Farmers' perception of soil carbon storage potential: Case studies from Mureș and Brașov counties

[1]F. Camelia Oroian, [2]Antonia Odagiu, [2]I. Valentin Petrescu-Mag, [1]Iulia C. Mureșan, [2]Cristian Iederan, [2]Paula Moraru, [2]Petru Burduhos

[1] Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania; [2] Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, Cluj-Napoca, Romania. Corresponding author: A. Odagiu, aodagiu@gmail.com

Abstract. Cultivation practices are essential for improving carbon storage in the soil. This research was conducted in the central region of Romania and focused on evaluating the perceptions of 38 farmers from Mureș and Brașov counties regarding soil carbon storage. The results show that respondents generally have a basic to moderate understanding of carbon sequestration practices, with notable variability in the adoption of different techniques to enhance soil carbon content. Although certain practices are moderately adopted, there may be room for improvement in areas such as water conservation technologies or regular soil analyses.
Key Words: agricultural practices, agronomy, carbon sequestration, cluster analysis, horticulture, respondents, Romania.

Introduction. Although previously criticized (Burrascano et al 2016), since 2021, the European Commission has focused on promoting carbon storage in agriculture (Bamière et al 2023). This initiative aims to encourage conservation agricultural practices that allow for the long-term storage of carbon in the soil (Arias-Navarro et al 2023; Radu et al 2024). The amount of carbon in the soil is primarily controlled by the balance between the inputs and outputs of organic matter, mainly due to decomposition (Wuest & Gollany 2013). These practices include methods such as using cover crops, crop rotation, incorporating shredded pruning residues, applying manure, restoring peatlands, and expanding agroforestry systems, among others (Creed et al 2022; Mrunalini et al 2022; Oroian et al 2023; Petrescu-Mag et al 2023). These conservation practices improve the biological, chemical, and physical properties of the soil by increasing soil organic carbon (SOC) (Cotrufo et al 2019). Therefore, it is necessary to identify the major factors affecting SOC changes in land use under future climate warming conditions to ensure the long-term provision of ecosystem services by the soil (Campbell & Paustian 2015). This research was conducted in the central region of Romania and focused on evaluating the perceptions of 383 farmers from Mureș and Brașov counties regarding soil carbon storage.

Material and Method. This study was conducted in the central development region of Romania, a region recognized for its good agricultural potential. To fulfill the objectives of this research, a quantitative survey was carried out between March and June 2024. A total of 38 questionnaires were developed and distributed to 38 farmers in Mureș and Brașov counties in order to collect data on their perceptions regarding the potential for organic carbon storage in agricultural soils. Each questionnaire comprised a number of 15 questions, offering various response options, ranging from yes/no to multiple-choice formats.

The sample size was determined using Cochran's formula (https://www.statisticshowto.com/probability-and-statistics/find-sample-size/):

$n_0 = z^2 \times p \times q/e^2$

$n = n_0/1 + [(n_0 - 1)/N]$

Where: e – desired level of precision; p – estimated proportion of the population; q = 1 – p; n_0 – Cochran sample size; N - population size; z=1.96 (https://www.statisticshowto.com/tables/z-table/).

For this study, we estimated the population proportion to be 0.5%, and the sample size calculation was based on the population of Mureș and Brașov Counties, which, according to the 2021 census, was 1064808 inhabitants (https://www.recensamantromania.ro/rezultate-rpl-2021/rezultate-definitive/).
Therefore, the calculation resulted in:

$n_0 = 3.481 \times (0.25/0.0229) = 38.01$

$n = 38.01/1 + [(37.35 - 1)/1064808] = 38.01$

Statistical analysis was conducted using STATISTICA v.10 for windows. To obtain a synthetic perception of respondents concerning their perceptions regarding the potential for organic carbon storage in agricultural soils, the histogram of the 15 items was analyzed, together with simple Spearman correlations between items and cluster analysis.

The x-axis of the histogram represents a specific range of responses for each variable, representing a scoring scale or frequency of certain practices. The y-axis indicates the number of respondents, and higher bars indicate that more respondents selected a particular range of responses. Each variable is represented by a different color, as indicated in the legend. The distribution for each variable is overlaid on the same graph, allowing for comparison between the different variables.

The linearity of correlations between items was tested, and due to the lack of linearity in most cases, the nonparametric Spearman test was employed to calculate simple correlations. Multi-exploratory techniques were applied for performing the cluster analysis. The x-axis lists the variables involved in the cluster analysis. Each of these variables corresponds to the considered items. The y-axis represents the "linkage distance" or the dissimilarity between clusters. The greater the vertical distance between two merged clusters is, the more dissimilar they are.

Results and Discussion. The distribution of responses for each of the 15 variables related to various aspects of carbon sequestration in agriculture is emphasized by the histogram (Figure 1). According to the graphic representation, most respondents have a basic to moderate understanding of carbon sequestration terminology. The awareness of methods aimed at enhancing carbon sequestration is generally moderate among the respondents. Concerning the utilization of soil tillage technologies, we find that distribution is more spread out, indicating a broader range of responses, meaning that some respondents may utilize these technologies to a higher extent than others. While there is some diversity, most respondents implement a limited variety of soil management practices. According to the histogram, the practice of using cover crops is relatively common among the respondents. Because the distribution is more evenly spread, it suggests a moderate use of various plants as cover crops. The responses indicate a moderate preference for certain crops to enhance soil carbon content. Considering that the distribution is slightly skewed towards higher values, we may observe a variability in how residues are managed. According to the respondents, a significant use of organic or natural fertilizers is reported. Conducting soil analyses is a moderately regular practice. The water conservation technologies are somewhat commonly used, but there might be room for increased adoption. The respondents more frequently evaluate the impact of their practices on SOC, and generally recognize a moderate number of technologies as effective. The conservation agriculture practices are moderately adopted, with some variability among respondents. A basic to moderate understanding among respondents of how agricultural practices relate to soil carbon sequestration and climate change is reported (Figure 1).

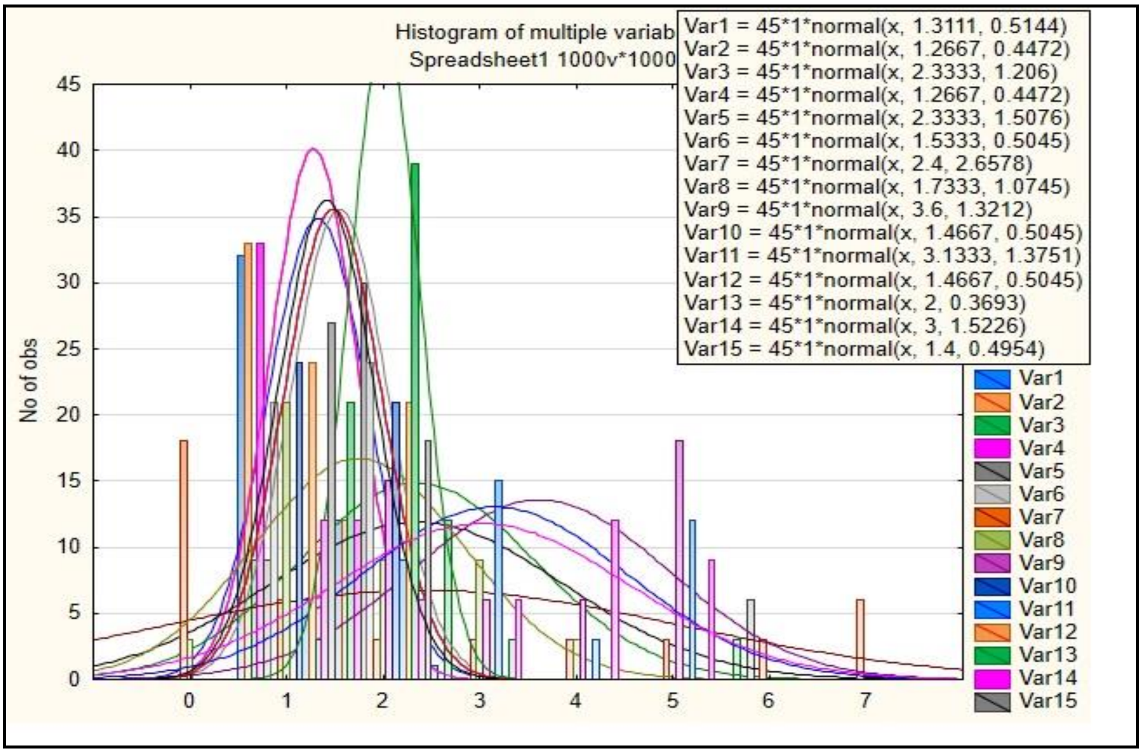

Figure 1. The histogram of variables concerning the carbon sequestration perceptions of respondents; Var 1 - understanding of carbon sequestration terminology; Var 2 - awareness of methods aimed at enhancing carbon sequestration in agriculture; Var 3 - the extent to which soil tillage technologies designed to preserve soil structure and integrity are utilized on the farm; Var 4 - varieties of soil management practices implemented on the farm; Var 5 - the extent of utilizing cover crops to maintain soil coverage and enhance the supply of organic matter; Var 6 - varieties of plants employed as cover crops; Var 7 - varieties of crops favored for the continuous enhancement of soil carbon content; Var 8 - management practices for handling plant and crop residues; Var 9 - the extent of using organic or natural fertilizers to enhance soil quality and boost carbon sequestration; Var 10 - the regularity of conducting soil analyses to evaluate organic carbon content and other key soil characteristics; Var 11 - the extent of utilizing water conservation technologies to maintain soil moisture; Var 12 - evaluation of the effects of agricultural practices on the dynamics of organic carbon in soil; Var 13 - technologies and agricultural practices identified as most effective in promoting carbon sequestration in soil; Var 14 - adoption of conservation agriculture to minimize soil disturbance and enhance carbon sequestration; Var 15 - understanding the relationships between agricultural practices, soil carbon sequestration, and climate change.

The overlaid distributions show that, while there is variability in responses across different variables, the histogram indicates that most practices and understandings are adopted or understood to a moderate extent. The evaluation of the effects of agricultural practices on the dynamics of organic carbon in soil, and the extent of using organic or natural fertilizers to enhance soil quality and boost carbon sequestration are practices that have greater variability among respondents. Worldwide, there are diverse approaches and variability among farmers in evaluating agricultural practices that impact soil organic carbon, particularly concerning the use of organic or natural fertilizers to improve soil health and sequester carbon (Dick & Gregorich 2003). The data indicates that, while certain practices are moderately adopted, there might be room for improvement in areas like water conservation technologies or regular soil analyses. The use of organic fertilizers and evaluation of practices are areas where respondents are more active, which could serve as a basis for encouraging further adoption of related practices. By analyzing these distributions emphasized by the histogram, areas where further efforts are needed to enhance adoption and understanding of sustainable agricultural practices can be easily identified.

The scatterplot correlation matrix. The scatterplot correlation matrix emphasizes the relationships between pairs of analyzed variables, helping to identify correlations, trends, and potentially redundant variables (Figure 2).

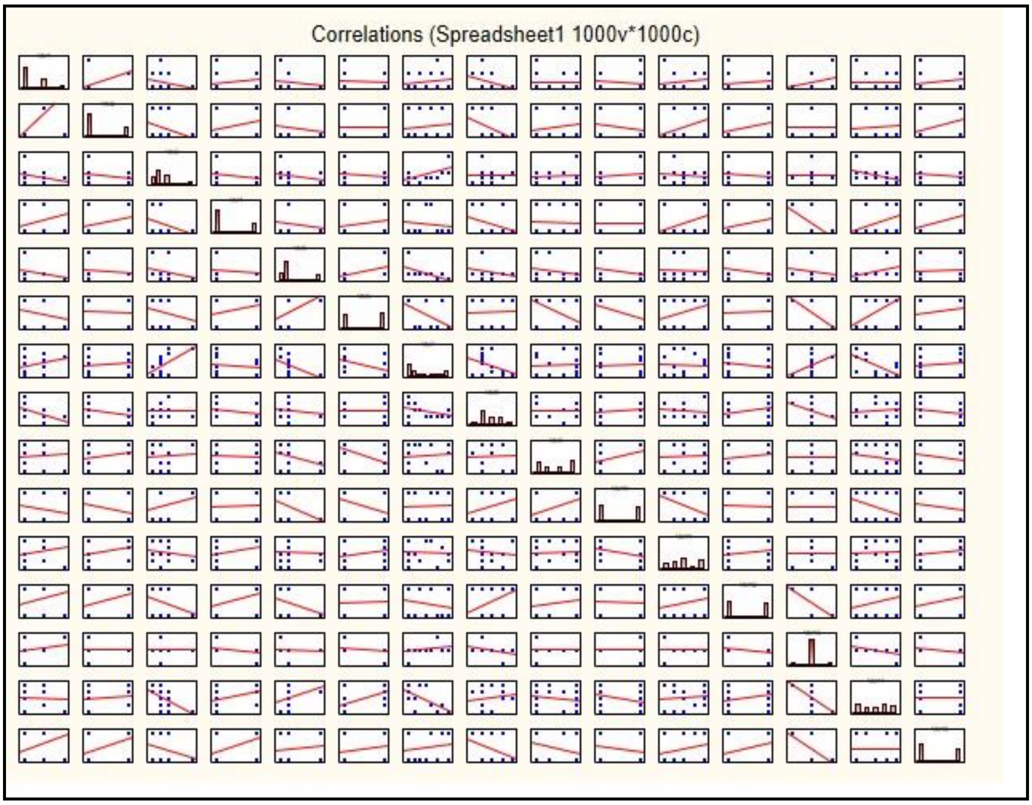

Figure 2. The graphic representation of the simple Spearman correlations between the variables concerning the carbon sequestration perceptions of respondents; Var 1 - understanding of carbon sequestration terminology; Var 2 - awareness of methods aimed at enhancing carbon sequestration in agriculture; Var 3 - the extent to which soil tillage technologies designed to preserve soil structure and integrity are utilized on the farm; Var 4 - varieties of soil management practices implemented on the farm; Var 5 - the extent of utilizing cover crops to maintain soil coverage and enhance the supply of organic matter; Var 6 - varieties of plants employed as cover crops; Var 7 - varieties of crops favored for the continuous enhancement of soil carbon content; Var 8 - management practices for handling plant and crop residues; Var 9 - the extent of using organic or natural fertilizers to enhance soil quality and boost carbon sequestration; Var 10 - the regularity of conducting soil analyses to evaluate organic carbon content and other key soil characteristics; Var 11 - the extent of utilizing water conservation technologies to maintain soil moisture; Var 12 - evaluation of the effects of agricultural practices on the dynamics of organic carbon in soil; Var 13 - technologies and agricultural practices identified as most effective in promoting carbon sequestration in soil; Var 14 - adoption of conservation agriculture to minimize soil disturbance and enhance carbon sequestration; Var 15 - understanding the relationships between agricultural practices, soil carbon sequestration, and climate change.

The strong positive correlation between understanding terminology and awareness of methods suggests that these items are related and possibly measuring similar constructs. For example, positive correlation between understanding terminology and understanding relationships with climate change suggest that those who understand the terminology well, also have a good grasp of how agricultural practices impact climate change; or positive correlation between the use of organic fertilizers and adoption of conservation agriculture indicates that respondents who use organic fertilizers are also likely to adopt conservation agriculture practices, suggesting a holistic approach to sustainable farming. The relationship between the use of organic fertilizers and the adoption of conservation agriculture, highlighting how farmers who embrace organic fertilizers often also adopt conservation practices, reflects a holistic approach to sustainability (Duiker & Thomason 2014; Friedrich et al 2014). The negative correlation between the extent of tillage and adoption of conservation agriculture indicates that these practices are seen as opposites or incompatible in the respondents' views. The weak and very weak correlations suggest that the concerned practices or understandings are independent. This independence could indicate that these practices or understandings are not necessarily related or are influenced by different factors. For example, the weak correlation between understanding relationships between practices, soil carbon, and climate change, on one hand, and varieties of plants employed as cover crops, and varieties of crops favored for the continuous enhancement of soil carbon content, on the other hand, suggests that this understanding does not translate into practical actions. The weak correlations between knowledge of sustainable soil carbon practices and practical choices of cover crops or crop varieties aimed at increasing soil carbon could represent a barrier to the effective implementation of sustainable agriculture principles aimed at ensuring carbon sequestration in soil (Funes et al 2002). By identifying patterns in relationships between analyzed items, results insights into how different practices and levels of awareness are interrelated, potentially guiding future interventions, educational efforts, or policy decisions aimed at enhancing carbon sequestration in agriculture.

The cluster analysis. The cluster analysis provides a visual representation of how the different variables related to carbon sequestration practices in agriculture group together based on respondent data. It highlights relationships between different practices and understandings, offering insights into how these practices might be interrelated in practical application. The hierarchical clustering (Figure 3) suggests practical groupings of related variables that can inform further analysis.

Var1 (understanding of carbon sequestration terminology) and Var2 (awareness of methods) are clustered together at a very low linkage distance, indicating that they are very similar. This makes sense conceptually, as understanding terminology and awareness of methods could be closely related. Var12 (evaluation of agricultural practices) and Var4 (varieties of soil management practices) are also closely related, suggesting that those who evaluate their agricultural practices are likely implementing a variety of soil management practices. According to Gliessman (2014), the link between understanding agricultural terminology and applying appropriate methods for sustainable farming are practices that improve soil carbon, such as crop rotation and the use of cover crops. The connection between agricultural practices, such as the selection of crop varieties, and the improvement of soil carbon levels underscores the importance of grasping the relevant terminology and methods. A clear understanding of these concepts is a limitative stage for effectively implementing strategies that enhance soil carbon through sustainable farming practices (Toensmeier 2016). Var3 (utilization of soil tillage technologies) and Var5 (utilization of cover crops) are grouped together in the clustering process, suggesting a relationship between tillage technologies and cover crop use. Both are practices aimed at improving soil structure and carbon content. Var8 (management of plant/crop residues) and Var10 (regularity of conducting soil analyses) clustered together indicate that those who manage plant residues also regularly analyze their soil, likely to monitor the effects of their residue management. Var11 (utilization of water conservation technologies) and Var9 (use of organic/natural fertilizers) form a cluster, indicating that these two practices are often used together, which aligns with sustainable farming practices focused on improving soil health and moisture retention. Var13 (effective technologies for carbon sequestration) clustered with Var6 (varieties of cover crops) suggest that the selection of effective technologies for carbon sequestration is related to the variety of cover crops used, as different crops might be chosen based on their carbon sequestration potential.

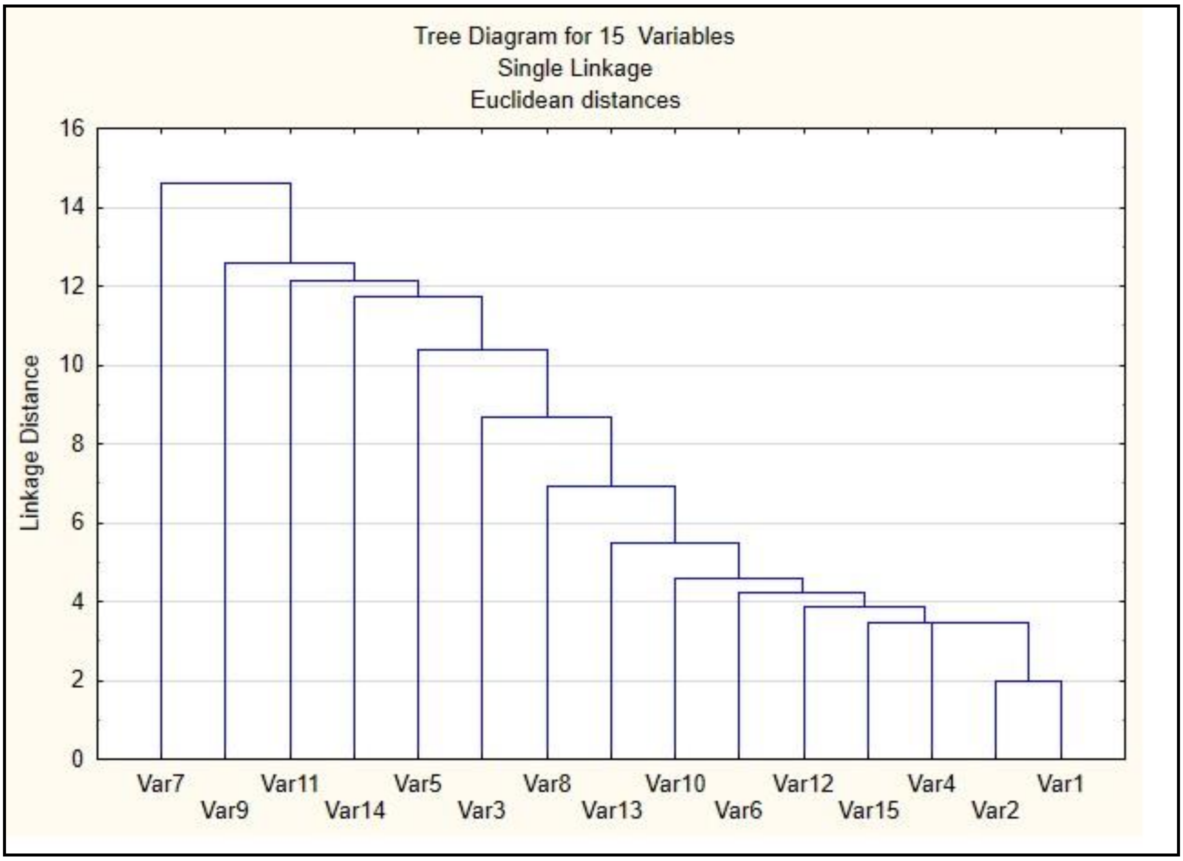

Figure 3. The cluster analysis applied to the variables concerning the carbon sequestration perceptions of respondents; Var 1 - understanding of carbon sequestration terminology; Var 2 - awareness of methods aimed at enhancing carbon sequestration in agriculture; Var 3 - the extent to which soil tillage technologies designed to preserve soil structure and integrity are utilized on the farm; Var 4 - varieties of soil management practices implemented on the farm; Var 5 - the extent of utilizing cover crops to maintain soil coverage and enhance the supply of organic matter; Var 6 - varieties of plants employed as cover crops; Var 7 - varieties of crops favored for the continuous enhancement of soil carbon content; Var 8 - management practices for handling plant and crop residues; Var 9 - the extent of using organic or natural fertilizers to enhance soil quality and boost carbon sequestration; Var 10 - the regularity of conducting soil analyses to evaluate organic carbon content and other key soil characteristics; Var 11 - the extent of utilizing water conservation technologies to maintain soil moisture; Var 12 - evaluation of the effects of agricultural practices on the dynamics of organic carbon in soil; Var 13 - technologies and agricultural practices identified as most effective in promoting carbon sequestration in soil; Var 14 - adoption of conservation agriculture to minimize soil disturbance and enhance carbon sequestration; Var 15 - understanding the relationships between agricultural practices, soil carbon sequestration, and climate change.

The cluster that includes Var7 (varieties of crops favored for enhancing soil carbon content) merges with the larger cluster of Var9 (use of organic/natural fertilizers), Var11 (utilization of water conservation technologies), and Var14 (adoption of conservation agriculture). This suggests that the choice of crops for enhancing soil carbon is related to both the adoption of conservation agriculture practices and the use of organic/natural fertilizers. According to Lal & Stewart (2013), the complementary roles of water conservation methods and organic fertilizers in promoting soil health and water retention are crucial components of sustainable agriculture.

The variables that cluster together at lower linkage distances are closely related, meaning respondents who scored similarly on one of these variables also scored similarly on the others. For instance, understanding terminology (Var1) and awareness of methods (Var2) are very closely linked, as are the varieties of crops used to enhance soil carbon (Var7) with other sustainable practices (Var9, Var11, and Var14). The connection between agricultural practices, such as the selection of crop varieties, and the improvement of soil carbon levels underscores the importance of grasping the relevant terminology and methods. A clear understanding of these concepts is crucial for effectively implementing strategies that enhance soil carbon through sustainable farming practices.

The larger clusters may indicate broader themes or strategies in carbon sequestration practices. For example, the cluster that includes Var7 (varieties of crops) and Var14 (conservation agriculture) could reflect a holistic approach to sustainable farming practices aimed at enhancing soil carbon.

Conclusions. The analysis of the data reveals that respondents generally possess a basic to moderate understanding of carbon sequestration practices, with notable variability in the adoption of different techniques. While the use of cover crops and organic fertilizers is relatively common, other sustainable practices, such as soil management and water conservation, are only moderately adopted. This highlights potential areas for improvement, particularly in promoting water conservation technologies and encouraging more frequent soil analyses. The variability in how plant residues are managed and the inconsistent evaluation of agricultural practices' impact on soil organic carbon suggest a need for targeted educational efforts and incentives to foster more consistent and widespread adoption of these practices. Overall, the findings emphasize the importance of enhancing both understanding and implementation of sustainable agricultural practices to improve soil carbon sequestration and mitigate climate change. The scatterplot correlation matrix shows strong positive correlations between understanding terminology and awareness of methods, and between the use of organic fertilizers and adoption of conservation agriculture, and this suggests a holistic approach to sustainable farming. However, negative correlations, like that between tillage extent and conservation agriculture adoption, indicate perceived incompatibility. Weak correlations between understanding agricultural practices' impact on climate change and the practical use of cover crops suggest a gap between knowledge and action. These findings highlight the need for targeted education and policy interventions to promote integrated and practical approaches to carbon sequestration in agriculture. The cluster analysis reveals that practices like understanding carbon sequestration terminology and awareness of methods, as well as evaluating agricultural practices and soil management, are closely linked, suggesting that respondents proficient in one area tend to excel in related areas. The clustering of soil tillage with cover crops, and plant residue management with regular soil analyses, reflects a synergistic approach to enhancing soil structure and carbon content. Additionally, the grouping of water conservation technologies with organic fertilizers highlights their combined role in promoting soil health and moisture retention. The larger clusters involving crop varieties, conservation agriculture, and organic fertilizers suggest holistic strategies for carbon sequestration. This analysis identifies key groupings of related practices, offering a framework for targeted interventions to promote more comprehensive carbon sequestration efforts in agriculture.

Acknowledgements. This research work was carried out with the support of Ministry of Agriculture and Rural Development, and also was financed from Project ADER Partnership No. 19.1.1/2023.

Conflict of Interest. The authors declare that there is no conflict of interest.

References

Arias-Navarro C., Panagos P., Jones A., Amaral M. J., Schneegans A., Van Liedekerke M., Wojda P., Montanarella L., 2023 Forty years of soil research funded by the European Commission: Trends and future. A systematic review of research projects. European Journal of Soil Science 74(5):e13423.

Bamière L., Bellassen V., Angers D., Cardinael R., Ceschia E., Chenu C., et al., 2023 A marginal abatement cost curve for climate change mitigation by additional carbon storage in French agricultural land. Journal of Cleaner Production 383:135423.

Burrascano S., Chytrý M., Kuemmerle T., Giarrizzo E., Luyssaert S., Sabatini F. M., Blasi C., 2016 Current European policies are unlikely to jointly foster carbon sequestration and protect biodiversity. Biological Conservation 201:370-376.

Campbell E. E., Paustian K., 2015 Current developments in soil organic matter modeling and the expansion of model applications: A review. Environmental Research Letters 10:123004.

Cotrufo M. F., Ranalli M. G., Haddix M. L., Six J., Lugato E., 2019 Soil carbon storage informed by particulate and mineral-associated organic matter. Nature Geoscience 12:989-994.

Creed I. F., Badiou P., Enanga E., Lobb D. A., Pattison-Williams J. K., Lloyd-Smith P., Gloutney M., 2022 Can restoration of freshwater mineral soil wetlands deliver nature-based solutions to agricultural landscapes? Frontiers in Ecology and Evolution 10:932415.

Dick W. A., Gregorich E. G., 2003 Developing and maintaining soil organic matter levels. In: Managing soil quality: Challenges in modern agriculture. Schjønning P., Elmholt S., Christensen B. T. (eds.), CABI, Oxfordshire, UK.

Duiker S. W., Thomason W., 2014 Conservation agriculture in USA. In: Conservation agriculture: Global prospects and challenges. Jat R. A., Sahrawat K. L., Kassam A. H. (eds), CABI, Oxfordshire, UK.

Friedrich T., Kassam A., Corsi S., 2014 Conservation agriculture in Europe. In: Conservation agriculture: Global prospects and challenges. Jat R. A., Sahrawat K. L., Kassam A. H. (eds), CABI, Oxfordshire, UK.

Funes F., Garcia L., Bourque M., Pérez N., Rosset P., 2002 Sustainable agriculture and resistance: Transforming food production in Cuba. Appropriate Technology 29(2):34.

Gliessman S. R., 2014 The ecology of sustainable food systems. 3rd Edition. CRC Press, Boca Raton, USA.

Lal R., Stewart B. A., 2013 Principles of sustainable soil management in agroecosystems. CRC Press, Boca Raton, USA.

Mrunalini K., Behera B., Somasundaram J., Abhilash P. C., Dubey P., Narayanaswamy G., Prasad J., Rao K. J., Krishnan P., Pratibha G., Rao C. S., 2022 Nature-based solutions in soil restoration for improving agricultural productivity. Land Degradation & Development 33(8):1269-1289.

Oroian F. C., Kovacs E., Bora F. D., Popescu M., 2023 Adapting agricultural crops to new regional climates post-climate change. AAB Bioflux 15(2):115-121.

Petrescu-Mag I. V., Oroian F. C., Burduhos P., Kovacs E., 2023 Climate, carbon, solutions and perspectives. AAB Bioflux 15(2):73-82.

Radu M., Bolohan C., Mihalascu C., Marutescu A., Newbert M., Vasileiadis V., 2024 Conservation agriculture impact on soil and crop productivity: a review of long-term field trials. AAB Bioflux 16(1):1-26.

Toensmeier E., 2016 The carbon farming solution: A global toolkit of perennial crops and regenerative agriculture practices for climate change mitigation and food security. Chelsea Green Publishing, USA.

Wuest S., Gollany H., 2013 Soil organic carbon and nitrogen after application of nine organic amendments. Soil Science Society of America Journal 77:237-245.

*** https://www.statisticshowto.com/probability-and-statistics/find-sample-size/

*** https://www.statisticshowto.com/tables/z-table/
*** https://www.recensamantromania.ro/rezultate-rpl-2021/rezultate-definitive/

Received: 19 August 2024. Accepted: 28 August 2024. Published online: 12 September 2024.
Authors:
Firuța Camelia Oroian, Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: camelia.oroian@usamvcluj.ro
Antonia Odagiu, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: aodagiu@gmail.com
Ioan Valentin Petrescu-Mag, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: ioan.mag@usamvcluj.ro
Iulia C. Mureșan, Faculty of Horticulture and Business in Rural Development, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: iulia.muresan@usamvcluj.ro
Cristian Iederan, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: cristi.iederan@usamvcluj.ro
Paula Moraru, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: paulaioana.moraru@usamvcluj.ro
Petru Burduhos, Faculty of Agriculture, University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, 400372 Cluj-Napoca, Romania, e-mail: petru.burduhos@usamvcluj.ro

How to cite this article:
Oroian F. C., Odagiu A., Petrescu-Mag I. V., Mureșan I. C., Iederan C., Moraru P., Burduhos P., 2024 Farmers' perception of soil carbon storage potential: Case studies from Mureș and Brașov counties. AES Bioflux 16(1):13-21.