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ROLE OF GRASSLANDS IN CARBON SEQUESTRATION: A HYPOTHETICAL RESEARCH APPROACH

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Abstract

Grasslands are among the most widespread terrestrial ecosystems, covering over one-third of the Earth's surface. They play a pivotal role in carbon sequestration and the accumulation of soil organic matter (SOM), processes essential for soil fertility, biodiversity conservation, and climate regulation. The degradation and conversion of grasslands into croplands have historically contributed to significant soil organic carbon (SOC) losses, intensifying global warming. This hypothetical research paper proposes a comparative analysis of SOM dynamics between grasslands and arable lands worldwide. A standardized experimental design is outlined, involving soil sampling at two depths (0-20 cm and 20-40 cm), across three land-use types (natural grassland, degraded grassland, and arable land). Hypothetical results, based on existing literature, indicate that grassland soils retain 30-50% more SOM than arable soils, particularly in the upper soil layers. Findings emphasize the necessity of protecting grasslands through sustainable management practices such as controlled grazing, overseeding, and restoration programs. Global policies must prioritize grassland conservation to achieve soil health, food security, and climate change mitigation objectives.

Key words*: arable lands, biodiversity, carbon sequestration, grassland, soil organic matter.*

INTRODUCTION

Soil organic matter (SOM) is important for terrestrial ecosystem productivity, regulating essential functions such as nutrient cycling, water, soil structure stability and biodiversity support (Hussain et al., 2023). Globally, soils contain more than three times the amount of carbon stored in the atmosphere, and grasslands alone are estimated to store around 343 billion tons of carbon in the first meter of soil, surpassing forest ecosystems in terms of soil carbon stocks (FAO, 2015). Despite this, grasslands are among the most threatened ecosystems due to land-use conversion, overgrazing, and climate change (Bai et al., 2008; IPCC, 2021).

In recent decades, the expansion of arable land has occurred at the expense of grassland areas, confirming the ongoing trend of their transformation into cropland (FAO, 2015).

Over the past century, approximately 20% of natural grasslands have been converted to agricultural land (Ramankutty et al., 2008), leading to SOM losses of up to 60% (Paustian et al., 1997). This decline not only reduces soil fertility but also exacerbates atmospheric CO_2 concentrations. Understanding and quantifying the contribution of grasslands to SOM accumulation is therefore crucial for sustainable land management and climate change mitigation strategies (Paustian et al., 1997).

Globally, policies promoting grassland conservation are unequal. In Europe, agri-environmental schemes have provided incentives for sustainable grazing, while in developing regions, overgrazing and conversion continue to dominate (Elliott et al., 2023). Future research must focus on quantifying regional variations in SOM accumulation and integrating socio-economic factors to ensure effective implementation of grassland management strategies.

In Romania, grasslands cover approximately 4.8 million hectares, representing nearly one third of the country's agricultural area (MADR, 2022). These ecosystems are highly diverse, ranging from alpine pastures in the Carpathians to lowland meadows in the Danube Plain, and they constitute a major reservoir of biodiversity and soil organic matter (SOM). However, their ecological and productive potential is often underutilized due to management challenges such as overgrazing, insufficient fertilization, and in some regions, land abandonment. Abandonment of pastures has become an increasingly widespread phenomenon, with negative consequences on biodiversity and the productive value of ecosystems. Studies conducted in the Apuseni Mountains show that grasslands go through distinct successional stages, in which floristic diversity decreases rapidly after the cessation of traditional use (Păcurar et al., 2015; Malinas et al., 2020).

Beyond their agronomic and ecological importance, Romanian grasslands also represent a basic principle for the transition to sustainable agriculture and the green economy. Natural grasslands and perennial crops are agricultural systems that are favourable for increasing the amount of organic matter in the soil. In the following paper, we will refer to natural grasslands in terms of their management to increase the amount of organic matter in the soil.

This study presents bibliographical research framework aimed at comparing the accumulation of soil accumulation in natural grasslands, degraded grasslands, and arable lands. The central hypothesis is that grasslands, due to their perennial root systems and reduced soil disturbance, accumulate and retain considerably more SOM than cultivated croplands.

MATERIALS AND METHODS

The bibliographical experimental design assumes a global comparative study after Guo and Gifford, 2002, involving three land-use types: (i) natural grasslands, (ii) degraded grasslands, and (iii) arable lands. Soil sampling is conducted at two standard depths: 0-20 cm (topsoil) and 20-40 cm (subsoil), with three replicates per site. Sites are assumed to represent diverse climatic zones, including temperate, tropical, and semi-arid regions, to capture the global variability of grassland ecosystems.

Soil organic matter is measured using the Walkley-Black method for organic carbon determination, with values converted to SOM by applying a factor of 1.724. Additional soil parameters include pH (measured in a 1:2.5 soil-to-water ratio), texture (hydrometer method), and bulk density (core method). Hypothetical values are derived from the synthesis of published literature (Guo & Gifford, 2002).

RESULTS AND DISCUSSIONS

The hypothetical results of Guo and Gifford, 2002 demonstrate clear differences in SOM content between land-use types and soil depths. Natural grasslands consistently show the highest SOM concentrations, followed by degraded grasslands, with arable lands having the lowest values. SOM content decreases with depth across all land uses (Figure 1).

The simulated results strongly support the hypothesis that grasslands serve as more effective carbon sinks compared to arable lands. The 30-50% higher SOM content observed in grasslands aligns with global meta-analyses (Guo & Gifford, 2002; Conant et al., 2017). Perennial grasses contribute continuous organic inputs through litterfall and extensive root systems, which penetrate deeper soil layers and enhance soil aggregation. Reduced soil disturbance in grasslands also minimizes carbon losses compared to frequently tilled croplands.

The comparative analysis between land-use types highlights not only quantitative differences in soil organic matter (SOM) levels, but also qualitative differences in the stability and turnover of organic fractions. These emphasize the role of grasslands in global climate strategies, reflecting the recommendations of the IPCC (2021) regarding nature-based solutions for carbon sequestration. In natural grasslands, the continuous input of root exudates and litter promotes the accumulation of stable humic substances, whereas in arable systems, frequent tillage accelerates the decomposition of labile organic matter (Rotar & Pacurar, 2010). Thus, the vegetation specific to well-established steppe grasslands produces annually 10-20 t/ha of plant residues consisting of roots, stems, leaves, etc. It is worth noting that the majority is represented by roots that accumulate within the soil over a thickness greater than 100 cm with a higher concentration in the first 40-50 cm (Blaga et al., 2005). On the other hand, SOM in croplands is more dynamic and vulnerable to losses under climatic conditions.

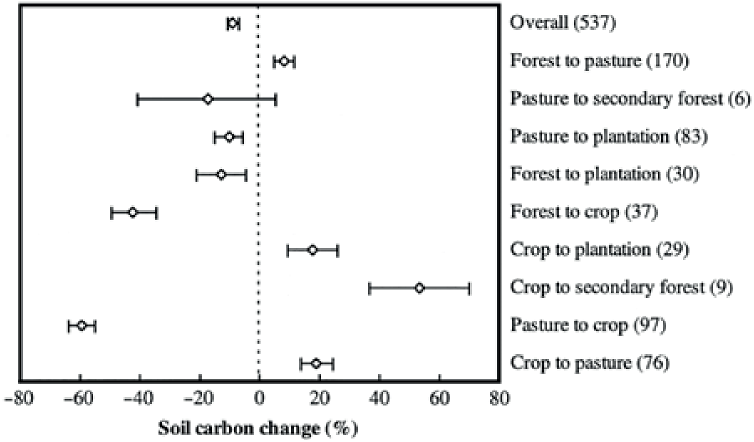

Figure 1. The presence of carbon in soil after different crop modification methods (after Guo & Gifford, 2002)

Recently, European strategies, such as the Biodiversity Strategy for 2030 and the Farm to Fork Strategy, emphasize the need to integrate semi-natural grasslands into more extensive sustainability objectives. In Romania, for example, these ecosystems contribute directly to the provision of public goods: clean water, pollination services, landscape preservation and important in preservation cultural heritage (Dragomir et al, 2023). Semi-natural pastures, many of which are Natura 2000 sites, host rare plant and animal species that cannot survive in intensive agricultural systems, that is the reason why from an economic point of view, grasslands offer opportunities for diversification, through the production of traditional dairy and meat products with high added value, as well as through the development of eco-tourism, species conservation and medicinal raw material. Certified products originating from extensive grassland systems can benefit from European quality schemes (e.g., Protected Designation of Origin-PDO, Protected Geographical Indication-PGI), linking environmental conservation with rural development (European Commission, 2023).

Nevertheless, challenges remain significant: land fragmentation, grassland's abandon and the effects of climate change (droughts, extreme weather) threaten the long-term sustainability of these natural ecosystems. Adaptive management, the integration of traditional practices with technological innovations, and the strengthening of farmer cooperatives are necessary measures to increase grassland resilience.

In this context, Romanian grasslands stand at the interface between tradition and innovation, offering both ecological stability and economic potential. By embedding them into national and European sustainability policies, they can play a decisive role in the transition towards a climate-neutral and resource-efficient agriculture.

Recent studies in Transylvania and the Subcarpathian hills highlight that permanent grasslands managed extensively (mowing and moderate grazing) store between 30-45% more SOM compared to adjacent arable lands (Blaga et al., 2005; Popovici & Ciubotariu, 1992). In contrast, grasslands subjected to frequent ploughing and reseeding exhibit accelerated organic matter mineralization, with losses comparable to those observed in degraded pastures. The role of microbial communities in the stability and functionality of grassland ecosystems is increasingly recognized, and recent research highlights the link between long-term fertilizer application and changes in the soil microbiome (Stoian et al., 2022; Vidican et al., 2023).

Similar experiments conducted on high-natural value grasslands in the Apuseni Mountains have shown that long-term fertilization modifies colonization strategies at the root level of dominant species, with implications for microbial and plant biodiversity (Corcoz et al., 2022).

The Romanian case provides additional insights. Measurements from the Apuseni Mountains and Subcarpathian areas (Popovici & Ciubotariu, 1992; Blaga et al., 2005) confirm that permanent grasslands managed extensively contain significantly higher organic carbon stocks in the upper 40 cm of soil compared to adjacent arable fields.

At the same time, results suggest that the depth distribution of SOM is critical. In natural grasslands, up to 60% of the total SOM stock is concentrated in the first 20 cm of soil, largely due to dense root mats. However, the deeper layers (20-40 cm) also retain significant amounts, ensuring long-term stability (Lisec et al., 2025). This contrasts with arable systems, where SOM is predominantly surface-bound and more easily lost through erosion or oxidation. The role of deep root systems in perennial grasses is thus central to the long-term sequestration of carbon.

Climate change introduces new dynamics in SOM accumulation. Drying climate, droughts, increasingly frequent even in Romania, may affect plant production, but evidence suggests that root allocation increases under water stress, potentially enhancing belowground carbon inputs (Vörös et al., 2025).

Another important aspect revealed by the simulated results of Guo and Gifford, 2002 is the resilience of degraded grasslands. Although their SOM content is reduced compared to natural grasslands, they still maintain higher levels than arable lands. This indicates that even partially degraded systems retain a carbon sequestration potential that could be restored through interventions such as overseeding with legumes, controlled grazing, or organic fertilization. Case studies from Brașov and Cluj counties show that, after 5-7 years of improved management, SOM levels in degraded grasslands increased by 15-20%, approaching those of semi-natural systems (Dumitrescu et al., 1987).

Sustainable management practices are essential to maintain and enhance SOM in Romanian grasslands. Controlled grazing systems, periodic overseeding with legumes and valuable grasses, as well as organic fertilization with manure or compost have shown positive effects on soil structure and carbon sequestration (Dumitrescu et al., 1987). Moreover, agri-environmental measures supported under the Common Agricultural Policy (CAP) encourage farmers to preserve semi-natural grasslands, recognizing their role in climate change mitigation.

Measures to improve grasslands that contribute to increasing green mass yields and the quantity of roots in the soil are important, like harrowing and overseeding. The success of the work depends mainly on the quality of execution and the era, and in case of success it has a favourable effect on the properties of the soil.

Routine maintenance work (weed control, removal of woody vegetation, area modelling, weed control, etc.) has a favourable effect on soil properties, which has a positive impact on the harvest. Partial mobilization works considerably reduce soil erosion, favourably influence the water balance and protect the soil structure to a greater extent.

Favourable effects on production appear starting from the second year after sowing (Dumitrescu et al., 1987).

Total soil mobilization works on grasslands have a considerable influence on the decomposition and accumulation of organic matter in the soil and, through this, on the soil structure.

Soil organic matter plays an important role in healthy soil functions. Major soil functions such as primary production, water purification and regulation, carbon sequestration and regulation, biodiversity, and nutrient cycling depend largely on soil organic matter. Soil organic matter is made up of approximately 58% carbon, which has largely been taken up from the atmosphere by plant photosynthesis (Grand & Michel, 2020).

Tillage works lead to rapid decomposition of the mobile fraction of the soil's organic matter, which thereby adversely influences the soil structure (the proportion of stable water aggregate decreases), processes is very rapid, occurring over a few years (Figure 2). Tillage has the opposite effect, leading to the accumulation of organic matter and, at the same time, to the improvement of soil structure. The process is very slow, with the balance between the amount of organic matter accumulated and the amount decomposed being achieved over decades (Dermatti, 1972).

At the opposite pole, increasing soil aeration through ploughing and stimulating the factors that determine its decline, especially in intensive agricultural systems, and over time exposes the soil to a series of degradation processes, sometimes irreversible.

The mineralization of organic matter in the soils of cleared meadows occurs at an accelerated rate in approximately 6 years, reaching the level of that in arable lands.

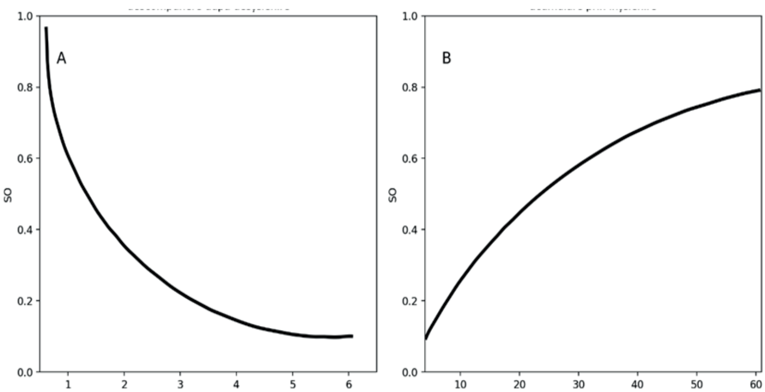

Figure 2. Scheme of the dynamics of organic matter (SO) in a grassland soil, after Dermatti, 1972 (A - the rate of decomposition of organic matter after tillage; mobile SO decomposes, for the most part, within a few years. B - the rate of accumulation of organic matter through tillage; the balance between accumulated SO and decomposed SO is achieved within a few decades

CONCLUSIONS

This bibliographical research emphasizes the role of grasslands in soil organic matter accumulation and carbon sequestration.

Grasslands contain 30-50% more SOM than arable lands, especially in the top 20 cm of soil.

Proper management of natural grasslands to increase harvest also implies an increase in the number of roots in the soil, making considerable progress in the accumulation of organic matter.

Sustainable management practices such as rotational grazing, overseeding, and reduced soil disturbance are essential to maintain SOM stocks.

Global policies must prioritize grassland conservation and restoration in soil health and climate change mitigation even if further research is needed to validate these.

REFERENCES

Bai, Z. G., Dent, D. L., Olsson, L., & Schaepman, M. E. (2008). *Global assessment of land degradation and improvement. Identification by remote sensing* (Report 2008/01). ISRIC – World Soil Information.

Blaga, G., Filipov, F., Udrescu, S., Rusu, I., & Vasile, D. (2005). *Pedology.* AcademicPres Publishing House. ISBN 973-744-004-8

Conant, R. T., Cerri, C. E. P., Osborne, B. B., & Paustian, K. (2017). Grassland management impacts on soil carbon stocks: A new synthesis. *Ecological Applications, 27*(2), 662–668. https://doi.org/10.1002/eap.1473

Corcoz, L., Păcurar, F., Pop-Moldovan, V., Vaida, I., Pleșa, A., Stoian, V., & Vidican, R. (2022). Long-term fertilization alters mycorrhizal colonization strategy in the roots of *Agrostis capillaris*. *Agriculture, 12*(6), 847. https://doi.org/10.3390/agriculture12060847

Dermatti, W. (1972). Effects of crops and grass on soil structure. In D. S. Kimber (Ed.), *Forage in the arable farm* (Occasional Symposium No. 7). British Grassland Society.

Dragomir, N., Mocanu, V., & Dragomir, N. (2023). Multifunctionality of grasslands – Permanent way of sustainable utilization of regional resources in Romania. *Journal of Energy and Natural Resources, 12*(4), 38–46. https://doi.org/10.11648/j.jenr.20231204.11

Dumitrescu, N., Silistru, D., & Calian, D. (1987). Regeneration of grasslands affected by surface erosion. *Scientific Papers of SCPCP Măgurele Brașov, 12*, 83–92.

Elliott, J., Tindale, S., Outhwaite, S., Nicholson, F., Newell-Price, P., Sari, N. H., Hunter, E., Sánchez-Zamora, P., Jin, S., Gallardo-Cobos, R., et al. (2024). European permanent grasslands: A systematic review of economic drivers of change, including a detailed analysis of the Czech Republic, Spain, Sweden, and UK. *Land, 13*(1), 116. https://doi.org/10.3390/land13010116

European Commission. (2023). *CAP strategic plan for Romania 2023–2027.* DG Agriculture and Rural Development.

FAO. (2015). *FAO STAT statistical database 2015.* Food and Agriculture Organization of the United Nations.

Grand, A., & Vincent, M. (2020). *Soil organic matter.* Landwirtschaft Grand & Agroscope. https://www.best4soil.eu/videos/18/ro

Guo, L. B., & Gifford, R. M. (2002). Soil carbon stocks and land use change: A meta-analysis. *Global Change Biology, 8*(4), 345–360. https://doi.org/10.1046/j.1354-1013.2002.00486.x

Hussain, A., Bashir, H., Zafar, S. A., Rehman, R. S., Khalid, M. N., Awais, M., Sadiq, M. T., & Amjad, I. (2023). The importance of soil organic matter (SOM) on soil productivity and plant growth. *Biological and Agricultural Sciences Research Journal, 2*(11).

IPCC. (2021). *Climate change 2021: The physical science basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press. https://doi.org/10.1017/9781009157896

Lisec, U., Prevolnik Povše, M., Podvršnik, M., & Kramberger, B. (2025). Impact of grassland management system intensity on composition of functional groups and soil chemical properties in semi-natural grasslands. *Plants, 14*(15), 2274. https://doi.org/10.3390/plants14152274

Mălinas, A., Rotar, I., Vidican, R., Iuga, V., Păcurar, F., Mălinas, C., & Moldovan, C. (2020). Designing a sustainable temporary grassland system by monitoring nitrogen use efficiency. *Agronomy, 10*(1), 149. https://doi.org/10.3390/agronomy10010149

Ministerul Agriculturii și Dezvoltării Rurale (MADR). (2022). *Raport privind suprafețele de pajiști permanente din România.* București, România.

Paustian, K., Collins, H. P., & Paul, E. A. (1997). Management controls on soil carbon. In E. A. Paul, K. Paustian, E. T. Elliott, & C. V. Cole (Eds.), *Soil organic matter in temperate agroecosystems* (pp. 15–49). CRC Press.

Popovici, D., & Ciubotariu, C. (1992). Research on long-term fertilization with different forms of nitrogen fertilizer on *Agrostis tenuis* and *Festuca rubra* meadows. *Scientific Papers of SCPCP Măgurele Brașov, 15*, 9–25.

Ramankutty, N., Evan, A. T., Monfreda, C., & Foley, J. A. (2008). Farming the planet: Geographic distribution of global agricultural lands in the year 2000. *Global Biogeochemical Cycles, 22*(1), GB1003. https://doi.org/10.1029/2007GB002952

Rotar, I., & Păcurar, F. (2010). Grassland management in Transylvania (Romania): Case studies and perspectives. *Romanian Journal of Grassland and Forage Crops, 1*, 35–48.

Stoian, V., Vidican, R., Florin, P., Corcoz, L., Pop-Moldovan, V., Vaida, I., Vâtcă, S.-D., Stoian, V. A., & Pleșa, A. (2022). Exploration of soil functional microbiomes - A concept proposal for long-term fertilized grasslands. *Plants, 11*(9), 1253. https://doi.org/10.3390/plants11091253

Vidican, R., Mihăiescu, T., Pleșa, A., Mălinaș, A., & Pop, B.-A. (2023). Investigations concerning heavy metals dynamics in *Reynoutria japonica* Houtt – soil interactions. *Toxics, 11*(4), 323. https://doi.org/10.3390/toxics11040323

Vörös, A. F., Mojzes, A., Cseresnyés, I., Kalapos, T., Kertész, M., Könnyű, B., Ónodi, G., & Kröel-Dulay, G. (2025). The effects of an initial extreme drought and chronic change in precipitation on plant biomass allocation in a temperate grassland. *Ecology and Evolution, 15*(9), e71625. https://doi.org/10.1002/ece3.71625

Walkley, A., & Black, I. A. (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science, 37*(1), 29–37.