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Soil organic carbon stock in a peat-wetland ecosystem in the Cerrado biome under different land covers and its role in water storage

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ABSTRACT: Wetlands provide important ecosystem services, including climate regulation through carbon sequestration and water storage. Identifying and protecting wetlands is a potentially significant opportunity for current global mitigation efforts. Cerrado wetlands commonly contain carbon-rich soils (peat); however, these environments have been neglected due to lack of knowledge on their characteristics and behaviors. Obtaining data in remote regions using a detailed sampling approach to characterize the organic carbon accumulation in these environments is extremely necessary. In this study, soil samples from 40 points of a peat-wetland (173.16 ha) in the Urucuia River watershed (Minas Gerais, Brazil) were analyzed every 0.20 m up to 1.20 m of depth. Their chemical and physico-hydraulic properties were studied to quantify organic carbon storage under different land covers. In addition, the influence of organic carbon accumulation on soil water storage in a dry period was also investigated. Considering the contribution of each vegetation type, the (weighted) average for the wetland stocks was 321.91 Mg ha^{-1} of carbon at full depth, whereby *vereda* (462.59 Mg ha^{-1}) and gallery forest (447.63 Mg ha^{-1}) were the biggest stockers compared to wet grassland (267.22 Mg ha^{-1}), pasture (123.46 Mg ha^{-1}), and Cerrado *stricto sensu* (57.77 Mg ha^{-1}). Also, the study area holds 677.38 mm of water, with the following water depths: 831.32 mm for gallery forest, 780.42 mm for *vereda*, 693.63 mm for wet grassland, 297.59 mm for pasture, and 220.33 mm for Cerrado *stricto sensu*. The total organic carbon mass and stored water volume were respectively 55,741.94 Mg and 1,155,635.21 m^3, respectively. A significant correlation between organic carbon and water stored was found (0.73), highlighting the role organic matter plays in water storage, whereby the latter is under greater influence and can be explained by layer depth rather than vegetation type. However, surface layers show evidence of a degradation process that may be linked to the lowering of the water level due to subsurface lateral flow, either through the indirect use of their soils and/or through the input of mineral material (erosion process). The study data highlight that riparian zones of the Cerrado biome must be protected to maintain their ecosystem services.

Keywords: peatlands, *veredas*, Histosol, land uses, climate change.

INTRODUCTION

Global carbon balance has been modified with the increase of anthropogenic processes, increasing the carbon dioxide (CO_2) concentration in the atmosphere and surpassing levels seen in previous millennia (Monnin et al., 2001). As direct consequences, global warming (~ 1.5 above pre-industrial levels; IPCC, 2021) and an increase in the frequency of extreme drought and flood events have been recorded (Kreibich et al., 2022). Thus, concerns have increased regarding mitigation strategies to reduce and stop carbon emissions and maintain ecosystem services, with the preservation of natural areas with carbon storage capabilities, such as wetlands, meriting attention (Chapin et al., 2006; Mackey et al., 2020). Ecosystem services are understood as any natural asset that is produced by ecosystems that can be used by humans, including clean air, water, food, and raw materials (Fisher et al., 2009; Barbier, 2011; Maltby and Acreman, 2011).

Wetlands containing carbon-rich soils (peat), in general treated as peatlands composed of Histosols (*Organossolos*), store the largest amount of CO_2 per hectare of soil (~4,700 tons) (Temmink et al., 2022), and their organic carbon storage is intrinsically related to chemical and physical soil properties (Horák-Terra et al., 2022a,b; Santos et al., 2023). According to Page and Baird (2016), this ecosystem accumulates dead organic matter when plant litter production and its accumulation surpasses peat decay, often under conditions of frequent or continuous waterlogging. However, about 35 % of the world's natural wetlands have been damaged since 1970 (Niu et al., 2012), leading to a loss of carbon storage (Liu et al., 2019).

Cerrado, inserted in the Brazilian Central Plateau, is the largest Neotropical savanna area (Bueno et al., 2017) and hosts extensive areas of tropical peat-wetlands along shallow kilometer-long valleys in the "core" area of this domain (Horák-Terra et al., 2022a,b). A multiplicity of natural vegetation types occurs in these areas, being represented by savanna formations like Cerrado *stricto sensu*, in addition to wet grasslands, *veredas* (palm swamps), *buritizais* (*Mauritia* palm groves), and gallery forests, among others, forming complex and dynamic mosaics on the landscape (Durigan et al., 2022). However, anthropogenic landscapes, where the original vegetation has been converted into areas for cattle grazing and agricultural areas containing non-native species, are common and are advancing over the remnants of native vegetation (Catterall, 2016). In general, plant remains of the different land covers are the main sources of organic matter for the formation of wetland soils (Wantzen et al., 2012; Witzgall et al., 2021; Horák-Terra et al., 2022a,b).

It is undeniable that a deeper comprehension of peat-wetlands aids in the proposition of strategies and mechanisms that promote the preservation of these natural habitats (Ritson et al., 2021). Considering mitigation strategies, particularly those focused on reducing soil carbon emissions or enhancing soil carbon fixation (Minasny et al., 2017), initiatives enabling the attainment of local soil data, especially in remote regions such as in more interior sites in extensive regions of central Brazil, are increasingly significant nowadays. In recent years, an effort has been directed towards studying peat-wetlands in the north and northwest of the state of Minas Gerais, bringing information related to the characterization of their soils (Horák-Terra et al., 2022a; Araújo et al., 2023; Santos et al., 2023) and vegetation and climate reconstruction studies (Cassino et al., 2020; Sabino et al., 2021; Horák-Terra et al., 2022b).

Many tributaries of the São Francisco River, which is one of the most important rivers in Brazil and South America (Jong et al., 2018; Dominguez and Guimarães, 2021), are in the north and northwest of Minas Gerais. Furthermore, the highest Brazilian productivity of different annual crops (beans, soybeans, corn, and sorghum) has also been verified in the northwest of Minas Gerais, and, interestingly, it has the highest concentration of center pivot irrigation (Cançado et al., 2023). Therefore, in addition to containing important natural resources, these regions have a high level of agricultural activity and intensive land use. The preservation of the few remaining peat-wetlands and the maintenance of their ecosystem services are urgent in a scenario where they are surrounded by croplands (Horák-Terra et al., 2022a). Agroecosystems can no longer be viewed in isolation as they interact with the surrounding systems in many ways (Zimmerer, 2010).

In a wetland in the municipality of Bonfinópolis de Minas, northwest of Minas Gerais, a study of morphological, chemical, physical, and microbiological characterization, in addition to the organic fractions of the soils of two profiles, one located upstream in a preserved state, and the other downstream and anthropized by the opening of an artificial drainage channel, confirmed the fragility of these ecosystems in this region (Horák-Terra et al., 2022a). The results suggested the anthropic action caused a strong reduction in organic carbon of ~22 %, and, after 20 years, the anthropized soil showed not only a large decline in carbon stock (~14 kg m^{-2}), but also impacts on other ecological functions, such as water retention capacity. Likewise, another anthropized wetland from the same region, in the urban perimeter of the municipality of Arinos surrounded by urbanization since the beginning of the 20th century, presented changes in morphological, physical, and chemical soil properties, and the organic carbon content was excessively reduced up to ~94 %, as was water retention capacity (Araújo et al., 2023).

In the north of Minas Gerais, the soil properties of wetlands of the Environmental Preservation Area (EPA) of the Pandeiros River, in the municipality of Bonito de Minas, were also influenced by drainage and anthropization conditions (Santos et al., 2023). Lower bulk density values were obtained from preserved wetland, and, in contrast, subsidence, reduced organic carbon content, and increased bulk density values were obtained from an anthropized wetland. Degradation considerably reduces soil carbon storage, with a greater decrease at the edges of the wetlands. When considering values of soil organic carbon stock, the losses were ~25 % (98.7 Mg ha^{-1}).

Determination of soil carbon stocks in three stream-valley-ecosystems (A, B, and C) in the Cerrado agroscapes of Central-West Brazil, in the state of Mato Grosso, by Wantzen et al. (2012), considering different land covers (gallery forest, *vereda*, Cerrado, pasture) and conservation status (reference and degraded sites), verified that in all the vegetation types along the stream-valley catena, average carbon stocks of the upper 0.30 and 0.60 m soil layers were generally higher at the reference sites than at the degraded sites. In addition, this study showed that riparian vegetations of the Cerrado, either woody riparian forests or predominantly herb-covered *vereda*, stock high amounts of soil carbon. The highest average values from all areas were found for *vereda* (reference: 90.2 Mg ha^{-1} of C; and degraded: 77.3 Mg ha^{-1} of C), being considerably higher than the remaining vegetation types (gallery forest reference: 67.0 Mg ha^{-1} of C; degraded: 38.3 Mg ha^{-1} of C; Cerrado reference: 60.1 Mg ha^{-1} of C; degraded: 31.5 Mg ha^{-1} of C; pasture reference: 28.9 Mg ha^{-1} of C; and degraded: 24.9 Mg C ha^{-1}). Losses of carbon stocks in the upper 0.30 m, averaged over all areas, were highest for Cerrado (47.6 %) and gallery forest (42.8 %), followed by *vereda* (14.3 %) and pasture (13.9 %).

Quantifying carbon stock in Cerrado peat-wetlands on a detailed sampling scale (higher density of sampling points) is necessary to obtain more accurate information and, therefore, contribute to the implementation of more efficient public policies focusing on the preservation of wetland ecosystems or putting them to the best uses possible. No studies have used this detailed sampling approach to characterize the organic carbon accumulation in such environments. Thus, soil samples of a peat-wetland were characterized, based on their chemical and physico-hydraulic properties, to quantify organic carbon storage under different vegetation types. In addition, the influence of the accumulated organic carbon on soil water storage in a dry period was also investigated. The hypotheses of this study were: (i) soils under distinct vegetation types of a Cerrado wetland store different amounts of organic carbon, which is a controlling factor for water storage in this environment; and (ii) anthropic actions in the surrounding areas of wetlands (intensive agriculture and livestock) contribute to the modification in soil organic carbon storage.

MATERIALS AND METHODS

Study area

Nevada wetland has an area of 173.16 ha and is located in the municipality of Arinos, in the northwestern region of Minas Gerais State (MG), Brazil (Figure 1). Its area belongs to a private property that has been producing grains irrigated by central pivots, distributed around the wetland, and pasture. The study area is inserted in the Urucuia River watershed, this being one of the largest tributaries of the São Francisco River, an important Brazilian watercourse (Figure 1). According to IGAM (2014), the Urucuia River watershed occupies a total area of 25.038,35 km^2, representing ~11 % of the São Francisco River watershed.

The studied wetland is inserted in a valley catchment dominated by detrital-lateritic coverings, detrital and eluvial deposits on a Tertiary-Quaternary flat surface, and with a great influence of colluvial, alluvial and terrace deposits. The Areado Group (sandstones, conglomerates, pelites, and ultrabasic-alkaline flows and intrusions) and Urucuia Formation (sandstones, conglomerates) in the northeastern portion of the Arinos and Paraopeba Subgroup (siltstones, slates, and limestone lenses) in the central-western portion surrounding the study area, also occasionally exert an influence on materials deposited in the wetland (Mourão et al., 2001).

Nevada wetland resembles the shape of a stingray, infilling the lower and flatter parts on plateaus (known as *chapadas*) (Figure 1). The valley floor along its area, combined with limited drainage and an oligotrophic environment provide adequate hydromorphic conditions for developing organic deposits. According to the classification system proposed by Lindsay (1995), Nevada is a minerogenic peatland presenting the following main characteristics: water gently flowing through pools and channels; waters originating from groundwater and surface and subsurface flow of mineral soils (minerotrophic); water table close to soil surface almost all year round; and dominant, strongly to slightly acidic, well-decomposed peat material (NWWG, 1988; Horák-Terra et al., 2014).

The climate of the study area is classified as tropical savanna (Aw) with dry-winter characteristics, according to the Köppen classification system (Alvares et al., 2013). Mean annual temperature is 24.8 °C, varying between 21.9 and 27.0 °C, where the months from May to August are considered the coldest and from September to April the warmest. Mean annual precipitation is 1,180 mm, with the highest frequency occurring from November to March and the driest period from April to October. Mean yearly potential evapotranspiration is 1,347 mm and its values are higher than precipitation in the driest period, when there is a precipitation deficit (Oliveira and Oliveira, 2019).

Five vegetation types occur in the study area, as follows: wet grassland (WG), with 66.21 ha (Figure 1a); gallery forest (GF), with 56.38 ha (Figure 1b); *veredas* (palm swamps) (Ver), with 20.50 ha (Figure 1c); pasture (Pt), with 23.27 ha (Figure 1d); and cerrado *stricto sensu* (Css), with 6.80 ha (Figure 1e). The three first vegetation types are mainly under permanent saturation conditions enabling peat accumulation; however, they also occur where there are seasonal variations of water content in hydromorphic mineral soils [*Gleissolo Melânico* (Umbric Gleysol) and *Gleissolo Háplico* (Dystric Gleysol)]. Pasture areas are viewed and treated as anthropogenic landscapes whose original vegetation has been converted into non-native grass species for cattle grazing. Also, a narrow range of Cerrado *stricto sensu* is observed bordering other phytophysiognomies in the southeastern section of the wetland. This vegetation classification presented in figure 1e was based on fieldwork combined with the interpretation of aerial images taken by drone (DJI mini 2 model), high spatial resolution satellite images from the Google Earth website, and annual coverage and land use maps from the MapBiomas platform (MapBiomas, 2019).

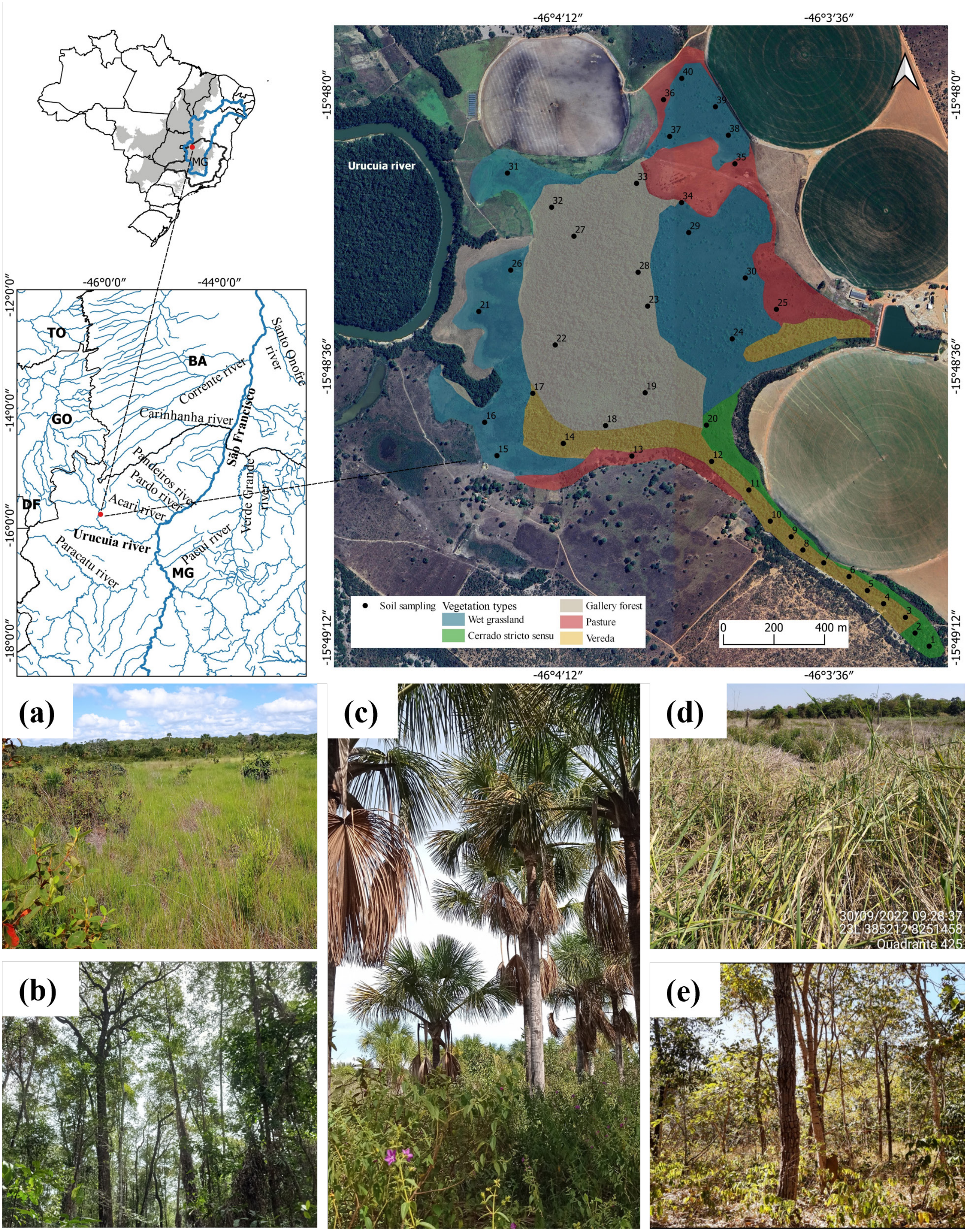

Figure 1. Location of the Nevada wetland in Minas Gerais State, Brazil. Left insertion: divisions of Brazilian states (BA: Bahia, DF: Distrito Federal, GO: Goiás, MG: Minas Gerais, and TO: Tocantins), with the distribution of the Cerrado biome in gray and the São Francisco River Basin in blue. Photographs of sampling sites in the five land covers: wet grassland (a), gallery forest (b), *vereda* (c), pasture (d), and Cerrado *stricto sensu* (e).

Botanically, the Nevada wetland is a swamp savanna complex, composed of three zones along a wetness gradient (Kauffman et al., 1994). According to Beer et al. (2024), moist grassland covers the outermost zone, which is a periodically dry upper part of this type of wetland (1st zone); moist grassland transitions into wet grassland or wet shrubland (pt: *Campo limpo úmido/ Campo sujo úmido*) that occurs in the middle zone (downslope), which is permanently to seasonally wet (2nd zone); and, finally, palm *Mauritia flexuosa* L.f. typically occurs in patches forming a palm swamp savanna towards the bottom and along the wettest parts of the valleys (3rd zone) (Bijos et al., 2023). Beer et al. (2024) also states that riparian forests (pt: *Mata de Brejo/Galeria*) in the Cerrado are highly diverse and have varying species compositions differing between poorly-drained, swampy areas (Gleysols and Histosols), and well-drained mineral soils, such as alluvial levees (Cambisols, Ferralsols, and Arenosols) (Mourão et al., 2001; Skorupa et al., 2013; Chiminazzo et al., 2021).

Soil samples and organic layer depths

Soil sampling was carried out in October 2022 (the driest period) at 40 points in as regular distribution as possible, due to access difficulty in obtaining a greater representation of the study area (Figure 1; and Supporting Table S1). All the sampling points were georeferenced. Soil samples were collected using an Edelman auger every 0.20 m up to 1.20 m deep (6 layers) or until a physical impediment such as lithic contact restricted sampling to deeper layers (Table 1). A total of 169 soil samples were obtained, packed in pre-identified plastic bags and taken for laboratory analysis.

Organic layer depths (OLD) were measured with the aid of a 6 m iron stick (rebar), which was driven into the ground until it contacted the mineral layer, identified by difficulty/impossibility in penetrating the bar, according to Campos et al. (2012). Whenever possible, depth checkpoints were positioned in the middle of 50 × 100 m quadrants from a grid (Supporting Figure S1) generated using geoprocessing software (QGIS Desktop 3.36.1). A total of 420 depth checkpoints were obtained, all of which were georeferenced in the period from January to September 2022.

Analytical determinations

According to the characterization tests for *Organossolos* [Histosols] (Lynn et al., 1974), described in Teixeira et al. (2017) and Santos et al. (2018), bulk density (BD) (Equation 1), gravimetric moisture (GM) (Equation 2), and volumetric moisture (VM) (Equation 3) were determined for the 169 soil samples.

$$BD = Md / V \qquad \text{Eq. 1}$$

$$GM = (Mw - MD) / Md \qquad \text{Eq. 2}$$

$$VM = GM \times BD \qquad \text{Eq. 3}$$

in which: BD is bulk density (g cm^{-3}); Md is soil sample mass dried in forced ventilation oven at 105 °C for 24 h (g); V is soil volume (2.5 cm^3); GM is gravimetric moisture (g^3 g^{-3}); Mw is wet soil sample mass (g); and VM is volumetric moisture (cm^3 cm^{-3}).

For soil organic carbon (SOC) quantification, all the soil samples were dried, ground, and sieved (0.053 mm), and the dry combustion method was applied using the LECO® CHNS/O elemental analyzer model TruSpec Micro. Two standards of known composition were used for calibration, these being soil (C% = 2.35) and orchid leaf (C% = 50.40).

Soil organic carbon stock (SOCS) was calculated for each sampling point and each layer, according to Penman et al. (2003) and Wang and Dalal (2006) (Equation 4).

$$SOCS = SOC \times BD \times d \times 0.1 \quad \text{Eq. 4}$$

in which: SOCS is soil organic carbon stock (Mg ha^{-1}); SOC is soil organic carbon content (g kg^{-1}); BD is bulk density (g cm^{-3}); and d is layer thickness (20 cm).

Soil water storage (SWS) corresponding to the period of sampling was calculated for each sampling point and each layer using the trapezoidal method, according to Libardi (2012) (Equation 5).

$$SWS = VM \times d \times 10 \quad \text{Eq. 5}$$

in which: SWS is soil water storage (mm); VM is volumetric moisture (cm^3 cm^{-3}); and d is layer thickness (20 cm).

Totals of organic carbon and water stored

Soil organic carbon stock and SWS values were interpolated and spatialized using Inverse Distance Weighted (IDW) to quantify the total contents of organic carbon and water stored in the soil under each vegetation type and for the entire wetland. The IDW enables the estimation of values in unsampled places based on sampling points with known values through a weighted mean of nearby observations, where closer points receive higher weights (Shepard, 1968). This spatial analysis was performed on QGIS Desktop 3.36.1 (QGIS.org, 2024) with all 40 sampling points distributed in 173.16 ha (0.23 observation per hectare), resulting in detailed maps (scale of 1:20,000) with minimum mappable area of 1.6 ha (pixel size of 126.5 m), according to Santos et al. (1995).

After spatialization, mean values of SOCS and SWS were obtained for each vegetation type and each layer using zonal statistics also on QGIS Desktop 3.36.1, a tool for calculating descriptive statistics for specified zones or pixels. With these mean values, accumulated totals of soil organic carbon stored (T-SOCS) and of soil water stored (T-SWS) were respectively calculated using equations 6 and 7.

$$T\text{-}SOCS = SOCS \times A \quad \text{Eq. 6}$$

$$T\text{-}SWS = SWS \times A \times 10 \quad \text{Eq. 7}$$

in which: T-SOCS is total soil organic carbon stored (Mg); SOCS is soil organic carbon stock (Mg ha^{-1}); T-SWS is total soil water stored (m^3); SWS is soil water storage (mm); and A is area of vegetation type (ha).

Statistical analysis

Descriptive statistics (mean, median, 1st and 3rd quartiles, minimum, maximum, standard deviation, and coefficient of variation) were calculated for the following soil properties: OLD, BD, GM, VM, SOC, SOCS, and SWS. These properties (except OLD) were tested for the assumptions of normality and homogeneity of variances using the Shapiro-Wilk test (p-value>0.05). Box-cox transformation (Box and Cox, 1964) was applied to address their normal distribution violations. Once these assumptions were met, multiple correlations were calculated for all soil properties, except for T-SOCS and T-SWS, to investigate the maximum degree of linear relationship between them. Linear regression models were adjusted specifically for SOC and SWS values, which were respectively considered independent and dependent variables, to evaluate how well water storage can be influenced and explained by carbon accumulation. These regressions were calculated considering different layer depths for the same vegetation type and different vegetation types for the same layer depth. All statistical analyses were performed on R software (R Core Team, 2021) using a significance level of 5 %.

Cluster analysis was also performed for the 40 sampling points (Figure 1) using SOCS and SWS values from 0 to 1.20 m (sum of the six layers) and OLD values as input data to verify the effects of the different vegetation types on carbon accumulation and water storage. The OLD values referring to the 40 depth checkpoints closest to the sampling points (Supporting Table S1) were used, as these points were not coincident with each other. Fuzzy k-means was the clustering algorithm used for this procedure, whereby homogeneous clusters are created, and membership degrees (from 0 to 1) are calculated, determining how much an object (point) belongs to a specific cluster and aiming to minimize the within-cluster variance (Ferraro, 2024). From 2 to 5 clusters were tested and the best clustering quality was defined by the following parameters: Partition Coefficient (PC) (Bezdek, 1974); Partition Entropy (PE) (Bezdek, 1981); Modified Partition Coefficient (MPC) (Dave, 1996); Silhouette Index (SIL) (Kaufman and Rousseeuw, 1990), Fuzzy Silhouette Index (SIL.F) (Campello and Hruschka, 2006); and Xie-Beni Index (XB) (Xie and Beni, 1991). The 'fclust' R package (Giordani et al., 2022) was applied for this clustering analysis.

RESULTS

Soil properties

Bulk density mean values varied from 0.25 ± 0.31 Mg m^{-3} in GF to 1.55 ± 0.23 Mg m^{-3} in Css, both at 0.80-1.00 m (Figure 2). The highest CV value (124 %) was found in GF at 0.80-1.00 m. In general, higher mean values of BD were found in the most superficial layers (from 0.00 to 0.60 m) for GF and Ver (Figures 2e and 2m), while WG, Pt, and Css presented higher values in the deepest layers (from 0.60 to 1.20 m) (Figures 2q, 2i, and 2a).

The Css was the vegetation type with the two lowest mean values of GM with 0.11 ± 0.10 g g^{-1} at 0.20-0.40 m and 0.13 ± 0.10 g g^{-1} at 0.00-0.20 m (Figure 2). The GF presented the highest mean values of GM among all the vegetation types, with 6.51 ± 5.26 g g^{-1} and 7.57 ± 4.65 g g^{-1} at 0.60-0.80 m and 0.80-1.00 m, respectively (Figure 2). The highest CV values of GM were observed for WG at 0.60-0.80 m (217 %) and 0.80-1.00 m (214 %). Mean VM values varied from 0.08 ± 0.05 cm^3 cm^{-3} for Css at 0.00-0.20 m to 0.84 ± 0.07 cm^3 cm^{-3} for GF at 0.80-1.00 m (Figure 2). The highest CV value of VM (100 %) was observed at 0.00-0.20 m for Pt. Higher water contents (for both mean GM and VM values) were observed in deeper layers for Css, GF, and Ver (Figures 2b, 2c, 2f, 2g, 2n, and 2o), and in more superficial layers for WG (Figures 2r and 2s). For Pt, the highest mean GM value was obtained in the first layer (0.00-0.20 m) (Figure 2j), while no remarkable variation for mean VM values was observed among layers of this vegetation type (Figure 2k).

Soil organic carbon mean values ranged from 3.20 ± 1.45 g kg^{-1} for Pt to 282.79 ± 171.61 g kg^{-1} for GF, both at 0.80-1.00 m (Figure 2). As in the case of GM, the highest CV values of SOC were observed for WG at 0.60-0.80 m (197 %) and 0.80-1.00 m (187 %). A decrease in mean SOC values with depth was observed for Css, Pt, and WG, whereby these vegetation types presented higher contents in the most superficial layers (0.00-0.60 m). This behavior was the opposite for GF and Ver, in which mean SOC values increased continuously towards the deeper layers (0.60-1.20 m) (Figures 2h and 2p). Considering the sum of mean SOC values of each layer, a trend of reduction in organic contents for the full depth can be seen when comparing all vegetation types as follows: gallery forest (1,232.20 g kg^{-1}) > *vereda* (925.82 g kg^{-1}) > wet grassland (511.53 g kg^{-1}) > pasture (145.13 g kg^{-1}) > Cerrado *stricto sensu* (28.70 g kg^{-1}). The BD, GM, VM, and SOC values of all 40 sampling points and all six layers are in Supporting Table S2.

OLD values

In all wetland as a whole, thicker organic layers are seen in the center of the studied area, mainly occupied by GF (3.68 ± 1.25 m), and the most extensive and central area of WG (2.33 ± 1.68 m) (Figures 3 and 4a). However, no difference was observed for mean OLD values between WG and Ver (2.52 ± 1.15 m). Shallower organic layers are positioned at the edges of the wetland, where Pt (0.96 ± 0.61 m) and Css (1.10 ± 0.91 m) are located. These two vegetation types presented the lowest mean OLD values, also with very similar values to each other, and Css presented the highest CV value (83 %). Considering the area of each vegetation type and its respective OLD mean, the total calculated volume of the organic layer in the wetland is 4,437,029 m^3. All 420 OLD checkpoints are in Supporting Table S2.

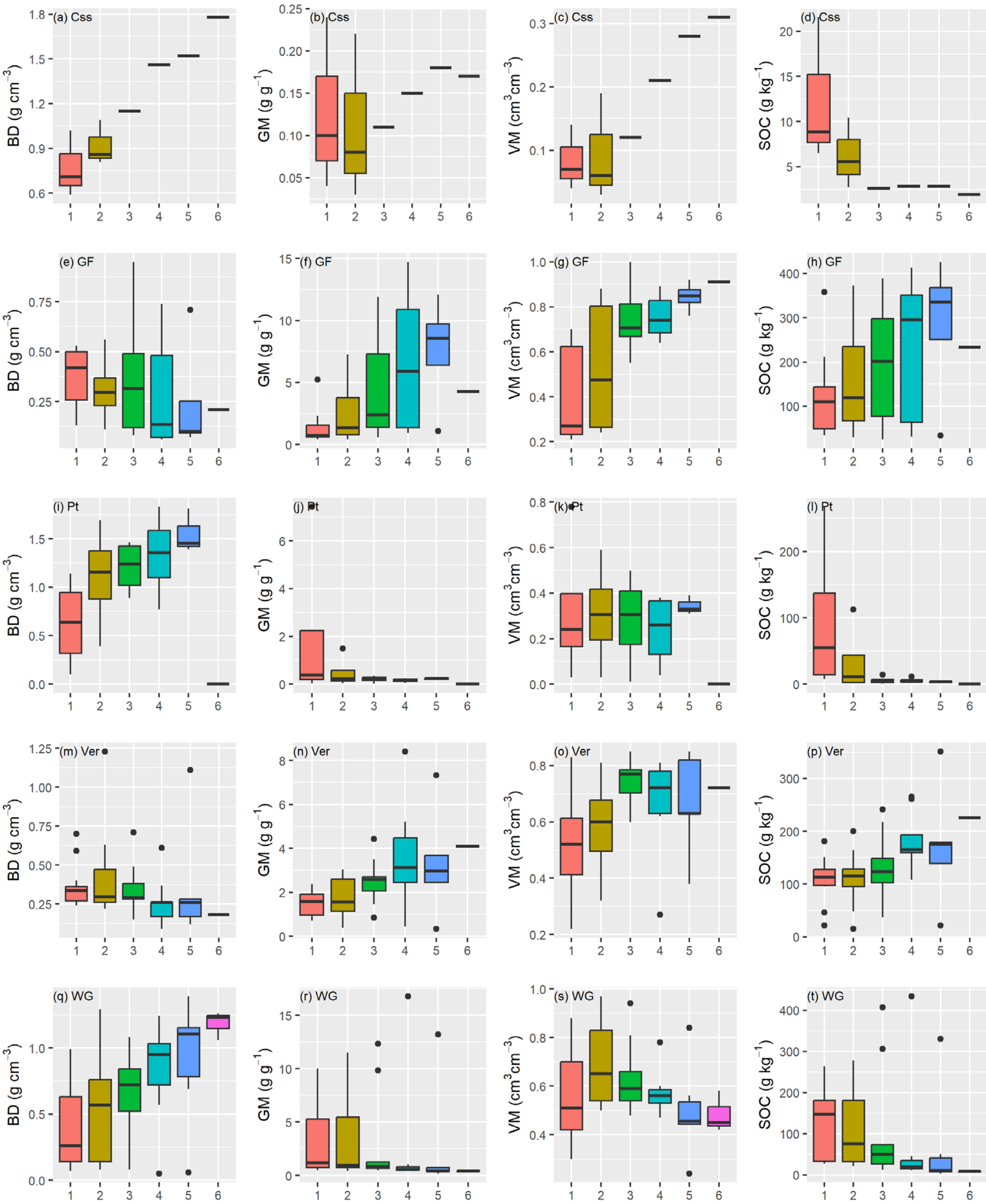

Figure 2. Boxplots of bulk density (BD), gravimetric moisture (GM), volumetric moisture (VM), and soil organic carbon (SOC) by layers (1: 0.00-0.20 m; 2: 0.20-0.40 m; 3: 0.40-0.60 m; 4: 0.60-0.80 m; 5: 0.80-1.00 m; and 6: 1.00-1.20 m) and land covers (Css: Cerrado *stricto sensu*; GF: gallery forest; Pt: pasture; Ver: *vereda*; and WG: wet grassland) in the Nevada wetland.

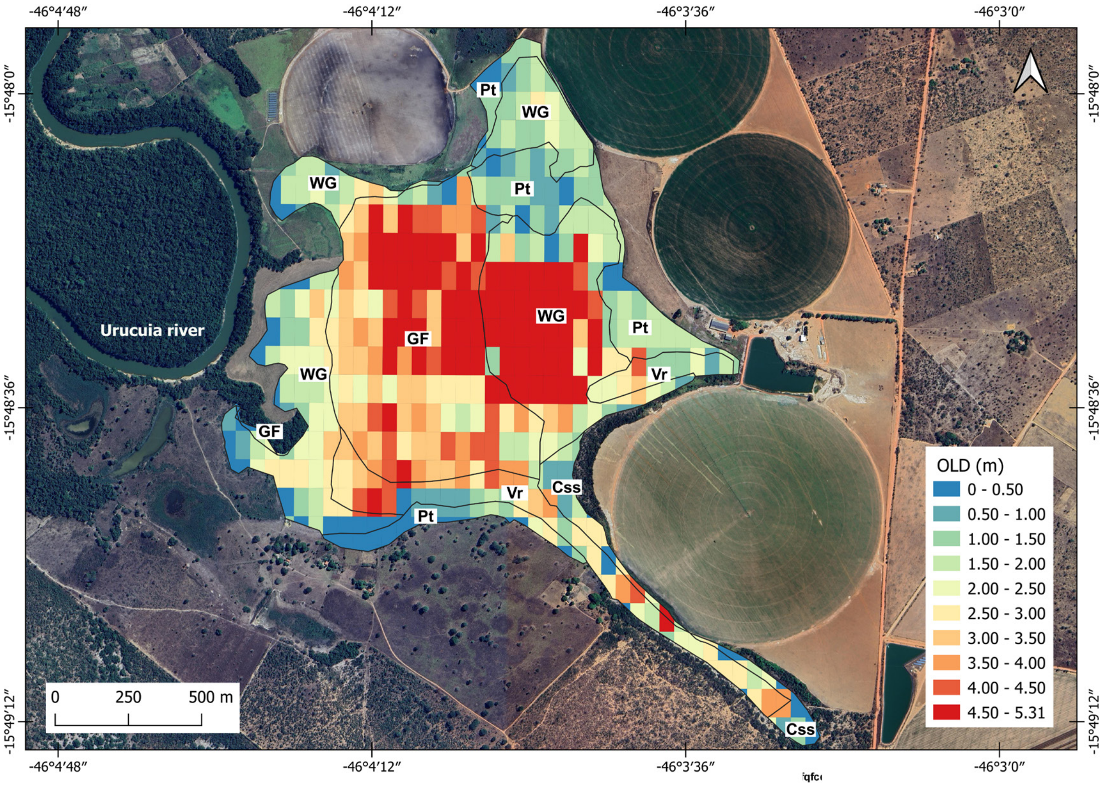

Figure 3. Organic layer depths (OLD) in the Nevada wetland (50 × 100 m grid), where delimitation of land covers is represented by black line (Css: Cerrado *stricto sensu*; GF: gallery forest; Pt: pasture; Ver: *vereda*; and WG: wet grassland).

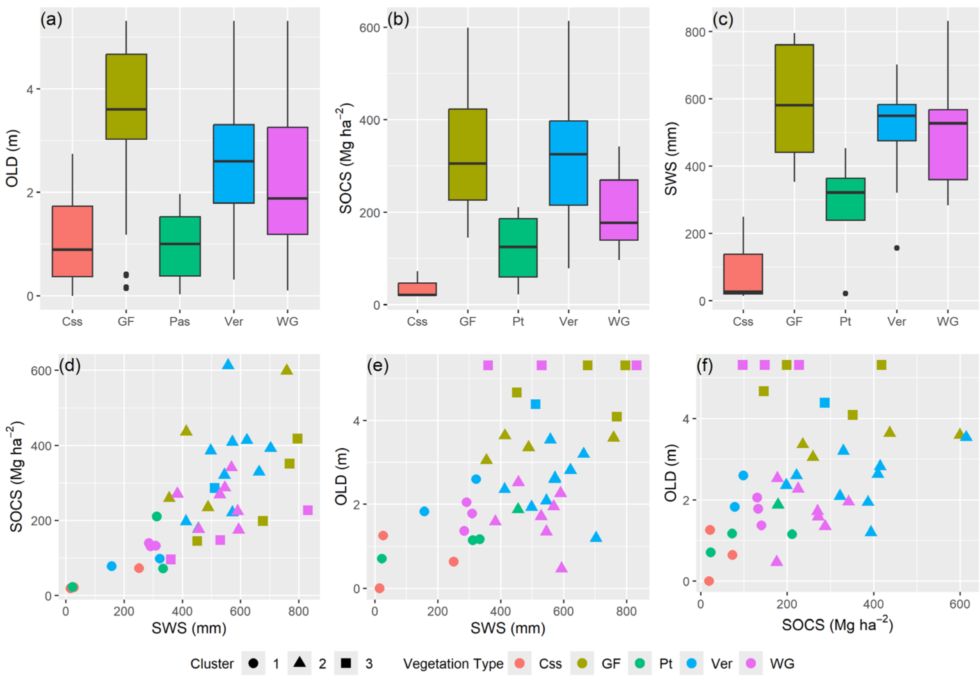

Figure 4. Boxplots of the organic layer depths (OLD) (a), soil organic carbon stock (SOCS) accumulated from 0 to 1.20 m (b), and soil water storage (SWS) accumulated from 0 to 1.20 m (c) of the sampling points by land covers (Css: Cerrado *stricto sensu*; GF: gallery forest; Pt: pasture; Ver: *vereda*; and WG: wet grassland) and scatterplots resulting from Fuzzy k-means clustering analysis applied to these points using SOCS, SWS, and OLD (d, e, and f).

Organic carbon stock

Considering each layer individually, mean SOCS values ranged from 5.93 Mg ha^{-1} (Css at 0.40-0.60 m) to 98.61 Mg ha^{-1} (GF at 1.00-1.20 m) (Table 1). In general, these values decreased with depth for Css, Pt, and WG, while the other vegetation types presented an almost linear trend to the base. Pasture presented the highest CV value of 113 % at 0.40-0.60 m. Considering the sum of the six layers, the highest and lowest mean SOCS values among the vegetation types were respectively observed in GF (330.00 ± 150.00 Mg ha^{-1}) and Css (37.80 ± 30.30 Mg ha^{-1}) (Figure 4b). *Vereda* (312.00 ± 149.00 Mg ha^{-1}) presented a similar mean value to GF, while WG showed an intermediate value (202.00 ± 74.40 Mg ha^{-1}). The second lowest mean SOCS value was 121.00 ± 88.30 Mg ha^{-1} for Pt.

Table 1. Descriptive statistics of soil organic carbon stock (SOCS) and soil water storage (SWS) and totals of soil organic carbon stored (T-SOCS) and soil water stored (T-SWS) by soil layer and vegetation type in the Nevada wetland

Vegetation type	Depth	SOCS			T-SOCS	SWS			T-SWS
		Mean	SD	CV		Mean	SD	CV	
	m	Mg ha^{-1}		%	Mg	mm		%	m^3
Cerrado stricto sensu	0.00-0.20	17.02	7.17	42.15	312.88	16.78	9.72	57.92	3,384.66
	0.20-0.40	10.99	6.25	56.89	319.20	19.12	17.01	88.97	4,377.15
	0.40-0.60	5.93*	...	...	289.92	24.82*	...	...	4,797.68
	0.60-0.80	8.26*	...	...	226.88	42.82*	...	...	4,633.27
	0.80-1.00	8.58*	...	...	59.85	55.70*	...	...	1,855.56
	1.00-1.20	6.77*	...	...	18.15	61.10*	...	...	1,180.82
Gallery forest	0.00-0.20	73.11	34.93	47.78	3,591.19	79.08	43.76	55.33	48,175.39
	0.20-0.40	70.51	33.97	48.17	3,560.34	104.35	54.81	52.53	60,724.97
	0.40-0.60	83.17	42.12	50.64	3,678.55	146.71	29.78	20.30	71,603.52
	0.60-0.80	60.54	18.21	30.08	2,668.06	151.08	1824	12.07	70,062.79
	0.80-1.00	61.69	10.42	16.89	1,395.26	168.81	13.30	7.88	39,362.28
	1.00-1.20	98.61*	...	...	452.04	181.30*	...	...	12,335.05
Pasture	0.00-0.20	45.29	26.05	57.52	1,359.95	64.55	64.41	99.79	20,111.82
	0.20-0.40	38.33	40.11	104.63	1,397.67	61.05	46.83	76.71	23,595.14
	0.40-0.60	15.04	16.92	112.51	919.08	55.82	41.68	74.66	19,093.80
	0.60-0.80	14.54	10.20	70.76	678.37	47.35	32.96	69.60	17,490.94
	0.80-1.00	10.26	6.03	58.79	277.49	68.82	7.94	11.54	10,893.65
	1.00-1.20				150.02				3,781.44
Vereda	0.00-0.20	70.77	19.55	27.63	1,254.48	103.71	32.93	31.75	20,888.18
	0.20-0.40	74.81	24.20	32.35	1,404.77	116.05	28.58	24.63	22,746.01
	0.40-0.60	77.03	22.40	29.08	1,196.29	148.68	15.19	10.21	24,562.55
	0.60-0.80	88.52	56.74	64.11	987.68	135.38	33.74	24.92	19,588.48
	0.80-1.00	71.78	17.54	24.44	458.35	132.36	37.89	28.63	10,730.79
	1.00-1.20	79.68*	...	...	106.63	144.23*	...	...	2,616.59
Wet grassland	0.00-0.20	56.09	16.26	28.99	3,783.87	112.72	36.93	32.76	71,228.51
	0.20-0.40	63.17	17.61	27.88	4,003.96	141.99	34.91	24.59	86,466.73
	0.40-0.60	55.47	21.68	39.08	3,087.23	127.73	30.14	23.60	70,843.27
	0.60-0.80	40.00	16.07	40.18	2,130.03	114.98	18.92	16.46	60,190.43
	0.80-1.00	31.42	21.88	69.64	1,425.42	99.71	39.65	39.76	42,815.04
	1.00-1.20	21.07	2.76	13.11	311.66	96.51	16.53	17.13	11,744.62

SD: standard deviation; CV: coefficient of variation; * Absolute value (only one value); ...: data not calculated.

Values of T-SOCS ranged from 18.15 Mg for Css at 1.00-1.20 m to 4,003.96 Mg for WG at 0.20-0.40 m (Table 1 and Figure 5). Considering the sum of T-SOCS of each layer, the sequence of vegetation types that accumulated the highest amounts of organic carbon in their soil profiles (0.00-1.20 m) was: GF (15,345.43 Mg) > WG (14,742.17 Mg) > Ver (5,408.19 Mg) > Pt (4,782.58 Mg) > Css (1,226.89 Mg).

Water storage

The SWS mean values varied from 16.78 ± 09.72 mm (Css at 0.00-0.20 m) to 181.30 mm (GF at 1.00-1.20 m) between the layers (Table 1). The mean values increased with depth up to 1.20 m for Css, GF, and Ver, while for Pt and WG, mean SWS values decreased from 0.00 to 0.80 m and from 0.20 to 1.20 m, respectively. The highest CV value was 99.79 % for Pt at 0.00-0.20 m. Among the vegetation types and considering the sum of the six layers, mean SWS values were very similar for GF (588.00 ± 180.00 mm), Ver (511.00 ± 152.00 mm), and WG (482.00 ± 156.00 mm) (Figure 4c). The lowest mean SWS was obtained for Css (97.40 ± 133.00 mm), while Pt (280.00 ± 183.00 mm) showed an intermediate mean value to all other vegetation types.

Extreme values of T-SWS ranged between 1,180.82 m^3 for Css at 1.00-1.20 m and 86,466.73 m^3 for WG at 0.20-0.40 m (Table 1 and Figure 6). After adding the T-SWS values of each layer, the types of vegetation with the highest volumes of water in their soils from 0.00 to 1.20 m followed the sequence: WG (343,288.59 m^3) > GF (302,264.01 m^3) > Ver (101,132.60 m^3) > Pt (94,966.80 m^3) > Css (20,299.14 m^3).

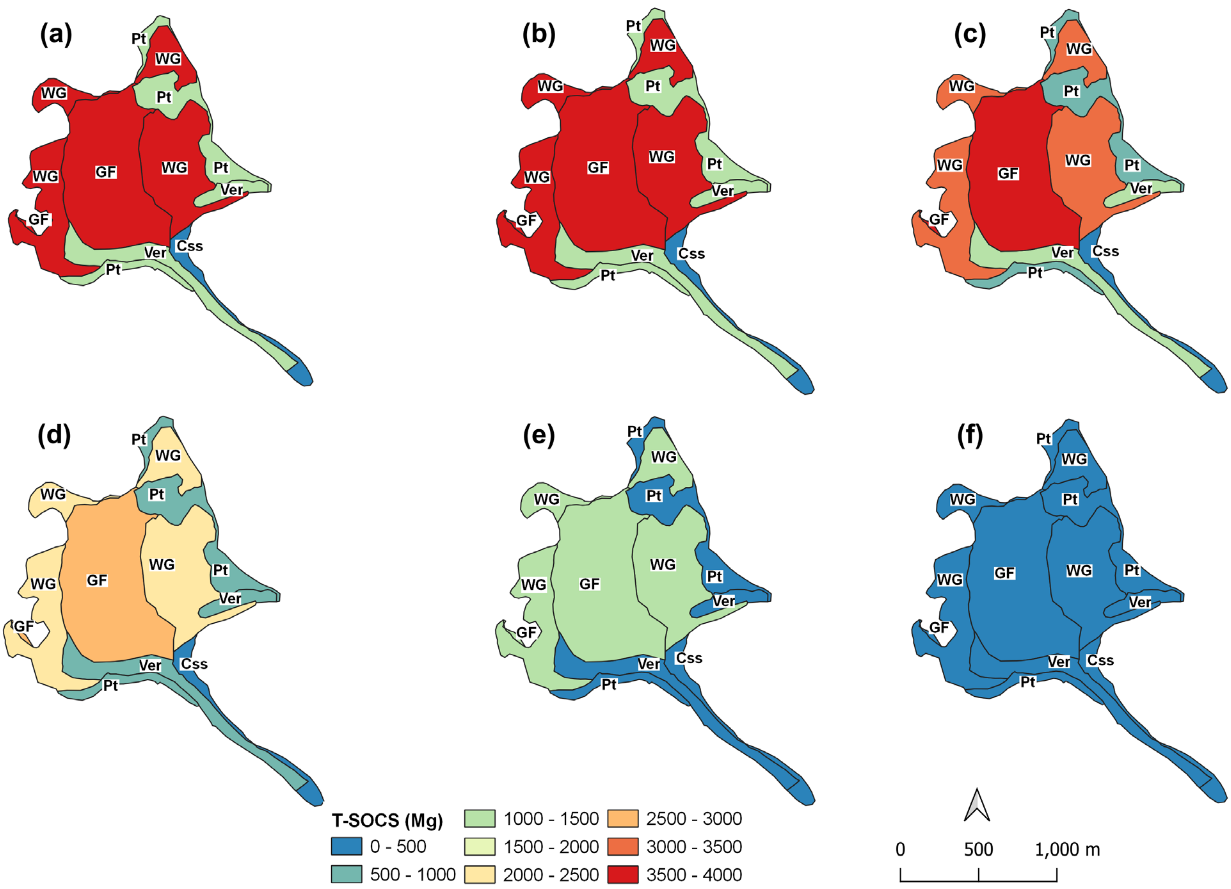

Figure 5. Total soil organic carbon stored (T-SOCS) for each land cover and layer depth of the Nevada wetland, where delimitation of land cover types is represented by black line (Css: Cerrado *stricto sensu*; GF: gallery forest; Pt: pasture; Ver: *vereda*; and WG: wet grassland) and layers are: (a) 0.00-0.20 m, (b) 0.20-0.40 m, (c) 0.40-0.60 m, (d) 0.60-0.80 m, (e) 0.80-1.00 m, and (f) 1.00-1.20 m.

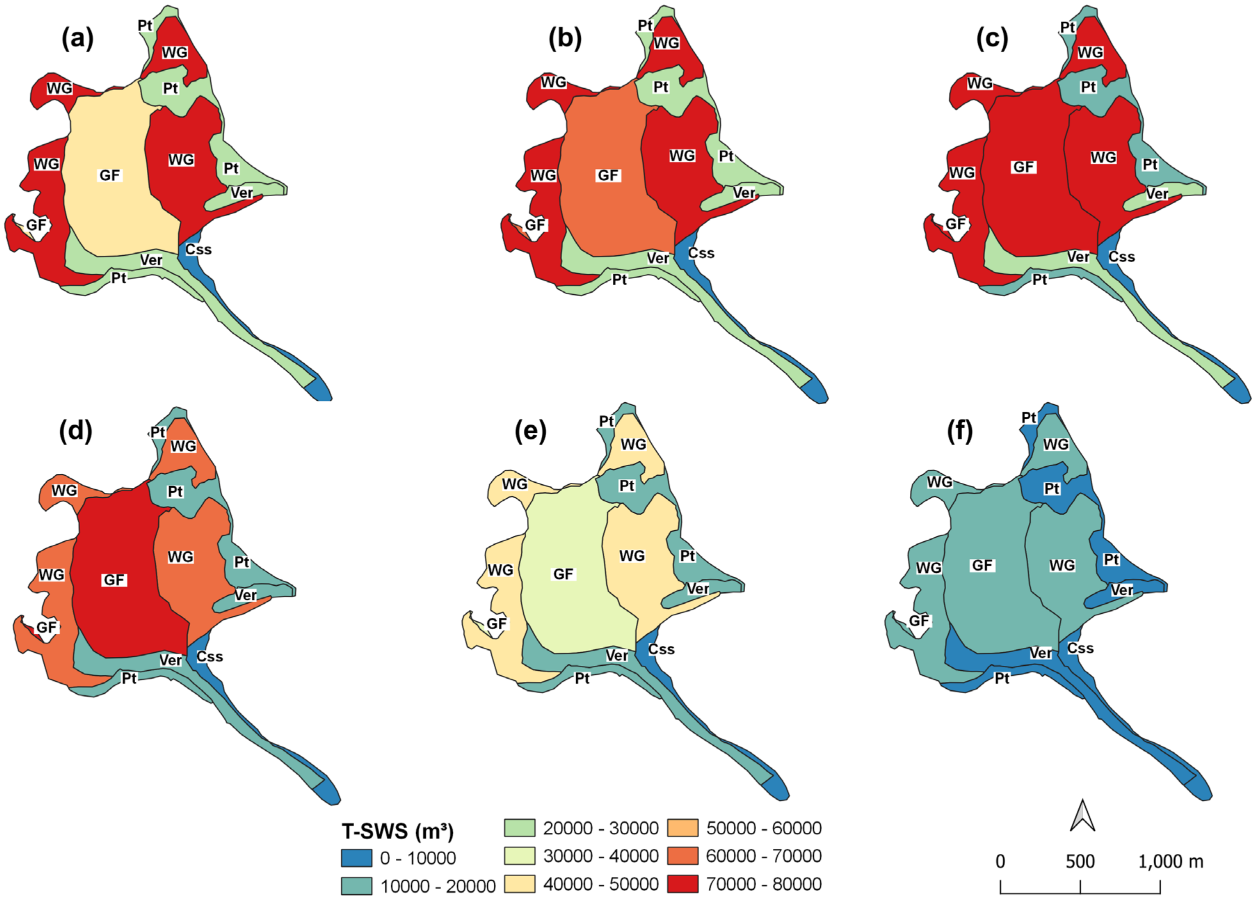

Figure 6. Total soil water stored (T-SWS) for each land cover and layer of the Nevada wetland, where delimitation of land cover types is represented by black line (Css: Cerrado *stricto sensu*; GF: gallery forest; Pt: pasture; Ver: *vereda*; and WG: wet grassland) and the layers are: (a) 0.00-0.20 m, (b) 0.20-0.40 m, (c) 0.40-0.60 m, (d) 0.60-0.80 m, (e) 0.80-1.00 m, and (f) 1.00-1.20 m.

Cluster analysis

After applying the Fuzzy k-means algorithm, the most suitable number of clusters was 3 (Figures 4d, 4e, and 4f), defined by the following quality parameters: PC = 0.81; PE = 0.33; MPC = 0.72; SIL = 0.53; SIL.F = 0.59; and XB = 0.33. The number of objects (sampling points) without unclear assignment (maximal membership degree < 0.5) was 0. Cluster 1 represents soil profiles with lower SOCS and SWS values and intermediate to low OLD values, grouping all the sampling points of Css and Pt and some from WG and Ver. Soil profiles with intermediate to high SOCS and SWS values and intermediate OLD values were represented by Cluster 2 with a respective predominance of sampling points from Ver, WG, GF, and one soil profile from Pt. Higher OLD values, intermediate to high SWS values, and intermediate to low SOCS values were joined into Cluster 3, which was predominantly occupied by points from GF and WG, in addition to one point from Ver.".

DISCUSSION

The GF, Ver, and WG are the vegetation types with the most humid soils and therefore with the highest GM and VM values in their layers, as well as the highest SOC values (Figure 2). Correlations among these properties are significant (p-values<0.001), strong, and positive, indicated by their coefficients of 0.91 between GM and SOC and 0.73 between VM and SOC (Figure 5). Carbon is the main constituent of soil organic matter (Ferdush and Paul, 2021). Therefore, these results suggest an interdependent relationship between soil organic matter and soil moisture, whereby accumulation of organic matter has been helping to retain more water and the increase in water content has been helping to preserve the organic matter, especially for those vegetation types mentioned above. A review of this direct and mutual influence can be seen in Védère et al. (2022).

While the highest GM, VM, and SOC values are seen in the most superficial layers in WG, the highest contents of these same properties are seen in the deepest layers in GF and Ver (Figure 2). Forest species are dominant for these last two vegetation types, such as: *Mauritia flexuosa, Duguetia lanceolata, Siphoneugena densiflora, Tapirira guianiensis, Sapindus saponaria, Inga nobilis, Miconia albicans, Cecropia lyratiloba, Hirtella martiana, Terminalia corrugata, Aspidorpema macrocarpon, Curatella americana, Protium heptaphyllum, Triplaris gardneriana, Eriotheca candolleana*, and *Guettarda viburnoides*, which contribute to more lignified organic matter for formation of their organic soils. On the other hand, WG is typically composed of herbaceous and some shrubs plants, such as Cyperaceae, Xyridaceae, Poaceae, Melastomataceae, Arecaceae, Annonaceae, Sapindaceae, Myrtaceae, Urticaceae, and Dilleniaceae families, that is, organic matter with lower lignin content (Mendes, 2024). More lignified vegetation provides greater recalcitrance for organic matter formation (Silva et al., 2013), and its incorporation into soil involves advanced processes of humification and time (Horwath, 2007), justifying the more enriched organic matter in SOC in deeper layers (Lorenz and Lal, 2005). On the other hand, typical grassland plants offer readily available organic matter due to their short life cycle, so they are more labile, and only one part remains and is incorporated (Koukoura et al., 2003). In the studied wetland, neither WG nor GF presents significant changes over time considering the upper 1.20 m. This information is corroborated by the almost constant $\delta^{13}C$ values at representative sampling points in these vegetation types, whereby more impoverished values are seen in GF (mean of -24.0 ± 0.66 ‰) and slightly more enriched values in WG (mean between -21.1 ± 0.92 ‰ and -20.6 ± 0.72 ‰) (Mendes, 2024).

Regarding these higher GM, VM, and SOC values at deeper depths in GF and Ver (Figure 2), a structural pattern for the studied wetland can be established based on the 'peatland structural model' proposed by Clymo (1992). According to this model, a peatland is composed of four structural layers of relatively fixed composition and four functional zones, two zones being above the water table (acrotelm) and two zones below (catotelm). In the most superficial layer (euphotic layer), photosynthetically active vegetation is present, while plant material is decomposing in the underlying layer, and the organic soil has high porosity and hydraulic conductivity. Due to the pressure exerted by the hydraulic weight of the upper levels, the material in the third layer is collapsed, with a sudden increase in density at the base, in addition to the predominance of lateral water flow and the accumulation of more organic matter (with higher SOC content). The last layer (anaerobic decomposition layer) has high density, low hydraulic conductivity, and permanent anoxia. Indeed, the GF and Ver layers of the Nevada wetland serve as a representation of Clymo's model up to the upper part of the third layer, albeit with the absence of the base of this layer (probably not sampled).

This dependent relationship between moisture (GM and VM) and SOC does not seem clear for more oxidized soils (mineral soils), which are mainly found in the Css and Pt areas. Despite the predominance of low GM and VM values in these vegetation types (Table 2), there is an increase in moisture in deeper layers, which may be influenced by an upward flow of water stored in the organic layers of other types of vegetation (GF, Ver, and WG), since the Css and Pt areas are located on the edges of the wetland.

When comparing SOC values of the Nevada wetland, their minimum (0.88 g kg^{-1} in Pt) and maximum (434.42 g kg^{-1} in WG) (Figure 2 and Supporting Table S2) are very close to those found in the Pandeiros River EPA (0-418 g kg^{-1}) (Santos et al., 2023) and in Grande Sertão Veredas PARNA (40-400 g kg^{-1}) (Horák-Terra et al., 2022a). For certain other wetlands, SOC values varied from 65 to 585 g kg^{-1} in Bonfinópolis de Minas (Horák-Terra et al., 2022b), from 45 to 538 g kg^{-1} in Brasília National Park (Viana, 2022), and from 158 to 259 g kg^{-1} in the municipality of Unaí (Araújo et al., 2023).

Significant negative correlations between BD and all other properties (p-values<0.001) were observed (Figure 7), especially for GM (-0.90) and SOC (-0.88). This inverse relationship is coherent, since BD is related to an increase in mineral matter content (Horák-Terra et al., 2022a), while GM, VM, SOC, SOCS, and SWS are related to an increment in organic matter (Yost and Hartemink, 2019; Horák-Terra et al., 2022a). Higher BD values in WG (1.39 g cm^{-3}), Pt (1.83 g cm^{-3}), and Css (1.78 g cm^{-3}) are clearly seen in the deeper layers, with an increasing trend with depth (Figure 2), which is very common in most wetland soils due to the greater contribution of mineral material from the basal substrate and/or from input through catchment erosion before the accumulation of organic deposits begins, as observed in Grande Sertão Veredas PARNA (1.10 g cm^{-3}) (Horák-Terra et al., 2022a) and Brasília National Park (1.64 g cm^{-3}) (Viana, 2022).

In the GF and Ver vegetation types of the studied wetland, the highest BD values (0.94 g cm^{-3} and 1.23 g cm^{-3}, respectively) were observed in the uppermost layers followed by a reduction with depth (Figure 2). Similar behavior was also observed by Horák-Terra et al. (2022b) for the Primavera wetland in Bonfinópolis de Minas, where BD values decreased from 0.31 Mg m^{-3} (top) to 0.09 Mg m^{-3} (bottom). In this case, the lowering of the surface water table caused by artificial drainage (channel opening) exposed and become unsaturated the surface layers, triggering the acceleration and intensification of organic matter decomposition (humification and mineralization) due to oxic conditions, increasing the BD values. This reasoning leads us to the conclusion that the organic soils of GF and Ver in the Nevada wetland may also be subject to the beginning of a similar degradation process to that mentioned above, whereby the main reason for lowering the water level in the surface layers is the subsurface lateral flow caused by hydraulic potential gradient due to the demand of surrounding drier mineral soils, especially during times of low precipitation. Mineral material input into organic soils of these two vegetation types by catchment erosion is not disregarded and may also be contributing to increasing BD values in the upper layers. Mendes (2024) found low fiber contents and von Post classes reflecting more decomposed organic matter in the most superficial layers for the same GF of the Nevada wetland, thereby corroborating the existence of possible indirect impacts.

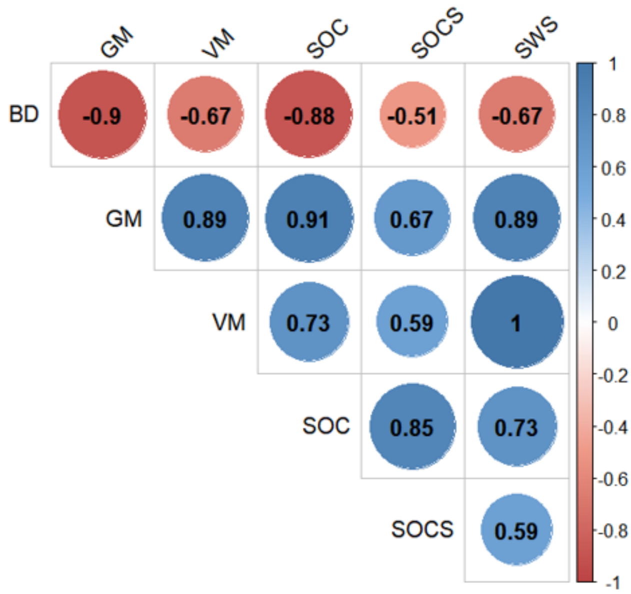

Figure 7. Correlogram of soil properties from the Nevada wetland. BD: bulk density; GM: gravimetric moisture; SOC: soil organic carbon; SOCS: soil organic carbon stock; and SWS: soil water storage.

Superficial layers of almost all the vegetation types presented higher SOCS values (Table 1), and its significant correlations (p-values<0.001) were: 0.85 with SOC; 0.67 with GM; and 0.59 with VM and SWS (Figure 5). These correlation values complement and corroborate the earlier statement that the most accentuated accumulation of soil organic matter may enable greater water storage in the soil, which in turn has been preserving the organic material in an interdependent relationship. Considering the contribution of each vegetation type, the (weighted) average for the Nevada wetland stocks was 321.91 Mg ha^{-1} up to 1.20 m, whereby GF (447.63 Mg ha^{-1}) and Ver (462.59 Mg ha^{-1}) were the biggest stockers compared to WG (267.22 Mg ha^{-1}), Pt (123.46 Mg ha^{-1}), and Css (57.77 Mg ha^{-1}). The SOCS values from the upper 0.60 m for GF (226.79 Mg ha^{-1}) and Css (33.94 Mg ha^{-1}) were lower when compared to Wantzen et al. (2012) for the same vegetation types (respectively, 360.00 Mg ha^{-1} and 57.70 Mg ha^{-1}) in reference sites positioned at catchments of stream-valley-ecosystems in the Brazilian Cerrado agroscapes (Paraguay River basin, in the state of Mato Grosso, Brazil). However, these authors found lower results for Ver (201.90 Mg ha^{-1}) and Pt (62.30 Mg ha^{-1}) in relation to SOCS values obtained for the studied wetland up to 0.60 m (respectively, 222.61.00 Mg ha^{-1} and 98.66 Mg ha^{-1}). For agricultural soils in the Cerrado biome, Carvalho et al. (2009) obtained the following mean SOCS values of 49.05 Mg ha^{-1} for native Cerrado vegetation, 52.23 Mg ha^{-1} for conventional tillage, and 60.08 Mg ha^{-1} for no-till from 0 to 0.30 m (the municipality of Vilhena, Rondônia, Brazil).

Comparing the present results to other tropical peat-wetlands in South America, Pérez-Rojas et al. (2019) studied two tropical lowland wetlands (fluvial and isolated) located in the Interandean valley of the Magdalena River in Colombia, and they found SOCS values of 178.34 Mg ha^{-1} up to 1.30 m and 200.86 Mg ha^{-1} up to 0.62 m, respectively. Martín-López et al. (2023) found SOCS of 83.10 Mg ha^{-1} in the first 0.30 m of soils from areas that experience long periods of flooding (semi-seasonal savannas) in the Casanare Flooded Savannas of the Colombian Llanos (Orinoco River basin, Colombia). In relation to some Brazilian peat-wetlands, the average SOCS accumulation in the present study area was higher than that obtained by Wantzen et al. (2012) of 125 Mg ha^{-1} up to 0.60 m for their entire study area and was lower than those obtained by Silva et al. (2013) of 341 Mg ha^{-1} up to 1.20 m for peatlands of the Serra do Espinhaço Meridional Brazil (Minas Gerais state), Soares et al. (2021) of 140 Mg ha^{-1} up to 0.30 m in palm swamps of the Triângulo Mineiro region (Minas Gerais), and Horák-Terra et al. (2022b) and Santos et al. (2023) of 500 Mg ha^{-1} up to 1.50 and 1.00 m, respectively, in palm swamps of the northwestern and northern regions of Minas Gerais.

Considering the entire studied area (173.16 ha) and depth (0-1.20 m), the total organic carbon mass accumulated in the Nevada wetland was 55,741.94 Mg. In comparison, an area of 1000 ha with mineral soil under major agricultural activities in Brazil (soybean, corn, sugarcane, and pasture/livestock) after conversion from conventional to no-till practices would take 136 years to accumulate this same amount of organic carbon mass from 0 to 0.20 m considering an average annual carbon sequestration rate of 0.41 Mg ha^{-1} yr^{-1} (La Scala Júnior et al., 2012).

Nevada wetland presents an average (weighted) SWS capacity of 677.38 mm up to 1.20 m, with the following sequence of water depths according to vegetation types: 831.32 mm for GF, 780.42 for Ver, 693.63 mm for WG, 297.59 mm for Pt, and 220.33 mm for Css. This arrangement was the same for SOCS. Compared to other wetlands, Notohadiprawiro (1997) found a mean SWS value of 850 mm in 1.00 m of depth for a tropical peat-wetland in Indonesia; Campos et al. (2011) obtained a soil water holding capacity ranging from 556 to 834 mm for swamp areas and from 687 to 880 mm for marshes in the upper 1.60 m of tropical forested wetlands and marshes of the Gulf of Mexico (Mexico); and Silva et al. (2013) obtained a mean SWS value of 994,8 mm up to 1.20 m for peatlands in the Serra do Espinhaço Meridional Brazil (Minas Gerais). The studied wetland stores a total water volume of 1,155,635.21 m^3, which would be enough to meet the consumption and hygiene needs of 350,192 people for one month, considering a per capita value of around 0.11 m^3 of water per day (United Nations, 2024).

Organic matter plays a crucial role in the storage and maintenance of water in the studied environment, mainly because it is a constituent with high porosity and a charged surface (hydrophilicity), whereby water is held via electrostatic forces at adsorption sites and/or surface tension (capillary forces) in its pores (Libohova et al., 2018). This influence is corroborated by significant correlation coefficients (p-values<0.001) between SWS and SOC (0.73) and SOCS (0.59) (Figure 7). The "sponge effect" of organic matter is a particular characteristic of these organic soils, enabling them to store rainwater and make it available to the main watercourses through slow discharge, even in the driest periods of the year (Ogden et al., 2013; Horák-Terra et al., 2022b; Assani et al., 2023).

Through the linear regressions between SOC and SWS, no significant effect of vegetation type on increasing the proportion of the variance of water storage explained by carbon content values is observed, since their coefficients of determination were -0.014 for Css (Figure 8a), 0.28 for GF (Figure 8b), 0.41 for Pt (Figure 8c), and 0.11 for Ver (Figure 8d). A reasonable R^2 value of 0.61 was observed only for WG (Figure 8e). On the other hand, coefficients of correlation become satisfactory when these regressions are organized by layer depths regardless of vegetation type, as follow: 0.50 for 0.20-0.40 m (Figure 9b), 0.72 for 0.40-0.60 m (Figure 9c), 0.61 for 0.60-0.80 m (Figure 9d), 0.85 for 0.80-1.00 m (Figure 9e), and 0.82 for 1.00-1.20 m (Figure 9f). Therefore, the variation of stored water in relation to soil carbon accumulation is more influenced and better explained by layer depth than vegetation type. The low R^2 value (0.42) for the first layer (Figure 9a) corroborates the previous idea that a degradation process may start in the wetland surface layers, triggered by lowering the water level due to subsurface lateral flow.

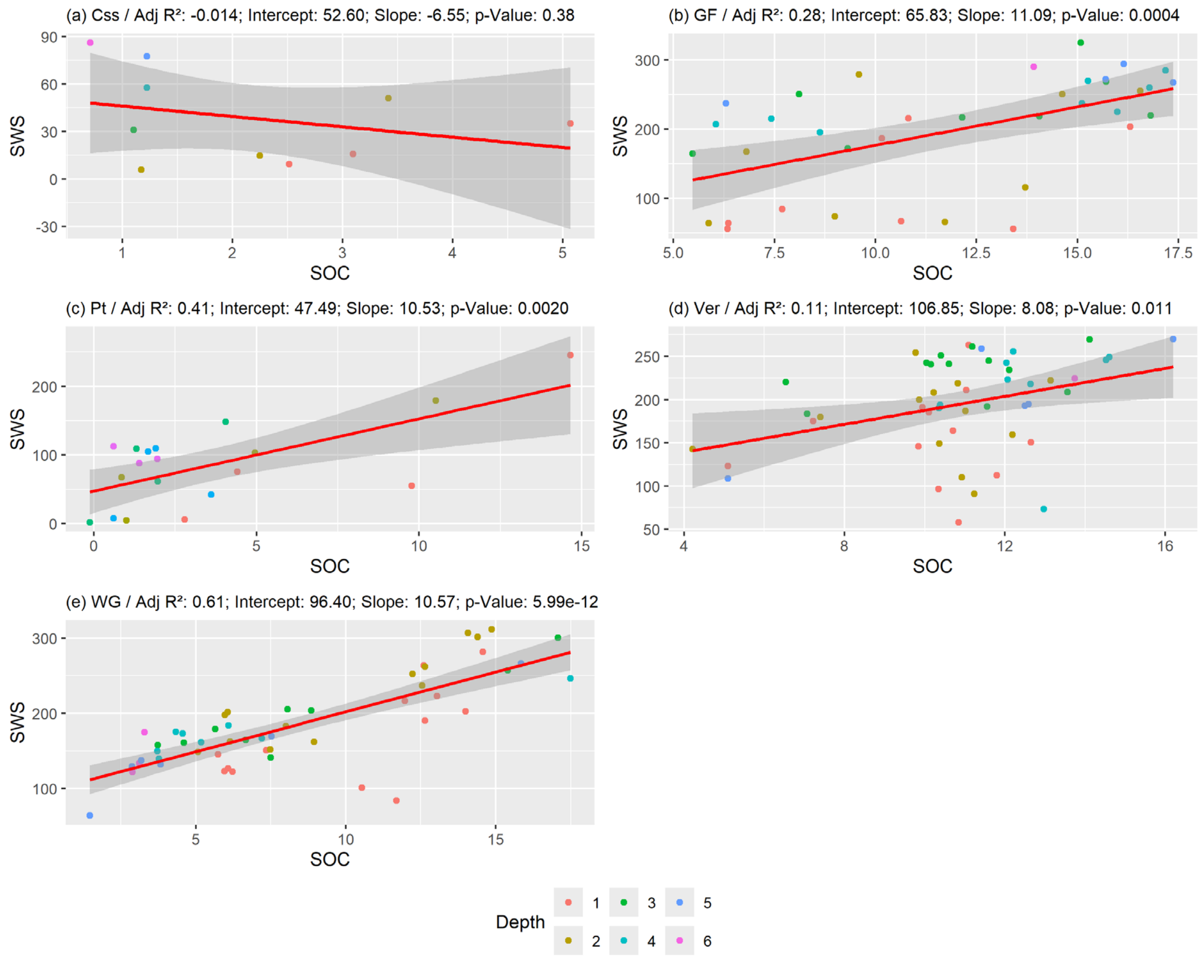

Figure 8. Linear regression analysis between soil organic carbon (SOC – independent variable) and soil water storage (SWS – dependent variable) for each land cover type of the Nevada wetland, as follow: (a) Cerrado *stricto sensu* (CSS), (b) gallery forest (GF), (c) pasture (Pt), (d) *vereda* (Ver), and (e) wet grassland (WG). Layers are: 1: 0.00-0.20 m; 2: 0.20-0.40 m; 3: 0.40-0.60 m; 4: 0.60-0.80 m; 5: 0.80-1.00 m; and 6: 1.00-1.20 m.

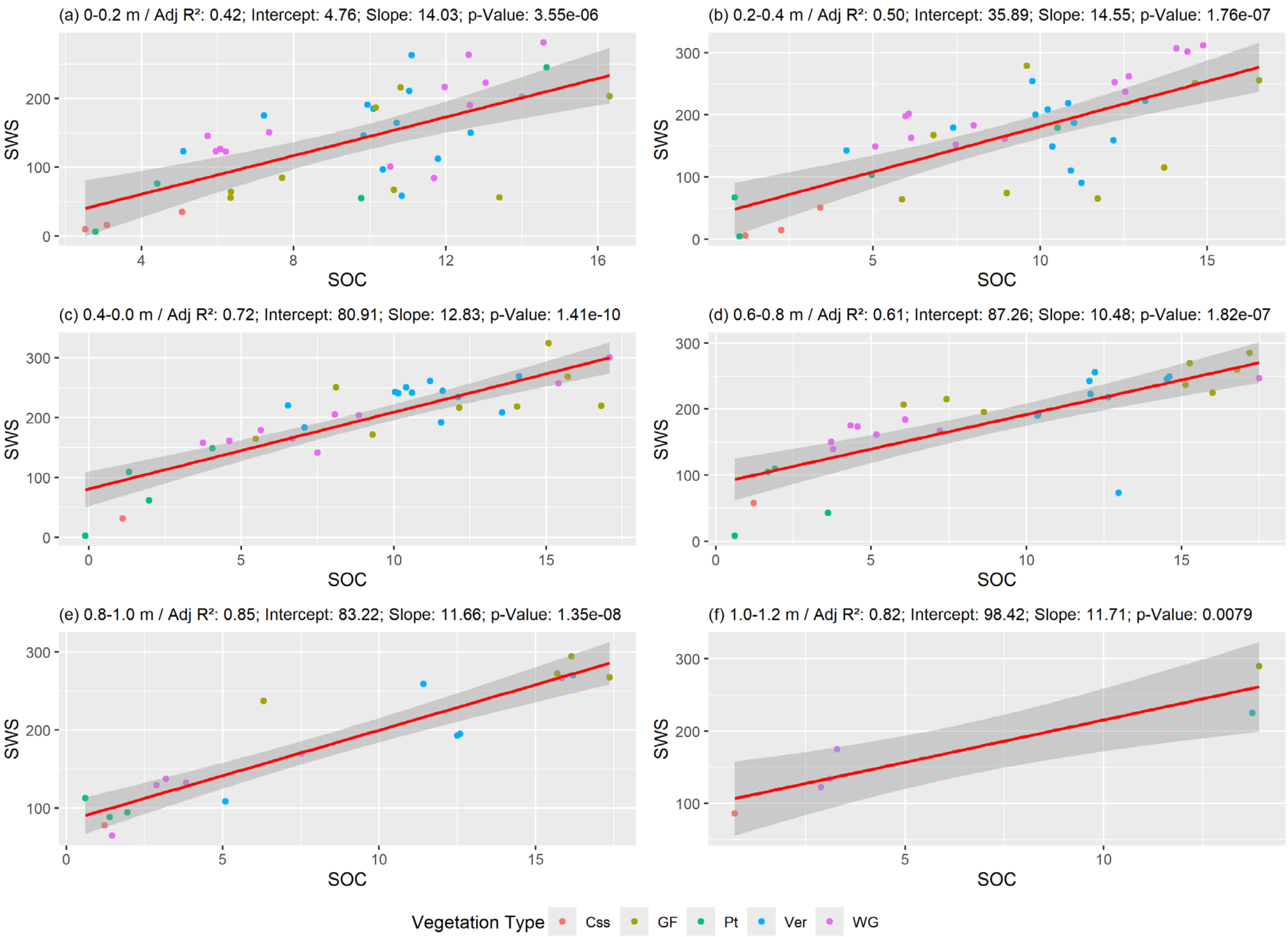

Figure 9. Linear regression analysis between soil organic carbon (SOC – independent variable) and soil water storage (SWS – dependent variable) for each layer of the Nevada wetland, as follow: (a) 0.00-0.20 m, (b) 0.20-0.40 m, (c) 0.40-0.60 m, (d) 0.60-0.80 m, (e) 0.80-1.00 m, and (f) 1.00-1.20 m. Vegetation types are: Cerrado *stricto sensu* (Css), gallery forest (GF), pasture (Pt), *vereda* (Ver), and wet grassland (WG).

Human actions in tropical wetlands (forest fires, livestock farming, artificial drainage, deforestation) cause soil degradation, reducing organic carbon content, increasing bulk density, and decreasing water storage, which compromises the ecosystem services of these environments, indicating that actions at local or governmental level must be encouraged to preserve and conserve such areas (Horák-Terra et al., 2022b; Santos et al., 2023). Wetlands soils have a high biochemical potential to metabolize organic carbon under standard conditions (i.e., aerobic), suggesting artificial or natural drainage may lead to organic matter losses and increased greenhouse gas emissions (Tan et al., 2020). Our results provide information about soils under different vegetation types (native or otherwise) of a wetland in the Cerrado biome that can be used to manage and monitor the quality of these threatened environments and the biome, mainly with regard to the genuine function of wetlands which is to stock organic matter and water.

CONCLUSION

Both hypotheses presented in this research were confirmed. Different land covers in the Nevada wetland control the soil organic carbon heterogeneity, whereby the riparian zones of the Cerrado biome (Gallery Forest - GF; Veredas - Ver; and Wet Grassland - WG) are the largest storage areas. In fact, soil organic carbon is a controlling factor for water storage in this environment; however, the variation of stored water in relation to carbon accumulation is more influenced and better explained by layer depth than vegetation type. A degradation process may start in the surface layers of the wetland, which is more evident in GF and Ver, being triggered by a lowering of the water level due to subsurface lateral flow from its central region into surrounding agricultural and pasture areas. These wet ecosystems must be urgently protected, since the advance of human disturbances can dramatically reduce their organic matter and water stocks and, therefore, reduce their ecosystem services.

SUPPLEMENTARY MATERIALS

Supplementary data to this article can be found online at https://www.rbcsjournal.org/wp-content/uploads/articles_xml/1806-9657-rbcs-49-e0240137/1806-9657-rbcs-49-e0240137-suppl01.pdf.

DATA AVAILABILITY

The data will be provided upon request

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AUTHOR CONTRIBUTIONS

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