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WHAT CARBON STORAGE FARMING ACTIVITIES ADOPTED BY FARMERS? A SURVEY FROM THE NORTH-WESTERN REGION OF ROMANIA

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Abstract

The organic carbon content is an important indicator for characterizing soil health in terms of maintaining environmental sustainability. The capacity of agricultural land to sequester carbon depends on a number of factors and specific management measures adopted at farm level. The present study aimed to identify farmer's perception regarding the evaluation of the organic carbon storage potential in the agricultural soils of some farms of different economic sizes in the central region of Romania, Cluj County. The results of the study highlight that there is a good understanding of the concept of carbon sequestration, among the specific measures most often are being adopted organic fertilization and the use of cover crops.

Key words: *carbon storage, soil, farmers perception.*

INTRODUCTION

Mankind has widely disrupted natural ecosystems and diminished their resilience, especially along the industrial revolution, facing extreme climate phenomena, more and more unpredictable, that affect terrestrial and aquatic resources (IPCC - Intergovernmental Panel on Climate Change, 2018; Oltenacu et al., 2022; Ruiz-González & Vicente, 2023).
Soils are a major and important carbon tank. Globally, is thought that soils contain more carbon than the total amounts that apear combined vegetation and the atmosphere (Swift, 2001). Agricultural activities in many parts of the world have led to large decreases in soil organic matter and concomitant degradation of soil fertility, resulting in lower crop yields and lower crop quality (Korschens 2002; Pop et al., 2023). Among practices that favor the role of carbon reservoir for agricultural soils we can relate crop rotation that ensures the judicious use of fertilizers, the use of cover crops and organic fertilizers, the improvement of pasture maintenance technologies and the use of deep-rooted crops (Laamrani et al., 2020).
Romania has a significant potential in terms of carbon sequestration through agriculture and grassland management, due to its characteristics and geographical location.
Romania has a considerable area of agricultural land and meadows, which can be used for carbon sequestration. More than that, there it has a long tradition of agricultural and grazing practices that can be adapted to promote carbon storage (Manolache et al., 2020; Panait & Cucu, 2020). Romanian agriculture is diversified, covering a wide range of crops and plant species (Nita et al., 2019). In the recent years, an increase in the interest on organic farming and agroecology has been reported (Popovici et al., 2022). These practices can promote carbon storage in soils by using specific techniques such as crop rotation, ground cover and the integration of livestock into farming systems. Also, agriculture for conservation purpose involves other practices such as minimizing tillage and using cover

crops, which can also contribute to carbon sequestration.

It might say that we know enought about famer adoption of some bahaviors regarding agricultural technologies, given decades of general research. But in fact, all this research has failed to converge on a stable explanation for why farmers adopt or not tehnologies and practices about sequestration carbon. Starting from this fact, the aim of present research was identifying the farmers' perception about the assessment of the organic carbon storage potential in agricultural soils in Romania.

MATERIALS AND METHODS

The current research was carried out in the North-Western development region of Romania, known for its potential agricultural.

To achieve the aim of the current research, we conducted a quantitative survey during January-April 2024. 45 questionnaires were designed and distributed with the aim of identifying the farmers' perception about the assessment of the organic carbon storage potential in agricultural soils in Romania. They were assigned to 45 farmers located in Cluj County. Each questionnaire consists of 15 items, with different possibilities of responses, from yes or no, to multiple choices.

The sample size was calculated according to Cochran formula (https://www.statisticshowto.com/probability-and-statistics/find-sample-size/).

$$n_0 = \frac{Z^2 pq}{e^2} \quad (1)$$

where:

e - desired level of precision;

p - estimated proportion of the population;

q = 1 – p ;

z = 1.96 (https://www.statisticshowto.com/tables/z-table/).

We consider a confidence level of 95% and 5% precision. The estimated proportion of population is considered 0.50% (https://www.statisticshowto.com/probability-and-statistics/find-sample-size/). Because the target subjects of the questionnaires are the farmers located in Cluj County, we took into consideration the population of the Cluj County according to the last census from 2021, which is 318.759 inhabitants (https://www.recensamantromania.ro/rezultate-rpl-2021/rezultate-definitive/). Thus, in our case:

$$n_0 = \frac{3.841 \cdot 5.94 \cdot (1 - 5.94)}{0.0025} = 45.08$$

XLSTATISTICS program was used for statistical data processing. Descriptive statistics (means, dispersion parameters, and Spearman correlations) was implemented together with multi exploratory analysis (Principal Components Analysis - PCA). The linearity of the dependence between correlated items was tested, and because in majority of cases it lacks, we perform the nonparametric Spearman test for calculation of the simple correlations. For testing the opportunity of implementing PCA we made the Bartlett and Keiser - Meyer - Olkin (KMO) tests (Merce & Merce, 2009).

RESULTS AND DISCUSSIONS

In our survey we took into considerations 15 items concerning agricultural practices and carbon sequestration. According to descriptive statistics, majority of questioned subjects know the terminology concerning carbon sequestration. The use of cover crops and organic fertilization are the main means for promoting carbon sequestration, while crop rotation is seldom used. More than a half of the respondents uses soil tillage technologies destined to maintain soil structure and integrity. The main agricultural practices for soil management used in farm are soil analysis, crop rotation and association, and direct sowing without chemical fertilization and herbicidation. Majority of respondents do not use cover crops for maintaining soil covering and increase the organic matter supply. Cereals are the main crops used for enhancing soil carbon sequestration. Weeding immediately after harvesting and leaving a part of the plant residues on the thickness of the germinal bed, well shredded and homogenized with the soil are preferred managament practices for vegetal and culture waste. The highest percentage of the survey subjects use organic or natural fertilizers for improuving soil quality and incerase carbon sequestration, being well-known that this type of fertilization has a positive contribution to both crop development and soil quality preservation (Lan et al., 2022; Lianget al., 2023). Majority of questioned subjects performs soil analysis to assess the organic carbon content and other important soil traits, once at 5 years, or they never use soil analysis. Majority of respondents uses or natural fertilizers for improving soil quality and incerase carbon sequestration. Major part of questioned subjects uses water preservations technologies for maintaing soil moisture. Most of the questioned subjects consider the impact of the agricultural practices on organic carbon dynamics in soil as moderate and/or strong.

Technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil are manure, compost, and wood waste, and suitable fertilizers doses. Implementation of preservation agriculture also known as "conservation agriculture" (Kassam et al., 2009) for minimizing the soil disruption and enhance carbon sequestration is an option for majority of the questioned subjects.

According to research in the field, preservation agriculture contributes to increase of soil carbon sequestration (Mangalassery et al., 2015). Low knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes is reported by the questioned subjects (Table 1).

The knowledge of relationship between climate change and soil carbon sequestration is of great importance mainly due to the importance of this connection in promoting food safety (Eswaran et al., 2000; Lal, 2004; Wang et al., 2006).

Table 1. Descriptive statistics applied to the carbon sequestration perceptions variables

Issue	N	Mean	Standard deviation	Variability, %
The knowledge of carbon sequestration terminology	45	1.31	0.31	23.98
Knowledge of means destined to promote carbon sequestartion in agriculture	45	2.33	0.62	26.57
The level of using in farm the soil tillage technologies destined to maintain soil structure and integrity	45	1.27	0.25	19.52
Types of agricultural practices for soil management used in farm	45	1.27	0.25	19.52
The level of using cover crops for maintaining soil covering and increase the organic matter supply	45	2.33	0.56	24.16
Types of plants used as cover crops	45	1.53	0.39	25.73
Types of cultures preferred for continuous improuvement the soil carbon content	45	2.40	0.55	22.92
Managament practices for vegetal and culture waste	45	3.60	0.72	20.00
The level of using organic or natural fertilizers for improuving soil quality and incerase carbon sequestration	45	1.73	0.47	27.12
The frequency of using soil analysis to assess the organic carbon content and other important soil traits	45	1.47	0.26	18.04
The level of using water preservations technologies for maintaing soil moisture	45	1.47	0.18	12.58
Assessment of the impact of the agricultural practices on organic carbon dynamics in soil	45	2.00	0.37	18.46
Technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil	45	3.13	0.73	23.30
Implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration	45	1.31	0.31	23.98
The knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes	45	1.27	0.25	19.52

A strong positive correlation (R = 0.82) is identified between the knowledge of the terminology concerning carbon sequestration and use of cover crops and organic fertilization as main means for promoting carbon sequestration, which suggests that better informed farmers could potentially lead to greater adoption of effective practices for carbon sequestration.

The implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration is moderate to strongly and positive correlated (R = 0.62) with use of the cereals as the main crops used for enhancing soil carbon sequestration, which suggests that adopting preservation agriculture practices is closely linked with the use of cereals to promote carbon sequestration in the soil (Aryal et al., 2015).

This indicates that these practices are less likely to be adopted by those who prioritize preservation agriculture methods. The implementation of preservation agriculture is negatively correlated with preference of the questioned subjects for weeding immediately after harvesting and leaving a part of the plant residues on the thickness of the germinal bed (R = -0.67), and using soil tillage technologies destined to maintain soil structure and integrity (R = -0.52), and this indicates that these practices are less likely to be adopted by those who prioritize preservation agriculture methods.

The use of certain cultures for continuous improvement the soil carbon content is moderate and positive correlated (R = 0.57) with using soil tillage technologies destined to maintain soil structure and integrity, but negatively (R = -0.53) with the use of cover crops for maintaining soil covering and increase the organic matter supply, and use of the cereals as the main crops used for enhancing soil carbon sequestration (R = -0.52). These findings suggest that while weeding and leaving plant residues are compatible with certain tillage practices, they are less aligned with the use of cover crops and cereals for improving soil carbon sequestration.

Performing soil analyses to assess the organic carbon content and other important soil traits is positively corelated (R = 0.59) with using cereals as the main crops planted for enhancing soil carbon sequestration, which indicates that farmers who regularly conduct soil analyses are more likely to plant cereals to improve soil carbon sequestration (Table 2).

For a better understanding of which factors are most relevant to soil carbon management, function of 15 items included in our survey we conducted the PCA. The identification of the simple Spearman correlations, significance of Barlett test ($p < 0.001$) and value of the KMO test (0.58) confirm the opportunity of performing the PCA.

The analysis emphasizes three principal factors. The first one is "The use of practices and soil conservation technologies" and explains 52.739% of variance. We consider that this factor is responsible for the largest part of variance because their wide-ranging effects on soil properties, broad applicability, synergistic impacts, extensive data collection, adaptive implementation, and external influences, all of which collectively influence soil carbon sequestration and overall soil health.

This factor has a mean of 0.409 (SD = 0.117) and contains four components focused on types of cultures preferred for continuous improuvement the soil carbon content (that is the most important component of the factor), management practices for vegetal and culture waste, level of using organic or natural fertilizers, technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil.

"Knowledges and practices concerning carbon sequestration" is the second factor. It accounts for a lower variance compared with the first factor (32.179). We consider that even though it significantly influences the adoption and implementation of carbon sequestration practices its impact is moderated by varying levels of knowledge, implementation variability, mixed adoption rates, and the influence of other external factors.

The mean of this factor is 0.491 (SD = 0.101), and it has five loadings focusing on knowledge of carbon sequestration terminology, and means destined to promote carbon sequestration in agriculture, level of using organic or natural fertilizers for improving soil quality and increase carbon sequestration, assessment of the impact of the agricultural practices on organic carbon dynamics in soil, implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration, and the knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes (Table 3).

Table 2. The simple Spearman correlations between the carbon sequestration perceptions variables

Issue	Var1	Var2	Var3	Var4	Var5	Var6	Var7	Var8	Var9	Var10	Var11	Var12	Var13	Var14	Var15
Var1	1.00	0.82	-0.28	0.22	-0.20	-0.13	0.21	-0.42	0.05	-0.13	0.20	0.22	0.24	-0.03	0.30
Var2	0.82	1.00	-0.29	0.32	-0.13	-0.04	0.14	-0.42	0.18	-0.26	0.38	0.34	0.01	0.10	0.43
Var3	-0.28	-0.29	1.00	-0.29	-0.25	-0.19	0.57	0.02	0.09	0.19	-0.15	-0.26	0.01	-0.52	-0.23
Var4	0.22	0.32	-0.29	1.00	-0.13	0.26	-0.15	-0.27	-0.05	0.04	0.38	0.34	-0.41	0.40	0.43
Var5	-0.20	-0.13	-0.25	-0.13	1.00	0.48	-0.53	-0.20	-0.31	-0.39	-0.05	-0.30	-0.12	0.42	0.09
Var6	-0.13	-0.04	-0.19	0.26	0.48	1.00	-0.52	0.02	-0.59	-0.46	0.29	0.07	-0.37	0.62	0.22
Var7	0.21	0.14	0.57	-0.15	-0.53	-0.52	1.00	-0.34	0.09	0.06	-0.07	-0.19	0.35	-0.67	0.13
Var8	-0.42	-0.42	0.02	-0.27	-0.20	0.02	-0.34	1.00	0.02	0.23	-0.11	0.36	-0.34	0.13	-0.31
Var9	0.05	0.18	0.09	-0.05	-0.31	-0.59	0.09	0.02	1.00	0.39	0.07	0.18	0.01	-0.17	-0.27
Var10	-0.13	-0.26	0.19	0.04	-0.39	-0.46	0.06	0.23	0.39	1.00	-0.39	-0.07	0.01	-0.36	-0.22
Var11	0.20	0.38	-0.15	0.38	-0.05	0.29	-0.07	-0.11	0.07	-0.39	1.00	0.20	0.01	0.07	0.22
Var12	0.22	0.34	-0.26	0.34	-0.30	0.07	-0.19	0.36	0.18	-0.07	0.20	1.00	-0.37	0.27	0.33
Var13	0.24	0.01	0.01	-0.41	-0.12	-0.37	0.35	-0.34	0.01	0.01	0.01	-0.37	1.00	-0.49	-0.37
Var14	-0.03	0.10	-0.52	0.40	0.42	0.62	-0.67	0.13	-0.17	-0.36	0.07	0.27	-0.49	1.00	0.00
Var15	0.30	0.43	-0.23	0.43	0.09	0.22	0.13	-0.31	-0.27	-0.22	0.22	0.33	-0.37	0.00	1.00

Var 1- The knowledge of carbon sequestration teminology; Var 2-Knowledge of means destined to promote carbon sequestartion in agriculture; Var 3-The level of using in farm the soil tillage technologies destined to maintain soil structure and integrity; Var 4-Types of agricultural practices for soil management used in farm; Var 5-The level of using cover crops for maintaining soil covering and increase the organic matter supply; Var 6-Types of plants used as cover crops; Var 7-Types of cultures preferred for continuous improuvement the soil carbon content; Var 8-Managament practices for vegetal and culture waste; Var 9-The level of using organic or natural fertilizers for improuving soil quality and incerase carbon sequestration; Var 10-The frequency of using soil analysis to assess the organic carbon content and other important soil traits; Var 11-The level of using water preservations technologies for maintaing soil moisture; Var 12- Assessment of the impact of the agricultural practices on organic carbon dynamics in soil; Var 13-Technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil; Var 14- Implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration; Var 15- The knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes.

The third factor is “Specific technologies and practices destined to soil management”. It explains 15.082% of variance, which is the lowest part of it.

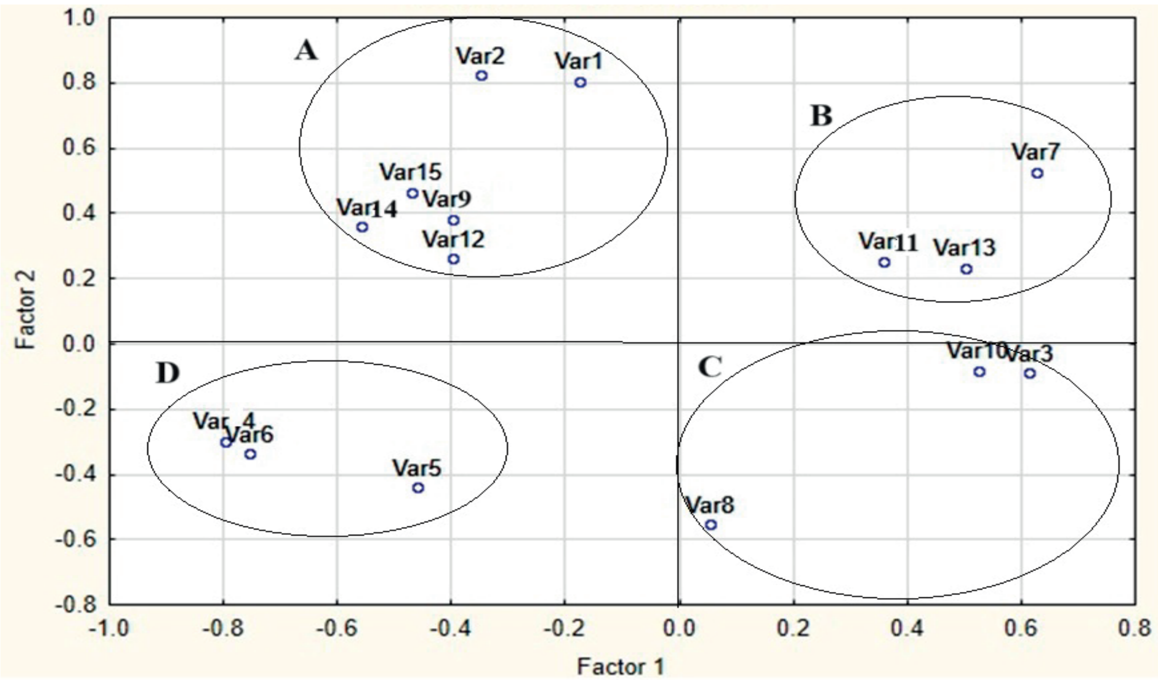
We consider that this factor is responsible for the lowest part of variance due to its narrow focus, specialized application, incremental changes, lower adoption rates, supportive role, and dependence on broader soil management strategies.

This factor has a mean of 0.427 (SD = 0.087) and contains five components focused on the level of using in farm the soil tillage technologies destined to maintain soil structure and integrity, types of agricultural practices for soil management used in farm, the level of using cover crops for maintaining soil covering and increase the organic matter supply, types of plants used as cover crops (that is the most important component of the factor) and frequency of using soil analysis to assess the organic carbon content and other important soil traits (Table 3). The PCA plot of the cases and variables concerning carbon sequestration perceptions variables is represented on two factors plane.

We took into consideration only Factor 1 and Factor 2, because Factor 3 has a sub unitary Eigenvalue. The types of cultures preferred for continuous improvement the soil carbon content, the level of using organic or natural fertilizers, technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil are positively correlated with both factors (Figure 1).

Table 3. The principal componets analysis on carbon sequestration perceptions variables

Eigenvalue	Variance, %	Factor	Item	Factor loading
1.471	52.739	The use of practices and soil conservation technologies Mean = 0.409 SD = 0.117	Types of cultures preferred for continuous improuvement the soil carbon content	0.577
			Managament practices for vegetal and culture waste	0.303
			The level of using water preservations technologies for maintaing soil moisture	0.390
			Technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil	0.368
1.021	32.179	Knowledges and practices concerning carbon sequestration Mean = 0.491 SD = 0.101	The knowledge of carbon sequestration teminology	0.491
			Knowledge of means destined to promote carbon sequestartion in agriculture	0.586
			The level of using organic or natural fertilizers for improuving soil quality and incerase carbon sequestration	0.549
			Assessment of the impact of the agricultural practices on organic carbon dynamics in soil	0.305
			Implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration	0.549
			The knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes	0.469
0.898	15.082	Specific technologies and practices destined to soil management Mean = 0.427 SD = 0.087	The level of using in farm the soil tillage technologies destined to maintain soil structure and integrity	0.352
			Types of agricultural practices for soil management used in farm	0.459
			The level of using cover crops for maintaining soil covering and increase the organic matter supply	0.450
			Types of plants used as cover crops	0.546
			The frequency of using soil analysis to assess the organic carbon content and other important soil traits	0.330



Var 1- The knowledge of carbon sequestration teminology; Var 2-Knowledge of means destined to promote carbon sequestartion in agriculture; Var 3-The level of using in farm the soil tillage technologies destined to maintain soil structure and integrity; Var 4-Types of agricultural practices for soil management used in farm; Var 5-The level of using cover crops for maintaining soil covering and increase the organic matter supply; Var 6-Types of plants used as cover crops; Var 7-Types of cultures preferred for continuous improuvement the soil carbon content; Var 8-Managament practices for vegetal and culture waste; Var 9-The level of using organic or natural fertilizers for improuving soil quality and incerase carbon sequestration; Var 10-The frequency of using soil analysis to assess the organic carbon content and other important soil traits; Var 11-The level of using water preservations technologies for maintaing soil moisture; Var 12- Assessment of the impact of the agricultural practices on organic carbon dynamics in soil; Var 13- Technologies and agricultural practices observed as most efficient in promotion the carbon sequestration in soil; Var 14- Implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration; Var 15- The knowledge of the connections between agricultural practices, soil carbon sequestration and climatic changes.

Figure 1. The PCA plot of the cases and variables on the factor plane concerning carbon sequestration perceptions variables

We consider that this positive correlation reflects alignment in goals, comprehensive strategy implementation, resource allocation, and recognition of performance and effectiveness in enhancing soil health and carbon sequestration. The level of using in farm the soil tillage technologies destined to maintain soil structure and integrity, the management practices for vegetal and culture waste and frequency of using soil analysis to assess the organic carbon content and other important soil traits are positively correlated with Factor 1 "The use of practices and soil conservation technologies".

The knowledge of carbon sequestration terminology, of means destined to promote carbon sequestration in agriculture, and the connections between agricultural practices, soil carbon sequestration and climatic changes, the level of using organic or natural fertilizers for improving soil quality and increase carbon sequestration, assessment of the impact of the agricultural practices on organic carbon dynamics in soil, implementation of preservation agriculture for minimizing the soil disruption and enhance carbon sequestration, are positively correlated with Factor 2 "Knowledges and practices concerning carbon sequestration".

Types of agricultural practices for soil management used in farm, plants used as cover crops and plants used as cover crops are negatively correlated with Factor 1 "The use of practices and soil conservation technologies" and Factor 2 "Knowledges and practices concerning carbon sequestration".

We consider the negative correlation arises because traditional agricultural practices, including the use of cover crops, often represent a different approach to soil management compared to the adoption of advanced soil conservation technologies and carbon sequestration practices.

CONCLUSIONS

According to our survey study we may conclude that there is a solid grasp of carbon sequestration concepts and significant adoption of beneficial practices such as cover cropping and organic fertilization, there are areas for improvement, particularly in increasing the use of cover crops, enhancing knowledge about climate-soil interactions, and increasing the frequency of soil analysis to optimize carbon sequestration efforts.

Our study emphasizes the importance of knowledge, adoption of effective practices, and strategic decision-making in enhancing soil carbon sequestration. It underscores the trade-offs and complex interactions among different agricultural practices, emphasizing the need for informed and integrated approaches to maximize carbon sequestration potential in agricultural systems.

The PCA shows diverse factors influencing soil carbon management, with significant emphasis on comprehensive soil conservation practices and technologies (Factor 1), followed by knowledge-based adoption of carbon sequestration practices (Factor 2), and specialized soil management technologies (Factor 3). Understanding these factors provides insights into optimizing practices for enhancing soil health and carbon sequestration in agricultural settings. underscores the importance of aligning goals, implementing comprehensive strategies, allocating resources effectively, and recognizing the effectiveness of practices in enhancing soil health and carbon sequestration. Factors 1 and 2 are focused on the complementary nature of practical and knowledge-based approaches, while negative correlations with traditional agricultural practices emphasize the need for education and innovation in promoting sustainable soil management practices.

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