Influence of land use on the chemical and physical characteristics of sediments from the Brazilian Savannah

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Influence of land use on the chemical and physical characteristics of sediments from the Brazilian Savannah

Ramom Rachide Nunes¹ and Maria Olímpia Oliveira Rezende¹∗

Abstract: This study analyzed the chemical and physical characteristics of replicate sediment samples from water bodies distributed along a gradient of environmental degradation in an agricultural landscape. To assess the effect of agricultural land use (farming and livestock activity) in the Brazilian Savannah, the following sediment attributes were evaluated: pH, cation exchange capacity, organic matter (OM), total organic carbon, humic acids (HAs), and texture (granulometric analysis). In addition, the structure of the HAs was analyzed by infrared spectroscopy (FTIR), and the degree of OM transformation (dOMt) was determined by emission fluorescence. Compared with the ecological station (ES) (reference site), sediments from the livestock were highly altered, with a higher OM content (~100% difference) and a predominance of smaller size particles (35.00% clay and 45.20% silt). Samples with a higher OM content were related to a smaller dOMt; for example, the ES sediments contained 8.37% OM and had 37.07 dOMt, compared to 16.12% OM and a 25.98 dOMt in the livestock area sediments. In general, these findings provide detailed insight into how the conversion of a natural environment to an area of agricultural use (farming or livestock) amends the chemical and physical characteristics of its sediments.

Subjects: Analytical Chemistry; Environmental Chemistry; Environmental Impact Assessment; Environmental Management

Keywords: Sediment analysis; agricultural land use; modified landscape; organic matter; humic acids

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Our area of research focuses on pragmatic solutions to environmental issues, such as land use and its impacts on natural resources, as well as environmental and resource management challenges. In addition, we research the diverse methods and technologies applied in the chemical, physical, and biological treatment of agro-industrial residues, producing compounds, vermicomposts, and biofertilizers to be used in the organic systems of agriculture and food production.

PUBLIC INTEREST STATEMENT

Agricultural activities transform the natural landscape and affect the characteristics of environmental resources: water, soil, sediments, etc. In attempting to understand how these activities can change and transform ecosystems, a detailed analysis of sediments can provide important information on agricultural land use and its impacts. In this study, we report several effects of agricultural practices on the physical and chemical characteristics of sediments from the Cerrado, also known as the Brazilian Savannah, an important biome in Brazil and the world.
1. Introduction

Land use involves the economic and cultural activities practiced at a given location that lead to alterations in the surrounding landscapes, i.e. agricultural, residential, industrial, etc. In general, land use changes occur constantly and on many scales and can have specific and cumulative effects on the air and water quality, watershed functions, waste generation, extent and quality of the wildlife habitat, climate, and human health (USEPA, 2013). Although land use practices vary greatly across the world, their ultimate outcome is generally the same: the acquisition of natural resources for immediate human needs, often at the expense of degrading environmental conditions (Foley et al., 2005).

In this paper, we report a study performed in the Brazilian Savannah, locally known as Cerrado. This biome is an important area of economic interest as the source of major Brazilian agricultural products for export. For example, 42 million of tons of soybeans are produced in the Midwest region, and the state of Minas Gerais produces 14 million of tons of coffee and stocks 24 million dairy and beef cows. In the state of São Paulo, the study area, 353 million of tons of sugar cane are cultivated, and a population of 11 million cows is fed in the Cerrado pasture grounds. Regarding food production, no other country practices agriculture in its savanna region as intensely as Brazil, making Cerrado one of the most important granaries in the world (Furley & Ratter, 1988; IBGE, 2015; Klink & Machado, 2005; Sano, Rosa, Brito, & Ferreira, 2008).

Despite the importance of these economic aspects, the agricultural exploration of the Cerrado territory cannot be prioritized over its preservation. Considered a global biodiversity hotspot, the Brazilian Savannah has been constantly threatened by agricultural land use. This complex biome covers approximately 2 million square meters of the Brazilian territory (24% of the country), extending from its borders up to Paraguay and Bolivia. Cerrado contains three of the largest South American watersheds, concentrating a third of the national biodiversity and 5% of the world’s flora and fauna. Furthermore, after the Amazon Rainforest, Cerrado constitutes the second largest type of Brazilian vegetation (BRASIL, 2015).

Natural and inherent, all human activities transform the environment, even if the changes are minimally perceived, for example, modifications of the composition or transformation of the physical, chemical, or biological characteristics of environmental compartments. Diverse studies have demonstrated how agricultural land use (farming and livestock) intensely modifies primarily soils and sediments, i.e. their organic matter (OM) content (Riezebos & Loerts, 1998; Tobiašová, 2011), maturation degree (Martins et al., 2011), and physical particle structure (Castellano & Valone, 2007; Pagliai, Vignozzi, & Pellegrini, 2004; Tobiašová, 2011; Wairiu & Lal, 2006).

How a biome interacts with an external influence must be understood to determine the chemical and physical characteristics of its environmental compartments, and awareness must be created about the role of the humans as transformative agents of the environment. Sediments play a key role in the assessment of environmental damage in that they can reveal the outcomes of an anthropogenic effect and provide important information about land use. Rich in OM and humic substances (HS), sediment particles act as a chemical deposit, particularly for organic compounds and toxic elements, keeping them adsorbed for future long-term analysis (Carvalho, 1994; Soares, Boaventura, Machado, & Esteves da Silva, 1999).

Considering the possible effect of agricultural land use on the transformation of natural landscapes and the importance of sediments in the assessment of environmental alterations, this study aimed to evaluate the influence of farming and livestock activities on the chemical and physical characteristics of sediments in the Brazilian Savannah (Cerrado).
2. Materials and methods

2.1. Site description
This study was conducted on sediments obtained from lentic water bodies located in three contrasting regions along a gradient of environmental degradation: (i) farming area (FA), land extensively used to cultivate sugar cane; (ii) livestock area (LA), land used to rear beef and dairy cattle, sediments were collected in pasture areas; and (iii) ecological station (ES), area of environmental protection named “Estação Ecológica de Jataí.”

The ES was considered a reference site, i.e. this area is minimally affected by anthropogenic activity and has never been cultivated or managed.

The research sites were located in the Luís Antônio municipality (21º33’ S 47º42’ W) in the State of São Paulo, Brazil (Figure 1). In this area, the original vegetation was humid, semi-deciduous, and subtropical. The climate is humid and subtropical, with a predominance of hot summers and without a long dry season. The annual precipitation is approximately 2,000 mm, with most of the rainfall in summer (October–March). Of the three study sites, only the ES has preserved the original vegetation. The FA and LA have a history of environmental degradation; therefore, the landscape has changed as a function of the land use.

2.2. Sediment sampling
Marginal sediments were sampled using a PVC tube that was placed at the border of different types of water bodies (ponds, swamps, lakes, reservoirs, etc). The number of sampling points was 47, 20, and 17 from FA, LA, and ES, respectively. All sediments were homogenized and air-dried. After completely drying, the samples were sieved to 2 mm, and 5 g of each sediment sample was mixed to compose a single sample.

2.3. Chemical characterization of sediments
Sediments from FA, LA, and ES were characterized through chemical analysis and a spectroscopic study of their humic acids (HAs).
The HAs were spectroscopically analyzed after their extraction and purification to determine the effect of land use on the structure, composition, and maturity/transformation of the OM (dOMt).

2.3.1. Chemical analysis
To assess the effect of land use on the sediment characteristics, the following sample attributes were assessed: pH (ISO 10390, 1994), OM (NEN 5754, 1994), total organic carbon (TOC) (ISO 10694, 1995), HAs (Swift, 1996), and cation exchange capacity (CEC). For the CEC determination, the amounts of sodium, potassium, calcium, magnesium, and aluminum were quantified (ISO 11260, 1994; ISO 14254, 1994).

2.3.2. Fractionation of HS
HAs, fulvic acids (FAs), and humin were fractioned based on the solubility differences of these HS in solution with controlled pH to isolate and purify the HAs. The HAs were considered the fraction of OM that was soluble in dilute acid solution and insoluble in alkali medium (Swift, 1996).

2.3.3. Infrared spectroscopy (FTIR) of HAs
The infrared spectra of HAs were acquired on a Bomem/MB-102 (Quebec, QC–Canada) using KBr pellets (3% of sample) and operating with resolution of 4 cm⁻¹ and an accumulation of 32 scans. The spectra were recorded over a range of 4000–400 cm⁻¹.

2.3.4. Fluorescence spectroscopy of HAs
Fluorescence emission spectra were acquired from ionic solutions of 20 mg L⁻¹ HAs dissolved in 0.05 mol L⁻¹ NaHCO₃ on a Hitachi F-4500 fluorometer (Chiyoda, Japan) by excitation of the samples at 465 nm in the wavelength range of 480–700 nm. In this method, the degree of OM transformation (dOMt) was determined by integrating the area below the emission spectrum curve (Milori, Martin-Neto, Bayer, Mięlniczuk, & Bagnato, 2002).

Other methods have been applied to measure the dOMt, i.e. UV spectroscopy (Saab & Martin-Neto, 2007) and synchronous-scan fluorescence spectroscopy, but they yielded non-significant results (Kalbitz, Geyer, & Geyer, 1999).

2.4. Sediment texture
Sediment particles sizes (granulometric analysis) and the sediment texture were the physical attributes assessed in this study. The particles were classified as clay (d < 2 μm), silt (2 > d > 63 μm), and sand (63 > d > 2,000 μm). The sand content was divided into fine sand (63 > d > 200 μm), medium sand (200 > d > 630 μm), coarse sand (630 > d > 1,250 μm), and very coarse sand (d > 2,000 μm). All these analyses were performed according to ISO 11277 (ISO 11277, 1998).

The sediment texture was determined by the PSD (particle size distribution), according to the proportions of each granulometric fraction assessed using the soil texture triangle proposed by the UN-FAO (UN-FAO, 2006).

2.5. Statistical analysis
Statistical significance was assessed using one-way ANOVA to evaluate the differences between the results at p < 0.05 by Duncan’s multiple range tests. IBM SPSS Statistics v.20 was used for the data analysis.

2.6. Laboratory competence
All sampling, analysis, and data treatment procedures were realized in agreement with the requisites of ISO 17025—General requirements for the competence of testing and calibration laboratories (ISO 17025, 2005).
3. Results and discussion

3.1. Chemical and physical characterization of sediments

Agricultural activity (farming and livestock) had adverse effects on the physical and chemical characteristics of sediments resulting from a landscape under management and human action (Table 1). Notably, among all parameters analyzed, the characteristics of two attributes were altered most significantly: the sediment texture (presence of a higher amount of particles with smaller sizes, i.e. clay and silt) and OM content. Both of these parameters were the most noticeable in the LA sediments.

In general, the differences in the following parameters were statistically significant: moisture (LA > FA = ES), pH (FA > LA > ES), CEC (FA = LA > ES), and OM (LA > FA = ES). However, no significant differences were observed in the analysis of TOC or HAs (one-way ANOVA, \( p < 0.05 \)).

Sediments from the LA had significantly more moisture than the other areas (35–28% compared with FA and ES, respectively). No significant differences were observed between the moisture content of the FA and ES (4% difference).

Land use also affected the pH of these sediments. Statistically significant differences were observed between the pH when comparing all the reported results (one-way ANOVA, \( p < 0.05 \)). However, the pH varied over small units, between 4.16 and 4.93 (Table 1). There is no information in the literature regarding a typical pH for Brazilian Savannah sediments, probably because of the diversity and plurality of biomes. Our results agree with the findings of Furley and Ratter (Furley & Ratter, 1988), who observed that the pH of Cerrado soil typically ranges between 4.3 and 6.2 and approximately 50% of Cerrado soils are highly acidic (≥5).

In the analysis of the organic sediment fractions, no significant difference was observed between the content of OM in the samples from the FA and ES (~28% difference). Sediments from the LA had significantly more OM than the ES samples (~100%). The difference between the OM in the LA and FA was approximately 60%, but it was non-significant (one-way ANOVA, \( p < 0.05 \)). According to the characterization presented in Furley and Ratter (Furley & Ratter, 1988), the OM in Brazilian Savannah soil ranges between 0.7 and 6.0%. In contrast, we determined that the studied sediments have

| Table 1. Chemical and physical characterization of sediments from the FA, LA, and ES |
|-----------------|-----------------|-----------------|
|                 | FA              | LA              | ES              |
| pH              | 4.93 ± 0.05a    | 4.51 ± 0.02b    | 4.16 ± 0.02c    |
| CEC/cmol kg⁻¹   | 15.42 ± 1.21b   | 19.38 ± 2.38c   | 1.04 ± 0.08a    |
| OM/%            | 10.72 ± 0.12b   | 16.12 ± 0.21c   | 8.37 ± 0.13a    |
| TOC/%           | 3.14 ± 0.04bc   | 3.00 ± 0.12b    | 2.57 ± 0.15a    |
| HAs/%           | 4.54 ± 0.00a    | 3.50 ± 0.00a    | 4.00 ± 0.00a    |
| PSD/% Clay      | 27.50           | 35.00           | 13.20           |
|                 | 17.50           | 45.20           | 11.10           |
| Silt            | 27.00           | 13.00           | 35.70           |
| Fine sand       | 27.10           | 6.80            | 37.70           |
| Medium sand     | 0.90            | 0.20            | 2.30            |
| Coarse sand     | 0.00            | 0.00            | 0.00            |
| Sediment texture| Sandy clay loam | Silt clay loam  | Sandy loam      |

Notes: CEC = Cation exchange capacity; OM = Organic matter; TOC = Total organic carbon; HAs = Humic acids; PSD = Particle size distribution. Values in the same row followed by the same letter are not significantly different from each other at \( p < 0.05 \) according to Duncan’s test.
~280% more OM than Brazilian Savannah soil, when compared with the ES sediments. The diverse contents of OM and particles of silt and clay may have been responsible for the varying levels of moisture and CEC between the sediment samples. In general, samples with higher contents of OM and HAs tend to absorb more moisture (Leelamanie, 2010).

The LA sediments had a higher CEC than the other samples (FA and ES), and the variation was greater between samples from the LA and ES. The highest CEC was detected in the LA (19.38 cmol_c kg\(^{-1}\)), which was approximately 1,700% higher than the highest value reported in the ES sediments.

Regarding the effect of land use on the contents of TOC and HAs, no significant difference was observed between any of the samples, indicating that both sediments statistically have the same content of organic carbon. Similarly, the content of HAs was the same in all of the sediments and was relatively low (one-way ANOVA, \(p < 0.05\)) at approximately 3.50–4.54 (Table 1). The differences between the OM and HAs may be interpreted in terms of the maturation degree of the OM. Although the sediments from the LA contained more OM, it was probably fresher, which implies a lower content of HAs (Adani, Genevini, Gasperi, & Tambone, 1999; Palak, Sułkowski, Bartoszek, & Papież, 2005; Sánchez-Monedero, Cegarra, García, & Roig, 2002).

Regarding the physical attributes of sediments, land use had a great effect on the size of sediment particles. The granulometric analyses indicated that the samples from the FA and ES had a higher content of sand (54 and 75%, respectively), whereas a small sand content was determined in the LA sediments, 20%. The highest content of small particles (clay and silt) was observed in sediments from the LA: 35% clay and 45.20% silt, for a total of ~80%.

The sediment texture was determined using the quantity of each particle size. According to the PSD, sediments from the FA had an intermediate composition of clay and a higher content of sand and can be classified as sandy clay loam. The sediments from the LA had an intermediate composition of clay and a higher content of silt and can be classified as silt clay loam. Finally, sediments from the ES had a very higher content of sand and can be classified only as sandy loam, typical of the Brazilian Savannah.

Diverse studies have demonstrated how livestock farming can modify soil structure and composition. Trampling by cattle causes wear of the larger particles (especially sand) that compose the soil and sediment, creating smaller particles, i.e. silt and clay, and increasing the cohesion of particles and the consequent compression (Castellano & Valone, 2007; Pagliai et al., 2004; Pietola, Horn, & Yli-Halla, 2005). This finding is in agreement with the results reported in the present study, as confirmed by the contrasting amounts of particles in the evaluated sediments.

### 3.2. Characterization of HAs

Analysis of the fluorescence emission (Figure 2) and FTIR (Figure 3) spectra revealed, on a microscopic level, how land use impacts—mainly represented by the replacement of OM on the soil cover—potentially influence the OM maturity, which consequently may permit the assessment of HAs with different structures.

OM transformations are related to time. For example, OM that was recently incorporated in soil is fresh, unmodified, typically rich in aliphatic chains, and typically lacking in aromatic groups (resulting in a smaller dOMt). Conversely, OM that has existed on the soil cover for a long period of time is more mature, stable, and rich in aromatic groups, conjugated or unconjugated (resulting in a higher dOMt) (Martins et al., 2011; Milori et al., 2002; Nunes, Benetti, Pigatin, Martelli, & Rezende, 2014; Nunes & Rezende, 2015). According to Stevenson (Stevenson, 1994) and Canellas & Santos (Canellas & Santos, 2005), the processes related to the dOMt are associated with an increase in the size and weight of the chemical groups present in OM. Thus, aliphatic groups tend to be condensed, increasing the aromaticity of the molecules.
A wide band with a maximum wavelength of 520 nm was observed in the fluorescence emission spectra (Figure 2). All samples presented similar spectra, varying only in the maximum absorption (Table 2). According to Milori et al. (Milori et al., 2006), the area under a fluorescence emission spectrum is directly related to the concentration of C. However, this C concentration refers only to C in rigid structures, such as aromatic rings and quinone groups.

The values of dOMt in the ES samples were significantly different from the other samples related to agricultural land use, i.e. ES > FA = LA (one-way ANOVA, p < 0.05). Sediments from the ES had a significantly higher dOMt (37.07 × 10^3) than those from the FA (26.13 × 10^3) and LA (25.98 × 10^3) (Table 2). Land use, according to this paper, decreases the dOMt by approximately 42%. No significant differences were observed between the LA and FA (~0.5% of difference).
Sediments from the ES showed a higher dOMt due a smaller deposition of OM (fresh OM) on the soil surface, a characteristic of the Brazilian Savannah. Because it is less frequently replaced, the OM remains above the soil cover for a long period of time; moreover, this soil cover is not managed, which favors its maturation. In this sense, sediments from the ES have a lower content of OM (Table 1) but, in terms of maturity, are more recalcitrant and stabilized (Table 2).

Differently, a large amount of cow manure had been constantly replaced in the LA. From a chemical perspective, this residue represents fresh OM, explaining the lower dOMt. Comparing the dOMt between these samples affirms that agricultural activity (farming and livestock) adversely affected the sediment characteristics, changing the OM content and its maturity. These results are in agreement with other studies reported in the literature (Martins et al., 2011; Milori et al., 2002).

The FTIR spectra provided information about the chemical bonds and groups in the structure of HAs (Figure 3). In general, the spectra of the samples are similar, except for small differences in certain spectral bands.

All spectra contained a wide and intense band at 3,600–3,070 cm⁻¹, which is generally attributed to OH stretching vibrations but may also be associated with the stretching of NH bonds (Silverstein, Webster, & Kiemle, 2005) (Table 3).

Two minor bands were observed between 2,918 and 2,925 cm⁻¹. Such bands indicate the presence of methyl and methylene groups, which have asymmetric vibrations (Silverstein et al., 2005). In particular, these groups indicate the presence of aliphatic chains in the structures of the HAs (Bloom & Leenheer, 1989; Nakanishi, 1962) (Table 3).

The region between 1,450 and 1,500 cm⁻¹ is characteristic of aromatic core vibrations (double bonds between carbons) (Silverstein et al., 2005). The band observed at 1,580 cm⁻¹ is intense when the phenyl groups of the HAs are conjugated to an unsaturation or are linked to atoms with pairs of free electrons (Bloom & Leenheer, 1989; Polak et al., 2005) (Table 3).

According to Silverstein et al. (Silverstein et al., 2005), the presence of carbonyl groups is detected at approximately 1,700 cm⁻¹, corresponding to vibrations of the double bond between the carbon and oxygen atoms (C=O) in ketones, quinones, and carboxylic groups present in the structure of HAs (Table 3).

The detected band at approximately 500 cm⁻¹ is generally attributed to the presence of minerals in the structure of the HAs (Bloom & Leenheer, 1989). This band was not detected in the HAs from the FA possibly because the content was below the limit of detection (Table 3).

| Table 2. dOMt of sediments obtained through emission fluorescence |
|---------------------------------------------------------------|
| **dOMt**         |                                      |
| FA               | (26.13 ± 1.22) × 10³                  |
| LA               | (25.98 ± 1.01) × 10³                  |
| ES               | (37.07 ± 1.80) × 10³                  |

Note: dOMt = degree of OM transformation.
4. Conclusions
The presented data confirm that the conversion of the natural environment for agricultural use (farming or livestock) amends the chemical and physical characteristics of sediments, in this case, from the Brazilian Savannah. The features of sediments from LA were altered to a greater extent than those from ES, particularly in terms of a high OM content and predominance of smaller sized particles (clay and silt) in the former sediments. Regarding the investigation of the extracted HAs, fluorescence emission spectroscopy was the best method to calculate the dOMt. The incorporation of OM into the soil—as occurs during agriculture activities—results in a lesser dOMt of its sediments. On other hand, the Brazilian Savannah biome does not have an intense deposition of OM to the soil, resulting in a higher dOMt.

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References
Adani, F., Genevini, P. L., Gasperi, F., & Tambone, F. (1999). Composting and humification. Compost Science & Utilization, 7, 24–33.
http://dx.doi.org/10.1080/1065657X.1999.10701949

Bloom, P. R., & Leenheer, J. A. (1989). Vibrational, electronic, and high-energy spectroscopic methods for characterizing humic substances. In M. H. B. Hayes, P. Maccarthy, R. L. Malcolm, & R. S. Swift (Eds.), Humic substances II: In search of structure (p. 764). New York, NY: John Wiley.

BRASIL (2015). O Bioma Cerrado [The Cerrado biome]. Brasília: Ministério Do Meio Ambiente.

Canellas, L. P., & Santos, G. A. (2005). Humosfera. Campos Dos Goytacazes: CCTA.

Carvalho, N. O. (1994). Hidrossedimentologia Prática (p. 372). Rio de Janeiro: CPRM.

Castellano, M. J., & Valone, T. J. (2007). Livestock, soil compaction and water infiltration rate: Evaluating a potential desertification recovery mechanism. Journal of Arid Environments, 71, 97–108. http://dx.doi.org/10.1016/j.jaridenv.2007.03.009

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Holloway, T. (2005). Global consequences of land use. Science, 309, 570–574. http://dx.doi.org/10.1126/science.1111772

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., … Holloway, T. (2005). Global consequences of land use. Science, 309, 570–574.

Furley, P. A., & Ratter, J. A. (1988). Soil resources and plant communities of the central Brazilian cerrado and their development. Journal of Biogeography, 15, 97–108. http://dx.doi.org/10.2307/2845050

IBGE (2015). Estatística Da Produção Agrícola [Statistics of the Brazilian Agricultural Production]. Brasília: Instituto Brasileiro de Geografia e Estatística.

ISO 10390. (1994). Soil quality–determination of pH. Geneva: International Organization for Standardization.

ISO 11260. (1994). Soil quality–determination of effective cation exchange capacity and base saturation level using barium chloride solution. Geneva: International Organization for Standardization.

ISO 14254. (1994). Soil quality–determination of exchangeable

Table 3. Main chemical groups characterized by FTIR

| Wavenumber/cm⁻¹ | Chemical groups characterized |
|-----------------|-------------------------------|
| 3,600–3,070     | O–H stretching present in large amounts in the OM and the structure of the HAs |
| 1,700           | Vibrations of double bonds between carbon and oxygen atoms that belong to ketones, quinones and carboxylic groups |
| 2,918–2,925     | Asymmetrical vibration of methyl and methylene groups (indicating the presence of aliphatic chains in the structure of the HAs) |
| 1,456           | Angular deformation of the C–H bonds from the aliphatic CH₃ and CH₂ groups |
| 1,450–1,500     | Vibrations of the aromatic rings (double bonds between carbons, C=C) |
| ~500            | Band generally attributed to the presence of mineral impurities present in the structure of the HAs |
acidity in barium chloride extracts. Geneva: International Organization for Standardization.
ISO 10694. (1995). Soil quality—determination of organic and total carbon after dry combustion. Geneva: International Organization for Standardization.
ISO 11277. (1998). Soil quality—determination of particle size distribution in mineral soil material—method by sieving and sedimentation. Geneva: International Organization for Standardization.
ISO 17025. (2005). General requirements for the competence of testing and calibration laboratories. Geneva: International Organization for Standardization.
Kalbitz, K., Geyer, W., & Geyer, S. (1999). Spectroscopic properties of dissolved humic substances—A reflection of land use history in a fen area. Biogeochemistry, 47, 219–238.
Klink, C. A., & Machado, R. B. (2005). A conservação do Cerrado Brasileiro [The conservation of the Brazilian Cerrado]. Mesoamérica, 1, 147–155.
Leelamanie, D. A. L. (2010). Changes in soil water content with ambient relative humidity in relation to the organic matter and clay. Tropical Agricultural Research and Extension, 13, 6–10. doi:10.4038/tarex.131.3130
Martins, T., Saab, S. C., Milori, D. M. B. P., Brinatti, A. M., Rosa, J. A., Cossaro, F. A. M., & Pires, L. F. (2011). Soil organic matter humification under different tillage managements evaluated by Laser Induced Fluorescence (LIF) and C/N ratio. Soil and Tillage Research, 111, 231–235. http://dx.doi.org/10.1016/j.still.2010.10.009
Milori, D. M. B. P., Galeti, H. V. A., Martin-Neto, L., Dieckow, J., Gonzalez-Perez, M., Beyer, C., & Salton, J. (2006). Organic matter study of whole soil samples using laser-induced fluorescence spectroscopy. Soil Science Society of America Journal, 70, 57–63. http://dx.doi.org/10.2136/sssaj2004.0270
Milori, D. M. B. P., Martin-Neto, L., Beyer, C., Mielenzczuk, J., & Bagnata, V. S. (2002). Humification degree of soil humic acids determined by fluorescence spectroscopy. Soil Science, 167, 739–749. http://dx.doi.org/10.1097/00010694-200211000-00004
Nakanishi, K. (1992). Infrared absorption spectroscopy (p. 233).
Nankondo: Tokio.
NEN 5754A. (1994). Determination of organic matter content in soil as loss-on-ignition. Netherlands: Normalisation Institute, Delft.
Nunes, R. R., Benetti, F., Pigatin, L. B. F., Martelli, L. F. A., & Rezende, M. O. O. (2014). Experimentos em química do solo: Uma abordagem interdisciplinar no ensino superior [Experiments in soil chemistry: An interdisciplinary approach in undergraduate courses]. Revista Virtual de Química, 6, 478–493. doi:10.5935/1984-6835.20140033
Nunes, R. R., & Rezende, M. O. O. (2015). Recurso solo: Propriedades e usos [Soil resource: Properties and uses]. São Carlos: Editora Cubo.
Paglioti, M., Vignozzi, N., & Pellegrini, S. (2004). Soil structure and the effect of management practices. Soil and Tillage Research, 79, 131–142. http://dx.doi.org/10.1016/j.still.2004.07.002
Pietola, L., Horn, R., & Yli-Halla, M. (2005). Effects of trampling by cattle on the hydraulic and mechanical properties of soil. Soil and Tillage Research, 82, 99–108. http://dx.doi.org/10.1016/j.still.2004.08.004
Polak, J., Sukelský, W. W., Bartoszek, M., & Papiez, W. (2005). Spectroscopic studies of the progress of humification processes in humic acid extracted from sewage sludge. Journal of Molecular Structure, 744, 983–989. http://dx.doi.org/10.1016/j.molstruc.2004.12.054
Ribeiro, H. T., & Loerts, A. C. (1998). Influence of land use change and tillage practice on soil organic matter in southern Brazil and Eastern Paraguay. Soil and Tillage Research, 49, 271–275. http://dx.doi.org/10.1016/S0101-6977(98)00176-7
Saab, S. C., & Martin-Neto, L. (2007). Anéis aromáticos condensados e relação E4/E6: Estudo de ácidos húmicos de gleisóis por rnm de 13c no estado sólido utilizando a técnica CP/MAS desacoplamento defasado [Condensed aromatic rings and E4/E6 ratio: Humic acids in gleysols studied by NMR CP/MAS13C, and dipolar dephasing]. Química Nova, 30, 260–263. http://dx.doi.org/10.1590/S0100-40422007000200003
Sánchez-Manedero, M. A., Cegarra, J., Garcia, D., & Roig, A. (2002). Chemical and structural evolution of humic acids during organic waste composting. Biodegradation, 13, 361–371. http://dx.doi.org/10.1023/A:1022888231982
Sano, E. E., Rosa, R., Brito, J. L. S., & Ferreira, L. G. (2008). Semidetailed land use mapping in the Cerrado. Pesquisa Agropecuária Brasileira, 43, 153–156.
Silverstein, R. M., Webster, F. X., & Kiemle, D. (2005). Spectrometric identification of organic compounds. New York, NY: John Wiley.
Soares, H. M. V. M., Boaventura, R. A. R., Machado, A. A. S. C., & Estives da Silva, J. C. G. (1999). Sediments as monitors of heavy metal contamination in the Ave river basin (Portugal): Multivariate analysis of data. Environmental Pollution, 105, 311–323. http://dx.doi.org/10.1016/S0269-7491(99)00048-2
Stevenson, J. F. (1994). Humus chemistry: Genesis, composition, reactions (p. 512). New York, NY: John Wiley.
Swift, R. S. (1996). Organic matter characterization. In D. L. Sparks, A. L. Page, P. A. Helmke, R. H. Loeppert, P. N. Soltanpour, M. A. Tabatabai ... M. E. Sumner (Eds.), Methods of soil analysis. Madison, WI: Soil Science Society of America.
Tobiasová, E. (2011). The effect of organic matter on the structure of soils of different land uses. Soil and Tillage Research, 114, 183–192. UN-FAO. (2006). Guidelines for soil description. Rome: Food and Agriculture Organization of the United Nation.
USEPA. (2013). Land use. Washington, DC: United States Environmental Protection Agency.
Wairiu, M., & Lol, R. (2006). Tillage and land use effects on soil microporosity in Ohio, USA and Kohombangora, Solomon Island. Soil and Tillage Research, 88, 80–84. http://dx.doi.org/10.1016/j.still.2005.04.013

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