

Environmental indicators for monitoring soil carbon under different vegetation covers: the case of the southern cerrado of Tocantins

Indicadores ambientais para monitoramento do carbono do solo sob diferentes coberturas vegetais: o caso do cerrado sul tocantinense

Indicadores ambientales para el monitoreo de carbono en suelo bajo diferentes coberturas vegetales: el caso del cerrado sur de Tocantins

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Abstract

The construction of environmental indicators has allowed improving management models of natural resources through the evaluation of measures adopted and the monitoring of strategic actions to be used in the search for sustainable development. This work aimed at the construction and evaluation of indicators related to changes in carbon behavior due to changes of vegetation cover in the southern cerrado of Tocantins. The methodology adopted was from the OECD (Organization for Economic Cooperation and Development), the Pressure-State-Impact/Effect-Response (PSI/ER) framework, for the construction of a matrix. For the validation of indicators, specific methodologies were used according to technical standards. The proposed matrix considers the following indicators: soil carbon, carbon stocks in humic fractions, labile carbon - C-Labile and carbon stocks in light organic matter - LOM. The use of indicators presented in this work is of great importance for the monitoring of carbon caused by changes in vegetation cover in the southern cerrado of Tocantins, as a subsidy for policies and actions aimed at reducing the impacts of environmental degradation.

Keywords: Matrix of indicators; Organic matter; Environmental degradation.

Resumo

A construção de indicadores ambientais vem possibilitar um aperfeiçoamento nos modelos de gerenciamento dos recursos naturais, por meio da avaliação das medidas adotadas e monitoramento das ações estratégicas a serem empregadas na busca do desenvolvimento sustentável. Esse trabalho teve como objetivo a construção e avaliação de indicadores relacionados as mudanças no carbono pela alteração da cobertura vegetal no cerrado sul do Tocantins. A metodologia adotada Foi da OCDE (Organização para a Cooperação e Desenvolvimento Econômico), o modelo de Indicadores de Pressão-Estado-Impacto/Efeito-Resposta (PEI/ER), para a construção de uma matriz. Para a validação dos indicadores foram utilizadas metodologias específicas conforme normas técnicas. A matriz proposta considera os seguintes indicadores: carbono no solo, carbono frações húmicas, carbono lábil – C-Lábil e carbono na matéria orgânica leve - MOL. A utilização dos indicadores apresentados neste trabalho é de grande importância para o monitoramento do carbono ocasionadas pela mudança de cobertura vegetal no cerrado sul tocantinense, como subsidio para políticas e ações voltadas a diminuição dos impactos a degradação ambiental.

Palavras-chave: Matriz de indicadores; Matéria orgânica; Degradação ambiental.

Resumen

La construcción de indicadores ambientales permite mejorar los modelos de gestión de los recursos naturales, a través de la evaluación de las medidas adoptadas y el seguimiento de las acciones estratégicas a emplear en la búsqueda del desarrollo sostenible. Este trabajo tuvo como objetivo la construcción y evaluación de indicadores relacionados con los cambios en el carbono debido a la alteración de la cobertura vegetal en el cerrado sur de Tocantins. La metodología adoptada fue de la OCDE (Organización para la Cooperación y el Desarrollo Económico), el modelo Presión-Estado-Impacto/Efecto-Respuesta Indicadores (PEI/ER), para la construcción de una matriz. Para la validación de los indicadores se utilizaron metodologías específicas según normas técnicas. La matriz propuesta considera los siguientes indicadores: carbono en suelo, carbono en fracciones húmicas, carbono lábil - C-lábil y carbono en materia orgánica ligera - MOL. El uso de los indicadores presentados en este trabajo es de gran importancia para el monitoreo del carbono causado por el cambio de cobertura vegetal en el cerrado sur de Tocantins, como subsidio para políticas y acciones dirigidas a reducir los impactos de la degradación ambiental.

Palabras clave: Matriz de indicadores; Materia orgánica; Degradación ambiental.

1. Introduction

Carbon is an essential chemical element in compounds of organic nature, being present in the oceans, atmosphere and terrestrial biosphere (RamesH et al., 2019). Worldwide, soils store four times more carbon than the biosphere and two to three times more carbon than the atmosphere (Le Quéré et al., 2018). Land use in the Cerrado generally leads to decrease in soil organic carbon through the adoption of inadequate management techniques, such as monocultures or unfertilized crops (Oliveira et al., 2016; Zinn et al., 2014). Intensive management practices and the use of conservation techniques have the potential to reduce soil organic carbon losses in agricultural lands (Bordonal et al., 2018).

One of the anthropic actions that contribute to CO₂ emission in the atmosphere is the change in vegetation cover, more specifically deforestation and fires, where changes caused by forest fragmentation and reduction of native areas result in the loss of ecological functions, including oxygen production, CO₂ storage and capture (Dantas et al., 2017). A study has shown that the interaction between forest and the absorbed carbon stock is directly linked to the regeneration stage, where the vegetation at advanced stage of regeneration has greater capacity to absorb carbon, compared to that at medium stage (Diniz et al., 2015).

Among the actions proposed to reduce these emissions, linked to the agriculture sector plan, pasture recovery, crop-livestock integration, biological nitrogen fixation, reforestation, treatment of animal waste, adaptation to climate change and expansion of the no-tillage area stand out (Assad, 2019).

The identification and assessment of environmental problems require the definition of a set of indicators aimed at the various elements involved (Guimarães et al, 2010). Through the evaluation and measurement of impacts, it is possible to reverse their effects using indicators that lead to the monitoring of these impacts, which, when mitigated, can promote system sustainability, requiring their qualification and quantification on a temporal-spatial scale (Ribeiro et al, 2010).

The model that has been internationally accepted and adopted for the study of global environmental indicators is the Pressure-State-Response (PSR) model developed by OECD (1998). The PSR framework is based on a concept of causality:

where human activities exert pressures on the environment and change the quality and quantity of natural resources (OECD, 1993). Rubio et al. (2018) used the Pressure-State-Response (PSR) model to define desertification indicators as an ordering landmark (OECD, 1991, 1998); however, they reinforce that currently, the most used analysis landmark is the Conductor Force or Driver-Pressure-State-Impact-Response (DPSIR) Framework.

Knowing the effects of changes in vegetation cover on soil carbon stocks (SCS) is of great importance for controlling CO₂ emissions (Santana et al., 2019). Generally, undisturbed forests have the highest C stocks among land covers, so they are constantly used as a reference for maximum achievable stocks and C saturation (Chen et al., 2019).

This work aimed at the construction and evaluation of indicators related to changes in soil carbon due to change of vegetation cover in the southern cerrado of Tocantins.

2. Methodology

The study area is located in the experimental farm of the Federal University of Tocantins, municipality of Gurupi, state of Tocantins at geographic coordinates 11° 46' 25" S and 49° 02' 54" W. The climate of the region according to Thornthwaite is of B1wA'a' type, with two well-defined seasons, with about six months of drought comprising the winter period and six months of rain corresponding to the summer. The average annual temperature is 27 °C and the average annual precipitation is 1,500 mm (SEPLAN/GIES, 2017).

The soil was classified as Petric Plinthosol, presenting plinthic diagnostic horizon B, which has the characteristics of having been formed in terrains with high water table or at least presenting temporary restriction to water percolation, favoring the development of a plinthic horizon, allowing the land to remain saturated with water for at least part of the year (Santos et al., 2018). The areas under study were located in *Eucalyptus* sp., natural pasture, agriculture and native vegetation areas of *sensu stricto* Cerrado as control.

The native vegetation area has 22.82 ha, aged over 50 years and located at coordinates 11°46'13" S and 49°03'25" W. The *Eucalyptus* sp. stand is 11 years old, has total area of 0.65 ha and is located at coordinates 11°46'28"S and 49°03'08"W. Implantation was carried out by means of deforestation with crawler tractor with frontal blade, then, land plowing and harrowing were carried out. The pasture area has predominance of *Andropogon* grass, with approximately 50 years and 11.25 ha, located at coordinates 11°46'19" S and 49°03'12" W. The area under corn cultivation has 0.95 ha and is located at coordinates 11°44'53" S and 49°03'11" W. Soil was prepared using a leveling harrow and disc plow, and weeds were controlled by manual weeding associated with the use of total action herbicides such as Glyphosate (Melo et al., 2017).

For the construction of descriptors and later of indicators, the methodology of the Organization for Economic Cooperation and Development (OCDE, 1993), Pressure/State/Response (PSR) (UNEP and CIAT, 1996) was adopted. The PSI/SR matrix comes from the conceptual framework for the selection of indicators that were systematized into Pressure – State – Response (PSR), created by the Organization for Economic Cooperation and Development (OECD) in 1993 and adapted to Pressure-State-Impact/Effect-Response (PSI/ER) Framework by the United Nations Environment Program – PNUMA-CIAT, in 1996. Practical indicators were constructed with a view to monitoring carbon and ways to control it. The proposed matrix considers the following indicators: soil carbon, carbon stocks in humic fractions, labile carbon – C-Labile and carbon in light organic matter – LOM.

3. Results and Discussion

Systems were defined with descriptors for monitoring carbon in the different vegetation covers based on the main characteristics of the evaluated system, and on the methodology adopted by the Organization for Economic Cooperation and Development (OECD, 1993). From descriptors selected for this system, 16 indicators were proposed (Table 1).

Table 1 – Scheme used to define environmental indicators for monitoring carbon in different vegetation covers.

Category	Element	Descriptors	Indicators
Resource Base	Soil	Carbon Monitoring	- Soil Carbon
			- Soil carbon stocks (g kg ⁻¹)
			- Carbon stocks in humic fractions (g kg ⁻¹)
			- labile carbon – C-Labile stocks (g kg ⁻¹)
			- Carbon stocks in light organic matter (g kg ⁻¹)
			- Carbon stocks in microbial biomass (check unit)
			- C/N ratio (%)
			- Light organic matter fractions
			- Microbial biomass (mg C kg ⁻¹ soil)
	- Microbiological activity *		
	Vegetation	Vegetation cover	Plant biomass (%)
System operation	Technical management	Carbon control	- Sustainable management practices (No.)
			- Research group actions (No.)
			- NGO Actions (No.)
			- Corporate actions (No.)

*Microbiological activity: C concentration in microbial biomass (C-CBM), basal soil respiration (BSR), microbial quotient (qMIC), and metabolic quotient (qCO₂). Fonte: OECD (1993).

Fifteen indicators were proposed that are always subject to questioning, since the selection of aspects of reality to be considered is influenced by political options and different visions of reality. The selected indicators will be used to monitor carbon in the vegetation cover. In addition, these indicators will serve as a basis for better carbon management in the area. Table 1 shows the indicators arranged as defined in the PSI/ER Matrix (Pressure, State, Impact/Effect and Response). Among the selected indicators, those that compete with more intensity in response to carbon are highlighted below.

Table 2 – Environmental indicators for monitoring carbon in vegetation covers in the Pressure/State/Impact/Effect/Response Matrix – (PSI/ER) Pressure Indicators (P) State Indicators.

Pressure Indicators (P)	State Indicators (E)	Impact/Effect Indicators (IE)	Response Indicator (R)
- Changes in vegetation cover (ha)	- C soil stocks (g kg ⁻¹)	- Soil C (g kg ⁻¹)	- Sustainable management practices (No.)
- Plant biomass (%)	- C stocks in humic fractions (g kg ⁻¹)	- Light organic matter fractions (g kg ⁻¹)	- Research group actions (No.)
- Microbiological activity *	- C-Labile stocks (g kg ⁻¹)	- Microbial biomass (g kg ⁻¹)	- NGO actions (No.)
	- C stocks in light organic matter (g kg ⁻¹)	- Humic fractions (g kg ⁻¹)	- Corporate actions (No.)
	- C stocks in microbial biomass (mg C kg ⁻¹ soil)	- Labile Carbon (g kg ⁻¹)	
	- C/N ratio (%)		

*Microbiological activity: C concentration in microbial biomass (C-CBM), basal soil respiration (BSR), microbial quotient (qMIC), and metabolic quotient (qCO₂). Source: Authors (2022).

3.1 Pressure Indicators

a) Changes in vegetation cover (ha)

Changes in vegetation cover alter the physicochemical structures of the soil, which can affect the edaphic microbiota and consequently the carbon behavior.

Such diversity is threatened due to factors such as: excessive use of natural resources, expansion of the agricultural and forestry frontier, urban and industrial growth (Peixoto et al., 2016). Anthropogenic activities have caused increase in the concentration of greenhouse gases (GHG) in the atmosphere (Le Quéré et al., 2018), mainly due to changes caused in soil exploitation, which alter the capacity of soils to store CO₂ adsorbed by plants (Santana et al., 2019).

One of the ways to increase carbon stock is in the preservation of native forests, reforestation, adoption of integrated farming, livestock and forestry systems, and the proper management of pastures and agriculture (Cook et al., 2016; Vicente et al., 2019; Magalhães et al., 2016), as these measures can remove large amounts of CO₂ from the atmosphere through the process of photosynthesis (Cassol et al., 2019) and store this carbon in aerial, underground and mainly soil biomass (Zelaryán et al., 2015).

In view of this, there is a need to assess soil carbon stocks in agricultural crops (Stockmann et al., 2015), given the large area occupied by agriculture in Brazil. Agriculture presents variations in SCS according to the type of management adopted. Conservation systems have better capacity to store carbon due to the lower intervention in soil preparation and planting processes compared to conventional cultivation (Bordonal et al., 2018). Coser et al. (2018) reported that in the short term, conservation systems will have great capacity to recover carbon lost with the implementation of agricultural crops.

Systems such as No-tillage (NT) represent a little more than 50% of agricultural land in the country (Rossetti and Centurion, 2015).

Over the years, soils in reforested areas show greater capacity to recover carbon lost in the deforested area (Frazão et al., 2014). Long-rotation forest plantations have greater capacity to store carbon because, over the time of forest maturation, there is greater litter deposition, which creates a physical barrier, helping soil properties and the potential to store carbon in the soil (Cassol et al., 2019).

b) Plant biomass (%)

The greater deposition of plant material and its decomposition causes the carbon concentrations in the soil and humic fractions to be higher. The higher C proportion in the humic fraction is important for soil organic carbon, and this fraction is composed of organic residues with high degree of decomposition, generating greater molecular stability, indicating longer permanence of C in the soil, giving the area greater capacity to store carbon (Petter et al., 2017). The plant biomass called litter that covers the soil surface is responsible for improving soil porosity, increasing water infiltration and moisture retention capacity. In addition, it assists in the breadth of diversity and biological activity of organisms present in the soil, increasing the availability of nutrients for plants and improving soil fertility.

c) Microbial activity (%)

Microbial activity was determinant in carbon stocks in the 0-20 cm soil layer. The metabolic quotient and the microbial quotient showed great sensitivity to changes in land use in the southern cerrado region, indicating greater stability and low degree of disturbance for areas of native forest, eucalyptus and pasture, pointing out to lower soil C losses in these areas.

Microbial diversity is an indicator of soil quality, as carbon present in soil microbial biomass (SMB) represents a highly sensitive indicator to assess soil changes (Dionísio et al., 2016).

BSR obtained variation from 0.44 to 0.82 mg C-CO₂ kg⁻¹ s h⁻¹ in the 0-10 cm soil layer and from 0.35 to 0.61 mg C-CO₂ kg⁻¹ s h⁻¹ in the 10-20 cm soil layer, presenting variation similar to that of the C-CBM between the evaluated areas and in soil layers, except for the agricultural area.

The qCO₂ of the evaluated soil showed variation from 1.68 to 4.36 mg C-CO₂ g⁻¹ C-CBM h⁻¹ in the 0-10 cm layer and from 1.55 to 4.31 mg C-CO₂ g⁻¹ C-CBM h⁻¹ in the 10-20 cm soil layer, with no significant difference between native forest, eucalyptus and pasture areas, with the highest values found in the agricultural area at both depths.

The microbial quotient (qMIC) presented variation at 0-10 cm from 0.92 to 2.15% and at 10-20 cm from 0.94 to 2.59%, showing that there was significant difference between areas and the soil layers evaluated.

3.2 State Indicators

a) Soil carbon stocks (Mg ha⁻¹)

Soil quality is defined by a series of physical (density and textural class) and biochemical (microbial activity and organic matter) factors, among other relevant factors, which play an important role in soil C storage (Freitas et al., 2017). Thus, this indicator represents great relevance.

Microbial activity was determinant in carbon stocks in the 0-20 cm soil layer. The metabolic quotient and the microbial quotient showed great sensitivity to changes in land use in the southern cerrado region, indicating greater stability

and low degree of disturbance for areas of native forest, eucalyptus and pasture, pointing out to lower soil C losses in these areas.

Eucalyptus plantation showed the highest soil carbon stocks in the 0-50 cm layer (95.7 Mg ha⁻¹) compared to the soil of the other evaluated areas, agriculture (95.54 Mg ha⁻¹), pasture (80.14 Mg ha⁻¹) and native forest (72.05 Mg ha⁻¹) in the 0-10 cm layer. In the 10-20 cm layer, likewise, the soil of the eucalyptus area presented the highest results, followed by the soil of areas of agriculture, pasture and native forest. Gomes et al. (2019) carried out a mapping of the carbon stock in Brazil and estimated that approximately 50% of C (36.0 PgC) is stored in the first 30 cm of soil. For Santos et al. (2019), this difference is due to the greater volume of roots in the surface layers, indicating that most of the soil matter in these managements comes from root residues.

b) Carbon stocks in humic fractions – humic C (Mg ha⁻¹)

This indicator is estimated in Mg ha⁻¹, where the highest C stock in the humic fraction is important for soil organic carbon, and this fraction is composed of organic residues with high degree of decomposition, generating greater molecular stability, indicating longer C permanence in the soil, indicating greater capacity of the area to store carbon (Petter et al., 2017).

The stock of humic C presented variation (0-50 cm) in the native forest, Eucalyptus, Pasture and Agriculture, respectively at depths of 0-50 cm of 31.68 Mg.ha⁻¹; 38.02 Mg.ha⁻¹; 28.14 Mg.ha⁻¹; 35.33 Mg.ha⁻¹.

The protection of humic C in aggregate fractions and the physical-biochemical protection through recalcitrant C in aggregates is one of the main mechanisms of C preservation in altered soils (Zhang et al., 2019).

c) Carbon stocks – labile (Mg ha⁻¹)

This indicator has strong correlation with microbial biomass carbon, suggesting that microbial activity and growth are strongly dependent on soil C-labile (Geraei et al., 2016).

The carbon present in soil microbial biomass is a good indicator of C-labile under different management practices. C-labile stocks showed significant difference with the change in land use, with reduction in C-labile stocks with increasing soil depth. According to Ramesh et al. (2019), C-labile stocks are scarce in many soils, since it presents rapid microbial decomposition.

Microbial biomass carbon stock represented a good part of C stocks in the labile soil fraction, representing average of 19.9% for the area of native forest; 22.1% for eucalyptus; 17.0% for pasture and 10.0% for agriculture in the first 20 cm of soil. As one of the labile soil fractions, CBM is an important indicator of soil changes caused by management practices (Culman et al., 2012).

d) Carbon stocks in light organic matter - CS-LOM (Mg ha⁻¹)

The change in land use established an increase in carbon stock in light organic matter (CS-LOM) of the analyzed areas compared to the native forest area, showing significant differences in all soil layers.

CS-LOM presented variation (0-50 cm) in the native Forest, Eucalyptus, Pasture and Agriculture, respectively at depths of 0-50 cm of 2.09 Mg.ha⁻¹; 3.05 Mg.ha⁻¹; 2.25 Mg.ha⁻¹; 2.61 Mg.ha⁻¹.

The native forest area showed the lowest stocks at all depths, which indicates that the change in land use generates an increase in carbon stocks in LOM. Studies by Moraes Sá et al. (2014) indicate that the light fraction is a sensitive indicator of change in land use. The superiority in CS-LOM in the first 30 cm of soil for the eucalyptus area may be associated with the high amount of litter available in the soil and microbial activity. The light fraction of soil organic matter is very sensitive to the

interaction of the effects of management systems, type of vegetation, organic residues deposited on the surface and the fine root biomass in the surface soil layer (Luo et al., 2019; Mayer et al., 2019; Pereira et al., 2010).

e) Carbon stocks in microbial biomass - C-CBM (Mg ha⁻¹)

C-CBM presented variation, and the stock of humic C presented variation in the native forest, Eucalyptus, Pasture and Agriculture, respectively at depths of 0-20 cm of 572.26 Mg.ha⁻¹; 924.99 Mg.ha⁻¹; 459.12 Mg.ha⁻¹; 256.57 Mg.ha⁻¹, where in general, there were no significant losses between the soil layers of areas, with the exception of agriculture. Kaschuk et al. (2010) evaluated soil microbial biomass over three decades in Brazilian ecosystems and found values ranging from 46 to 1386 mg C kg⁻¹ of soil in different soil covers in the Cerrado region. Most likely, the low organic matter supply in the agricultural area has reduced the activity of soil microorganisms and consequently reduced C-CBM in contrast to the greater availability of organic matter mainly via litter for the area of native forest and eucalyptus, and via fine root system for the pasture area has ensured a more stable microbial activity and possibly higher CBM content.

f) C/N Ratio (%)

The carbon/nitrogen ratio (C/N) showed little variation between soil layers and evaluated areas. On average, the lowest and highest C/N ratios were in the 40-50 cm layer, with values of 10.87 and 12.56, respectively. Stability in the C/N ratio is attributed to simultaneous and proportional changes (gains or losses) in soil organic carbon and N (Zinn et al., 2018). Kirkby et al. (2016) evaluated the C/N ratio at two different times in an Australian soil and found that in both times, there was reduction in the C/N ratio with increasing depth, presenting very similar results, which corroborates the proposal that C and N present proportional losses and gains.

Regarding the average C/N indicator, the lowest and highest ratio were in the 40-50 cm layer, presenting values of 10.87 and 12.56, respectively. Stability in C/N ratio is attributed to simultaneous and proportional changes (gains or losses) in soil organic carbon and N (Zinn et al., 2018).

3.3 Impact/Effect Indicators

a) Soil C (g kg⁻¹)

In general, soil carbon concentrations decreased with increasing depth for all vegetation covers, showing significant differences mainly in the surface soil layer (0-10 cm). The eucalyptus and agriculture areas had the highest soil carbon concentrations in the 0-10 cm (22.86 and 17.49 g kg⁻¹) and 10-20 cm (17.58 and 15.48 g kg⁻¹) soil layers, respectively, exceeding the area with native forest and pasture, which did not present significant differences from each other.

Considering the surface soil layer (first 30 cm), there is approximate concentration of 800 GtC, equating to the amount of C present in the atmosphere, emphasizing the importance of C stocks in the soil, which, undergoing changes, can cause significant impacts on the CO₂ concentration in the atmosphere (Lucena, 2019). The exchange of carbon between terrestrial ecosystems and the atmosphere is estimated to be between 100 and 120 GtC and much of this exchange is due to the effect of human activities on land use, such as the conversion of forests into agricultural land, and natural variation and indirect effects on the environment such as eutrophication, increased atmospheric CO₂ concentrations or climate changes (Houghton, 1993).

The C-labile content, on average, represented 9.7% of the total carbon concentration of areas and was found at higher concentrations in the surface soil layer, given the greater presence of biomass on the soil surface, reducing with increasing soil depth.

b) Light organic matter fractions (C-LOM) (g kg⁻¹)

C-LOM is an intermediate fraction between the organic material accumulated by plants and wet SOM; thus, TOC is directly related to C-LOM (Filho et al., 2018).

C-LOM in the soil of eucalyptus, pasture and agriculture areas compared to the reference area (native forest) presented concentrations of 69.2%, -2.6% and 23.1%, respectively, in the 0-10 cm soil layer, 54.5%; -3.0% and 27.3% in the 10-20 cm soil layer, 50.0%; 12.5% and 29.2% in the 20-30 cm soil layer, 28.6%; 9.5% and 33.3% in the 30-40 cm soil layer and 5.6%; 11.1% and 38.9% in the 40-50 cm soil layer (Figure 10). Apparently, there is significant reduction in C-LOM with increasing depth for eucalyptus and increase for agriculture, indicating lower C-LOM losses in deeper layers for the latter.

Carbon in the light organic matter (C-LOM) presented itself differently according to soil management, showing significant differences in the surface soil layer and small variations between areas evaluated in the last soil layer, ranging from 0.38 to 0.66 g kg⁻¹ in the 0-10 cm soil layer; from 0.32 to 0.51 g kg⁻¹ in 10-20 cm; from 0.24 to 0.36 g kg⁻¹ in 20-30 cm; from 0.21 to 0.28 g kg⁻¹ in 30-40 cm and from 0.18 to 0.25 g kg⁻¹ in 40-50 cm soil layer.

C-LOM in the soil of eucalyptus, pasture and agriculture areas compared to the reference area (native forest) presented concentrations of 69.2%, respectively; - 2.6% and 23.1% in the 0-10 cm soil layer, 54.5%; - 3.0% and 27.3% in the 10-20 cm soil layer, 50.0%; 12.5% and 29.2% in the 20-30 cm soil layer, 28.6%; 9.5% and 33.3% in the 30-40 cm soil layer and 5.6%; 11.1% and 38.9% in the 40-50 cm soil layer. Apparently, there is significant reduction in C-LOM with increasing depth for eucalyptus and increase for agriculture, indicating lower C-LOM losses in deeper layers for the latter. This phenomenon was explained by Tan et al. (2007), who evaluated the light fractions of soil organic carbon related to land use and preparation, and attributed this smaller reduction of C-LOM in conventional plantations to soil homogenization due to its preparation for planting, causing the content of carbon to be higher in the underground soil.

Apparently, there is significant reduction in C-LOM with increasing depth for eucalyptus and increase for agriculture, indicating lower C-LOM losses in deeper layers for the latter.

c) Microbial biomass (g kg⁻¹)

This indicator plays an essential role in the soil as it acts in the organic matter decomposition and accumulation and in the stocks of nutrients. So, soils with high microbial biomass content store and cycle more nutrients (Samarão, 2007).

The greatest changes in soil microbial biomass (SMB) are concentrated in the surface soil layers, which confirms the greater presence of microbial activity in the first soil layers (Leeuwen et al., 2017). According to study carried out by Fedrigo et al. (2020), grazing intensities interfere with the incidence of CO₂, e.g., in intermediate ones of 12%, disturbances in the soil microbial biomass are lower when compared to heavy grazing > 12%, emitting less CO₂ for the atmosphere for each animal unit produced. The soil organic matter contents and microbial biomass in grazed systems are lower than those in areas excluded from grazing for a long period.

d) Humic fractions (g kg⁻¹)

The carbon concentrations in the humic soil fractions decreased with increasing depth, with maximum values in the 0-10 cm soil layer and minimum values in the 40-50 cm soil layer, presenting variation in AF, AH and HUM, respectively, from 2.28 to 0.67 g kg⁻¹, 3.20 to 0.93 g kg⁻¹; and 8.22 to 2.41 g kg⁻¹. Filho et al. (2018) attribute the higher carbon concentration in the soil and in the humic fractions in the surface layer to the death of fine roots, mainly herbaceous, disposal of plant biomass in the soil and the microbial activity, which acts in the stabilization of organic matter present in the soil.

e) Labile Carbon (g kg⁻¹)

Labile carbon (C-labile) is a primary energy source that can be easily degradable or consumed by soil microorganisms (Ramesh et al., 2019). The C-labile content, on average, represented 9.7% of the total carbon concentration of areas and was found at higher concentrations in the surface soil layer, given the greater presence of biomass on the soil surface, reducing with increasing soil depth.

The agricultural area showed the lowest C-labile levels, 23.8% lower than the reference area (native forest). According to Blair et al. (1995), where there is recent change in land use, there is reduction in C-labile. In conventional crops, soil disturbance due to land preparation, low biomass input and loss of soil nutrients generate a rapid decrease in the C-labile content (Dias et al., 2019; Bongiorno et al., 2019).

3.4 Response indicator

a) Sustainable Management Practices (No.).

Intensive management practices and use of conservation techniques have the potential to reduce COS losses in agricultural lands (Bordonal et al., 2018). On average, C accumulation rates in soils under conventional and no-tillage systems vary between 0.3 and 1.91 Mgha⁻¹ year⁻¹ (Bayer et al., 2010). Changes in land use and inadequate management practices lead to degradation and loss of soil quality, especially in surface layers, which causes changes in microbial activity, changing the functional role of microorganisms in the C cycle in the soil, which confirms the mediator role of microorganisms in soil turnover and nutrient recirculation, promoting C sequestration (Kooch et al., 2019; Tiwari et al., 2019; Shao et al., 2019).

The different types of management adopted in agricultural crops can reduce, maintain or increase SOM stocks compared to native vegetation, thus having a significant influence on their stocks (Costa et al., 2013).

b) Research group actions (No.)

The survey of the number of researches and publications carried out by the laboratory allows monitoring carbon. Research publication allows the dissemination of ideas about this topic, as well as contact with other researchers in the area. This indicator is measured from the number of publications (No.) (Brasil, 2010).

c) NGO actions (No.)

Some NGOs are concerned with carbon sequestration, such as WWF-Brasil, which leads an action to alert governments, companies and civil society to the challenge of climate change, a phenomenon caused by the accumulation of greenhouse gases in the atmosphere.

d) Corporate actions (No.)

Global warming has grown noticeably in recent years. In 1997, the Kyoto protocol was created, in which goals were established to be carried out and fulfilled from 2008 to 2012 by signatory countries. The protocol proposes emissions trading and the clean development mechanism (CDM), through reduced emissions certificates, but does not currently recognize the mitigation of emissions through the preservation of natural forest areas existing prior to the signing of the agreement (Nishi et al. al 2005).

The Kyoto Protocol established that developed countries formally committed to reduce their gas emissions to mitigate the greenhouse effect by 5% below 1990 levels with the objective for the 2008 - 2012 period. The second important point of the protocol is that the concept of commercialization of credits for the sequestration or reduction of greenhouse gases will be

accepted. Therefore, companies that reduce emissions below their targets may sell this credit to another country or companies that have not reached the expected degree of reduction (Kyoto, 1998).

4. Conclusion

The identification of environmental indicators for monitoring carbon in the different vegetation covers constitutes a very important tool for a better understanding of the system, allowing more viable recovery practices.

The proposed matrix of environmental indicators for carbon monitoring proved to be satisfactory, contributing to a better understanding of the processes that occur in the different land uses in the southern cerrado of Tocantins in relation to soil carbon, in addition to allowing better management choices.

The use of indicators presented in this work can serve as a subsidy for policies and actions aimed at reducing the impacts of environmental degradation.

For future work, be sure to survey the carbon in the aerial biomass.

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