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Quality index of an Oxisol under different management systems in the Brazilian Cerrado[1]

Índice de qualidade de um Oxisol sob diferentes sistemas de manejo no Cerrado brasileiro

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HIGHLIGHTS:

Different management systems and cover crops alter the soil quality.
Monitoring the quality index can minimize the degradation of managed soils.
Soil quality indices quantify the magnitude of changes caused by soil management systems.

ABSTRACT: Assessing soil quality under different cover crops or different management systems is essential to its conservation. This study aimed to evaluate an Oxisol cultivated with corn and cotton, after different crop successions and under no-tillage system (NTS) and conventional tillage system (CT), through the soil quality index (SQI), using an area of native Cerrado as reference. The study was carried out in the municipality of Luís Eduardo Magalhães, Western Bahia, Brazil. Soil samples with the preserved and non-preserved structure were collected in the layers of 0-0.05 m, 0.05-0.10 m, and 0.10-0.20 m to determine the macroporosity, the soil bulk density, the available water, the levels of total organic carbon, the clay dispersed in water, and the degree of flocculation. The averages of the attributes measured in the treatments and the soil quality index, which was elaborated by the method of deviations of the values of the attributes measured in the treatments concerning the reference area, followed by normalization, were compared by the Duncan test ($p \leq 0.05$). The soil under CT, in all treatments, had its quality reduced when compared to the NTS. Also, the SQI used was sensitive to detect the changes caused by the management systems and assign consistent scores to the evaluated soil quality.

Key words: soil conservation, sustainable management, crop rotation, conventional tillage, no-tillage system

RESUMO: Avaliar a qualidade dos solos sob diferentes culturas de cobertura ou sob diferentes sistemas de manejo torna-se essencial à sua conservação. Objetivou-se neste estudo avaliar um Oxisol cultivado com milho e algodão, após diferentes sucessões culturas e sob sistema plantio direto (SPD) e plantio convencional (PC), por meio de índice de qualidade do solo (IQS), utilizando como referência uma área de Cerrado nativo. O estudo foi realizado no município de Luís Eduardo Magalhães, Oeste da Bahia, Brasil. Amostras de solo com estrutura preservada e não preservada foram coletadas nas camadas de 0-0,05 m; 0,05-0,10 m e 0,10-0,20 m, para determinação da macroporosidade, densidade do solo, água disponível, teores de carbono orgânico total, argila dispersa em água e grau de floculação. As médias dos atributos mensurados nos tratamentos e o índice de qualidade do solo, que foi elaborado pelo método dos desvios dos valores dos atributos medidos nos tratamentos em relação à área de referência, seguido da normalização, foram comparados pelo teste de Duncan ($p \leq 0,05$). O solo sob PC, em todos os tratamentos, teve a sua qualidade reduzida quando comparado com o SPD, além disso, o IQS utilizado foi sensível para detectar as alterações provocadas pelos sistemas de manejo e atribuir escores coerentes à qualidade do solo avaliado.

Palavras-chave: conservação do solo, manejo sustentável, rotação de culturas, plantio convencional, sistema plantio direto

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Introduction

It is defined as a quality soil, one that can work within the limits of an ecosystem, sustain productivity, maintain environmental quality and promote the health of animal and plants through the performance of ecological functions related to their ability to supply nutrients to plants, support root growth, and development, resist erosion, retain water (Loke et al., 2012; Raiesi, 2017) and influence social aspects, defining itself as one of the most essential natural resources (Chaves et al., 2012) essential to life. However, human activity has shown to be efficient in promoting soil quality reduction, generally resulting in degradation processes.

Several attributes and indexes have been used to assess soil quality. Karlen & Stott (1994) integrated several attributes, obtaining normalized indexes and scores, and Doran & Parkin (1994) used simple multiplicative functions. Maia (2013) used the deviation of the attributes measured in the treatments concerning a reference area, and Reis et al. (2019), who used the method of Maia (2013) associated with factor analysis to select a minimum set of attributes and elaborate the SQI for Alfisol in southern Brazil, as well as Vasu et al. (2016), who use principal component analysis to develop an SQI for a semiarid region in India.

Given the above, this study aimed to evaluate an Oxisol quality in the West of Bahia, Brazil, grown with corn and cotton after different crop successions, under the no-tillage system (NTS) and conventional tillage (CT), using a native Cerrado area as a reference.

Material and Methods

The study was carried out in an experimental area inserted in the Cerrado biome, using corn and cotton crops, after different crop successions, under the no-tillage system (NTS) and conventional tillage (CT). The experimental area is in the municipality of Luís Eduardo Magalhães, Bahia, Brazil, at the geographical coordinates: 12° 5' 36.52" S, 45° 42' 40.30" W, and 720 m above sea level. The soil was classified as Oxisol with a sandy-loam texture (801, 74 and 125 g kg^{-1} of sand, silt, and clay, respectively) at a 0.0-0.20 m layer.

According to the Köppen classification (Alvares et al., 2013), the local climate is Aw-type, tropical with an average annual temperature of 24 °C, an average annual rainfall of 1,200 mm distributed between November and March, and a period well-defined dry season between April and September.

A randomized block design with four replicates was used. The following treatments T1 - corn under conventional planting (CT); T2 - corn intercropped with brachiaria under the no-tillage system (NTS); T3 - corn intercropped with brachiaria under NTS in succession to soy, millet, and cotton; and T4 - corn intercropped with crotalaria under NTS; T5 - cotton under CT; T6 - cotton intercropped with millet under CT; T7 - cotton under NTS in succession to soybean, sunn hemp, corn, and brachiaria; and T8 - cotton under NTS in succession to soy and sorghum were evaluated. The history of the experimental plots is shown in Table 1.

A native Cerrado area was used as a reference area, adjacent to the experiment area, under the same soil class and texture, not anthropized and with a phytophysiognomy of Campo Sujo, characterized exclusively by the presence of sparse shrubs and sub-shrubs whose plants are mainly composed of less developed individuals of Cerrado tree species in a restricted sense.

Soil sampling was performed between the sowing rows at the 0-0.05 m, 0.05-0.10 m, and 0.10-0.20 m layers in February 2018. Soil samples with the preserved structure were collected using volumetric rings with dimensions of approximately 0.05 m in height and 0.05 m in diameter, totaling 288 samples (8 treatments x 3 rings x 3 layers x 4 replications), which were used to determine macroporosity (Ma), soil bulk density (Bd) and available water (AW) (Teixeira et al., 2017). Soil samples with an unpreserved structure were collected using a shovel, totaling 96 samples (8 treatments x 1 sample x 3 layers x 4 replications) that were used to determine the clay dispersed in water (CDW), the degree of flocculation (DF), and the total organic carbon (TOC) (Teixeira et al., 2017).

In order to determine the soil quality index (SQI), the Ma, Bd, AW, TOC, CDW, and DF were used, using the method described by Maia (2013), and used by Reis et al. (2019) after the constitution of a minimum set of attributes (macroporosity, soil resistance to penetration and soil density in the pre-consolidation pressure) through factor analysis.

The deviation from the values of the attributes measured in the treatments concerning the reference area (NC) was determined by Eq. 1, where z_i represents the standardized value of the selected variable, x the value of the attribute evaluated in the treatments; x the mean and s the standard deviation of the attribute evaluated in the reference area.

$$z_i = \frac{x - \overline{x}}{s} \qquad (1)$$

Table 1. Description of the history from crop succession of the evaluated treatments

Treatments	System	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
T1	CT	C	C	C	C	C	C
T2	NTS	S	C+B	S	M+B	S	C+B
T3	NTS	Mt+Ct	S+Mt	C+B	Ct	S+Mt	C+B
T4	NTS	Mt+Ct	S+Sh	C+Sh	Ct	S+Sh	C+Sh
T5	CT	Ct	Ct	Ct	Ct	Ct	Ct
T6	CT	Mt+Ct	Mt+Ct	Mt+Ct	Mt+Ct	Mt+Ct	Mt+Ct
T7	NTS	S+Sh	C+B	Ct	S+Sh	C+B	Ct
T8	NTS	S+So	Ct	S+So	Ct	S+So	Ct

CT - Conventional tillage; NTS - No-tillage system; C - Corn; S - Soy; Mt - Millet; B - Brachiaria; Ct - Cotton; Sh - Sunn hemp; So - Sorghum. T1 - C under CT; T2 - C intercropped with B under NTS; T3 - C intercropped with B under NTS in succession to S, Mt, and Ct; T4 - C intercropped with Sh under NTS; T5 - Ct under CT; T6 - Ct intercropped with Mt under CT; T7 - Ct under NTS in succession to S, Sh, C, and B; T8 - Ct under NTS in succession to S and So

To estimate the values of the quality indexes (QI_i) of the evaluated attribute, Eqs. 2, 3 and 4 were used for the conditions of "more is better", "less is better", and "maximum value", respectively, with $\beta = \exp(-1.7145zi)$ (Maia, 2013).

$$QI_i = \frac{1}{1+\beta} \tag{2}$$

$$QI_i = \frac{4\beta}{(1+\beta)^2} \tag{3}$$

$$QI_i = \frac{\beta}{1+\beta} \tag{4}$$

The "more is better" curve has a positive derivative and is used for indicators that improve soil quality; the "maximum value" has a positive derivative up to the maximum value and is used for indicators that have a positive effect on soil quality up to a specific value, from which its influence is negative. The "less is better" curve has a negative derivative and is used for indicators that have a negative effect on the soil (Maia, 2013; Zhang et al., 2016).

Similar to that adopted by Thomazini et al. (2015), Mukhopadhyay et al. (2016), Raiesi (2017), Reis et al. (2019), and Raiesi & Salek-Gilani (2020) for the evaluated attributes, TOC, DF, and AW were considered as "more is better" due to their positive influence on the structuring, soil aggregation and water availability (if the values of these attributes increase, the soil quality also increases). Ma was considered "maximum value", in which the most positive association with soil quality goes up to an optimal value, beyond which soil quality decreases, and as "less is better" CDW and Bd, which indicate low soil quality as their values are high.

The determination of the SQI was performed using Eq. 5, in which SQI is the soil quality index of the evaluated area, QI_i is the quality index of the evaluated attribute, and n the number of attributes evaluated (Maia, 2013).

$$SQI = \frac{\sum_{i=n}^{n} QI_i}{n} \tag{5}$$

QI_i values, therefore, assess soil quality. For the conditions of "more is better", "maximum value", and "less is better", the absence of changes concerning the reference area would result in QI_i equal to 1 (one) because the smaller the unit, the greater the changes in the soil caused by the management systems concerning the reference area, consequently reflecting in the SQI (Maia, 2013).

The normality of the data was verified by the Shapiro-Wilk (W) test ($n \leq 200$). Outliers were identified through the measurements of the lower limit (LI) and the upper limit (LS), considering the first quartile (Q1), the third quartile (Q3), and 1.5 interquartile range and replaced by the average of the values immediately superior and inferior. The treatments under corn, under cotton, and the SQI were subjected to analysis of variance. The means were compared by the Duncan test ($p \leq 0.05$), excluding the NC, using the SAS statistical software (1999).

RESULTS AND DISCUSSION

Higher values of Ma and CDW and lower values of Bd, TOC, DF and AW, in general, obtained in Oxisol grown with corn and cotton under CT, result from the practices of plowing and harrowing, which break and reorganize the aggregates, favoring its breakdown and transport of mineral and organic particles (Loss et al., 2017), reducing soil quality, contrasting with the values observed in treatments under NTS (Tables 2 and 3).

Similar to what was observed in the results of this study, Silva et al. (2015) also found a reduction in Bd and an increase in porosity and TOC in Ultisol and Entisol under organic cultivation systems when compared to a conventional system and in conversion system and concluded that cultivation on organic bases provides maintenance of soil quality in conditions similar and/or better than the condition of native forest. Similarly, Pessoa et al. (2018) found deterioration in the quality of an Oxisol under soybean and pasture monocultures due to increased Bd and reduced pores and aggregates, recommending the use of these attributes, due to the sensitivity to changes caused by management systems, to assess the soil quality, as well as Chaves et al. (2012) who conclude that organic matter and soil bulk density stand out as quality indicators.

However, Palm et al. (2014) highlight the divergence on the effects of NTS and CT on different layers and attributes, mainly on Bd and pore volume, which are inversely related variables, as well as CDW and DF and being associated with the type and clay content of Oxisol, are strongly influenced by texture.

About the higher Bd values observed in treatments under NTS, these may be related to the absence of soil disturbance, resulting in a natural rearrangement and densification of mineral particles, which decrease the volume of pores (Singh et al., 2014) (Tables 2 and 3), without however resulting in processes that limit plant growth and development.

The tendency of the clay fraction to disperse and suspend itself in water is a phenomenon that can occur naturally due to the activity of the clay or can be promoted by anthropic action. In this sense, soil dispersion is related to the interaction of electrical charges on the surface of colloids, which can be generated by isomorphic substitution (permanent) or by dissociation of radicals (variable and pH-dependent), resulting in a flocculated or dispersed environment, respectively, which directly affect soil structure and aggregation (Lier, 2010).

Regarding physical attributes, the higher content of organic matter in the soil promotes positive changes in the Bd, aggregation, porosity, as well as in water retention, highlighting the importance and the need for the adoption of agricultural practices that minimize carbon losses (Cotrufo et al., 2011; Odriozola et al., 2014). In this sense, the NTS has been highlighted as a conservation management system due to the continuous supply of crop residues, absence of soil surface tillage, and crop rotation that increase the carbon content in the soil, which in turn acts as a cementing agent for mineral particles promoting DF and improving soil quality.

Table 2. Means, standard deviation (SD), and coefficient of variation (CV) from the native Cerrado area (NC); averages from soil attributes of treatments cultivated with corn under no-tillage (NTS) and conventional tillage (CT); and Quality Index (QI$_i$) for macroporosity (Ma), clay dispersed in water (CDW), soil bulk density (Bd), total organic carbon (TOC), degree of flocculation (DF), and available water (AW)

	Ma	CDW	Bd	TOC	DF	AW
			Native Cerrado 0-0.05 m			
Mean	0.14	6.96	1.45	13.54	53.35	0.23
SD	0.00	0.21	0.02	0.50	0.23	0.07
CV (%)	1.43	3.04	1.03	3.69	0.44	29.13
			Treatments			
T1	0.15 a	10.20 a	1.45 b	8.65 b	22.97 c	0.22 a
T2	0.14 ab	4.87 b	1.49 a	13.82 a	54.62 a	0.24 a
T3	0.12 ab	6.00 b	1.45 a	13.30 a	39.63 b	0.25 a
T4	0.09 b	5.01 b	1.61 a	13.06 a	44.38 b	0.24 a
			QI$_i$			
T1	0.01	0.09	0.79	0.00	0.06	0.37
T2	0.09	0.98	0.30	0.76	0.81	0.52
T3	0.12	0.08	0.43	0.00	0.11	0.37
T4	0.00	0.99	0.00	0.29	0.55	0.48
			Native Cerrado 0.05-0.10 m			
Mean	0.14	6.88	1.44	13.22	38.57	0.27
SD	0.00	0.21	0.06	0.87	0.23	0.09
CV (%)	3.00	3.08	4.44	6.58	0.61	33.22
			Treatments			
T1	0.12 a	9.69 a	1.53 b	8.65 b	25.43 b	0.22 a
T2	0.08 b	6.09 b	1.70 a	12.74 a	40.80 a	0.19 a
T3	0.09 b	7.07 b	1.72 a	12.14 a	41.36 a	0.22 a
T4	0.08 b	5.86 b	1.68 a	11.86 a	41.85 a	0.22 a
			QI$_i$			
T1	0.48	0.00	0.01	0.00	0.07	0.37
T2	0.00	0.86	0.00	0.04	0.39	0.22
T3	0.00	0.00	0.00	0.00	0.02	0.37
T4	0.00	0.52	0.00	0.00	0.38	0.33
			Native Cerrado 0.10-0.20 m			
Mean	0.13	6.52	1.48	13.62	39.63	0.21
SD	0.01	0.21	0.01	0.6	0.23	0.06
CV (%)	3.85	3.25	0.61	4.41	0.59	27.19
			Treatments			
T1	0.12 a	10.54 a	1.55 b	7.09 b	21.79 c	0.22 a
T2	0.07 b	7.29 b	1.73 a	11.78 a	46.54 a	0.19 a
T3	0.08 b	6.78 b	1.70 a	11.22 a	34.79 b	0.22 a
T4	0.08 b	7.27 b	1.68 a	11.54 a	38.95 b	0.22 a
			QI$_i$			
T1	0.04	0.00	0.00	0.00	0.02	0.35
T2	0.00	0.49	0.00	0.03	0.49	0.18
T3	0.00	0.39	0.00	0.00	0.21	0.34
T4	0.00	0.50	0.00	0.00	0.39	0.36

Means followed by the same lowercase letter in the columns within each attribute and soil layer evaluated do not differ by the Duncan test at $p \leq 0.05$. T1 - corn under conventional tillage (CT); T2 - corn under the no-tillage system (NTS) intercropped with brachiaria; T3 - corn under NTS intercropped with brachiaria in succession to soy, millet, and cotton; and T4 - corn under NTS intercropped with sunn hemp

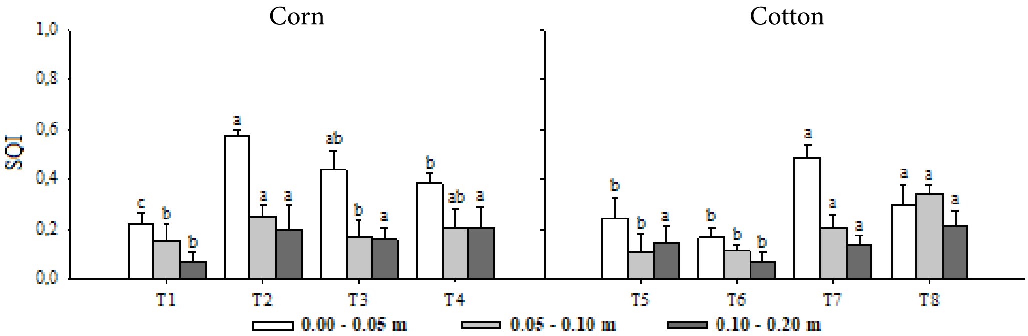
The treatments T2 (0.58) under corn cultivation and T7 (0.49) under cotton cultivation in the 0-0.05 m layer presented the highest SQI values under NTS. In the soil under corn and cotton cultivation in the 0.05-0.10 m layer, the highest SQI values were found in T2 (0.44) and T8 (0.34), while in soil under corn and cotton cultivation, in the 0.10-0.20 m layer, the highest SQI values were found in T2 (0.20) and T8 (0.21), allowing to affirm that corn cultivation intercropped with brachiaria under NTS; as well as the cultivation of cotton under NTS, respecting the succession of crops, were the most efficient treatments to promote the quality of the evaluated soil (Figure 1).

Table 3. Means, standard deviation (SD), and coefficient of variation (CV) from the native Cerrado area (NC); averages from soil attributes of treatments cultivated with cotton under no-tillage (NTS) and conventional tillage (CT); and Quality Index (QI$_i$) for macroporosity (Ma), clay dispersed in water (CDW), soil bulk density (Bd), total organic carbon (TOC), degree of flocculation (DF), and available water (AW)

	Ma	CDW	Bd	TOC	DF	AW
			Native Cerrado 0-0.05 m			
Mean	0.14	6.96	1.45	13.54	53.35	0.23
SD	0.00	0.21	0.02	0.50	0.23	0.07
CV (%)	1.43	3.04	1.03	3.69	0.44	29.13
			Treatments			
T5	0.14 a	10.94 a	1.45 b	7.81 b	17.01 b	0.20 a
T6	0.13 a	7.92 a	1.51 ab	10.90 ab	35.88 b	0.23 a
T7	0.09 b	6.30 b	1.56 a	15.15 a	49.05 a	0.23 a
T8	0.10 b	5.43 b	1.53 a	13.06 a	47.06 a	0.22 a
			QI$_i$			
T5	0.47	0.00	0.69	0.00	0.02	0.29
T6	0.23	0.00	0.09	0.00	0.25	0.42
T7	0.00	0.77	0.15	1.00	0.56	0.44
T8	0.00	0.74	0.01	0.14	0.46	0.41
			Native Cerrado 0.05-0.10 m			
Mean	0.14	6.88	1.44	13.22	38.57	0.27
SD	0.00	0.21	0.06	0.87	0.23	0.09
CV (%)	3.00	3.08	4.44	6.58	0.61	33.22
			Treatments			
T5	0.12 a	10.38 a	1.58 b	7.09 b	14.57 b	0.22 a
T6	0.08 b	8.21 a	1.66 ab	9.98 ab	35.58 b	0.23 a
T7	0.07 b	7.01 b	1.69 a	10.32 a	43.91 a	0.23 a
T8	0.08 b	5.95 b	1.69 a	11.01 a	48.16 a	0.23 a
			QI$_i$			
T5	0.02	0.10	0.15	0.00	0.00	0.35
T6	0.00	0.00	0.00	0.00	0.25	0.42
T7	0.00	0.31	0.00	0.00	0.49	0.44
T8	0.00	0.74	0.00	0.25	0.62	0.44
			Native Cerrado 0.10-0.20 m			
Mean	0.13	6.52	1.48	13.62	39.63	0.21
SD	0.01	0.21	0.01	0.60	0.23	0.06
CV (%)	3.85	3.25	0.61	4.41	0.59	27.19
			Treatments			
T5	0.11 a	9.44 a	1.60 b	7.27 b	31.60 b	0.19 a
T6	0.08 b	8.90 a	1.67 ab	9.20 ab	32.67 b	0.21 a
T7	0.07 b	7.95 b	1.68 a	9.54 a	45.89 a	0.21 a
T8	0.08 b	7.02 b	1.71 a	10.18 a	44.29 a	0.20 a
			QI$_i$			
T5	0.12	0.25	0.01	0.00	0.25	0.24
T6	0.00	0.00	0.00	0.00	0.09	0.31
T7	0.00	0.00	0.00	0.00	0.53	0.31
T8	0.00	0.48	0.00	0.00	0.51	0.29

Means followed by the same lowercase letter in the columns within each attribute and soil layer evaluated do not differ by the Duncan test at $p \leq 0.05$. T5 - cotton under conventional tillage (CT); T6 - cotton under CT intercropped with millet; T7 - cotton under the no-tillage system (NTS) in succession to soybean, sunn hemp, corn, and brachiaria; and T8 - cotton under NTS in succession to soy and sorghum

On the other hand, treatments under CT (T1, T5, and T6) showed SQI values statistically lower than those observed in treatments under NTS (T2, T3, T4, T7, and T8), corroborating the results also found by Askari & Holden (2015), which evaluated 20 areas under CT, minimum tillage, monoculture or crop rotation, using 22 attributes integrated into different SQI's concluded that there are favorable influences of minimum tillage in combination with crop rotation and the harmful effect of monoculture on the soil quality in Ireland. Veum et al. (2014) developed an SQI based on TOC, Bd, aggregate stability, and pH; they found that areas with perennial crops exhibited



T1 - corn under conventional tillage (CT); T2 - corn under the no-tillage system (NTS) intercropped with brachiaria; T3 - corn under NTS intercropped with brachiaria in succession to soy, millet, and cotton; and T4 - corn under NTS intercropped with sunn hemp; T5 - cotton under conventional tillage (CT); T6 - cotton under CT intercropped with millet; T7 - cotton under the no-tillage system (NTS) in succession to soybean, sunn hemp, corn, and brachiaria; and T8 - cotton under NTS in succession to soy and sorghum; Lowercase letters on the error lines in the columns indicate the statistical difference among treatments by the Duncan test at $p \leq 0.05$. The vertical bars represent the SQI averages obtained in the different treatments evaluated (n = 4)

Figure 1. Soil quality index (SQI) under corn cultivation in conventional tillage (CT) and no-tillage system (NTS)

the highest quality index, followed by areas managed under no-tillage and conventionally cultivated areas, corroborating efficiency SQI.

The SQI used in this study proved to be sensitive in detecting changes caused by the management systems evaluated, corroborating the studies by Mota et al. (2014), Duval et al. (2016), and Reis et al. (2019). Thus, according to the results obtained, the SQI allows sustaining the assertions about the importance of NTS in the improvement or conservation of soil quality and pointing out the potential losses related to the adoption or permanence of the CT in this Biome.

CONCLUSIONS

1. Changes in Oxisol quality under different cover crops and management systems were detected by the soil quality index used, elaborated from macroporosity, soil bulk density, total organic carbon, clay dispersed in water, and the degree of flocculation.

2. The soil under the no-tillage system showed higher quality than the soil under the native Cerrado used as a reference, and conventional planting reduced the soil quality.

3. Among all the evaluated treatments, corn intercropped with brachiaria under the no-tillage system increased the soil quality index.

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