



## Impact of short-term land-use change on soil organic carbon dynamics in transitional agro-ecosystems: a case study in the Brazilian Cerrado

Fabiane Pereira Machado Dias, Wilson Mozena Leandro, Paulo Marçal Fernandes & Francisco Alisson da Silva Xavier

To cite this article: Fabiane Pereira Machado Dias, Wilson Mozena Leandro, Paulo Marçal Fernandes & Francisco Alisson da Silva Xavier (2022) Impact of short-term land-use change on soil organic carbon dynamics in transitional agro-ecosystems: a case study in the Brazilian Cerrado, Carbon Management, 13:1, 238-248, DOI: [10.1080/17583004.2022.2074313](https://doi.org/10.1080/17583004.2022.2074313)

To link to this article: <https://doi.org/10.1080/17583004.2022.2074313>



© 2022 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group



Published online: 14 May 2022.



[Submit your article to this journal](#)



Article views: 1351



[View related articles](#)





[View Crossmark data](#)



Citing articles: 6 [View citing articles](#)

## Impact of short-term land-use change on soil organic carbon dynamics in transitional agro-ecosystems: a case study in the Brazilian Cerrado

Fabiane Pereira Machado Dias<sup>a</sup> , Wilson Mozena Leandro<sup>a</sup>, Paulo Marçal Fernandes<sup>a</sup> and Francisco Alisson da Silva Xavier<sup>b</sup> 

<sup>a</sup>Federal University of Goiás, School of Agronomy, Graduate Program in Agronomy, Goiânia, Brazil; <sup>b</sup>Embrapa Mandioca e Fruticultura, Brazilian Agricultural Research Corporation, Bahia, Brazil

### ABSTRACT

Agricultural expansion directly impacts the dynamics of organic carbon (C) in the soil. After land use change, agricultural systems with greater resilience of soil C stocks could be preferentially adopted. The objective of the present study was to determine the impact of short-term conversion of grassland into different agricultural systems on soil organic C stocks and their resilience in a site-specific region of Brazilian Cerrado in the State of Goiás. The following systems were evaluated: pasture (PAST), no-tillage system (NT), four organic production systems (ORG) at different years of cultivation (2, 6, 8 and 10 years), and a continuous monoculture corn cropping system (CC). An area of native Cerrado ('Savanna', CE) was selected and sampled for use as a steady state reference point. Resilience of soil organic C was measured based on calculation of the C resilience index and C management index. Soil C stocks in the 0-0.40 m depth varied from 61 to 111 Mg ha<sup>-1</sup> and were reduced by 33% when converting from CE to cultivation regardless of management system. The labile C contents varied from 425 to 900 mg kg<sup>-1</sup>, and increased when PAST soils were converted to ORG cultivation. The highest values of C resilience and management indexes occurred in the ORG-2 and ORG-6 soils, showing that organic systems can recover organic C levels in the soil faster than other agricultural systems. On the other hand, no-tillage system when converted from pasture presents the lowest potential of soil C resilience in short-term in the site-specific conditions of studied Cerrado of Goiás State.

### KEYWORDS

conventional cultivation; organic cultivation; lability of C; soil resilience index

### Introduction

Agricultural soils, depending on management practices, can intensify or mitigate the effects of climate change caused by greenhouse gas emissions [1]. More conservative agricultural systems, which promote less soil turnover and greater input of organic matter, result in greater C sequestration in the soil, and consequently exhibit lower losses of C stocks during changes in land use [2].

In the Brazilian Cerrado (Savanna biome) the predominant soils are Ferralsols. They are naturally acidic with low available nutrients [3] and low organic C concentrations in the range of 2 to 3 dag kg<sup>-1</sup>. However, organic matter is a key component for soil functionality in the Cerrado since it is positively correlated with physical, chemical and biological attributes, with major implications on soil structure, aeration, water infiltration and holding capacity [4].

Considering the importance of organic C in key processes of Cerrado soils and its productive potential, studies that focus on developing production technologies are needed with the goal of redesigning sustainable agriculture systems and improving management practices that contribute to restoring soil functions and sequestering atmospheric C [5]. Agroecosystems based on no-tillage and/or organic cultivation have been widely adopted as important strategies to recover soil health and provide long-term C sequestration [6–8], resulting from the increase in organic matter inputs and decrease of soil disturbance. The extra C storage in organic cropping systems has mainly been attributed to greater organic matter inputs (e.g. livestock manure, green manure, mulch, compost) and less intensive tillage, which reflects their ability to store more C in relation to conventional systems [9, 10]. Both no-tillage and organic farming have been adopted as suitable options for

**CONTACT** Francisco Alisson da Silva Xavier  [alisson.xavier@embrapa.br](mailto:alisson.xavier@embrapa.br)  Embrapa Mandioca e Fruticultura, Brazilian Agricultural Research Corporation, Rua Embrapa, s/n, Cruz das Almas, 44380-000, Bahia, Brazil

© 2022 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group

This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Table 1. History of land-use and management of selected agro-ecosystems.

		Systems of use and management <sup>1</sup>						
Coordinates	CE	PAST	NT	CC	ORG-2	ORG-6	ORG-8	ORG-10
Area (ha)	16°58'8"S 49°11'16"W 8.8	16°58'9"S 49°11'42"W 8.8	16°58'12"S 49°11'51"W 6.2	16°57'55"S 49°10'26"W 7.5	16°57'39"S 49°11'3"W 1.0	16°57'49"S 49°11'4"W 0.8	16°57'51"S 49°11'0"W 0.5	16°57'47"S 49°11'1"W 0.4
Agricultural year 2007	Historical of land-use Preserved native savannah	Degraded pasture	Pasture	Pasture	Pasture	Pasture	Conventional tomato	Tomato Bean Tomato Bean
2008							Organic Maize	Maya Maize Bean
2010							Azuki beans	Rice
2011							Ground tomato	Bean
2012					Bean		Tomato	Maize Bean
2013							Maize	Manioc
2014			Maize	Maize under continuous cropping		Maize Bean	Onion	
2015			Peanut			Maize Bean		
2016			Soy		Maize	Maize + Bean		
2017					Fallow	Fallow		
Soil fertilization	Without any intervention	Without management	Application of chemical pesticides and NPK fertilization	Fallow Application of chemical pesticides and fertilization with NPK	2 t/ha of composted chicken manure	Green manure by using cover crops.	Yoorin + 2 L of composted chicken manure / pit	Fallow > Bean Green manure by using cover crops.
Soil management	Area of tropical savanna (known as 'Cerradão') preserved, without any history of anthropic interference.	Area used as pasture dominated by <i>Brachiaria brizantha</i> which did not receive any fertilization or management over last 30 years. Before pasture this area was covered by native 'Cerrado'.	In the process of conversion to no-till, soil preparation was initially done by disc harrow/plow.	Peanuts and soybeans crops were also cultivated in rotation. Soil preparation was usually done by mechanical disc harrow/plow. In the winter area was left under fallow without any cultivation.	Area was previously used as pasture, which was further converted into organic cultivation of maize as main crop. Soil preparation was done by using disc harrow.	Area was previously used as pasture, which was further converted into organic cultivation. Soil preparation was done by using disc harrow.	Area was previously used as pasture, which was further converted into organic cultivation of tomato, beans and maize in crop rotation. Further, this area was converted into a polyculture system.	Area was previously used as pasture, which was further converted into organic cultivation of tomato, beans, rice and maize in crop rotation. Further, this area has been cropped with cassava under organic management.

CE: native 'Cerrado' (savanna forest), PAST: pasture, NT: no-tillage system, ORG-2 to ORG-10: organic systems with 2, 6, 8 and 10 years of cultivation.

**Table 2.** Physical and chemical attributes of a Haplic Ferralsol under pasture in the 0.0–0.20 and 0.20–0.40 m layers, Hidrolândia, Goiás, Brazil, 2018.

Soil attributes	Depth (m)	
	0.0 – 0.20	0.20 – 0.40
Sand, g kg <sup>-1</sup>	516	476
Silt, g kg <sup>-1</sup>	119	128
Clay, g kg <sup>-1</sup>	365	396
Available P [26], mg dm <sup>-3</sup>	1.0	1.0
K <sup>+</sup> , cmol <sub>c</sub> dm <sup>-3</sup>	0.09	0.06
Ca <sup>2+</sup> + Mg <sup>2+</sup> , cmol <sub>c</sub> dm <sup>-3</sup>	0.82	0.56
Al <sup>3+</sup> , cmol <sub>c</sub> dm <sup>-3</sup>	0.4	0.5
SB <sup>2</sup> , cmol <sub>c</sub> dm <sup>-3</sup>	0.92	0.63
CEC <sup>3</sup> , cmol <sub>c</sub> dm <sup>-3</sup>	5.53	4.73
BS <sup>4</sup> , %	17	13
Organic C, g kg <sup>-1</sup>	16.0	12.2

<sup>1</sup>extracted by Mehlich-1; <sup>2</sup>sum of bases (K + Ca + Mg + Na); <sup>3</sup>cations exchange capacity; <sup>4</sup>bases saturation: (SB/CEC) x 100.

restoring soil functions and food production in the Brazilian Cerrado (Marafon et al. 2016), [11], however few studies have sought to investigate the level of resilience of such systems in restoring soil organic C after land use change, especially in short-term period of conversion. This is a very important issue which involves understanding of the environmental cost-effectiveness of less intensive agricultural systems, necessary to motivate new public policy that supports farmers who adopt more resilient agricultural models.

The absolute values of soil organic C contents or stocks are necessary for evaluation of C dynamics as a result of soil use and management. Nevertheless, several indices have been useful to evaluate how disturbed a system is compared to a reference area, such as the C management index (CMI) and resilience index (RI) [12–18]. The CMI, initially proposed by [12], evaluates the impacts of agricultural systems on soil C stocks caused by use and management compared to a reference area (e.g. native forest) at steady state. Higher CMI values indicate that the system is being rehabilitated. The RI determines the ability of the soil to recover its functionality after a specific impact (i.e. land use change), as initially reported by [14]. Nevertheless, there are no ideal and predetermined values for the CMI and RI indices. Instead, the values are a sensitive parameter of comparison in relation to a reference area with undisturbed soil.

It was hypothesized that land use change to a more conservative agricultural system, even in short-term, will promote fewer C stock losses in the soil and greater resilience after the conversion. To test this hypothesis, the objectives of this study were to quantify the organic C concentrations and stocks of a Ferralsol under several land use and management systems and their resilience indices

in a specific study of case in the Cerrado of Goiás State, Brazil.

## Material and methods

The present study was conducted in the experimental area of the Nossa Senhora Aparecida Farm, located in the municipality of Hidrolândia, Goiás (16°96'54" S; 49°18'42" W, 787 m elevation) in the same areas as a previous study developed by [11]. The soil was classified as Haplic Ferralsol (Loamic, Dystric) [19], with a sand clay loam texture. The climate in the region is characterized by a dry winter and rainy summer, classified as Aw (tropical rainy) according to the Köppen system [20] with an average annual rainfall of 1,500 mm and average annual temperature ranging from 22° to 27° C [21].

The history of land use and management of the studied areas is listed in Table 1.

Disturbed soil samples were collected at depths of 0.0–0.10, 0.10–0.20 and 0.20–0.40 m. To standardize soil sampling, each area selected was subdivided into four sections with similar dimensions. In each section, five soil cores were collected and subsequently mixed to create a composite sample, which were considered field pseudoreplicates. The samples were air dried, broken apart and sieved through a 2.00 mm mesh sieve. Pseudoreplication is very common in field surveys (i.e. non-conventional experiments) where treatments are not replicated in the space. It was very well described by [22] and applied to similar comparisons of management systems as conducted in the present study [23, 24].

Undisturbed soil samples were collected using the volumetric ring method [25] to determine the soil bulk density (BD). For general physicochemical characterization of the soil studied the attributes of the pasture area were determined, which is a system commonly used prior to conversion to agriculture (Table 2).

The total organic C contents (TOC) of the soil were determined by a modified [27] method, where organic C was initially oxidized with 0.667 mol L<sup>-1</sup> of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> in a sulfuric medium and then measured using colorimetry with a maximum transmission filter of 650 nm [28]. The modification was properly calibrated to the original method using previous tests with high correlation coefficients (R<sup>2</sup> > 0.80). Because the inorganic C fraction was considered negligible in the soil, TOC contents represented the total C in the soil.

**Table 3.** Soil bulk density (BD), soil total organic carbon (TOC), labile carbon ( $C_L$ ) and non-labile carbon ( $C_{NL}$ ) contents at 0.0–0.10, 0.10–0.20 and 0.20–0.40 m depths of a Ferralsol under different systems of use and management.

Systems	BD (g cm <sup>-3</sup> )	TOC (g kg <sup>-1</sup> )	$C_L$ (mg kg <sup>-1</sup> )	$C_{NL}$ (g kg <sup>-1</sup> )
0.0-0.10 m				
CE	1.13	26.70	938	25.76
PAST	1.29	16.99	678	16.32
NT	1.21	14.82	686	14.13
CC	1.28	18.13	770	17.35
ORG-2	1.26	20.87	900	19.97
ORG-6	1.29	22.28	899	21.38
ORG-8	1.29	17.84	831	17.01
ORG-10	1.32	16.78	733	16.05
<i>Cultivation</i>	1.28	18.45	803	17.65
ORG	1.29	19.44	841	18.60
0.10-0.20 m				
CE	1.17	24.18	677	23.51
PAST	1.34	14.67	306	14.36
NT	1.36	14.21	275	13.93
CC	1.39	15.79	724	15.07
ORG-2	1.32	18.20	550	17.65
ORG-6	1.41	20.57	647	19.92
ORG-8	1.27	15.78	582	15.20
ORG-10	1.49	15.07	579	14.49
<i>Cultivation</i>	1.37	16.60	559	16.04
ORG	1.37	17.41	589	16.82
0.20-0.40 m				
CE	1.17	22.40	715	21.69
PAST	1.27	12.17	500	11.67
NT	1.33	11.53	442	11.09
CC	1.48	13.45	635	12.81
ORG-2	1.23	16.21	550	15.66
ORG-6	1.35	18.72	687	18.03
ORG-8	1.38	12.00	425	11.58
ORG-10	1.37	12.56	477	12.08
<i>Cultivation</i>	1.36	14.08	536	13.54
ORG	1.33	14.87	535	14.34

CE: native 'Cerrado' (savanna forest), PAST: pasture, NT: no-tillage system, CC: conventional cropping system, ORG-2 to ORG-10: organic systems with 2, 6, 8 and 10 years of cultivation. *Cultivation*: mean value of a given attribute calculated among all cultivated sites, excluding PAST. ORG: mean value of a given attribute calculated from ORG-2 to ORG-10.

The C stocks in the soil profile were calculated according to [29], using the same soil mass to a depth of 0.40 m. The CE area was used as a reference to correct the soil density in the other systems, since the sampled areas had significantly different density values in function of the management type. The C stock was calculated using the following:

$$C_s = \sum_{i=1}^{n-1} C_{Ti} + [M_{Tn} - \left( \sum_{i=1}^n M_{Ti} - \sum_{i=1}^n M_{Si} \right)] C_{Tn} \quad (1)$$

Where:

$C_s$  = total C stock, corrected based on the soil mass of a reference area;

$\sum C_{Ti}$  = sum of the soil C stocks of the first to the penultimate layer sampled, in the treatment considered (Mg ha<sup>-1</sup>);

$M_{Tn}$  = soil mass of the last layer sampled in the treatment (Mg ha<sup>-1</sup>);

$\sum M_{Ti}$  = sum of the total mass of soil under treatment (Mg ha<sup>-1</sup>);

$\sum M_{Si}$  = sum of the total mass of soil sampled in the reference area (Mg ha<sup>-1</sup>);

$C_{Tn}$  = soil C content in the last layer sampled (Mg C Mg<sup>-1</sup> of soil).

The extraction of soil labile C ( $C_L$ ) was performed by oxidation in potassium permanganate according to [30]. In summary, 2.5 g soil samples (>2.0 mm) were transferred to 50 mL centrifuge tubes. Then, 20 mL of deionized water and 2 mL of 0.2 mol L<sup>-1</sup> KMnO<sub>4</sub> were added. The tubes were agitated for 15 min at 200 rpm using a horizontal shaker and centrifuged for 5 min at 3000 rpm to separate the supernatant. The  $C_L$  contents were quantified using colorimetry with a spectrophotometer at a wavelength of 550 nm. Contents of non-labile C ( $C_{NL}$ ) were calculated as the difference between the TOC and  $C_L$  levels.

To evaluate the losses or gains in soil C stocks based on the change in soil use and management compared to the reference area (CE), the CMI was calculated as proposed by [12]. The CMI was calculated as follows:

$$CMI = CCI \times LI \times 100 \quad (2)$$

Where:

CCI = C compartment index;

LI = C lability index.

The CCI was calculated as the ratio between the TOC in the managed system and in the reference area ( $CCI = TOC_{management}/TOC_{reference}$ ). Similarly, the LI was calculated as the ratio between the C lability (L) in the managed system and in the reference area (Cerrado) ( $LI = L_{management}/L_{reference}$ ), where L corresponds to the ratio between the levels of  $C_L$  and  $C_{NL}$  ( $L = C_L/C_{NL}$ ).

The resilience of organic C in function of the change in soil use was evaluated based on the conceptual approach of soil resilience of [14], and also as used by other studies [13, 18]. Assuming soil resilience is the ability of the soil to recover its functional integrity after equilibrium loss, the C resilience index (CRI) was calculated using the following:

$$CRI = \frac{(Cst_{current\ management} - Cst_{pasture})}{(Cst_{native\ cerrado} - Cst_{pasture})} \quad (3)$$

Where:

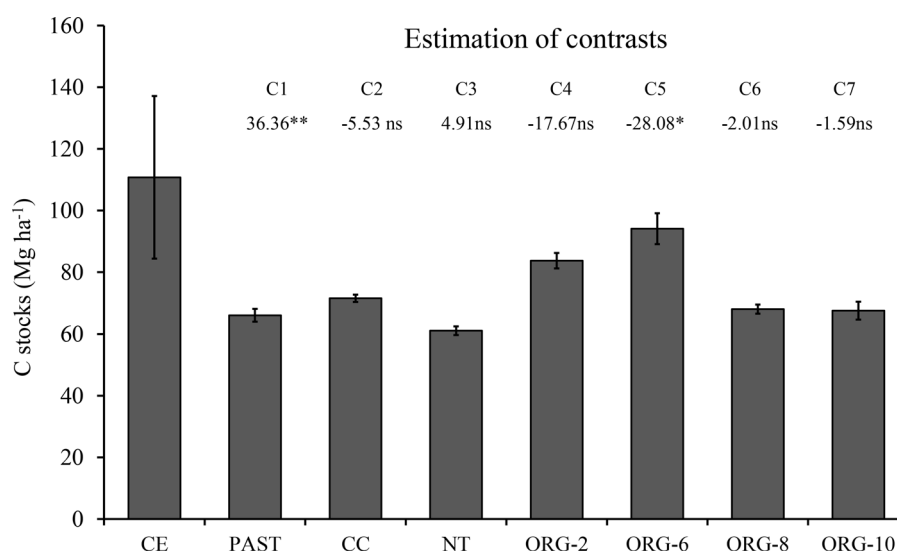
$Cst_{current\ management}$  = soil C stock in the agricultural management system after conversion;

$Cst_{pasture}$  = soil C stock in the pasture;

**Table 4.** Estimates of orthogonal contrasts for soil bulk density (BD), soil total organic C (TOC), labile C ( $C_L$ ) and non-labile C ( $C_{NL}$ ) at 0.0–0.10, 0.10–0.20 and 0.20–0.40 m depths of a Ferralsol under different systems of use and management.

CONTRAST	BD (Mg m <sup>-3</sup> )	TOC (g kg <sup>-1</sup> )	$C_L$ (mg kg <sup>-1</sup> )	$C_{NL}$ (g kg <sup>-1</sup> )
	0.0-0.10 m			
CE vs Cultivation	-0.15**	8.25**	133.76*	8.11**
PAST vs CC	0.01 ns	-1.13 ns	-91.76 ns	-1.04 ns
NT vs CC	-0.07*	-3.31 ns	-83.58 ns	-3.22 ns
CC vs ORG	-0.01 ns	-1.32 ns	-70.67 ns	-1.25 ns
PAST vs ORG	0.00 ns	-2.45 ns	-162.43**	-2.29 ns
CE vs ORG	-0.17**	7.26**	96.27 <sup>o</sup>	7.16**
ORG-2 vs (ORG-8 + ORG-10)	-0.05 <sup>o</sup>	3.56 ns	117.83 <sup>o</sup>	3.44 ns
	0.10-0.20 m			
CE vs Cultivation	-0.20**	7.58**	117.52 ns	7.46**
PAST vs CC	-0.05*	-1.12 ns	-418.17**	-0.71 ns
NT vs CC	-0.04 ns	-1.59 ns	-449.11**	-1.14 ns
CC vs ORG	0.02 ns	-1.61 ns	134.47 ns	-1.74 ns
PAST vs ORG	-0.03 <sup>o</sup>	-2.73 ns	-283.70**	-2.45 ns
CE vs ORG	-0.20**	6.78**	87.50 ns	6.69**
ORG-2 vs (ORG-8 + ORG-10)	-0.06**	2.77 ns	-30.93 ns	2.81 ns
	0.20-0.40 m			
CE vs Cultivation	-0.18**	8.33**	179.34*	8.15**
PAST vs CC	-0.21**	-1.28 ns	-134.98 ns	-1.15 ns
NT vs CC	-0.15**	-1.92 ns	-192.27*	-1.73 ns
CC vs ORG	0.14**	-1.43 ns	99.55 ns	-1.53 ns
PAST vs ORG	-0.06**	-2.71 ns	-35.43 ns	-2.67 ns
CE vs ORG	-0.16**	7.53**	180.48*	7.35**
ORG-2 vs (ORG-8 + ORG-10)	-0.15**	3.92 ns	98.78 ns	3.83 ns

CE: native 'Cerrado' (savanna forest), PAST: pasture, NT: no-tillage system, CC: conventional cropping system, ORG-2,8 and 10: organic systems with 2, 8 and 10 years of cultivation. *Cultivation*: mean value of a given attribute calculated among all cultivated sites, excluding PAST. ORG: mean value of a given attribute calculated from ORG-2 to ORG-10. All measured values are in Table 2. ns, <sup>o</sup>, \*, \*\*: not significant, significant to 10, 5 and 1%, respectively, by the F test.



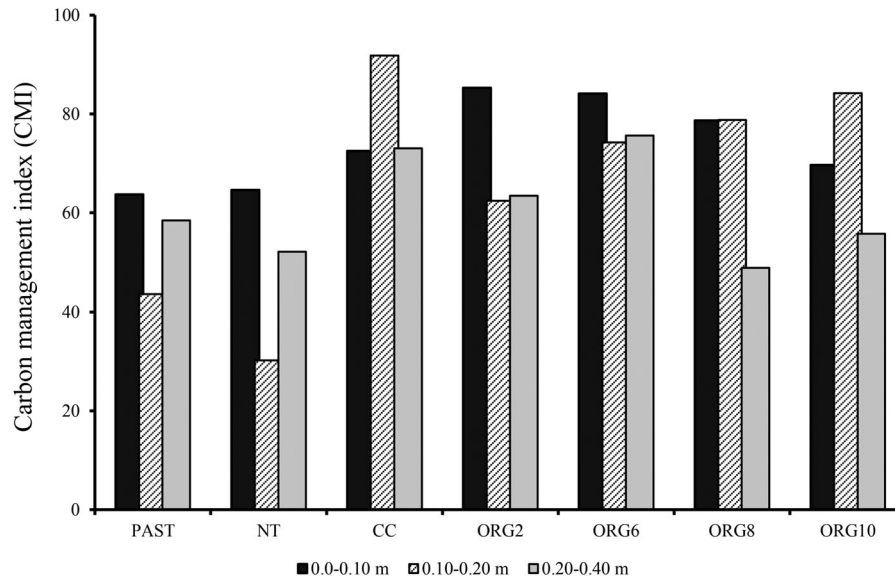
**Figure 1.** Soil organic C stocks at the 0–0.40 m depth of a Ferralsol under different systems of use and management. Values under the bars represent the estimate of the orthogonal contrasts. CE: native 'Cerrado' (savanna forest), PAST: pasture, NT: no-tillage system, CC: conventional cropping system, ORG: organic systems with 2, 6, 8 and 10 years of cultivation. C1: CE vs cultivation1; C2: PAST vs CC; C3: PAST vs NT; C4: PAST vs ORG-2; C5: PAST vs ORG-6; C6: PAST vs ORG-8; C7: PAST vs ORG-10. 1cultivation: represents the average of soil C stock in all managed areas except PAST. ns, <sup>o</sup>, \*, \*\*: not significant, significant to 10, 5 and 1%, respectively, by the F test.

$C_{st_{native\ cerrado}}$  = soil C stock in the reference area (CE).

According to the resilience concept proposed by [14], it was assumed that the pasture area had the lowest limit after conversion.

Differences between the use and management systems were evaluated by the F-test at 1, 5 and 10% significance levels using orthogonal contrasts. The effect of converting native Cerrado to cultivation was tested by contrasting CE vs CULTIVATION;

in this case, 'cultivation' represents, hereafter, the average of the values of a given measurement found in the cultivated sites (e.g. CC, NT and ORG), excluding PAST. The conversion of pasture to a conventional cropping system was evaluated by the contrasting PAST vs CC. The contrast NT vs CC tested the selected attributes between no-tillage and conventional cultivation, whereas the difference between conventional cultivation and organic cultivation was evaluated by the contrast



**Figure 2.** Carbon management index (CMI) for a Ferralsol in different management systems (PAST: pasture, NT: no-tillage system, CC: conventional cropping system, ORG: organic systems with 2, 6, 8 and 10 years of management) at depths of 0.0–0.10, 0.10–0.20 and 0.20–0.40 m.

CC vs ORG. The conversion of pasture to organic cultivation was tested by the contrast PAST vs ORG. In order to measure the ability of organic cultivation to recovery soil C in relation to reference soil, the CE vs ORG contrast was proposed. In the last three contrasts, 'ORG' represents the average value of a given attribute found in all organic sites (e.g. ORG with 2, 6, 8, and 10 years of cultivation). Finally, the contrast ORG-2 vs (ORG-8 + ORG-10) was proposed to evaluate the effect of cultivation time among the organic systems. All analyses were conducted using the statistical program Sisvar 5.6 [31].

## Results

In order to evaluate the impact of conversion of CE into croplands, it was calculated the mean value of each measured soil attribute among all cultivated sites, excluding PAST. On such comparison, this means value will be hereafter named as 'Cultivation'. Similarly, a mean of each attribute was calculated among organic system with different years of cultivation, which was named as 'ORG' (Tables 3 and 4).

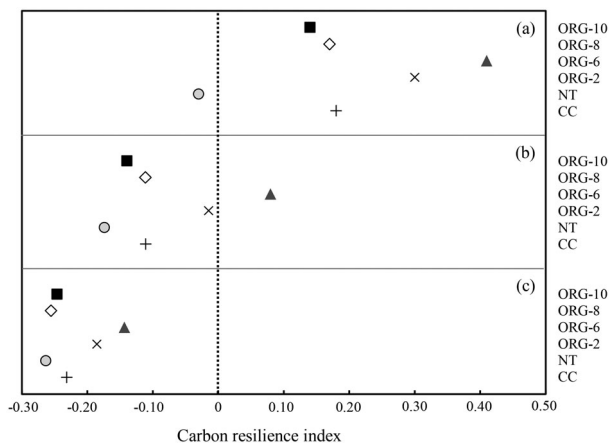
The soil BD varied from 1.13 to 1.49 Mg m<sup>-3</sup> (Table 3) and tended to increase from the top soil to the deepest layer. The lowest BD values were observed in the CE soil. To the depth of 0.20 m, soil BD in the CC did not differ from average calculated for organic cultivation systems (ORG), however it was higher ( $p < 0.05$ ) when compared to the other systems in the 0.20–0.40 m layer (Tables 3 and 4).

The contrast CE vs Cultivation (Table 4) showed that soil TOC contents were greater ( $p < 0.01$ ) in the CE than average value found in the cultivated systems for all evaluated depths (Tables 3 and 4). On average, soil TOC losses after conversion of CE were 44% in the NT, 32% in the CC and 26% in the organic systems. There were no significant differences in the soil C levels when pair-compared PAST, NT, CC and ORG systems at any of the evaluated depths (Table 4).

Soil C stocks in the 0–0.40 m layer varied from 61 to 111 t ha<sup>-1</sup> (Figure 1) and were significantly reduced by about 33% due to conversion from native CE into Cultivation, regardless of the management system adopted.

After CE clearing, PAST becomes the most common land use until a new agroecosystem is implanted. Hence, the loss or gain of soil C was also evaluated considering the PAST system as a new reference of equilibrium. Conversion of PAST into agricultural systems promotes a new impact on soil C stocks, which depending on the management system adopted, generates a positive or negative balance of organic C stocks in the soil. Only the ORG-2 and ORG-6 systems demonstrated the ability to recover soil C stocks after conversion of the PAST area. In the ORG-2 and ORG-6 areas significant increases in soil C stocks were observed in relation to PAST soil (Figure 1, C4 and C5), equivalent to 18 and 28 Mg ha<sup>-1</sup>, respectively. Soil C stocks in ORG-8 and ORG-10 were statistically similar to C stock in the PAST soil in the 0.0–0.40 m depth.

The C<sub>L</sub> contents of the soil varied from 425 to 900 mg kg<sup>-1</sup> (Table 3) and were greater ( $p < 0.05$ )



**Figure 3.** Carbon resilience index (CRI) at 0.0–0.10 (a), 0.10–0.20 (b) and 0.20–0.40 m (c) depths of a Ferralsol after conversion from native Cerrado and pasture to the following management systems: ORG: organic cultivation with 10, 8, 6 and 2 years of cultivation; NT: no-tillage system; CC: conventional cropping system. Positive CRI values indicate recovering of soil organic stocks in relation to inferior limit represented by PAST system.

in the CE compared to the average calculated for the cultivated soils in the 0–0.10 m layer (Table 4). The average  $C_L$  losses when CE area was converted to CC, NT and PAST systems were 18, 27 and 28%, respectively, while the average loss in relation to organic systems was 10%. For the organic systems, the magnitude of  $C_L$  loss varied based on the cultivation time, reaching 4% after two years of management and 22% after 10 years of cultivation. In the 0.10–0.20 m layer, the  $C_L$  content of the CC soil was greater than in the PAST and NT systems.

Conversion of CE to PAST reduced  $C_L$  contents by 28, 55 and 30% in the 0.0–0.10, 0.10–0.20 and 0.20–0.40 m depths, respectively. When organic cultivation was established after conversion of PAST, there was an average increase of 24, 77 and 7% in the  $C_L$  contents in the 0.0–0.10, 0.10–0.20 and 0.20–0.40 m soil depths, respectively. When PAST soil was converted to CC system, soil  $C_L$  content increased 58% in the 0.10–0.20 m depth, and was significantly greater than NT soil in the 0.10–0.20 and 0.20–0.40 m depths (Table 4).

On average, the  $C_{NL}$  fraction represented about 96% of the soil TOC for all land-use, showing the high level of stabilization of organic C in the soil mineral matrix. The highest  $C_{NL}$  contents were observed in the CE soil and significantly differed from *Cultivation* in all soil layers (Tables 3 and 4). Reductions in  $C_{NL}$  contents after conversion of CE area were about 22, 17, 34, 38, 33 and 45% for the ORG-2, ORG-6, ORG-8, ORG-10, CC and NT systems, respectively. Pair-comparisons involving PAST, NT, CC and ORG were not significant to the soil  $C_{NL}$

contents (Table 4), suggesting that  $C_{NL}$  fraction was few affected by land-use change.

The CMI (Figure 2) represents a tool to evaluate loss or gain of organic C in the soil of a managed system compared to a reference area [12]. In the 0.0–0.10 m depth, organic cultivated soils showed higher CMI values compared to the other agricultural systems. When comparing only the organic areas it was observed that, in the surface soil CMI values decreased over the years of cultivation (Figure 2), as also noted for TOC stocks (Figure 1). In the 0.0–0.10 m layer, CC soil presented an intermediate CMI level between the ORG and the NT, however it was higher compared to the other systems in the 0.10–0.20 m depth, demonstrating that at this depth there was more C recovery.

The C resilience index (CRI) was calculated based on the conceptual approach preconized by [14], assuming that soil resilience is the ability of soil to recover its functional and structural integrity after a disturbance or stress, as also carried out by [18]. Conversion of CE soil into PAST was considered the main disturbance event (upper limit) and conversion of PAST into agricultural systems as the lowest stress limit. In the 0.0–0.10 cm depth, positive CRI values were observed in all ORG and CC systems (Figure 3). The highest CRI values occurred in the ORG-6 and ORG-2 soils. At depths exceeding 0.10 m, all systems had negative CRI values, except for ORG-6 at the 0.10–0.20 m depth. The NT system was the only one that showed negative CRI values at all soil depths (Figure 3).

## Discussion

Higher TOC contents in CE compared to cultivated soils is widely supported by literature and can be mainly attributed to the higher biomass input in the native area in relation to cultivation [32]. Soil TOC losses of around 33% from the initial level in cultivated sites indicates that change in land use promotes organic C losses in the soil, independent of the management system adopted. In cultivated sites, lower biomass inputs by crops compared to CE, associated with soil disturbance and high temperatures in the Cerrado, favor the rapid mineralization of organic C [15]. The negative impacts of converting areas of native Cerrado on C levels in the soil were also observed in other studies [13, 33, 34].

In general, only few differences were observed in the TOC stocks when comparing different management systems (e.g. PAST, NT, CC and ORG). This

study assessed very short transition periods of land-use change in most cases, although in organic farming periods up to ten years were also assessed. This transition provides only a temporary analysis of changes in soil C as a result of land-use changes. For instance, no-tillage is usually very positive for increasing soil C in long term as compared to conventional (tilled) maize-soy systems [13, 23]. However, no consistent differences in TOC stocks were observed when comparing CC and NT in the present study of case, which represent an uncertainty that should be stressed by future studies in the same region.

On the other hand, the greater ability of the ORG-2 and ORG-6 soils to recover organic C stocks after conversion compared to the other areas can be attributed to the constant organic matter inputs and to the lower soil turnover, especially in relation to NT and CC systems. The balance of C stocks in the ORG-8 and ORG-10 areas suggests that there is a gradual loss in the soil capacity to store organic C. This is probably related to how the soil is prepared and tilled, since more crops are rotated in these areas. Enclosing soil C within aggregates is one of main mechanisms of protection against the biochemical degradation of organic matter, because it inhibits the access of microbiota to the organic substrate [35]. Constant soil disturbance over time accelerates C mineralization through break down of soil aggregates, which compromises the physical protection of the organic matter [36, 37].

Higher  $C_L$  contents in CE soil are directly associated with the greater and continuous supply of organic matter and biodiversity of arboreal species compared to crops in the cultivated areas (Lal 2004). Furthermore, absence of soil disturbance decreases the decomposition rate of organic matter [5], favoring  $C_L$  accumulation in the soil. The organic  $C_L$  fraction in the soil has been considered one of the most sensitive indicators of management changes in different agricultural systems [38]. After conversion of native CE, ORG soils showed the lowest  $C_L$  reductions among cultivated sites, which indicate organic C recovery. These results can be attributed to maintenance of organic matter inputs and reduced soil disturbance [15].

On average, conversion of CE into PAST reduced soil  $C_L$  in 37% by the full 0.0–0.40 m profile. Brito *et al.* (2019) also observed that land use change from Cerrado to pasture can reduce the soil labile C fractions by up to 56%. In general, soils under organic cultivation recovered  $C_L$  levels compared

to the PAST area (Table 3). Considering PAST as the closest reference of land use before cultivation, the increase in  $C_L$  indicates a state of recovering soil quality promoted by organic management, because maintenance of the labile-C fraction from organic matter in the soil reflects the enhancement of nutrient cycling in the system [39]. On the other hand, soil  $C_L$  in ORG systems decreased over the cultivation time (Table 4), indicating that labile C becomes more stabilized in non-labile structures over the years so that  $C_L$  maintenance in the soil depends on the replacement of fresh organic matter in the oldest ORG areas.

The higher soil  $C_L$  content in CC compared to NT differed from results obtained by [16] for an Oxisol, where average  $C_L$  levels were around 50% greater in no-tillage compared to conventional system. It is possible the increase of labile-C in the deepest soil layers in CC system could be a result of the incorporation of fresh organic residues during frequent soil plowing and harrowing during soil preparation. In addition, the short establishment period of the NT evaluated in the present study could justify the lower  $C_L$  levels in deeper layers compared to CC. According to [32], no-tillage systems only start to differ and surpass conventional cropping systems between the fifth and seventh management year when the system reaches maturity.

More than 90% of the soil organic C content was represented by the  $C_{NL}$  fraction, showing the high level of C stabilization in the soil matrix. The higher  $C_{NL}$  contents in CE soil compared to the cultivated areas in all layers (Table 4) demonstrate that substituting native vegetation for agricultural systems not only depletes labile-C forms, but also results in losses of the most stable compartment of soil organic matter. The lower reduction of  $C_{NL}$  in the ORG-6 soil in relation to other systems indicates that management of soil organic matter favored labile C stocks and reduced losses of the most stable C fraction.

Higher CMI values in the 0.0–0.10 m depth of ORG soils compared to the others systems show that management practices used in organic cultivation are the most efficient for maintaining the quantity and quality of soil organic C. However, the lowest CMI values in PAST and NT suggest losses in soil organic C stocks and organic matter quality. The capacity of the soil to store organic C in no-tillage systems is also governed by the quantity and quality of the biomass, which is directly dependent on the diversification of plant species

[40]. The lowest CMI observed in the NT system indicates the low capacity of soil to recover organic C, which contradicts other studies performed in the Brazilian Cerrado [41, 42]. However, a more conclusive analysis of the potential for C sequestration by the NT and organic cultivation system must consider, above all, the establishment time of such agricultural system. In the present study, two years of cultivation does not appear to be enough to effectively change organic C stocks in the soil. Continuous monitoring of C levels in this area is necessary to more accurately evaluate the C sequestration potential in the soil in function of conversion to the NT or organic cultivation systems.

The positive CRI values for ORG-2 and ORG-6 demonstrate the greater efficiency of these systems for recovering C sequestration in the soil [16], especially at the surface. In the ORG-8 and ORG-10 systems, the CRI indicates loss of C resilience in function of cultivation time, reaching levels similar to those found in CC soil. This behavior has a close relationship with the soil  $C_L$  losses as previously discussed. Negative CRI values at all depths in the NT system reveal that the addition of C *via* mulch biomass is not sufficient to restore the soil TOC level after land use change. The C sequestration potential in no-tillage only differs from conventional cultivation when there is a greater contribution of N in the system [29]. Based on this assumption, the low accumulation of soil organic C in the NT system could be related to low N input *via* the corn/peanut/soybean rotation. According to [29], the large export of N by soybean crops contributes to a N balance close to zero, which influences the ability of the soil to store C. It is suggested to use winter and summer cover plants when rotating crops in NT to compensate for the export of N when soybeans are cultivated only in rotation with a grass, such as corn [26]. N is a fundamental element that stabilizes more complex organic molecules, such as humic substances, which make up the organic reserve of soil [43].

## Conclusion

Land use change promotes in short-term significant changes in the levels of organic C stocks in the soil. On average, converting native Cerrado to cultivated areas reduces the organic C stocks in the soil by 33%, independent of the management type adopted. The organic system increases soil C resilience, which maintains and recovers C stocks

until the sixth year of cultivation. Organic cultivation should be considered a suitable management strategy for soil C recovering in the Goiás Cerrado region; but the cultivation time and crop rotation used in organic management can reverse the process of C accumulation in the soil over the medium and long term. During the initial implementation phase, the no-tillage system converted from pasture was not able to recovery organic C stocks in the soil. But such uncertainty must be further investigated in future long term studies in the same region.

## Acknowledgments

The authors would like to thank the Pudica Produtos Orgânicos Company for granting permission to use the experimental area of Nossa Senhora Aparecida farm, and for all technical and logistical assistance. We also acknowledge the Embrapa Mandioca e Fruticultura (Brazilian Agricultural Research Corporation) for technical support during all laboratory analyses. Thanks are extended to the National Council for Scientific and Technological Development (CNPq).


## Disclosure statement


No potential conflict of interest was reported by the authors.

## Data available on request from the authors

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

## ORCID

Fabiane Pereira Machado Dias  <http://orcid.org/0000-0002-1153-9613>

Francisco Alisson da Silva Xavier  <http://orcid.org/0000-0002-8141-2343>

## References

1. Lal R. Sequestering carbon in soils of agro-ecosystems. *Food Policy*. 2011;36:S33–S39. <https://doi.org/10.1016/j.foodpol.2010.12.001>.
2. García-Palacios P, Gattinger A, Bracht-Jørgensen H, et al. Crop traits drive soil carbon sequestration under organic farming. *J Appl Ecol*. 2018;55(5):2496–2505. doi:10.1111/1365-2664.13113.
3. Lopes AS, Guilherme LG. A career perspective on soil management in the Cerrado region of Brazil. *Adv Agron*. 2016;137:1–72. doi:10.1016/bs.agron.2015.12.004.
4. Craswell ET, Lefroy RDB. The role and function of organic matter in tropical soils. *Nutr Cycling in Agroecosyst*. 2001;61(1/2):7–18. doi:10.1023/A:1013656024633.

5. Badole S, Datta A, Chaitanya AK, et al. Soil carbon dynamics under different land-use and management systems. *Carbon Manage Trop Sub-Trop Terrest Syst.* 2020;1:103–121. doi:10.1007/978-981-13-9628-1\_7.
6. Chaudhary S, Dheri GS, Brar BS. Long-term effects of NPK fertilizers and organic manures on carbon stabilization and management index under rice-wheat cropping system. *Soil and Tillage Res.* 2017;166:59–66. doi:10.1016/j.still.2016.10.005.
7. Luo G, Li L, Friman VP, et al. Organic amendments increase crop yields by improving microbe-mediated soil functioning of agroecosystems: a Meta-analysis. *Soil Biol Biochem.* 2018;124:105–115. doi:10.1016/j.soilbio.2018.06.002.
8. Wulanningtyas HS, Gong Y, Li P, et al. A cover crop and no-tillage system for enhancing soil health by increasing soil organic matter in soybean cultivation. *Soil and Tillage Res.* 2021;205:104749. doi:10.1016/j.still.2020.104749.
9. Gomiero T, Pimentel D, Paoletti MG. Environmental impact of different agricultural management practices: conventional vs. organic agriculture. *Crit Rev Plant Sci.* 2011;30(1–2):95–124. doi:10.1080/07352689.2011.554355.
10. Tuomisto HL, Hodge ID, Riordan P, et al. Does organic farming reduce environmental impacts?—a meta-analysis of European research. *J Environ Manage.* 2012;112:309–320. doi:10.1016/j.jenvman.2012.08.018.
11. Dias FPM, Rodrigo H, Flávia JN, et al. Effects of land-use change on chemical attributes of a ferralsol in Brazilian Cerrado. *Catena.* 2019;177:180–188. doi:10.1016/j.catena.2019.02.016.
12. Blair GJ, Lefroy RDBY, Lisle L. Soil carbon fractions based on their degree of oxidation. and the development of a carbon management index for agricultural systems. *Aust J Agric Res.* 1995;46(7):1459–1466. doi:10.1071/AR9951459.
13. Dieckow J, Bayer C, Conceição PC, et al. Land use, tillage, texture and organic matter stock and composition in tropical and subtropical Brazilian soils. *Eur J Soil Sci.* 2009;60(2):240–249. doi:10.1111/j.1365-2389.2008.01101.x.
14. Herrick JE, Wander MM. 1997. Relationships between soil organic carbon and soil quality in cropped and rangeland soils: the importance of distribution, composition and soil biological activity. In: Lal R, Kimble JM, Follet RF, Stewart BA, editors. *Soil process and the carbon cycle.* Boca Raton: CRC Press. p. 405–425.
15. Loss A, Pereira MG, Schultz N, et al. Organic fractions and carbon management index of soil under different organic production systems. *Idesia.* 2011;29(2):11–19. doi:10.4067/S0718-34292011000200002.
16. Moraes Sá SJC, Tivet F, Lal R, et al. Long-term tillage systems impacts on soil C dynamics, soil resilience and agronomic productivity of a Brazilian Oxisol. *Soil and Tillage Res.* 2014;136:38–50. doi:10.1016/j.still.2013.09.010.
17. Rossi CQ, Pereira MG, Giacomio SG, et al. Frações orgânicas e índice de manejo de carbono do solo em Latossolo Vermelho sob plantio de soja no cerrado goiano. *Agraria.* 2012;7(2):233–241. doi:10.5039/agraria.v7i2a1387.
18. Silva FD, Amado TJC, Ferreira AO, et al. Soil carbon indices as affected by 10 years of integrated crop–livestock production with different pasture grazing intensities in Southern Brazil. *Agri Ecosyst Environ.* 2014;190:60–69. doi:10.1016/j.agee.2013.12.005.
19. FAO. 2014. IUSS Working Group WRB. World Reference Base for Soil Resources 2014. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Rome: FAO.
20. Köppen W, Geiger R. *Klimat der Erde.* Gotha: Verlag Justus Perthes, Wall-Map. 1928.
21. Klink CA, Machado RB. Conservation of the Brazilian Cerrado. *Conserv Biol.* 2005;19(3):707–713. doi:10.1111/j.1523-1739.2005.00702.x.
22. Hurlbert SH. Pseudoreplication and the design of ecological field experiments. *Ecol Monographs.* 1984;54(2):187–211. doi:10.2307/1942661.
23. Autret B, Mary B, Chenu C, et al. Alternative arable cropping systems: a key to increase soil organic carbon storage? Results from a 16 year field experiment. *Agri Ecosyst Environ.* 2016;232:150–164. doi:10.1016/j.agee.2016.07.008.
24. Brandani CB, Abbruzzini TF, Conant RT, et al. Soil organic and organomineral fractions as indicators of the effects of land management in conventional and organic sugar cane systems. *Soil Res.* 2017;55(2):145–161. doi:10.1071/SR15322.
25. Empresa Brasileira De Pesquisa Agropecuária – EMBRAPA. 2011. Manual de métodos de análise de solo. 3.ed. rev. atual. Rio de Janeiro: Embrapa Solos (Documentos/Embrapa Solos).
26. Amado TJC, Bayer C, Conceição PC, et al. Potential of carbon accumulation in no-till soils with intensive use and cover crops in Southern Brazil. *J Environ Qual.* 2006;35(4):1599–1607. doi:10.2134/jeq2005.0233.
27. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29–38.
28. Cantarella H, Quaggio JA, Andrade JC. 2001. Determinação da matéria orgânica. In: Rajj BV, Andrade JC, Cantarella H, Quaggio JA, editors. *Análise química Para avaliação da fertilidade de solos tropicais.* Campinas: Instituto Agrônômico.
29. Sisti CP, Santos HP, Kohmann R, et al. Change in carbon and nitrogen stocks in soil under 13 years of conventional or zero tillage in Southern Brazil. *Soil and Tillage Res.* 2004;76(1):39–58. doi:10.1016/j.still.2003.08.007.
30. Weil RR, Islam KR, Stine MA, et al. Estimating active carbon for soil quality assessment: a simplified method for laboratory and field use. *Am J Alternative Agr.* 2003;18:3–17. doi:10.1079/AJAA200228.
31. Ferreira DF. Sisvar: a computer statistical analysis system. *Ciênc Agrotec.* 2011;35(6):1039–1042. doi:10.1590/S1413-70542011000600001.
32. Franchini JC, Debiasi H, Junior AAB, et al. Evolution of crop yields in different tillage and cropping systems over two decades in Southern Brazil. *Field Crops Res.* 2012;137:178–185. doi:10.1016/j.fcr.2012.09.003.

33. Ferreira EAB, Bustamante MMDC, Resck DVS, et al. Carbon stocks in compartments of soil organic matter 31 years after substitution of native cerrado vegetation by agroecosystems. *Rev Bras Ciênc Solo*. 2016; 40:e0150059. doi:[10.1590/18069657rbc20150059](https://doi.org/10.1590/18069657rbc20150059).
34. Gmach MR, Dias BO, Silva CA, et al. Soil organic matter dynamics and land-use change on Oxisols in the Cerrado, Brazil. *Geoderma Regional*. 2018;14:e00178. doi:[10.1016/j.geodrs.2018.e00178](https://doi.org/10.1016/j.geodrs.2018.e00178).
35. Zimmermann M, Leifeld J, Conen F, et al. Can composition and physical protection of soil organic matter explain soil respiration temperature sensitivity? *Biogeochem*. 2012; 107(1–3):423–436. doi:[10.1007/s10533-010-9562-y](https://doi.org/10.1007/s10533-010-9562-y).
36. Six J, Paustian K. Aggregate-associated soil organic matter as an ecosystem property and a measurement tool. *Soil Biol Biochem*. 2014;68:A4–A9. doi:[10.1016/j.soilbio.2013.06.014](https://doi.org/10.1016/j.soilbio.2013.06.014).
37. Spaccini R, Piccolo A. Effects of field managements for soil organic matter stabilization on water-stable aggregate distribution and aggregate stability in three agricultural soils. *J Geochem Expl*. 2013;129: 45–51. doi:[10.1016/j.gexplo.2012.10.004](https://doi.org/10.1016/j.gexplo.2012.10.004).
38. Duval ME, Galantini JA, Martínez JM, et al. Labile soil organic carbon for assessing soil quality: influence of management practices and edaphic conditions. *Catena*. 2018;171:316–326. doi:[10.1016/j.catena.2018.07.023](https://doi.org/10.1016/j.catena.2018.07.023).
39. Conceição PC, Amado TJC, Mielniczuk J, et al. Soil organic matter and other attributes as indicators to evaluate soil quality in conservation systems. *Rev Bras Ciênc Solo*. 2005;29(5):777–788. doi:[10.1590/S0100-06832005000500013](https://doi.org/10.1590/S0100-06832005000500013).
40. Coser TR, Figueiredo CC, Jovanovic B, et al. Short-term buildup of carbon from a low-productivity pastureland to an agrisilviculture system in the Brazilian savannah. *Agri Syst*. 2018;166:184–195. doi:[10.1016/j.agry.2018.01.030](https://doi.org/10.1016/j.agry.2018.01.030).
41. Marafon G, Barbosa RS, Lacerda JJ, et al. C and P Pool restoration by a no-tillage system on Brazilian Cerrado Oxisol in Piauí State. *Environ Monit Assess*. 2020;192(4):1–14. doi:[10.1007/s10661-020-8221-6](https://doi.org/10.1007/s10661-020-8221-6).
42. Souza ED, Carneiro MAC, Paulino HB, et al. Organic matter and soil aggregation after the conversion of "murundu fields" into a no-tillage system. *Pesq Agropec Bras*. 2016;51(9):1194–1202. doi:[10.1590/s0100-204x2016000900019](https://doi.org/10.1590/s0100-204x2016000900019).
43. Stevenson FJ. 1994. *Humus chemistry*. 2nd ed. New York: John Wiley & Sons.