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SOIL FUNCTIONS DEPENDING ON SOIL INDICATORS IN VARIOUS ENVIRONMENTS AND LAND USES – A CASE STUDY OF ROMANIA

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Abstract: Soil is an indispensable natural resource for the existence of various ecosystems and human activities, such as agriculture, silviculture and, pastoral activity. In addition to water, soil is the most important resource for life on Earth. Internationally, soil functions were defined and dealt with at the European level. The purpose of this study is to define, adapt, quantify, and assess some soil health functions and their component indicators related to land uses and to the main soil classes and soil types across Romanian territory. Five soil functions were studied over 10 soil classes and 22 soil types: 1) organic matter cycle, 2) nutrient cycle, 3) biodiversity support cycle, 4) water cycle, and 5) contaminant cycle. These five soil functions show that most of the Romanian soils present a satisfactory average health situation because there were not severe degradation processes occurring on a large scale. However, individual soil profiles may present even extreme values. From all the five soil functions, *the contamination cycle function* is critical for soil health. All non-polluted Romanian soils are in a different degree of health, while the polluted hotspot soils are in a different degree of illness. The more numerous and more uniformly distributed soil data, the more accurate the results for the studied territory. Including soil sub-types and varieties, as well as more new experiments on the soil indicators, would extend, typify, and enlarge the range of functions' scores. Thus, the presented method has the potential to be continuously improved.

Keywords: organic carbon cycle; nutrient cycle; biodiversity support cycle; water cycle

1. INTRODUCTION

Soil is an indispensable natural resource needed not only for the existence of various ecosystems but also for many human activities, such as agriculture, silviculture, and pastoral activity. As a matter of fact, in addition to water, soil is the most important resource for life on Earth (Leeuwen et al., 2017). Due to the intense anthropogenic activities that mainly occurred in the past centuries, the soils have been affected by degradation and pollution to various degrees, especially in countries where their governments have not paid sufficient attention. The soils state can be characterized by the concepts of soil health and ecosystem services or functions, which are not uniquely defined or/and entirely agreed upon among the scientists (Hatfield et al., 2017). Ecosystem services are defined as the contribution of a certain ecosystem for the economic, social, cultural, and otherwise viewpoint, which the people get from it. The term soil functions was used, among others, by Ritz et al. (2009), Dominati et al. (2010), Rutgers et al. (2012), Robinson et al. (2014). According to Hatfield et al. (2017), there is no single definition of soil functions.

After Schulte et al. (2014) and Leeuwen et al. (2017), the following five soil functions are having the same or similar names: (1) primary agricultural production, (2) water purification and regulation, (3) carbon sequestration and climate regulation, (4) soil biodiversity and habitat provisioning, and (5) recycling of nutrients/agro-chemicals and mitigation against climate change. The sum of the weighting factors for their integrated attributes (soil biology, soil nutrients, soil structure, soil hydrology, each with 0.25 weight) is always set to one in their approach. All these functions or soil-based ecosystem services can be estimated with the help of some soil attributes (properties).

Some studies usually approach the soil characteristics only for 0.2 m depth, while Torres-Sallan et al. (2018) expressed his concern about the limitations derived from sampling only the topsoil. They emphasized that the subsoils cannot be neglected for all soil functions, specifically for carbon sequestration and climate regulation functions. Similar ideas were also reported for Romanian territory by Lăcătusu et al. (2024), Dumitru et al. (2024), and Paltineanu et al. (2024).

Sere et al. (2024) have reported that relevant soil indicators based either on *in situ* description, *in situ* measurements or laboratory analysis should be chosen for soil functions. In their case, there were nine functions and sub-functions to meet the relevant expectations on soil health in urban contexts. According to Leeuwen et al. (2017), the overall picture emphasized an unbalanced dataset in defining soil functions, in which predominantly chemical soil parameters were considered, while soil physical and biological properties were underrepresented. In this sense, Bispo et al. (2009) and Faber et al. (2021) deepened this idea and added that the biological properties, such as soil respiration, microbial biomass, invertebrate diversity and abundance are less commonly investigated and that it is difficult to find a set of indicators due to the complexity of soil biota and functions.

Concerning soil physical properties, some of them related to soil water, like soil permeability and saturated hydraulic conductivity (Ksat), are also important for the transport process of water, nutrients and contaminants toward groundwater (Lăcătusu et al., 2019; Domnariu et al., 2020; Paltineanu et al., 2021, 2022). Along with other soil hydraulic properties such as field capacity and total capacity, Ksat represents an important variable characterizing soil health.

Another severe problem is represented by the soil degradation produced by various pollutants across Romania. This was earlier synthesized by Dumitru et al. (2011), Vrînceanu et al. (2019) for heavy metals, and Preda et al. (2019) for pesticides in cropland. However, there is a knowledge gap concerning soil functions at the country's level.

The purpose of this study is to define, adapt, quantify and assess some soil health functions and their component indicators related to land uses and to the main soil classes and soil types across Romanian territory.

2. MATERIAL AND METHODS

2.1. Studied material

2.1.1. Environmental conditions

The study included a vast area of different ecological regions in Romania, from plains to hills, tablelands, plateaus, and mountains. These environments have a temperate-continental climate pattern after the Köppen-Geiger climate classification (Peel et al., 2007), with Bsk in the south-eastern parts, Dfa in the southern parts and Dfb and Dfc types in the rest of the country. Altitude generally diversifies the above climate types over small distances, specifically in the mountainous regions.

As a consequence of various landforms and climate types, there are specific flora zones from steppes and forest-steppes to deciduous trees as well as coniferous trees and specific shrubs and grasses in the mountains. The land uses are forestland (28%), grassland (20%), and cropland (41%) (Andrei, 2015). Croplands are represented by arable crops and permanent crops. Most of the forestlands occur between ca. 280 and 1040 m altitude, and their mean slope for the studied soils is between 10 and 42%. There is a trend of increasing land slope with altitude. The analyzed soils occurring within forestlands have a sandy-loamy texture, while the pH mean is strongly acid. The studied grasslands generally occur between 20 and 730 m a.s.l., having a lower mean slope, 0 - 22.5%, with a mean loamy texture, while pH is slightly acid. The studied croplands are mainly situated between 60 and 330 m altitude, and have the lowest slopes (0 to 12%), and a loamy texture, while the mean pH is slightly acid.

For the present study, 991 soil profiles from Romania were analyzed, processed, and interpreted from an internal database (Archive of ICPA Bucharest). These profiles were carried out mainly in the past decade, in forestland, grassland, and cropland. Locations and further details of these soil profiles were given in previous papers (Dumitru et al., 2024; Paltineanu et al., 2024).

Romanian Taxonomic Soil System (Florea & Munteanu, 2012) was used to characterize the soil classes (10) and soil types (22). This classification system has similar or close soil type names to WRB (IUSS, 2022): a) Antrisols class (soil type-Anthrosol, 15 soil profiles; b) Cambisols class, 255 profiles, (soil types are Eutricambosols and Districambosols); c) Chernisols class, 188 profiles, (soil types: Chernozems, Phaeozems, Kastanozems, Rendzinas); d) Hydrisols class, 31 profiles (soil types: Gleysols and Stagnosols); e) Luvisols class, 259 profiles (soil types: Preluvosols, Luvosols, Alosols), f) Protisols class, 174 profiles (soil types: Aluviosols, Psamosols, Regosols, Lithosols); g) Salsodisols class, 18 profiles (soil types: Solonchaks/Solonetzes); h) Spodisols class, 38 profiles (soil types Prepodzols and Podzols); i) Umbrisols class, 2 profiles (soil types: Humosiosols); and j) Vertisols class, 11 profiles (soil types: Pelosols and Vertosols).

2.1.2. Soil sampling and analyzing

Soil profiles were first described morphologically. Both disturbed and undisturbed soil samples were taken from their horizons, and chemical and physical properties were determined from each horizon in the laboratories of ICPA-Bucharest using standardized methods (Florea et al., 1987): particle-size distribution, bulk density, soil organic carbon content (SOC, modified Walkley-Black method), total soil nitrogen content (TN) (Kjeldahl method), pH (glass electrode in 1:2.5 water suspension), sum of exchangeable base cations (SB), soil carbonates content using the gas-volumetric method (Scheibler), plant available (mobile) soil phosphorous (SAP) and potassium (SAK) (Egnér-Riehm-Domingo method, Egnér et al., 1960).

The saturation potential of soil organic carbon (SOCpot) was calculated as a soil content using Hassink's formula (Hassink, 1977):

SOCpot ($g \cdot kg^{-1}$) = $4.09 + 0.37 \times$ (% of clay and silt, i.e. particles < 20 μm)

Then, the 0.5 m depth stocks of SOC, SOCpot, TN, SAP, and SAK, as well as various soil water stocks (Mg/ha) were calculated from their soil content values (% or mg/kg) by multiplying the percent values with bulk density (kg/dm^3) and horizon thickness (cm), and subtracting the skeleton particles that are larger than 2 mm.

The 0.5 m soil depth was chosen to assess soil function scores because that depth was found to be highly important for various different-rooted crops and wild flora in Romania (Paltineanu et al., 2016, 2017, 2020; Dumitru et al, 2024), as opposed to 0.2 m topsoil frequently reported in literature (Orgiazzi et al., 2018; Ballabio et al., 2019; Fernandez-Ugalde et al., 2022).

Microsoft Excel and SPSS Statistics version 21, were used for data processing, normality testing, analysis of variance (ANOVA) of the calculated scores for each of the 991 soil profiles of the database, and graphics design. ANOVA was used to calculate the indicator means depending on land uses, soil class and soil types. These averages of groupings were compared and tested for significance using Duncan's multiple range test.

2.2. Methods

Five soil functions were defined and analyzed for the average values of 0.5 m depth in this study. These functions represent adaptations and modifications of some soil functions already reported in the literature, e.g. by Schulte et al. (2014) and Leeuwen et al. (2017). The current soil functions were thus quantified through their indicators (properties) to meet the general expectations concerning soil health, by using either existing scientific standards based on published domestic research papers or a supported long-based expertise of soil scientists in Romania. The scores of all soil functions were obtained as mean values of the indicator's components, which varied between 0, representing the least favorable situation, and 1, showing the most favorable conditions. The present methodology differs considerably from the ones of the above foreign authors, and represents a novelty through the way the scores were attributed; their algorithms are shown below for each function.

2.2.1. Soil functions scores

Function 1: Organic matter cycle. Soil indicators are defined and characterized below for the organic carbon cycle (SOC cycle) function, as a potential to support life and mitigate climate warming. Scores for the following indicators: SOC stock, SOCpot stock, and the resulting SOC stock overall are used in this study. More information on these indicators can be found in a recent paper (Paltineanu et al., 2024). After Sere et al. (2024), this function supports the service of global climate regulation.

For each soil profile, a score was given to SOC stock, in a similar way to the soil humus stock coefficients depending on soil texture: coarse, moderate and fine texture, according to the homogeneous ecological land methodology, as Teaci (1980, 1989), Predel et al. (1987) and Florea et al. (1987) reported for various crops (averaged) as cropland, or land uses (grassland, forestland). Then, SOCpot stock was also given a score that resulted from the recommendations of Paltineanu et al. (2024) and obtained as a function of soil texture, after using Hassink's formula (Hassink, 1977). Finally, the arithmetic mean of these two stocks was calculated as SOC stock overall (cycle or function score), and this one was interpreted as follows: very low (≤ 0.50), low (0.51, 0.65], moderate (0.65, 0.80], large (0.80, 0.90], extra (highly) large (> 0.90).

Function 2: The nutrient cycle (storage, retention capacity, recycling) is defined by the following soil indicators and their scores: total nitrogen (TN) stock, mobile P stock, mobile K stock, and the synthetic soil nutrient as an average of the first three (function score). The nutrient cycle function supports the service biomass provisioning (Sere et al., 2024).

As for the previous soil function, a score was given for each of the soil stocks of the above nutrients according to the method reported by Florea et al.

(1987) for their soil contents, from very low soil contents (0.6 - 0.7) to highly large (1.0) contents. Because there were no soils with zero nutrient contents throughout the analyzed data set, and no annihilating conditions (as for instance in the case of frost that may destroy plants or yield during the growing season), the threshold scores were attributed taking into account the normal distribution of the indicator values, starting with moderate score values as suggested by the land rating method (Teaci, 1980, 1989; Predel et al. 1987). Soil nutrient cycling scores were calculated based on the same considerations presented above, as mean values of these three nutrients and were interpreted as follows: very low (≤ 0.70), low (0.71, 0.80], moderate (0.81, 0.87], large (0.88, 0.95], and extra-large (>0.96).

Function 3: Biodiversity support function supplies several ecosystem services. In the present study, this function is assessed by the most soil indicators' scores characterizing the environmental conditions: texture, clay content, land slope, pH value, available volume, gleyzation, stagno-gleyzation, salinization/alkalization, and porosity. Other less quantified soil description attributes for this function are: rooting depth, abundance of soil invertebrates, presence of soil engineering fauna (earthworms), bacterial amount and activity, and enzymatic activities. This function shows the soils capacity to support life and biodiversity (Sere et al., 2024); it thus supports the biomass provisioning service.

The following scores for soil clay, land slope, pH, soil available (edaphic) volume, gleyzation, stagno-gleyzation, salinization/alkalization and soil porosity were given according to the "land rating" method of Teaci (1980, 1989) and Predel et al. (1987). From these scores, soil clay and soil pH scores received the maximum value of 1.0 for moderate attributes, e.g. loamy texture and neutral pH, while for land slope, soil available volume, gleyzation, stagno-gleyzation, salinization/alkalization, and soil porosity the scores were given from the lower to the higher scales that were either at the lowest or highest end of the range, depending on the direct or inverse correlations between these variables.

The biodiversity support function score was calculated as average values for each soil property/attribute and soil profile according to the obtained statistical distribution of the analyzed dataset. Interpretation of the biodiversity support score is as follows: very low (≤ 0.80), low (0.81, 0.90], moderate (0.91, 0.94], large (0.95, 0.97], extra-large (> 0.98).

Function 4: The water cycle function is linked to the ecosystem services of biomass production, through irrigation and drainage, and through regulation of environmental risk through flood regulation as some scientists reported (Sere et al., 2024). The specific soil indicators are permeability, retention capacity, soil water availability for plants and total soil water capacity. These properties are characterized by the scores of: saturated hydraulic conductivity (Ksat), field capacity (FC), plant available soil water (PAW), total soil water capacity (TWC), and the resultant Soil water (SW) score (function score). For each of the individual soil parameters' distribution, from the lowest to the highest property values, the scores were generally assigned from 0.6 to 1.0, with 1 as the most favorable one. SW scores were calculated as mean values for all the above soil parameter scores and were interpreted using the statistical distribution as follows: very low (≤ 0.75), low (0.76, 0.80], moderate (0.81, 0.85], large (0.86, 0.90], extra-large (0.91, 0.95], extremely large (> 0.96).

Function 5: The contaminant cycle function shows the soil's capacity to cope with contaminants (Sere et al., 2024). It is characterized by the presence or stock of contaminants (over-fertilization, pesticides, organic and heavy metal pollutants, etc.) in the environment. Soil properties such as infiltration, transport, sorption, degradation, etc. are important indicators for the pollutants' fate (Sere et al., 2024). For example, Lăcătusu et al. (2021), Gökmen et al. (2024) and Wu et al. (2024) reported various aspects of soil degradation or pollution, as well as experiments designed to ameliorate the soils. Even if this function has theoretically a universal character, unlike the other soil functions it has not a large spreading area; it rather has a local character, as hot spots, being linked by the pollution event and pollutant source. The scoring method should be applied depending on the nature and intensity of pollution.

Finally, except for the recycling of nutrients/pollutants score that applies to local spots, the scores of all the other four soil functions that apply to large areas were summed up for land uses, soil classes, and soil types.

3. RESULTS AND DISCUSSION

3.1. Function 1. Organic matter cycle - SOC, SOCpot and SOC stock overall scores

3.1.1. Depending on land use

SOC stock and SOCpot stock scores are significantly different among land uses (Figure 1a-b). SOC stock score was the highest (close to 1.0) for forestland, due to higher altitude enhancing SOC sequestration attributed to the wet and cold climate, followed by grassland and cropland (0.94), but these differences are small. SOCpot score is minimum in forest (0.60), has an intermediary value in grassland and is maximum in cropland (0.78), with higher differences between its values because SOCpot strongly depends on clay content.

The resultant SOC stock overall (function) score shows almost equal values (0.85) for grassland and cropland, and an unexpectedly lower value for forest soils (0.79) due to the SOCpot score (Figure 1c). Even if forestlands have higher current organic matter and implicitly SOC, the greater soil clay content of the other two land uses facilitates a higher SOC stability if neglecting the artificial activity. At the same time, this result also shows that the potential increase in SOC is higher in cropland and grassland, the forest soils being already almost saturated with C and is exposed to stronger erosion through its higher slope. This function is also important for climate change mitigation, with farmers being encouraged to sequester more C, especially deeper in the soils.

3.1.2. Depending on soil class

SOC stock scores are maximum for the mountain-spread Spodisols and Umbrisols, as well as for Vertisols (near 1.0) (Figure 2a). The lowest SOC values were found for Antrisols (0.91) and Luvisols (0.93), which are significantly different from the first ones. SOCpot stocks scores were maximum for the fine-textured soils, i.e. Vertisols (0.94), which are significantly different from coarser Umbrisols (0.40), Spodisols (0.52) and Cambisols (0.61); there are again large differences between soil classes scores (Figure 2b). As for the land use case, the SOC stock overall (function) score is strongly influenced by the large differences between SOCpot scores. This means that SOC stock overall score is maximum in Vertisols (0.97), followed by Salsodisols, Chernisols and Cambisols (around 0.90), while the lowest overall scores occurred for the mountain soils (Umbrisols 0.71, Spodisols 0.75, and Cambisols and Protisols around 0.80) as shown in Figure 2c.

3.1.3. Depending on soil type

SOC stock scores were highest (close to 1.0) not only for many mountain soils (Podzols, Prepodzols, Humosiosols, Rendzinas, Districambosols) developed in wet conditions that favor C sequestration, but also for fine-textured soils such as Vertosols, Pelosols, for Phaeozems or for steppe-specific Chernozems (Figure 3a). Generally, the SOC stock scores have a large range of values within each soil type, the differences being significant only versus Stagnosols. Particular attention should be given to Psamosols that have a low SOC stock; however, their score is larger than a finer-textured soil type having the same SOC stock, according to the methodology reported by Teaci (1980, 1989), Predel et al. (1987) and Florea et al. (1987).

As presented for soil class, SOCpot scores were strongly dependent on soil texture, with the fine-textured soil types showing the highest score values, i.e. Vertosols and Pelosols (>0.90), while the coarse-textured soils such as Psamosols, Podzols, Humosiosols and Lithosols presented significantly lower scores (between 0.32 and 0.45); there were also high and significant differences among soil types. Intermediary values were obtained for the other studied soils (Figure 3b).

The resultant SOC stock overall (function) scores showed a similar pattern as SOCpot scores (Figure 3c). The highest scores (0.96-0.97) occurred for the heavy-clay soil types of Vertosols and Pelosols, followed by Phaeozem, Gleysol and Solonetz, which had either a high clay content or moisture content. Psamosols, Lithosols, Podzols and Humosiosols presented the lowest significant scores versus the first ones, even if the last two had high current SOC stocks. As for the land use case, the potential to increase SOC is higher for the plain and plateaus soils mainly occupied by cropland.

3.2. Function 2. Soil nutrient cycle scores

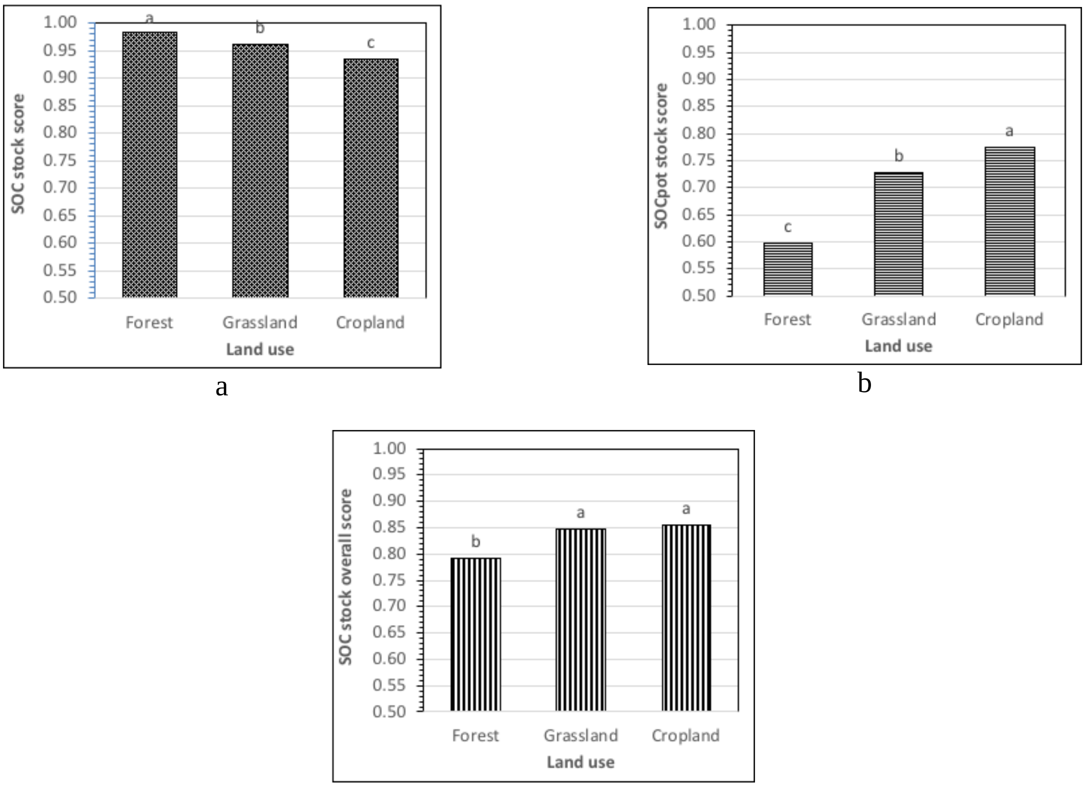
3.2.1. Depending on land use

Total soil nitrogen (TN) stock scores were significantly higher in forest and grassland soils versus cropland soils, similar to SOC stock score, while mobile SAP and SAK stock scores were significantly higher in cropland, versus grassland soils scores, which in turn were significantly higher than forest soils scores (Figure 4a-c). The TN scores can be explained by the direct correlation between SOC and TN contents as was also shown by Lăcătusu et al. (2024) and Paltineanu et al. (2024), while the soil mobile P (SAP) stock primarily depends on fertilizers application on cropland soils (Dumitru et al., 2024). The higher soil mobile K (SAK) stock in cropland soils is also attributed to the direct correlation with the clay content, which is higher in cropland soils.

The soil nutrient (function) score, averaging the above TN, SAP, and SAK scores, is essentially influenced by the last two nutrient scores, being thus, significantly higher in cropland soils, versus the other land uses (Figure 4d).

3.2.2. Depending on soil class

TN stock scores were significantly higher for the mountain soil classes, with high-organic matter, Spodisols and Umbrisols (0.85), than Antrisols (0.75), Hydrisols (0.76), Luvisols (0.72) and Protisols (0.74) (Figure 5a). The other soil classes present intermediary situations.

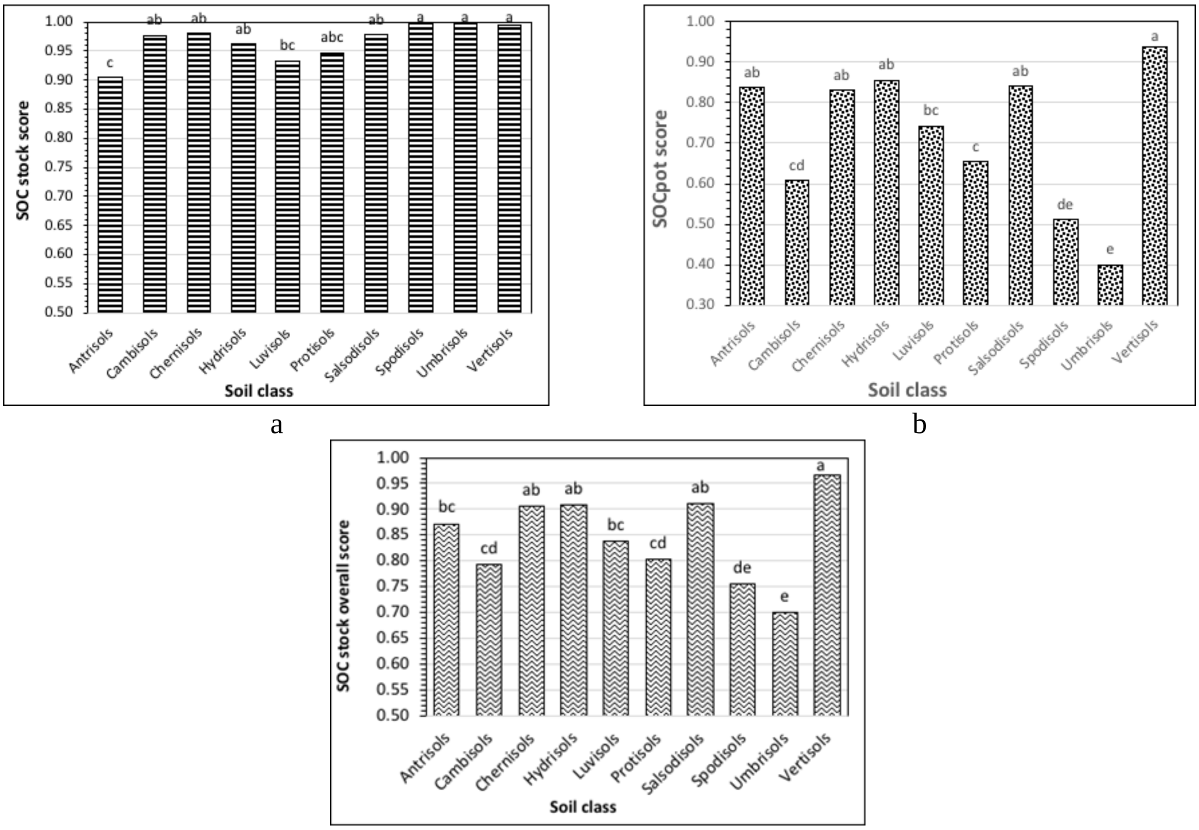


a

b

c

Figure 1. SOC stock (a), SOCpot stock (b) and SOC stock overall scores (c) depending on land use



a

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Figure 2. Scores of SOC stock (a), SOC pot stock (b) and overall SOC stock (c) depending on soil class

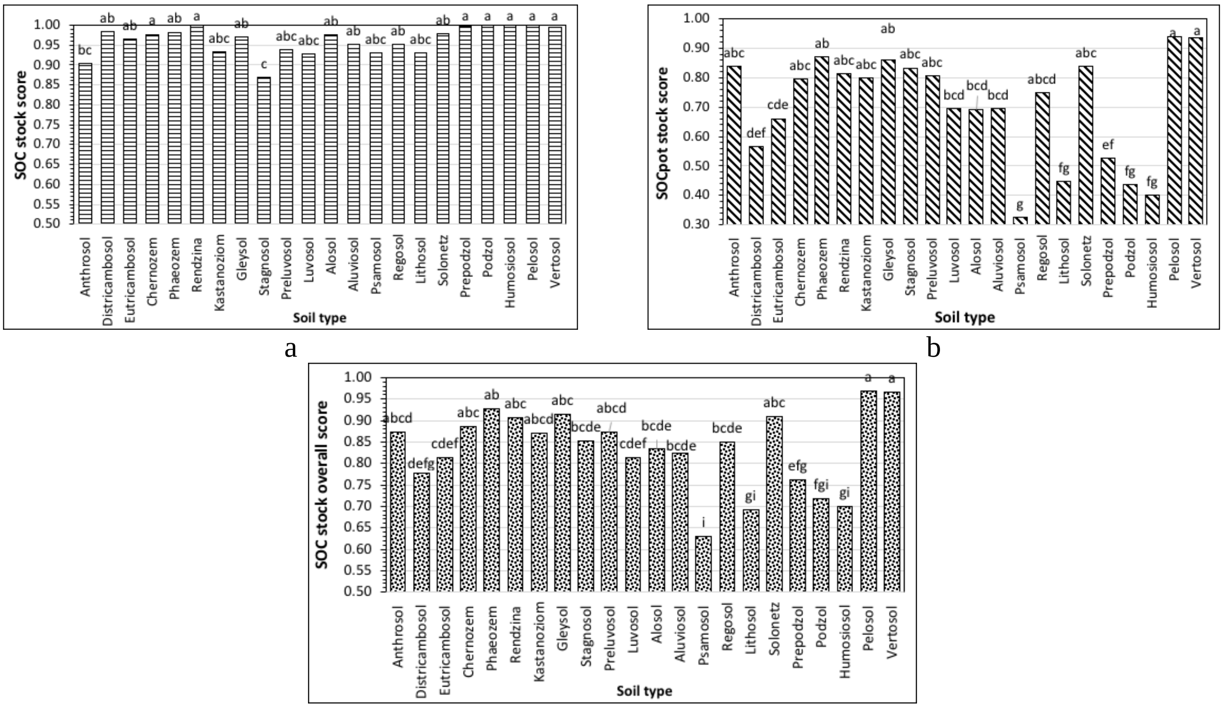

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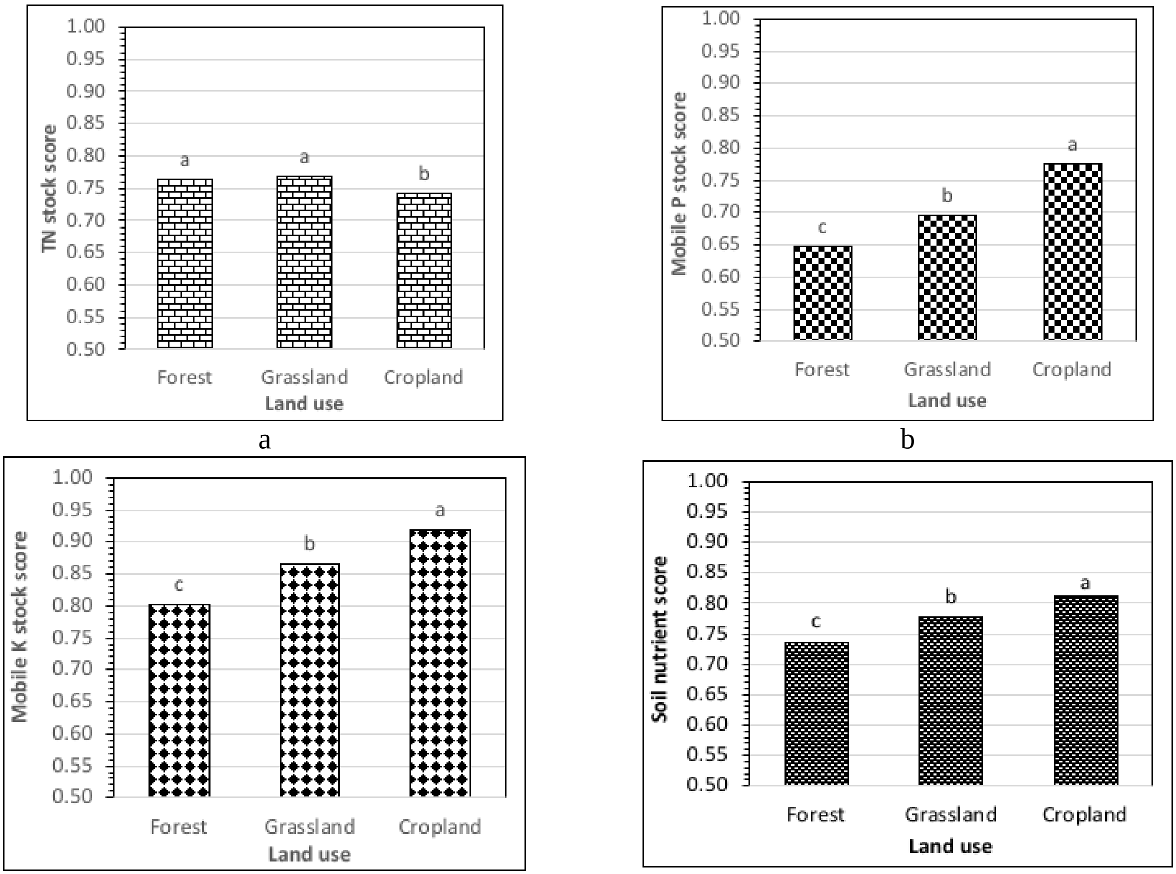
Figure 3. Scores of SOC stock (a), SOC pot stock (b) and overall SOC stock (c) depending on soil type



a b

c d

Figure 4. Scores of TN stock (a), mobile P stock (b), mobile K stock (c) and overall soil nutrient (d) depending on land use

Mobile P stock scores show another pattern, Chernisols and Hydrisols, primarily occupied by cropland, having the maximum values (0.73-0.74), significantly higher than the mountain Umbrisols (0.60), Cambisols (0.66) and Spodisols (0.67), or Luvisols (0.67) (Figure 5b). A somehow similar pattern has the mobile K stock scores, the significantly minimum values having again the mountain coarse-textured soils of Spodisols (0.78), Umbrisols (0.70) and Cambisols (0.80) (Figure 5c).

The synthetic indicator of soil nutrient (function) score emphasized the highest values for Chernisols (0.79), Vertisols (0.84), mostly being cropland soils, where farmers usually apply complex fertilizers, being significantly higher than the mountainous soil classes of Umbrisols (0.72), Cambisols and/or Luvisols (0.75) (Figure 5d).

3.2.3. Depending on soil type

Soil type scores generally show the soil class scores pattern for each soil nutrient score. Thus, TN stock scores were highest for high-altitude mountain Podzols, Prepodzols, and Humosiosols, with more than 0.85. The above soil types presented significantly higher scores than other soil types, such as Lithosols and Psamosols (0.70), or Preluvosols (Figure 6a). The same pattern was found in the case of the other two soil macro-nutrients, mobile P and K stocks.

The highest mobile P stock scores were found for Cherozems, Stagnosols, and Psamosols, significantly higher than the scores found for many mountain soil types, such as Alosols and Humosiosols (0.60), Districambosols (0.65), and Rendzinas (0.66) (Figure 6b).

The highest mobile K stock scores occurred for Chernozems (0.93), Vertosols, and Solonetz (around 0.95), significantly higher than for Districambosols (0.78), Alosols (0.75), Lithosols (0.77) and Humosiosols (0.70) (Figure 6c). The other soil types presented intermediary scores.

The synthetic soil nutrient (function) scores, calculated as average values between TN, mobile P, and K scores, were highest for Chernozems, Stagnosols, and Vertosols, with around 0.85, while the lowest were for Alosols, Lithosols, and Humosiosols (0.70 - 0.72) (Figure 6d); the other soil types presented intermediary scores.

3.3. Function 3. Biodiversity support score

The biodiversity support score is assessed by most of the soil indicators scores characterizing the environmental conditions: texture, clay content, land slope, soil pH, available soil volume, soil gleyzation, soil stagno-gleyzation, soil salinization/alkalization, and soil porosity; the synthetic biodiversity support (function) score averages the above component scores and shows the soil capability to support vegetation and biodiversity.

3.3.1. Depending on land use

The scores of the following soil indicators: clay content, land slope, pH, and available soil volume present a similar pattern, i.e. an increase from forest toward grassland and cropland, in most cases being significantly different among land uses (Figure 7a-d). Total soil porosity and stagno-gleyzation scores were not significantly different between land uses, while gleization only differentiated significantly the cropland versus the forest and grassland; salinization and alkalization (solonization) induced significant differentiation for grassland, because generally salt-affected soils are occupied by pastures (Figure 7e-f).

The synthetic biodiversity support (function) score was mainly determined by the indicators scores of clay content, land slope and its involved erosion potential, available soil volume, and pH, highlighting significantly best environmental conditions for cropland soils, followed by grassland and forestland (Figure 7g).

3.3.2. Depending on soil class

Clay content scores were highest for Antrisols, Chernisols, Hydrisols, and Salsodisols (>0.95) and significantly different than the coarser-textured Spodisols and Umbrisos (Figure 8a). Land slope and soil pH scores showed some similarities, i.e. the high-elevation plain or alluvial plain soil classes (Chernisols, Hydrisols, Salsodisols, and Vertisols) scores were highest, and in some cases significantly different from mountainous soil classes of Cambisols and Spodisols (Figure 8b-c), while the available soil volume scores were maximum (1.0) for all soil classes, excepting some short-profiled Protisols (Figure 8d). Total soil porosity scores were significantly lower for Spodisols and Umbrisols compared to the other soils (Figure 8e).

The scores related to stagno-gleyzation, gleyzation (Hydrisols), and salinization/solonization (Salsodisols) were minimum, i.e. significantly lower, only in the case of the soil classes that were defined as being affected just by these processes, versus the others (Figure 8f-g).

As a resultant score of the above indicators, biodiversity support function scores presented the highest values for Chernisols and Vertisols (0.98) due to the favorable physical and chemical properties, followed by Antrisols, Luvisols, Protisols, etc. (Figure 8h). The significantly different, lowest

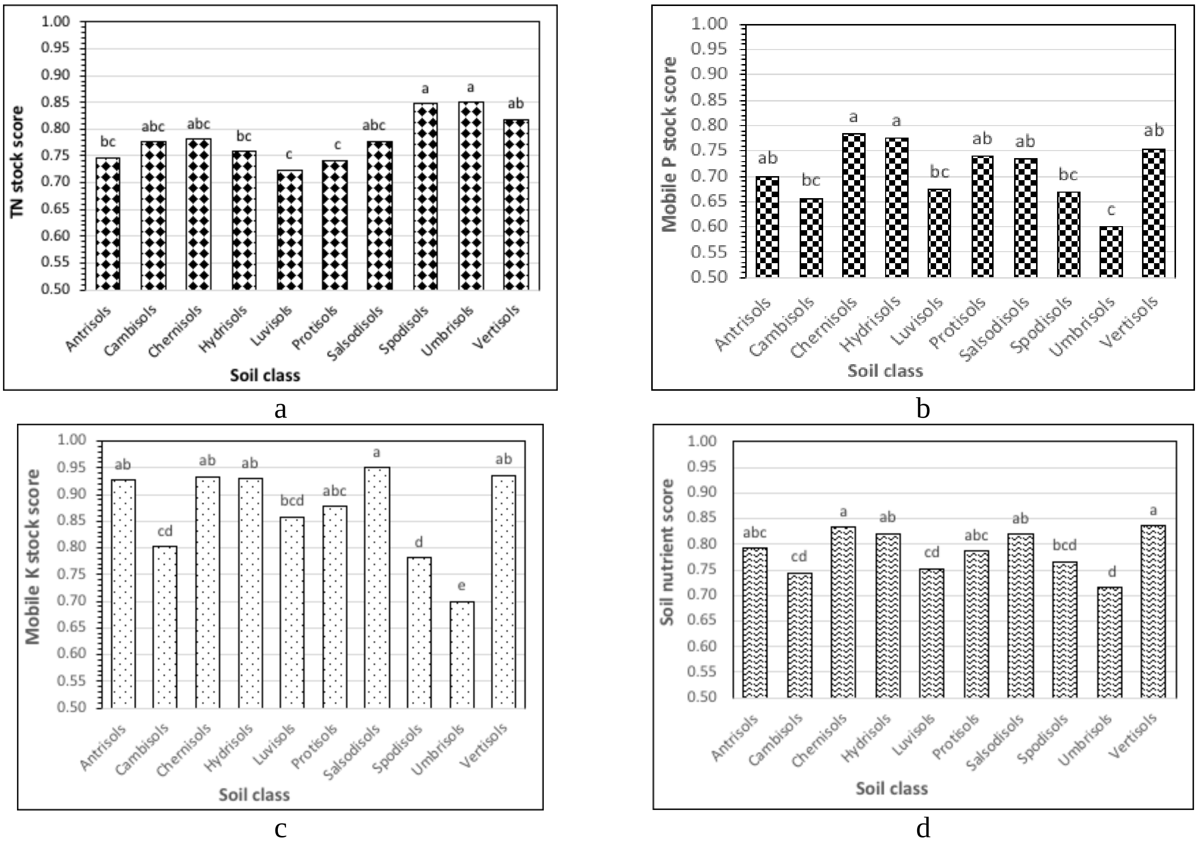


Figure 5. Scores of TN stock (a), mobile P stock (b), mobile K stock (c) and overall soil nutrient (d) depending on soil class

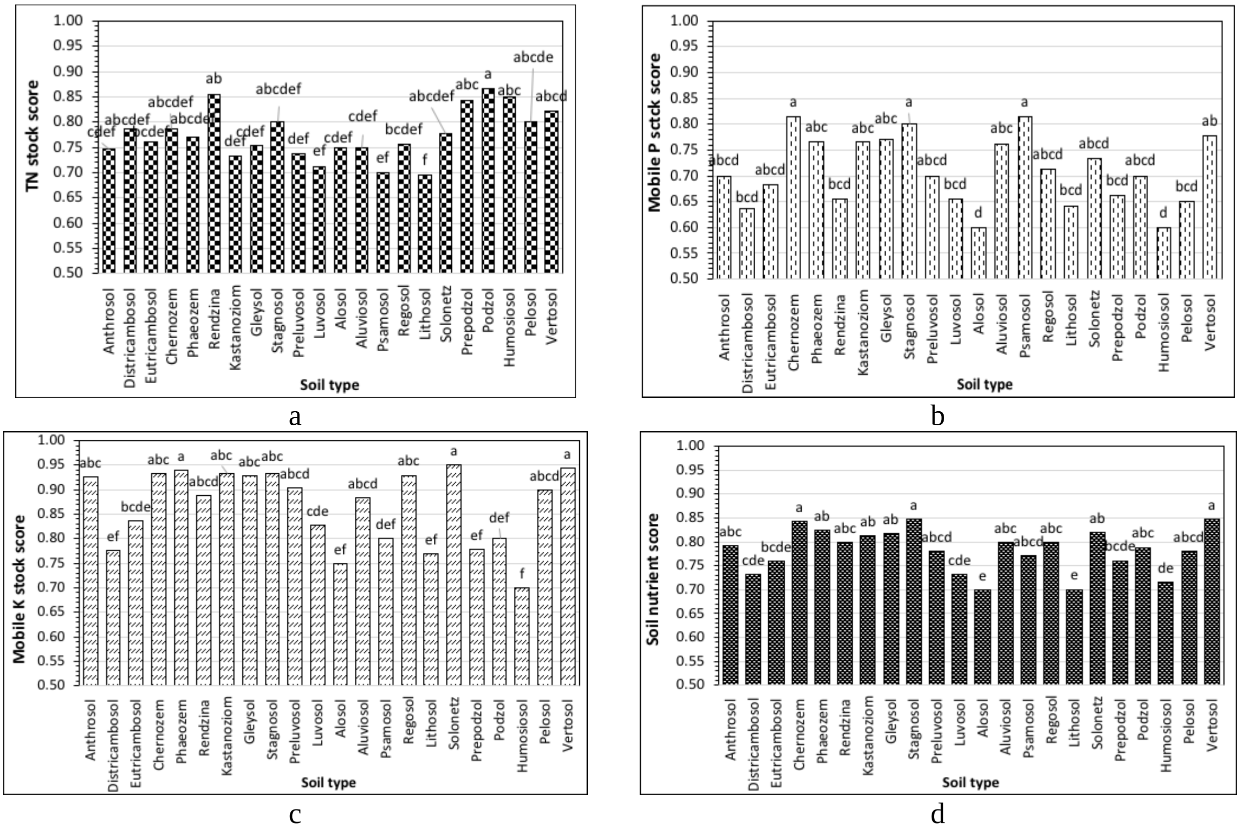


Figure 6. Scores of TN stock (a), mobile P stock (b), mobile K stock (c) and overall soil nutrient (d) depending on soil type

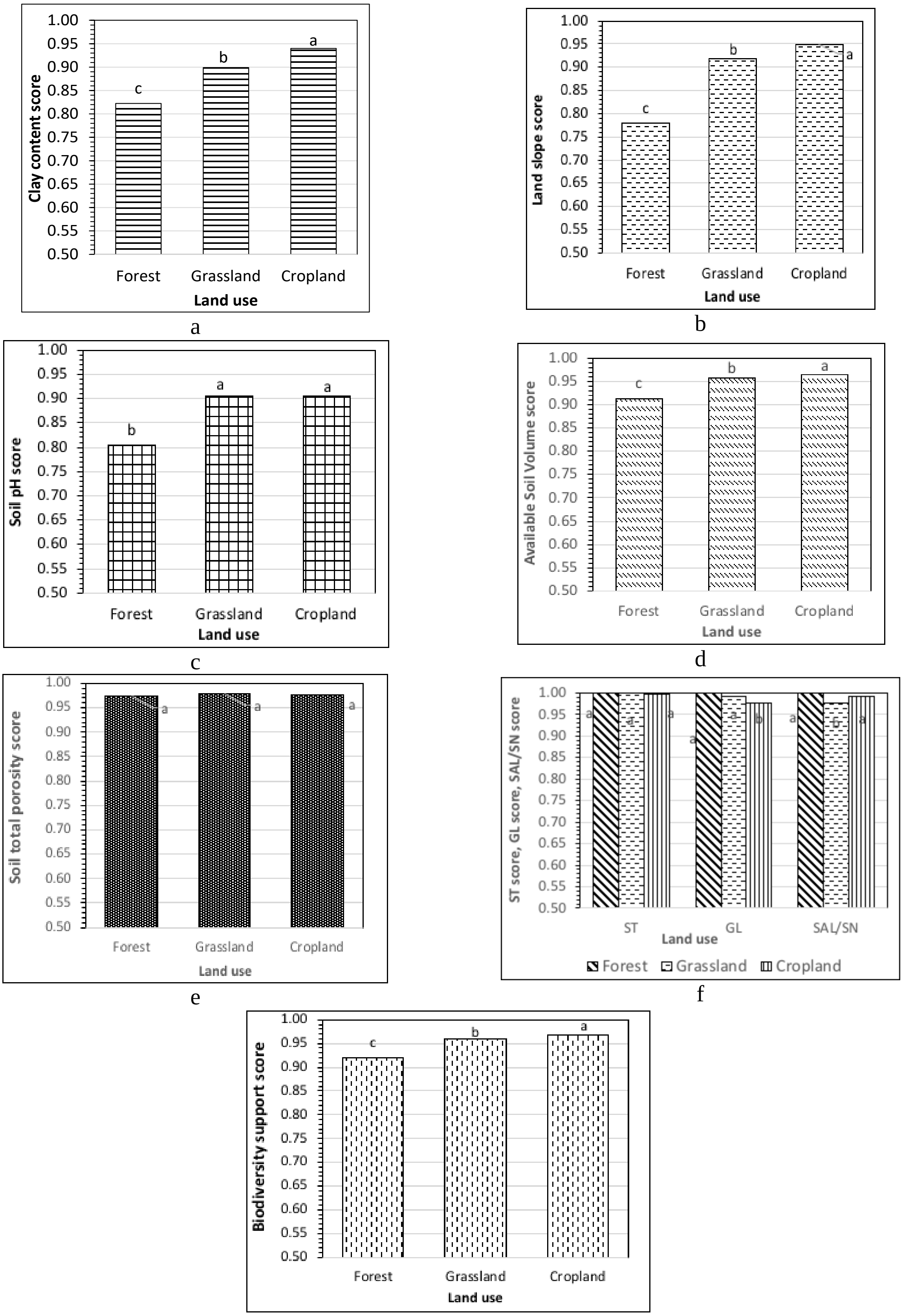
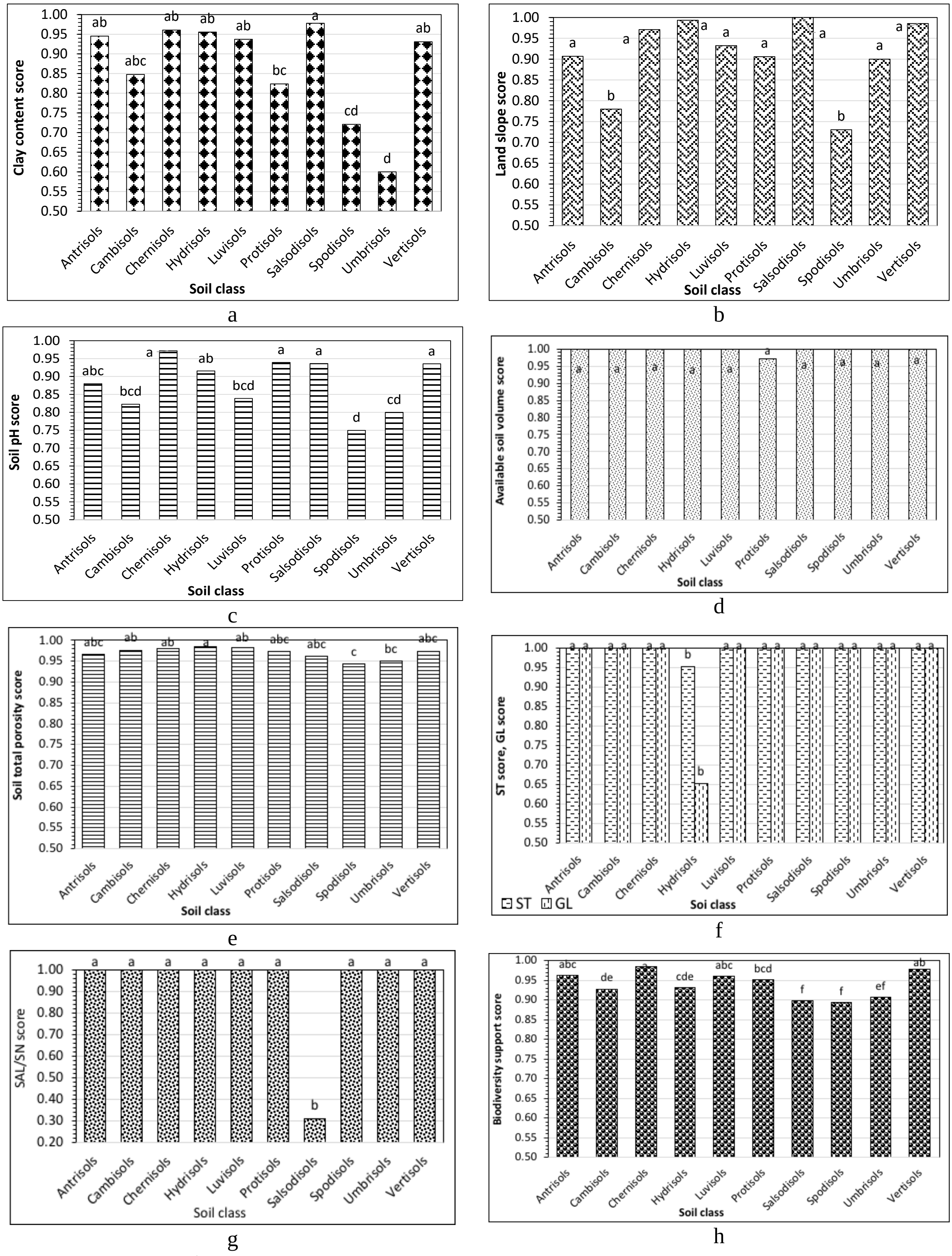


Figure 7. Scores of clay content (a), land slope (b), soil pH (c), available soil volume (d), total soil porosity (e), ST=Stagno-gleyzation, GL=gleyzation, and SAL/SN=Salinization/Solonization (f), and biodiversity support (g), depending on land use; unlike the land rating method, the available soil volume also refers to 0.5 m depth in this study



a b c d e f g h

Figure 8. Scores of clay content (a), land slope (b), soil pH (c), available soil volume (d), total porosity (e), ST=Stagno-gleyzation and GL=gleization (f), SAL/SN=Salinization/Solonization (g), and biodiversity support (h), depending on soil class

biodiversity support scores were found for Salsodisols, Spodisols, and Umbrisols (around 0.90), due to the toxic effect of the salts and pH in the first case, and to low nutrient content, clay content as well as to the involved erosion potential of the steep land slopes in the second case, but their differences are not large.

3.3.3. Depending on soil type

Clay content score differentiated the soil types as follows: most soil types, e.g. Antrisols, Chernozems, Phaeozems, Stagnosols, Solonetz, and Vertosols, have the highest scores, while Psamosols, Lithosols, Podzols and Humosiosols have the lowest ones, with significantly different values (Figure 9a).

Just like the soil classes, land slope and pH scores presented somewhat similar pattern, the flat or low-sloped land soils such as Chernozems, Phaeozems, Kastanoziom, Aluviosols, Psamosols, Solonetz, as well as Vertosols and Pelosols, showed the highest significant scores versus the mountainous soil types of Districambosols, Prepodzols, Podzols, Lithosols (Figure 9b-c).

Available soil volume scores were significantly lower for Lithosols versus the other soil types, as well as for soils strongly affected by stagno-gleyzation, gleyzation and salinization/alkalization processes (Figure 9d, f-g).

A lower than 0.95 score for soil total porosity was only found for Alosols, Lithosols and Podzols, while the rest were not significantly affected by this indicator (Figure 9e). The resultant biodiversity/vegetation (function) score, averaging the previously presented indicators scores, were highest (close to 1.0) for the fertile Chernozems, Phaeozems, Kastanozioms, Aluviosols, Pelosols and Vertosols, being significantly different from the lowest scores found for Lithosols, Solonetz, Prepodzols, Podzols and Humosiosols (around 0.90) (Figure 9h); however, the differences are small, showing real capabilities for Romanian soils to accommodate plants or cultivated crops under proper conditions.

3.4. Function 4. Water cycle in soils

3.4.1. Depending on land use

Ksat score was highest in the grassland soils, followed by forest soils and cropland soils probably because the first two land uses are less affected by compaction due to human activity (Figure 10a). All these values were significantly different from each other. From all soil physical properties, Ksat shows the most scattered values due especially to many macropores usually occurring in the first part of soil profile, as in the present case.

Field capacity scores, depending on clay content, were highest in cropland soils, followed by grassland soils and forest soils, also significantly different from each other, while total soil water capacity scores were inversely related (Figure 10b); plant available soil water (PAW) scores were higher in cropland soils, being significantly different from the other two land uses' scores (Figure 10c), while TWC in forest soils (Figure 10d).

Because these soil property scores compensated for each other, the resultant soil water (function) scores barely exceeded 0.85 and were not significantly different among land uses (Figure 10e). Thus, soil water properties are favorable for vegetation growth if climate variables such as precipitation and potential evapotranspiration are balanced across the year.

3.4.2. Depending on soil class

Ksat scores did not significantly differentiate the soil classes, all scores being included in the 0.90 - 1.0 interval, while field capacity scores were highest for Vertisols, followed by Antrisols, Chernisols, Hydrisols and Salsodisols, while Spodisols, Cambisols and Umbrisols showed the lowest significant scores (Figure 11a-b).

PAW scores were highest for Umbrisols (0.85), while all the other soil classes had PAW scores between 0.70 and 0.80 (Figure 11c). A similar small difference occurred in the case of total soil water capacity scores, from 0.90 to 1.0, the lowest found for Vertisols, due to the high wilting point values attributed to the high shrinking-swelling clay content (Figure 11d). As found for the land use case, the overall soil water scores were not significantly different (0.84 and 0.87) between classes (Figure 11e).

3.4.3. Depending on soil type

Ksat scores were highest in Kastanozioms and Podzols (1.0), due to their high-moderate permeability and texture, being significantly lowest in Alosols, Psamosols, and Humosiosols due to their excessive permeability, or Solonetz and Pelosols due to their very low permeability generally attributed to the presence of soluble salts or high clay content (Figure 12a). Field capacity scores showed the highest values for Vertosols (0.85), followed by Pelosols, Anthrosols, and Phaeozems, while the significant lowest values were for short-sized Lithosols, Podzols, and Psamosols (Figure 12b). PAW scores had the maximum values for Humosiosols, followed by many soil types, while the significantly lowest values occurred for Lithosols, Vertosols, Prepodzols, and Podzols (Figure 12c).

Total soil water capacity scores generally showed values higher than 0.85, the lowest values being for Psamosols, Kastanozioms, Podzols and Vertosols, due either to a coarse or coarse-loamy texture, or to a clayey texture (Figure 12d).

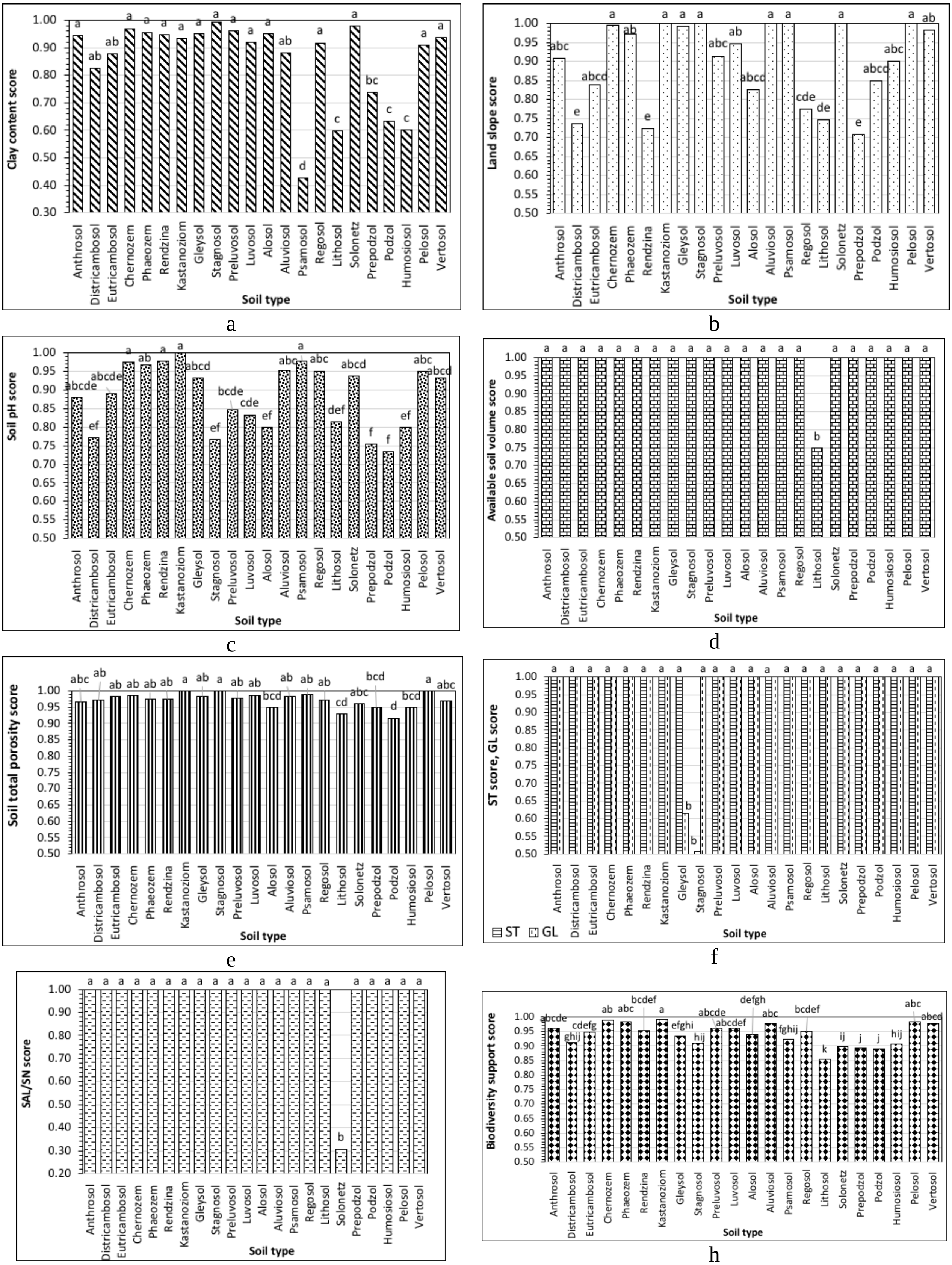
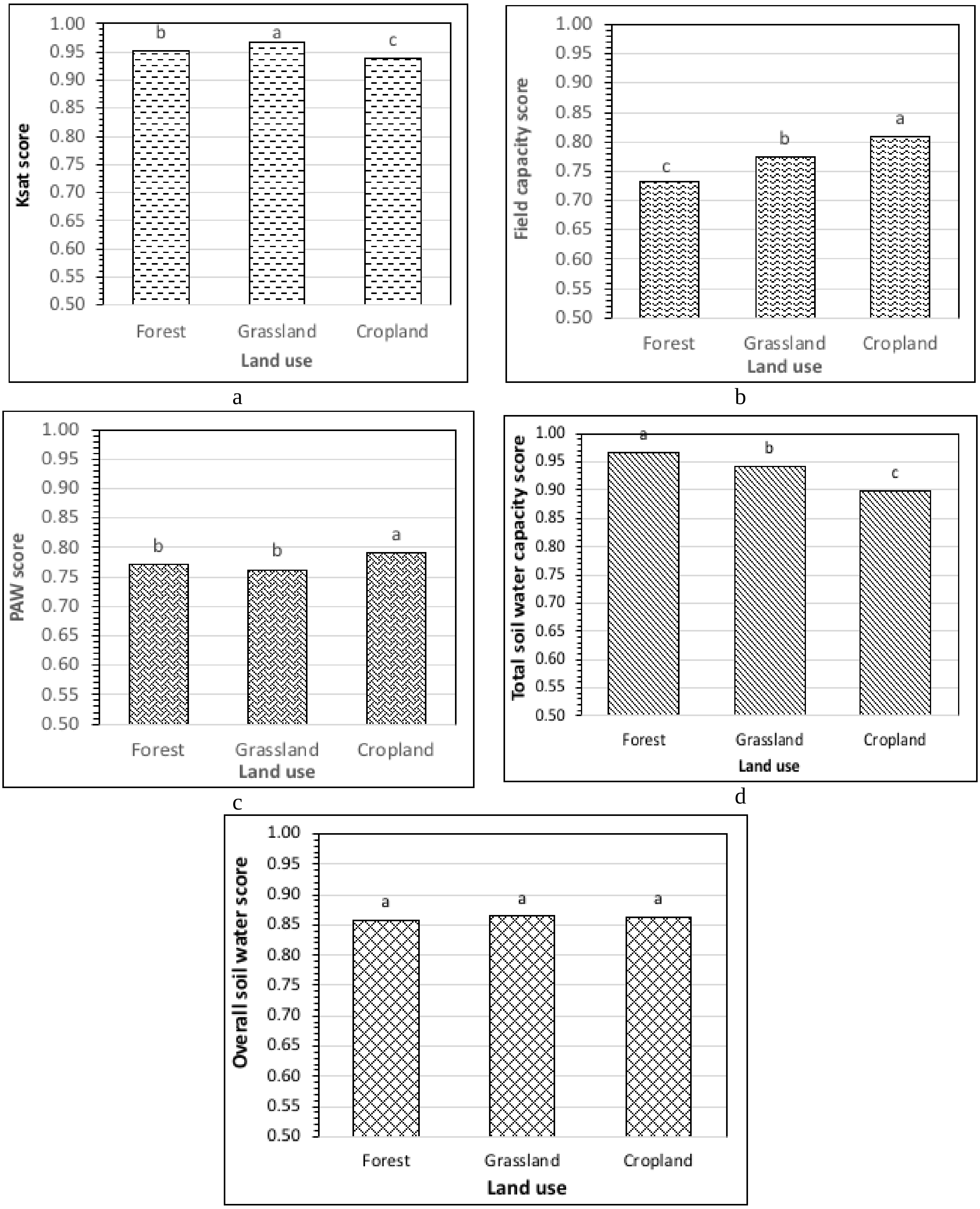


Figure 9. Scores of clay content (a), land slope (b), soil pH (c), available soil volume (d), total porosity (e), ST (Stagno-gleyzation) and GL (gleyzation) (f), SAL/SN (Salinization/Solonization) (g), and biodiversity support (h) depending on soil type



a

b

c

d

e

Figure 10. Scores of soil Ksat (a), field capacity (b), plant available soil water (PAW), (c), total soil water capacity (d) and overall soil water (e) depending on land use

The resultant soil water (function) scores had a small amplitude due to the favorable or unfavorable soil attribute values. The lowest scores were found for Lithosols (0.79) and Psamosols (0.83), while the rest soil types presented a score range between 0.84 and 0.90 (Figure 12e).

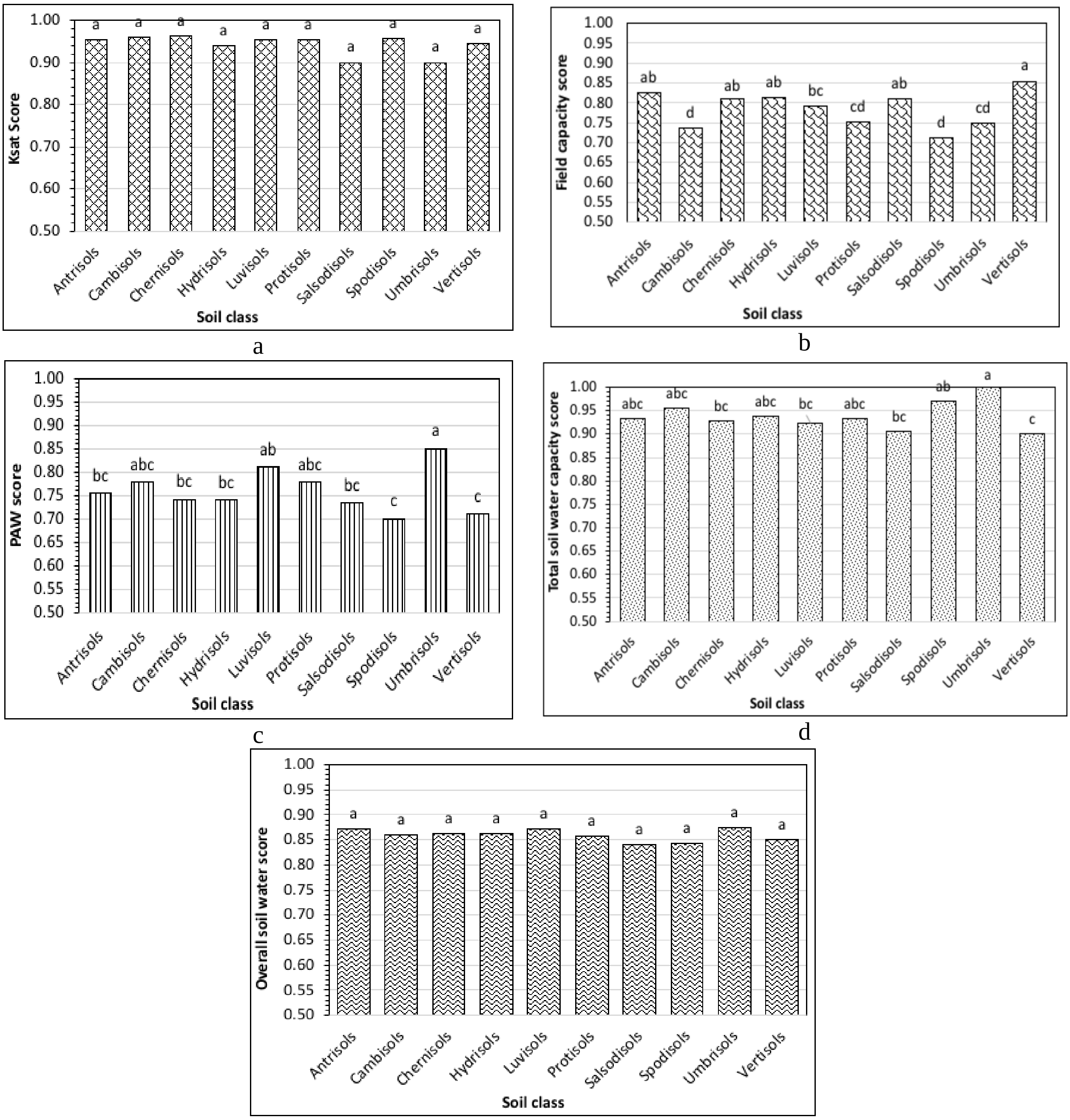
3.5. Function 5. Contamination cycle

This function is especially used for local hotspots, and depends on some industries such as oil industry, coal mining industry, metallurgical industry, etc., which accidentally or permanently determine pollution. Pollution might also result from agricultural fields where soils received overdoses of nutrients (nitrogen, phosphorous, potassium, micro-nutrients) and pesticides, and so on. This function should be treated in detail for each hotspot Soil properties like permeability, texture, SOC stock, depth to groundwater, land slope, etc. contribute to the transit of such pollutants to either groundwater, through internal transport and drainage, or surface waters through runoff. Due to its local but serious importance, this function should be treated carefully, as a function of the nature and severity of the pollutant.

Examples of severely polluted areas in Romania could be found in former places from the communist period, where there were oil exploitations, metallurgic industries, or other hotspots, such as Poieni in Teleorman county, Copsa Mica in Sibiu country, etc.

3.6. The resultant scores of the sum of soil functions

Figure 13 shows the synthetic results concerning the first four soil function scores for land uses (Figure 13a), soil classes (Figure 13b), and soil types (Figure



a

b

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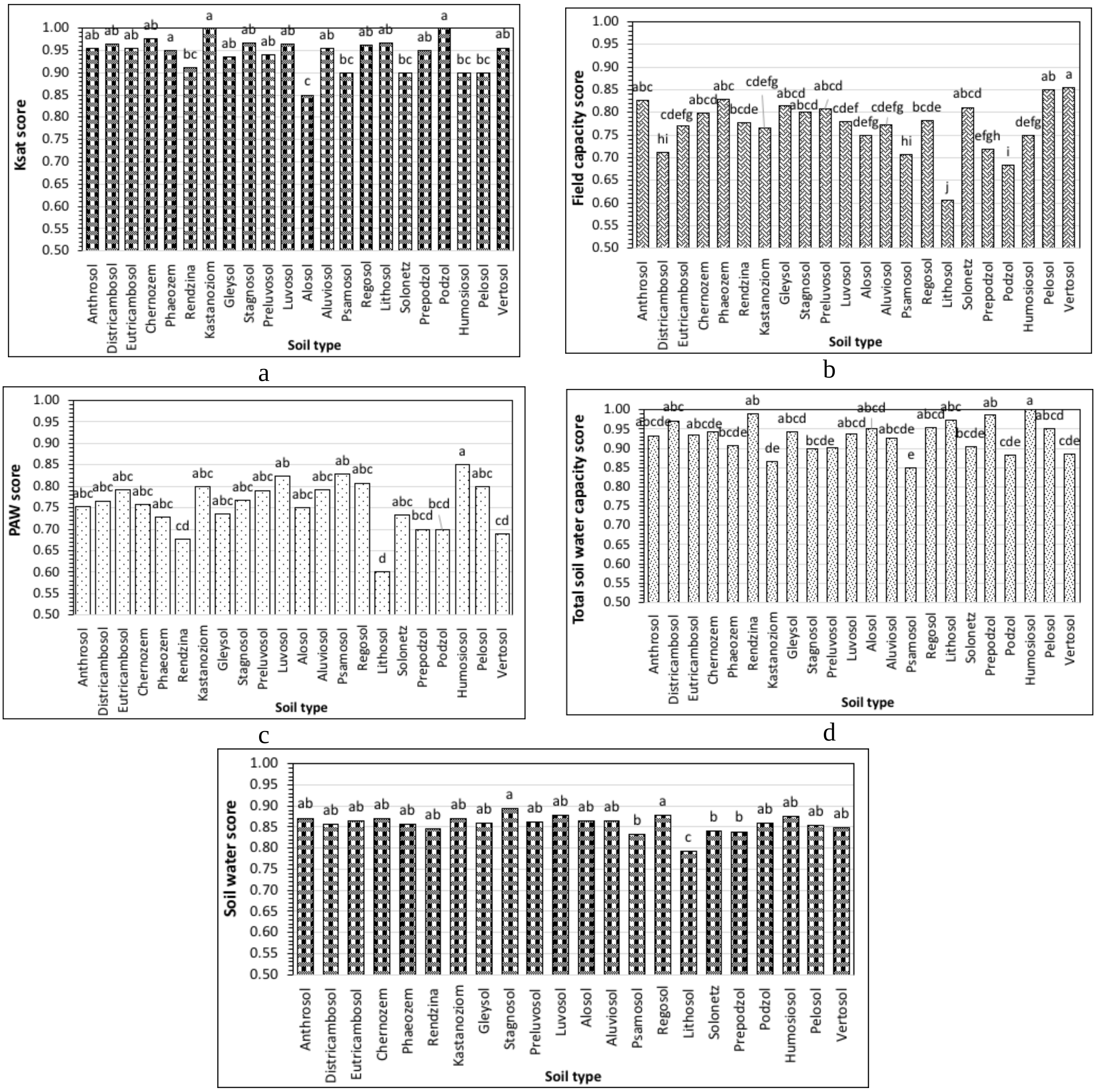
Figure 11. Scores of Ksat (a), field capacity (b), plant available soil water (c), total soil water capacity (d), and overall soil water (e) score depending on soil class

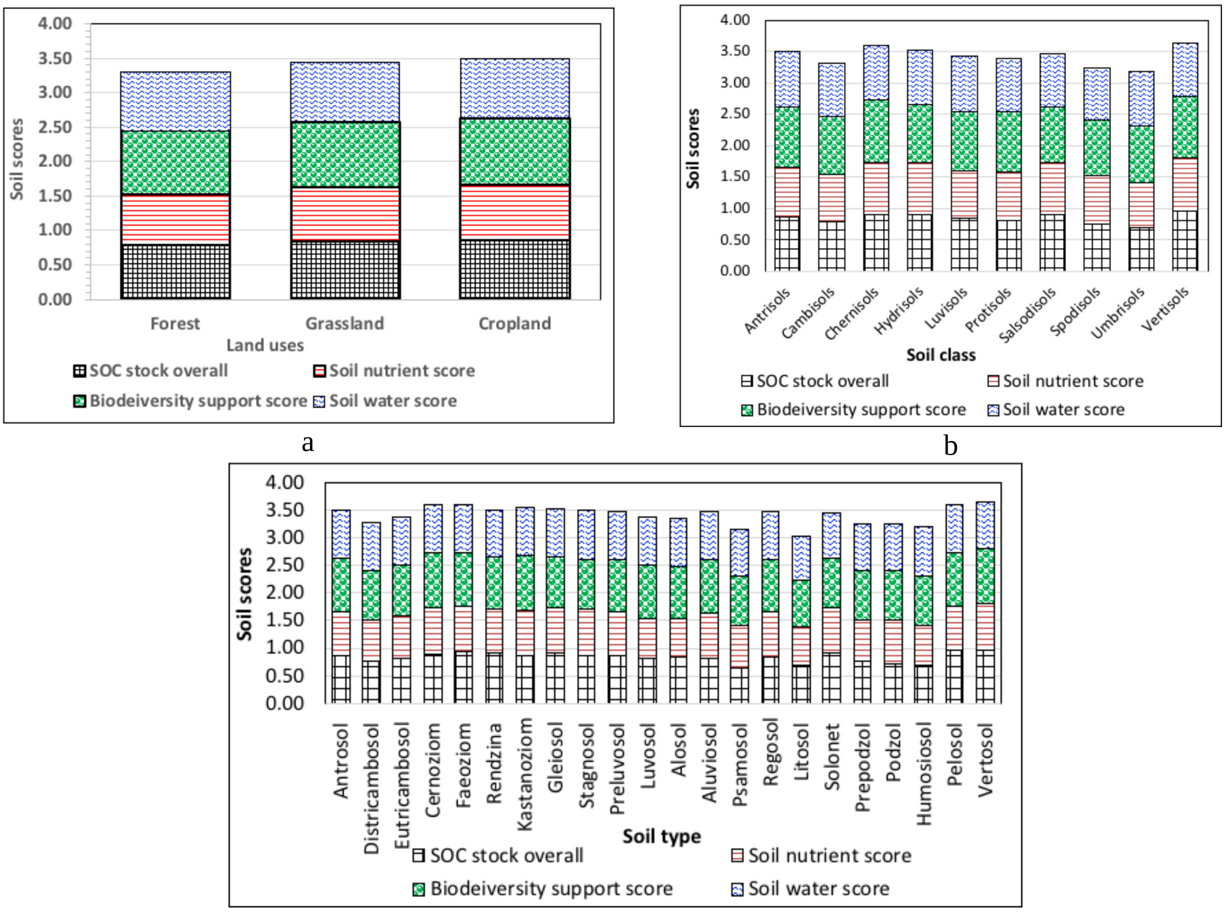


a b c d e

Figure 12. Scores of Ksat (a), field capacity (b), plant available soil water (c), total soil water capacity (d), and overall soil water (e) depending on soil type

13c), irrespective of the fifth function. As a general image, the differences between these three land uses are small, and there was no summed function score lower than the value of 3, most of them around 3.50 out of 4.0. The only soil type that presented the lowest score was for the short-sized Lithosols, followed by the coarse-textured Psamosols, which are indeed the less fertile soils as characterized by land rating method.

Anyway, these five presented soil functions are not sufficient to characterize satisfactorily the soil health. For example, Paltineanu et al. (2024, data not yet published), have found that some low-fertile soils (Psamosols) present higher soil-health standards, when using another soil attribute and score, i.e. SOC/Clay ratio, than some fertile Chernozems and Phaeozems. The SOC/Clay ratio was proposed as a health indicator of soil organic matter status for mineral soils (European Soil Monitoring Law proposal, European Commission, 2023a, 2023b), and its values of 1/8 (0.125), 1/10 (0.10) and 1/13 (0.077) were considered thresholds to characterize soils state as: very good, good, moderate, and degraded levels of structural conditions (Johannes et al., 2017; Prout et al., 2021). Nevertheless, some scientists (Poeplau & Don, 2023; Mäkipää et al., 2024; Rabot et al., 2024) criticized this indicator, while Poeplau & Don (2023) and Feeney et al. (2024) proposed alternatives to the SOC/clay ratio, because all the soil functions are under an intense dynamic.



a

b

c

Figure 13. Sum of all functions' scores for land uses (a), soil classes (b) and soil types (c)

There are also limitations of this current method of evaluating the soil functions, due to both the number of studied soils and the used algorithms, which can further be improved using in-depth approaches.

4. CONCLUSIONS

The present paper proposes a method to assess the health of Romanian soils located across different natural conditions. The analyzed soils are characterized by relatively recent (last ten years) analyses of different soil parameters. Thus, soil function scores reflect the current situation for most of the Romanian soil classes and types.

From the analyzed data and the obtained results interpretation, most of the soils present a satisfactory average health situation, because there were not really severe degradation processes occurring on a large scale, and the scores were presented as mean values for land uses, soil classes and soil types. However, individual soil profiles may present more scattered scores, even extreme values, but their presentation was not the purpose of this study. The soil health characterization is different from the potential of favorability assessed by the land rating method (Teaci, 1987; Florea et al., 1987), which additionally considers decisive climate variables such as air temperature and precipitation related to land slope and aspect, and groundwater depth. In other words, soil health is partly correlated with land favorability potential, or rather is a component of the latter.

Of all the five presented soil functions, the last one, *the contamination cycle function*, is critical for soil health. This is somehow similar to von Liebig's Law of the Minimum (Liebig & Playfair, 1840.), stating that plant yield is proportional to the amount of the most limiting nutrients, which in the present case might be assimilated with the maximum pollutants influence. Practically, plants can grow in and adapt to either of the presented land uses or soils as a function of their specificity, but the soil pollution level determines the existence and/or plant growth capability.

All non-polluted Romanian soils are in a different degree of health, while the polluted hotspot soils are in a different degree of illness. As a continuation of this sentence and extending the exploration area worldwide, a question is arising from this study: are certain natural uninhabited regions, such as warm or cold deserts, healthy because are not polluted, or not healthy because plant and animal life is impossible without sufficient water? Soil scientists should reflect upon such questions and give the right answers.

For the polluted hotspots, specific determinations should be carried out depending on the pollutant nature and severity, while the scores should be attributed according to scientific recommendations, standards, regulations or laws.

The actual database does not necessarily contain all typical cases for the land uses, soil classes or soil types regarding their physical and chemical properties (indicators), which determined the function scores. The more numerous and more uniformly distributed soil data, the more accurate the results for the studied territory. A future enrichment of the soil database as well as modifying how scores are attributed might change some function scores and the way land uses, soil classes and types are related to each other. For instance, soil sub-types and varieties, as well as more new experiments on the soil indicators, would extend, typify, and enlarge the range of functions' scores. Thus, the presented method has the potential to be continuously improved.

Scientists are looking for new and better soil function indicators, and future research is therefore needed to help improve them at both European and worldwide level.

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REFERENCES

Andrei, T., 2015. *Date generale despre agricultura României.* Anuarul statistic al României. https://madr.ro/docs/agricultura/agricultura-romaniei-2015.pdf.

Ballabio, C., Lugato, E., Fernández-Ugalde, O., Orgiazzi, A., Jones, A., Pasquale Borrelli, P., Montanarella, L. & Panagos P., 2019. *Mapping LUCAS topsoil chemical properties at European scale using Gaussian process regression.* Geoderma, 355, 113912, DOI:10.1016/j.geoderma.2019.113912.

Bispo, A., Cluzeau, D., Creamer, R., Dombos, M., Graefe, U., Krogh, P.H., Sousa, J.P., Pérès, G., Rutgers, M., Winding, A. & Römbke, J., 2009. *Indicators for monitoring soil biodiversity.* Integrated environmental assessment and management, 5(4), 717-719.

Dominati, E., Patterson, M. & Mackay, A., 2010. *A framework for classifying and quantifying the natural capital and ecosystem services of soils.* Ecol. Econ., 69, 1858–68, DOI: 10.1016/j.ecolecon.2010.05.002.

Domnariu, H., Paltineanu, C., Marica, D., Lăcătușu, A.R., Rizea, N., Lazăr, R., Popa, G.A., Vrinceanu, A. & Bălăceanu, C., 2020. *Influence of soil-texture on nitrate leaching from small-scale lysimeters toward groundwater in various environments.* Carpathian Journal of Earth and Environmental Sciences, 15(2), 301-310, DOI:10.26471/cjees/2020/015/130.

Dumitru, M., Manea, A., Ciobanu, C., Dumitru, S., Vrînceanu, N., Calciu, I., Tănase, V., Preda, M., Rîșnoveanu, I., Mocanu, V. & Eftene, M., 2011. *Monitoringul stării de calitate a solurilor din Romania.* ICPA Bucureşti, Editura Sitech, Craiova. 82 pp. https://www.icpa.ro/proiecte/Proiecte%20nationale/monitoring/atlasICPA.pdf.

Dumitru, S., Paltineanu, C., Vizitiu, O. & Domnariu, H., 2024. *Soil available phosphorous and potassium stocks related to environmental properties, land uses and soils.* The Journal of Agriculture Science, Cambridge University Press, 1-14, DOI:10.1017/S0021859624000339.

Egnér, H., Riehm, H. & Domingo, W.R., 1960. *Untersuchungen uber die chemische Bodenanalyse als Grundlage fur die Beurteilung des Nahrstoffzustandes der Boden. II. Chemische Extraktionsmethoden zur Phosphorund Kaliumbestimmung.* Kunglia Lantbrukshogskolans Annaler, 26, 199-215.

European Commission, 2023a. *Proposal for a Directive of The European Parliament and of The Council on Soil Monitoring and Resilience* (*Soil Monitoring Law*). Brussels, 5.7.2023, COM(2023) 416 final, 2023/0232 (COD). EUR-Lex - 52023PC0416 - EN - EUR-Lex.

European Commission, 2023b. *Annexes. Proposal for a Directive of The European Parliament And of The Council on Soil Monitoring and Resilience (Soil Monitoring Law*). Brussels, 5.7.2023, COM(2023) 416 final, 2023/0232 (COD). https://eur-lex.europa.eu/resource.html?uri=cellar:01978f53-1b4f-11ee-806b-01aa75ed71a1.0001.02/DOC_2&format=PDF.

Faber, J.H., Marshall, S., Brown, A.R., Holt, A., van den Brink, P.J. & Maltby, L., 2021. *Identifying ecological production functions for use in* *ecosystem services-based environmental risk assessment of chemicals.* Science of The Total Environment 791: 146409, DOI: 10.1016/j.scitotenv.2021.146409.

Feeney, C.J., Bentley, L., De Rosa, D., Panagos, P., Emmett, B.A., Thoma,s A. & Robinson, D.A., 2024. *Benchmarking soil organic carbon (SOC) concentration provides more robust soil health assessment than the SOC/clay ratio at European scale*. Science of the Total Environment, 951, 175642, DOI: 10.1016/j.scitotenv.2024.175642.

Fernandez-Ugalde, O., Scarpa, S., Orgiazzi, A., Panagos, P., Van Liedekerk,e M., Marechal, A. & Jones, A., 2022. *LUCAS 2018 Soil Module. Presentation of dataset and results*. EUR 31144 EN, Publications Office of the EU, Luxembourg. DOI:10.2760/215013, JRC129926. Project of the JRC, European Soil Data Centre (ESDAC). https://esdac.jrc.ec.europa.eu/projects/lucas.

Florea, N. & Munteanu, I., 2012. *Sistemul român de taxonomie a solurilor–SRTS*. Sitech, Craiova, 206 p.

Florea, N., Balaceanu, V., Rauta, C. & Canarache, A., 1987. *Methodology of elaboration of soil science studies. Partea I, II, III.* (In Romanian) Redactia de Propaganda Tehnica Agricola, ICPA Bucuresti.

Gökmen, F., Sukuşu, E., Şimşek, U. & Uygur, V., 2024. *The role of liming in copper adsorption of acidic soils.* Carpathian Journal of Earth and Environmental Sciences, Vol. 19, No. 2, p. 313 – 320, DOI:10.26471/cjees/2024/019/301.

Hassink, J., 1977. *The capacity of soils to preserve organic C and N by their association with clay and silt particles*. Plant and Soil 191, 77–87 (1997), DOI:10.1023/A:1004213929699.

Hatfield, J.L., Sauer, T.J. & Cruse, R.M., 2017. *Chapter One - Soil: The Forgotten Piece of the Water, Food, Energy Nexus*. Advances in Agronomy. Volume 143: 1-46, DOI: 10.1016/bs.agron.2017.02.001.

IUSS Working Group WRB, 2022. *World Reference Base for Soil Resources.* International soil classification system for naming soils and creating legends for soil maps. 4th edition. International Union of Soil Sciences (IUSS), Vienna, Austria.

Johannes, A., Matter, A., Schulin, R., Weisskopf, P., Baveye, P.C. & Boivin, P., 2017. *Optimal organic carbon values for soil structure quality of arable soils. Does clay content matter?* Geoderma, 302, 14-21, DOI:10.1016/j.geoderma.2017.04.021.

Lăcătusu, A.R., Domnariu, H., Paltineanu, C., Dumitru, S., Vrîceanu, A., Moraru, I., Anghel, A. & Marica, D., 2024. *Influence of some environmental variables on organic carbon and nitrogen stocks in grassland mineral soils from various temperate-climate ecosystems.* Environ. Exp. Bot., 217, 105554, DOI:10.1016/j.envexpbot.2023.105554.

Lăcătușu, A.R., Paltineanu, C., Domnariu, H., Vrinceanu, A., Marica, D. & Cristea, I., 2021. *Risk Assessment of Hydrocarbons' Storing in Different Textured Soils in Small-Scale Lysimeters.* Water Air Soil Pollution. 232, 169, 1-12, DOI:10.1007/S11270-021-05126-Y.

Lăcătușu, R., Paltineanu, C., Vrinceanu, A. & Lăcătușu, A.R., 2019. *Influence of Domestic Activity on the Quality of Groundwater and Surface Water in the Rural Built-Up Area of the Southern Romanian Danube Plain – A Case Study in the Glavacioc Catchment*. Carpathian Journal of Earth and Environmental Sciences, 14(2): 323-334, DOI:10.26471/Cjees/2019/014/083.

Liebig, J. & Playfair, L.P., 1840. *Organic Chemistry in its Applications to Agriculture and Physiology*. Justus Liebig; Edited From the Manuscript of the Author by Lyon Playfair. Taylor & Walton (1840).

Mäkipää, R., Menichetti, L., Martínez-García, E., Törmänen, T. & Lehtone, A., 2024. *Is the organic carbon-to-clay ratio a reliable indicator of soil health*? Geoderma, 444, 116862, DOI:10.1016/j.geoderma.2024.116862.

Orgiazzi, A., Ballabio, C., Panagos, P., Jone, A. & Fernández-Ugalde, O., 2018. *LUCAS Soil, the largest expandable soil dataset for Europe: A review*. European Journal of Soil Science, 69(1), 140-153, DOI:10.1111/ejss.12499.

Paltineanu, C., Dumitru, S.I. & Lacatusu, A.R., 2022. *Assessing land susceptibility for possible groundwater pollution due to leaching – a case study on România*. Carpathian Journal of Earth and Environmental Sciences 17(1), 49-57, DOI:10.26471/cjees/2022/017/199.

Paltineanu, C., Lacatusu, R., Vrinceanu, A. & Lacatusu, A.R., 2020. *Organic carbon sequestration and nitrogen content in forest soils versus arable soils within a heavy-clay Phaeozem landscape: a Romanian case study*. Arch. Agron. Soil Sci. 66(14), 2026-2038, DOI:10.1080/03650340.2019.1706170.

Paltineanu, C., Domnariu, H., Marica, D., Lăcătușu, A.R., Popa, G.A., Grafu, I. & Neagoe, A.D., 2021. *Fertilizers` leaching from the root system zone – a potential environmental risk for groundwater pollution in coarse and medium-textured soils*. Carpathian Journal of Earth and Environmental Sciences, 16(1), 139–150, DOI:10.26471/cjees/2021/016/162.

Paltineanu, C., Dumitru, S., Vizitiu, O., Mocanu, V., Lacatusu, A.R., Ion, S. & Domnariu, H., 2024. *Soil organic carbon and total nitrogen stocks related to land use and basic environmental properties - assessment of soil carbon sequestration potential in different ecosystems*. Catena, 246, 108435, DOI: 10.1016/j.catena.2024.108435.

Paltineanu, C., Nicolae, S., Militaru, M., Butac, M., Chitu, E., Tanasescu, N., Calinescu, M. & Coman, R., 2017. *Spatial Distribution of Roots in Medium-Textured Soils in the Case of Cherry Trees Grafted on Gi Sel A5 Rootstock*. Scientia Horticulturae, Volume 217, 15 March 2017, 48–54, DOI:10.1016/J.Scienta.2017.01.033.

Paltineanu, C., Septar, L., Gavat, C., Chitu, E., Oprita, A., Moale, C., Calciu, I., Vizitiu, O. & Lamureanu, G., 2016. *Characterising root density of peach trees in a semi-arid Chernozem to increase plant density*. Int. Agrophys, 30(1), 67–74, DOI: 10.1515/intag-2015-0079.

Peel, M.C., Finlayson, B.L. & McMahon, T.A., 2007. *Updated world map of the Köppen-Geiger climate classification*. Hydrology and Earth System Sciences, 11(5), 1633–1644, DOI:/10.5194/hess-11-1633-2007.

Poeplau, C. & Don, A., 2023. *A simple soil organic carbon level metric beyond the organic carbon-to-clay ratio*. Soil use and management. DOI:10.1111/sum.12921.

Preda, M., Tanase, V. & Vrinceanu, N.O., 2019. *Occurrence of pesticides in agricultural fields and orchards*. Journal of Environmental Protection and Ecology. Vol. 20 (1): 83-90.

Predel, F., Teaci, D., Lazaroiu, A., Florea, N., Tutunea, C., Munteanu, M. & Motelica, D. 1987. *Bonitarea microzonelor pedo-climatice ale Romaniei, baza pentru zonarea productiei agricole*. Productia vegetala-Cereale si plante tehnice, no 1.

Prout, J.M., Shepherd, K.D., McGrath, S.P., Kirk, G.J.D. & Haefele, S.M., 2021. *What is a good level of soil organic matter? an index based on organic carbon to clay ratio*. Eur. J. Soil Sci., 72, 2493-2503, DOI:10.1111/ejss.13012.

Rabot, E., Saby, N.P.A., Martin, M.P., Barré, P., Chenu, C., Cousin, I., Arrouays, D., Angers, D. & Bispo, A., 2024. *Relevance of the organic carbon to clay ratio as a national soil health indicator*. Geoderma, 443, March 2024, 116829.

Ritz, K., Black, H.I., Campbell, C.D., Harris, J.A. & Wood, C., 2009. *Selecting biological indicators for monitoring soils: a framework for balancing scientific and technical opinion to assist policy development.* Ecol. Indic., 9, 1212–21, DOI:10.1016/j.ecolind.2009.02.009.

Robinson, D., Robinson, D.A., Fraser, I., Dominati, E.J., Davíðsdóttir, B., Jónsson, J.O.G., Jones, L., Jones, S.B., Tuller, M., Lebron, I., Bristow, K.L., Souza, D.M., Banwart, S. & Clothier, B.E., 2014. *On the value of soil resources in the context of natural capital and ecosystem service delivery.* Soil Sci. Soc. Am. J., 78, 685–700, DOI: 10.2136/sssaj2014.01.0017.

Rutgers, M., Wijnen, H., Van Schouten, A., Mulder, C., Kuiten, A., Brussaard, L. & Breure, A., 2012. *A method to assess ecosystem services developed from soil attributes with stakeholders and data of four arable farms.* Sci. Total Environ, 415, 39–48, DOI:10.1016/j.scitotenv.2011.04.041

Schulte, R.P.O., Creamer, R.E., Donnellan, T., Farrelly, N., Fealy, R., O'Donoghue, C. & O'hUallachain, D. 2014. *Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture*. Environmental Science & Policy, Vol. 38, 45-58, DOI:10.1016/j.envsci.2013.10.002.

Sere, G., Le Guern, C., Bispo, A., Layet, C., Ducommun, C., Clesse, M., Schwartz, C. & Vidal-Beaudet, L., 2024. *Selection of soil health indicators for modelling soil functions to promote smart urban planning.* Science of the Total Environment, 924, 171347, DOI: 10.1016/j.scitotenv.2024.171347.

Teaci, D., 1980. *Bonitarea terenurilor Agricole* (Rating of agricultural lands). Editura Ceres, Bucureşti.

Teaci, D., 1989. *Concepte moderne pentru definirea si determinarea capacitatii de productie a terenurilor agricole prin modelare matematico-euristica* (Modern concepts to define and determine land production capacity using mathematical modelling). Lucrarile Confeintei Nationale de Stiinta Solului, no. 26B:143-154, Pitesti, 29-31 August, 1988.

Torres-Sallan, G., Creamer, R.E., Lanigan, G. J., Reidy, B. & Byrne, K.A., 2018. *Effects of soil type and depth on carbon distribution within soil macroaggregates from temperate grassland systems*. Geoderma, Vol. 313, 52-56, DOI:10.1016/j.geoderma.2017.10.012.

van Leeuwen, J.P., Saby, N.P.A., Jones, A., Louwagie, G., Micheli, E., Rutgers, M., Schulte, R.P.O., Spiegel, H., Toth, G. & Creamer, R.E., 2017. *Gap assessment in current soil monitoring networks across Europe for measuring soil functions.* Environ. Res. Lett., 12, 124007, DOI:10.1088/1748-9326/aa9c5c.

Vrînceanu, N.O., Motelică, D.M., Dumitru, M., Calciu, I., Tănase, V. & Preda, M., 2019. *Assessment of using bentonite, dolomite, natural zeolite and manure for the immobilization of heavy metals in a contaminated soil: The Copșa Mică case study (Romania*). Catena, (176), 336–342, DOI:10.1016/j.catena.2019.01.015.

Wu, L., Shen, J., Zhang, Y., Fan, L. & Wang, X., 2024. *Effect of desulfurization gypsum on saline-alkali soil in Ningxia under ridge cultivation and drip irrigation*. Carpathian Journal of Earth and Environmental Sciences, Vol. 19, No. 2, p. 401 – 410, DOI:10.26471/cjees/2024/019/308.

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