

5- Spatial variability in climatic and topographical factors contributes to variations in SOM composition. The findings highlight the complex interplay between environmental conditions, topography, and land use in shaping SOM dynamics and composition. Local environmental conditions may overwrite land use determined variations in SOM composition.

7. References

- Amelung, W., Zech, W., &. and Flach, K. W. (1997). Climatic Effects on Soil Organic Matter Composition in the Great Plains, Soil Science Society of America Journal, 61(1), pp. 115-123. https://doi.org/: 10.2136/sssaj1997.03615995006100010018x

- Chabbi, A., Rumpel, C., Hagedorn, F., Schrumpf, M., & Baveye, P. C. (2022). Editorial: Carbon Storage in Agricultural and Forest Soils, Frontiers in Environmental Science, 10 (February), pp. 1–5. https://doi.org/: 10.3389/fenvs.2022.848572.

- Chen, W. and Yu, H. Q. (2021) 'Advances in the characterization and monitoring of natural organic matter using spectroscopic approaches', Water Research. Elsevier Ltd, 190, p. 116759. doi: 10.1016/j.watres.2020.116759.
- Dossa, L. H. *et al.* (2011) 'Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: An attempt towards a regional typology', *Landscape and Urban Planning*. Elsevier B.V., 102(3), pp. 197–206. doi: 10.1016/j.landurbplan.2011.04.005
- Demyan, M. S. et al. (2012) 'Use of specific peaks obtained by diffuse reflectance Fourier transform mid-infrared spectroscopy to study the composition of organic matter in a Haplic Chernozem', European Journal of Soil Science, 63(2), pp. 189–199. doi: 10.1111/j.1365-2389.2011.01420.x.
- Evrendilek, F., Celik, I. and Kilic, S. (2004) 'Changes in soil organic carbon and other physical soil properties along adjacent Mediterranean forest, grassland, and cropland ecosystems in Turkey', *Journal of Arid Environments*, 59(4), pp. 743–752. doi: 10.1016/j.jaridenv.2004.03.002.
- Feng, X. and Simpson, M. J. (2011) 'Molecular-level methods for monitoring soil organic matter responses to global climate change', Journal of Environmental Monitoring, 13(5), pp. 1246–1254. doi: 10.1039/c0em00752h.
- Grandy, A. S., and Robertson, G. P. (2007). 'Land-use intensity effects on soil organic carbon accumulation rates and mechanisms, Ecosystems, 10(1), pp. 58–73. https://doi.org/: 10.1007/s10021-006-9010-y.
- González-Pérez, M. et al. (2007) 'A laser-induced fluorescence spectroscopic study of organic matter in a Brazilian Oxisol under different tillage systems. *Geoderma*, 138 (1-2), pp. 20-24.doi: https://doi.org/10.1016/j.geoderma.2006.10.010.
- Jiménez-González, M. A., Álvarez, A. M., Carral, P., & Almendros, G.A. et al. (2020). Influence of soil forming factors on the molecular structure of soil organic matter and carbon levels. Catena, 189, p. 104501. https://doi.org/: 10.1016/j.catena.2020.104501.
- Keen, Y. C. *et al.* (2011) 'Soil organic matter and related soil properties in forest, grassland and cultivated land use types', *International Journal of Physical Sciences*, 6(32), pp. 7410–7415. doi: 10.5897/IJPS11.427

- Lal, R. (2004 b). Soil carbon sequestration to mitigate climate change. *Geoderma*, 123(1–2), pp. 1–22. https://doi.org/: 10.1016/j.geoderma.2004.01.032

- Lorenz, K. et al. (2007) ‘Strengthening the soil organic carbon pool by increasing contributions from recalcitrant aliphatic bio(macro)molecules’, Geoderma, 142(1–2), pp. 1–10. doi: 10.1016/j.geoderma.2007.07.013.

- Lal, R. et al. (2021). Soils and sustainable development goals of the United Nations: An International Union of Soil Sciences perspective, Geoderma Regional, 25. https://doi.org/: 10.1016/j.geodrs.2021.e 00398.

- Loveland, P., and Webb, J. (2003). Is there a critical level of organic matter in the agricultural soils of temperate regions: A review, Soil and Tillage Research, 70(1), pp. 1–18. https://doi.org/: 10.1016/S0167-1987(02)00139-3.

- Lei, W. et al. (2023) ‘How does soil organic matter stabilize with soil and environmental variables along a black soil belt in Northeast China? An explanation using FTIR spectroscopy data’, Catena, 228(May 2022). doi: 10.1016/j.catena.2023.107152.

- Margenot, A. J., Calderón, F. J., Bowles, T. M., Parikh, S. J., & Jackson, L. E (2015). Soil Organic Matter Functional Group Composition in relation to Organic Carbon, Nitrogen, and Phosphorus Fractions in Organically Managed Tomato Fields, Soil Science Society of America Journal, 79(3), pp. 772–782. https://doi.org/: 10.2136/sssaj2015.02.0070.

- Navarro-Pedreño, J., Almendro-Candel, M. B., and Zorpas, A. A. (2021). The Increase of Soil Organic Matter Reduces Global Warming, Myth or Reality? In’, Sci (Vol. 3, Issue 1). https://. doi.org/: 10.3390/sci3010018.

- Oldfield, E. E., Bradford, M. A., and Wood, S. A. (2019). Global meta-analysis of the relationship between soil organic matter and crop yields, Soil, 5(1), pp. 15–32. https://doi.org/: 10.5194/soil-5-15-2019.

-Rowley, M. C., Grand, S. and Verrecchia, É. P. (2018) ‘Calcium-mediated stabilization of soil organic carbon’, Biogeochemistry, 137(1–2), pp. 27–49. doi: 10.1007/s10533-017-0410-1.

- Schnitzer, M. et al. (2006) ‘Long-term cultivation effects on the quantity and quality of organic matter in selected Canadian prairie soils’, Geoderma, 130(1–2), pp. 141–156. doi: 10.1016/j.geoderma.2005.01.021.

- Szatmári, G. et al. (2023) ‘Countrywide mapping and assessment of organic carbon saturation in the topsoil using machine learning-based pedotransfer function with uncertainty propagation, Catena, 227(May 2022). https://doi.org/: 10.1016/j.catena.2023.107086.
- Thai, S. *et al.* (2021) ‘Comparison of soil organic matter composition under different land uses by DRIFT spectroscopy’, *Plant, Soil and Environment*, 67(5), pp. 255–263. doi: 10.17221/11/2021-PSE.
- Turalija, L. (2022). Organic agriculture, biodynamic agriculture, Quantum agriculture and permaculture - differences and similarities, 54(4), pp. 136–143
- Veum, K. S., Goyne, K. W., Kremer, R. J., Miles, R. J., & Sudduth, K. A. (2014). Biological indicators of soil quality and soil organic matter characteristics in an agricultural management continuum, Biogeochemistry, 117(1), pp. 81–99. https://doi.org/: 10.1007/s10533-013-9868-7.
- Vancampenhout, K. et al. (2009) ‘Differences in chemical composition of soil organic matter in natural ecosystems from different climatic regions - A pyrolysis-GC/MS study’, Soil Biology and Biochemistry. Elsevier Ltd, 41(3), pp. 568–579. doi: 10.1016/j.soilbio.2008.12.023.
- Yeasmin, S., Singh, B., Smernik, R. J., & Johnston, C. T. (2020). Effect of land use on organic matter composition in density fractions of contrasting soils: A comparative study using 13C NMR and DRIFT spectroscopy, Science of the total environment, Elsevier B.V., 726, p. 138395. https://doi.org/: 10.1016/j.scitotenv.2020.138395.
- Zuo, W. et al. (2023) ‘Soil organic carbon sequestration in croplands can make remarkable contributions to China’s carbon neutrality, Journal of Cleaner Production. Elsevier Ltd, 382(November 2022), p. 135268. https://doi.org/: 10.1016/j.jclepro.2022.135268.
- Wu, Z. et al. (2022) ‘Influences of Environmental Variables and Their Interactions on Chinese Farmland Soil Organic Carbon Density and Its Dynamics’, Land, 11(2). doi: 10.3390/land11020208.

6- List of publications

1-**Masoudi M**, Estimation of the spatial climate comfort distribution using Tourism Climate Index (TCI) and Inverse Distance Weighting (IDW) (Case study: Fars Province, Iran. Arabian journal of geoscience. 14, 363 (2021) (Springer). IF: 1.3-1.5. (**Q2**)

2-**Masoudi M**, Centeri Csaba, Jakab Gergely, Nel Lyndré, Mojtahedi, Mehdi. GIS-based multi-criteria and multi-objective evaluation for sustainable land use planning (Case study: Qaleh Ganj County, Iran). International Journal of Environmental Research. 15:457–474. (Springer) (**Q2**)

3-**Masoudi M**., Centeri1 Cs, Karlik M, Jakab G (2023), Extracted and in-situ soil investigations to assess the effects of different land use and tillage management practices on soil organic matter composition. Land degradation and development, 34(9), 2560–2572. https://doi.org/10.1002/ldr.4629, IF: 4.95 (**Q1**)

4-Al-Maliki, S., Ibrahim, T. I., Jakab, G., **Masoudi, M**., Makki, J. S., & Vekerdy, Z. (2022). An Approach for Monitoring and Classifying Marshlands Using Multispectral Remote Sensing Imagery in Arid and Semi-Arid Regions, Water, 14(10):1523, IF; 3 - Q2

5-Jakab, G., Madarász, B., **Masoudi, M**., Karlik, M., Király, C., Zacháry, D., ... & Szalai, Z. (2023). Soil organic matter gain by reduced tillage intensity: Storage, pools, and chemical composition. Soil and Tillage Research, 226, 105584, 7.04, (**Q1**)

6- Jakab, G., Bede-Fazekas, Á., Vona, V., Madarász, B., Karlik, M., Zacháry, D., ..., **Masoudi, M** & Szalai, Z. (2024). Beyond land use: Understanding variations in topsoil bulk versus recalcitrant organic matter. Catena, 244, 108232. 6.06, (**Q1**)

7-Nel, L. **Masoudi, M**. (2020). Potential carbon sequestration across Szentendre Island. Journal of Landscape Ecology, 18 (2): 165–173. (**Q4**)

8-**Masoudi, M**, Vona, V, Vona, M. (2021). Assessment of the relationship between soil properties in an old woodland and its relation to tree density and tree trunk circumference. Journal of Landscape Ecology, 19 (2): 81–89. (**Q4**)

Conferences:

9-**Masoudi M**, Assessment and zoning of climatic comfort condition using tourism climatic index and GIS (A case study from Fars province, IRAN). Bratislava, Slovakia, Institute of Hydrology SAS (2019), pp. 128-139.

10-**Masoudi M**, Mapping soil organic carbon using remote sensing techniques. Water management, focus on climate. Szarvas: Szent István University, Institute of Irrigation and Water Management. (2020), pp 103-113.

11-**Masoudi M**, Centeri Cs, Jakab G, Vona V, Vona M. Heterogeneity of soil organic carbon content in an old tree line and its relation to some tree properties. Hungarian Soil Science Conference, (2020). Hungarian Abstract

12-**Masoudi M**, Centeri Cs, Jakab G. Qualitatively assessment impact of land use change on soil horizon and soil color. Bratislava, Slovakia, Institute of Hydrology SAS, (2021) pp 9-10.

13-Jakab G. Filep, T. Király Cs. Madarász, B. Zacháry, D. Ringer, M. Vancsik, A. **Masoudi, M** and Szalai, Zoltán. Characterizing soil organic matter differences among extracts and the solid phase – the role of conservation tillage. EGU General Assembly, (2020). English Abstract.

14-**Masoudi M**, Centeri Cs, Jakab G, Vona V, Vona M. Using technique of Near-Infrared spectrometry for soil measurement. every drop count: Szarvas, MATE Hungarian University of Agriculture and Life Sciences, Institute of Irrigation and Water Management, (2021), pp 12

15-**Masoudi M**, Centeri, Cs, Jakab G, Vona V, Vona M. Near-infrared spectroscopy for rapid assessment of soil properties under different land-use management. Eurosoil. (2021). Geneva, English abstract

16-**Masoudi M**, Centeri, Cs, Jakab, G. Comparison of NIR spectroscopy and Tyurin methodology for predicting soil organic matter in cropland. Bratislava, Slovakia, Institute of Hydrology SAS, (2021), pp 20-24.

17-**Masoudi M**, Centeri, Cs, Jakab G (2022). The effect of different agricultural management on Soil Organic Matter content A case study: Józsefmajor, Hungary. 22nd World Congress of Soil Science 31 July-5 August Scotland, Glasgow

18-**Masoudi M**, Centeri Cs, Jakab, G. (2022). Mapping soil organic matter using ordinary kriging. 4th International Conference of Young Scientists Soil in the Environment. Poland

18-**Masoudi M**, Centeri Cs, Vona V, Vona M , Jakab G.. (2022).Assessment of soil properties under different tillage operations. The 13th ICEEE-2022 Online International

Annual Conference on “Global Environmental Development & Sustainability: Research, Engineering & Management”. 4pp
20-**Masoudi M**, Centeri Cs, Jakab G, Biró Z, Nel L, Kovács E, Prohaszka V. (2022). The effect of different land uses on soil organic matter content in the Zselic region, Hungary. VIth International Symposium on “Biosphere & Environmental Safety” 7 pp
21-**Masoudi, M**. (2022). 22nd World Congress of Soil Science 31 July-5 August Scotland, Glasgow. Journal of Landscape Ecology, 20 (2): 137-139