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Article *in* Soil Use and Management · March 2019

DOI: 10.1111/sum.12508

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Received: 8 January 2018 | Revised: 25 January 2019 | Accepted: 22 February 2019

DOI: 10.1111/sum.12508

RESEARCH PAPER

WILEY Soil Use and Management

Soil organic carbon temperature sensitivity of different soil types and land use systems in the Brazilian semi-arid region

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Funding information
Foundation for Research Support of the State of Alagoas (FAPEAL); the National Council for Scientific and Technological Development (CNPq)

Abstract

Quantifying the sensitivity of soil organic matter decomposition (SOM) to global warming is critical for predict future impacts of climate change on soil organic carbon stocks (SOC) and soil respiration, especially in semi-arid regions such as northeastern Brazil, where SOC stocks are naturally small. In this study, the responses of the labile and recalcitrant carbon components and soil respiration dynamics were evaluated in three different soil types and land use systems (native vegetation, cropland and pasture) of the Brazilian semi-arid region, when submitted to temperature increase. After 169 days of incubation, the results showed that an increase of 5°C generated an average increase in CO_2 emission of 12.0%, but which could reach 28.1%. Overall, the labile carbon (LC) in areas of native vegetation showed greater sensitivity to temperature than in cropland areas. It was also observed that recalcitrant carbon (RC) was more sensitive to warming than LC. Our results indicate that Brazil's semi-arid region presents a substantial vulnerability to global warming, and that the sensitivity of RC and of LC in areas of native vegetation to warming can enhance SOC losses, contributing to positive feedback on climate change, and compromising the productive systems of the region. However, further studies evaluating other types of soil and texture and management systems should be carried out to consolidate the results obtained and to improve the understanding about SOM decomposition in the Brazilian semi-arid region.

KEYWORDS
global warming, labile carbon, Q_{10}, recalcitrant carbon, soil respiration

1 | INTRODUCTION

According to the fifth report of the Intergovernmental Panel on Climate Change (IPCC, 2013), even with the increasing number of climate change mitigation policies, annual greenhouse gas (GHG) emissions in the 2000–2010 period have increased at a rate of 2.2% per year (i.e., between 1970 and 2000 the rate was 1.3%), resulting in the emission of 49 (± 4.5) Gt CO_2eq year^{-1} in 2010. Consequently, global temperature increased by 0.85°C between 1880 and 2012, and the scenarios show that this increase may reach 4.8°C by the end of the century if GHG emissions are not controlled. In this context, soil plays a key role since it is the largest terrestrial carbon reservoir (Lal, 2008), and the increase in temperature may enhance the CO_2 concentration in the atmosphere due to the acceleration of soil organic carbon (SOC) decomposition, resulting in positive feedback for future climate warming (Craine, Fierer, & McLauchlan, 2010).

However, the large biochemical complexity of soil organic matter (SOM) and the variety of stabilization mechanisms have led to a great discussion about the real sensitivity of SOM to temperature, including aspects such as the decomposition of the labile versus stable components (Liang et al., 2015; Plante et al., 2010; Powlson, 2005), as well as the relationship between soil respiration and SOM availability and microbial activity (Birge et al., 2015). Therefore, the understanding of SOM dynamics is a critical aspect, especially in semi-arid regions such as north-eastern Brazil, which, like other semi-arid regions, has small SOC stocks and agricultural production is limited by climatic conditions (Hamdi et al., 2011). The Brazilian semi-arid region comprises an area of 980,133 km^2 of which approximately 34.0% (33.3 million ha) are currently used for agricultural purpose (Bustamante et al., 2015). However, it is a poor region, where agriculture is based predominately on small family farms and developed at the expense of indiscriminate deforestation. Cultivation practices tend to be conventional with inadequate fallow periods. Overgrazing is common under cattle ranching, with herds grazing in cropland areas after harvest (Maia, Xavier, Oliveira, Mendonça, & Araujo Filho, 2006). Thus, changes in soil carbon dynamics, besides being a significant source of CO_2 emissions, can contribute to the compromise of agricultural production and food security of the region.

Some studies have shown that soil respiration (SR) is less temperature sensitive in hotter than cold areas (Bradford et al., 2008; Richardson, Chatterje, & Jenerette, 2012); however, there are few studies evaluating SR sensitivity at temperatures exceeding 30°C (Gershenson, Bader, & Cheng, 2009; Plante et al., 2010; Steinweg, Plante, Conant, Paul, & Tanaka, 2008), especially under semi-arid conditions (Escolar, Maestre, & Rey, 2015; Hamdi et al., 2011). More studies on SOC dynamics in semi-arid conditions are needed, as temperatures above 30°C (INMET, 2017) are relatively common and can easily reach 40°C at the soil surface (Hamdi et al., 2011). Therefore, among the several variables that regulate the SOC decomposition, temperature has certainly gained attention (Conant et al., 2008; Cui et al., 2014; Hou, Ouyang, Maxim, Wilson, & Kuzyakov, 2016; Plante et al., 2010), and this theme has been approached in several aspects, such as the role of substrate availability (Hamdi et al., 2011); different soil types and tillage systems (Birge et al., 2015; Hou et al., 2016; Zhang, Li, Yang, & Sun, 2016), moisture levels (Richardson et al., 2012), and the responses of different SOM fractions (Carrillo, Pendall, Morgan, & Newcomb, 2011; Fang, Smith, Moncrieff, & Smith, 2005; Hou et al., 2016; Plante et al., 2010; Xu, Zhou, Ruan, Luo, & Wang, 2010).

Soil organic carbon is conceptually divided into discrete pools with different lability (Smith et al., 1997; Xu et al., 2010), such as into fast, slow and passive pools of the well-known CENTURY model (Parton, Schimel, Cole, & Ojima, 1987). However, in laboratory studies (Conant et al., 2008; Plante et al., 2010; Xu et al., 2010) SOC is often divided into two fractions: recalcitrant organic carbon (RC) and labile organic carbon (LC). The latter is defined as being easily decomposed by microorganisms (Shaver et al., 2006), whereas RC is considered more resistant to decomposition (Davidson & Janssens, 2006; Hartley & Ineson, 2008). However, there is no consensus on the responses of the different fractions to warming.

Some studies have suggested that the sensitivity of LC to temperature is equal to the sensitivity of the recalcitrant C (Conen, Leifeld, Seth, & Alewell, 2006; Fang et al., 2005), other studies suggest that the sensitivity is greater (Carrillo et al., 2011; Conant et al., 2008), yet others report less sensitivity (Conant et al., 2008; Fierer, Craine, McLaughlan, & Schimel, 2005; Xu et al., 2010). Nevertheless, given that the SOM dynamics depends on several factors, such as different degrees of protection (Six et al., 2002), the variety of organic compounds that decompose at different rates (Davidson & Janssens, 2006), their different responses to disturbances (Bayer, Martin-Neto, Mielniczuk, Pavinato, & Dieckow, 2006; Maia et al., 2013), and all these factors are subject to the different soil, climate and management conditions, the absence of consensus on the sensitivity of SOM fractions to temperature is unsurprising. Consequently, more emphasis should be given to assessing the magnitude of the effect of temperature increase in different soil types and management systems, since this type of information can contribute to provide data in support of models of SOC dynamics (e.g., Roth-C and Century). Such data would also inform the development of agricultural systems more adapted to the effects of global warming and climate change. Therefore, the aim of this study was to examine the effect of temperature on soil respiration and on the labile and recalcitrant components of soil C under different soil types and land use systems (native vegetation, pasture and cropland) in the Brazilian semi-arid region.

2 | MATERIALS AND METHODS

2.1 | Site description and soil sampling

The study areas were located in three municipalities of the semi-arid state of Alagoas, north-eastern Brazil. The average annual temperature was 28°C, and the average annual rainfall of 550 mm distributed between the months of April and August (INMET, 2017). Soil samples were collected from three different soil types and land use systems, as described in Table 1.

All croplands were in production (non-experimental) areas, where there was alternation of the crops identified in Table 1. Crop residues were generally available for animal grazing.

TABLE 1 Soil types, land use systems, geographical coordinates and clay contents of studied sites

Soil type	County	Land use systems	Geographical coordinates	Clay content (%)
Entisol Quartzipsamments (Eq)	Delmiro Gouveia	Native vegetation (Caatinga) – EqNV	09°29′004″S; 37°56′24.3″W	7.8
		Cropland for 4 years of cultivation with corn, beans and cassava – EqCr4		5.1
		Cropland for 15 years of cultivation with corn, beans and cassava – EqCr15		11.0
Ultisol (Ul)	Inhapi	Native vegetation (Caatinga) – UlNV	09°12′13,20″S; 37°44′11.44″W	15.7
		Cropland for 30 years of cultivation with corn and beans – UlCr30		20.7
Entisol Psamments (Ep)	Pariconha	Native vegetation (Caatinga) – EpNV	09°17′04,7″S, 38°02′43.4″W	5.2
		Cropland for 4 years of cultivation with corn and beans – EpCr4		7.0
		Area of pasture for 10 years – EpPa10		2.6

It was common in the region to adopt fallow periods of 2 or 3 years after 4 or 5 years of cultivation, and typically the soil was prepared using a plough drawn by animal traction (conventional tillage). The pasture area was dominated by pangola grass (*Digitaria umfolozi* D.W.Hall) and at the time of collection had not been tilled for 10 years, although previously the area was cultivated for 30 years to corn and beans.

At each Study Area, soil samples were collected from five pits of each land use (native vegetation, cropland and pasture) arranged in a square of 100 × 100 m, having one pit at each corner and one in the centre. Soil sampling in the cropland areas occurred 1 week before soil tillage. Consequently, the last soil tillage process had taken place 1 year prior to sampling. While the pasture area was under fallow for approximately 4 months, without receiving any type of grazing. At each location, the area of native vegetation was adjacent to the cropland or pasture area, being at most 100 m distance and with similar landscape, soil type and texture. Soil samples were collected from 0 to 10 cm, and the samples were air-dried and sieved with 2 mm mesh sieve to remove stones and plants fragments.

2.2 | Soil incubation

For each of the eight land use systems described in Table 1, five soil samples (80 g) (from the five soil pits) were placed in 0.8-L glass jars, moistened to 70–80% of field capacity and pre-incubated under aerobic conditions for 7 days at 25°C. Samples were then incubated at two different temperatures (28 and 33°C) also under aerobic conditions. Each jar contained a vial with 30 ml of 0.5 M NaOH to capture CO_2 and another with 30 ml of water to maintain soil moisture. CO_2 capture was measured after 2, 4, 7, 11, 16, 22, 29, 36, 43, 50, 57, 64, 71, 78, 85, 92, 99, 106, 113, 120, 127, 134, 141, 148, 155, 162 and 169 days by opening the jars and removing the vials of NaOH, which were replaced with vials containing fresh NaOH. This procedure also served to promote aeration of the jars. CO_2 capture was determined by titrating the NaOH with 0.25 M HCl in the presence of $BaCl_2$. There were control samples (from jars without soil) for each measurement day. The temperature of 28°C corresponded to the historical average air temperature of the study region (INMET, 2017), whereas a temperature of 33°C was chosen, based on the fifth report of the IPCC (IPCC, 2013), which shows that in the most pessimistic scenario (RCP 8.5), the average air temperature increase could reach 4.8°C by the end of the century. Therefore, in this study, we adopted an increase of 5°C in relation to the average temperature of the region (28°C).

2.3 | Q_{10} calculations

For the evaluation of temperature increase on labile carbon (LC) and recalcitrant carbon (RC) components, we used the procedure described in Conant et al. (2008):

$$Q_{10} = \left(\frac{t_c}{t_w}\right)^{\left(\frac{10}{(T_w - T_c)}\right)},$$

where t_c and t_w are the times required to respire a given amount of soil C at 'relatively' cold (28°C) and warm (33°C) temperatures during incubation and T_w-T_c is the differential of temperature incubation. The Q_{10} values for the labile C pool were estimated by dividing the time taken to respire the first 1% of the initial C at 28°C by that at 33°C. For the RC component, Q_{10} values were determined using the time taken to respire an additional 1% of initial C after 8% of initial C was decomposed (Conant et al., 2008; Xu et al., 2010). The treatments UlCr30, EpNV and EpCr4 under 28°C, and UlNV under 33°C did not reach 9.0% of initial SOC content (see Table 2). Thus, for these treatments, the time required to

TABLE 2 Soil organic carbon (SOC), microbial carbon (Cmic) contents, proportion of initial SOC, and total C-CO_2 respired for the different soil types/land use systems and temperatures after 169 days of incubation

			Proportion of initial soil C		Total C-CO_2 respired	
Soil type/ Land use	SOC	Cmic	28°C	33°C	28°C	33°C
	mg g^{-1} soil	mg Cmic. g^{-1} soil	%		mg C-CO_2. g^{-1} soil	
EqNV	10.3 a (1.30)[a]	0.097 ab (0.021)	9.8 (1.29)	10.2 (1.43)	1.005 Aa (0.12)	1.053 Aa (0.072)
EqCr4	8.7 ab (0.36)	0.027 b (0.003)	11.5 (1.47)	12.2 (1.69)	1.002 Aa (0.08)	1.06 Aa (0.103)
EqCr15	6.7 b (0.06)	0.170 a (0.04)	13.6 (1.74)	14.3 (2.06)	0.915 Ba (0.063)	0.956 Aa (0.094)
UlNV	13.8 a (0.98)	0.088 a (0.034)	8.9 (1.12)	8.4 (1.16)	1.220 Aa (0.085)	1.149 Bb (0.103)
UlCr30	14.1 a (5.23)	0.108 a (0.032)	7.2 (0.89)	9.2 (1.29)	1.014 Bb (0.076)	1.299 Aa (0.098)
EpNV	14.3 a (1.70)	0.046 a (0.012)	7.8 (1.12)	9.7 (1.38)	1.119 Ba (0.072)	1.385 Aa (0.094)
EpCr4	12.2 a (0.98)	0.050 a (0.022)	7.7 (0.98)	9.8 (1.29)	0.941 Bb (0.098)	1.196 Aa (0.116)
EpPa10	8.8 b (0.40)	0.036 a (0.013)	9.5 (1.29)	10.3 (1.34)	0.835 Ab (0.072)	0.902 Ab (0.121)

Note. Means followed by the same letter, lower case in the column and upper case in the lines, do not differ according to Tukey′s test at 5% level of probability.

[a] Values within brackets represent the standard error ($n = 5$).

respire this percentage was estimated using the exponential equations described below.

2.4 | Soil organic carbon and microbial biomass C

Soil carbon contents were determined on element analyzer (CHNS – Thermo Scientific FLASH 2000). Microbial carbon (Cmic) was determined by the irradiation-extraction method using a microwave oven (Mendonça & Matos, 2005). The extractor used was 0.5 M K_2SO_4 and the carbon contained in extracts was quantified by means of wet oxidation (Yeomans & Bremner, 1998) without external heating. The conversion factor (K_c) used to convert C flow into microbial biomass C was 0.33 according to Sparling and West (1988).

2.5 | Statistical analysis

The results were evaluated through three different statistical procedures: (1) One-way ANOVA was used to compare the total CO_2-C respired between the land use systems under a same temperature as well as the effect of the temperatures into each land use system. One-way ANOVA was also used to assess soil organic carbon and microbial biomass C contents; (2) the dataset of cumulative CO_2-C emission and the decomposition rates (taking in account the measures of each day of incubation) were submitted to simple linear regression analysis, and a t test method was used to examine the significance of angular coefficient (β_1) between the land use systems under a same temperature as well as the effect of the temperatures in each land use system. Detailed description of the t test method can be found in Alencar, Mantovani, Bufon, Sediyama, and Silva (2014); (3) additionally, the dependency of soil respiration (cumulative CO_2-C emission) on incubation time was evaluated by fitting an exponential model, according to the equation below:

$$C_{cum} = Ci + Cf(1 - \exp^{-r \times day}),$$

where C_{cum} is the cumulative CO_2-C emission (mg CO_2-C g^{-1} soil), Ci and Cf are the initial and final CO_2-C cumulative content (mg CO_2-C g^{-1} soil), r is the maximum rate of relative accumulation, and day represents the incubation time. We fitted the model for each soil type and land use system under both temperatures (28 and 33°C). The exponential model fit was evaluated by the coefficient of determination (R^2), and by the statistical t test between the observed and estimated values. All statistical analyses were performed using the SIGMAPLOT software version 10.

3 | RESULTS

Overall, after 169 days of incubation, the increase of 5°C resulted in the average increase of CO_2 emission of 12.0%. Among the soil types, the emission increase was, respectively, 5.0%, 11.0% and 19.6% for Entisol Quartzipsamments, Ultisol and Entisol Psamments (Table 2). The ANOVA showed that only in the land use systems EqNV, EqCr4 and EpPa10 was there no significant difference in the temperature effect. Among the land use systems, the cropland in the Ultisol (UlCr30) presented the highest increase (28.1%), followed by EpNV and EpCr4 with 27.1% and 23.7%, respectively. Only for UlNV, there was an inverse response, with a reduction of 5.8% (Table 2). The SOC percentage that was decomposed after the incubation ranged from 7.2% in UlCr30 at 28°C to 14.3% in EqCr15 at 33°C (Table 2). The SOC decomposition dynamic presented a two-phase (relatively fast and slow) pattern with substantial different decomposition rates (Figure 2).

The evaluation of the results through the angular coefficient confirms the ANOVA, but allows a different perspective, since it takes into account not only the total value of accumulated CO_2-C (Table 2), but also the entire dataset of soil respiration. For example, according to ANOVA, the increase in temperature did not result in a significant difference for the EqNV system. Nevertheless, when using β_1 it verified a difference ($p < 0.01$) and that the increase of 5°C resulted in a β_1 of 1.179 (Table 3), which means that the emission of CO_2-C at 33°C during the 169 days of incubation was on average 17.9% higher than the emission at 28°C. This difference can be observed in Figure 1, which presents cumulative CO_2-C emissions data.

In general, the results of *t* test for the cumulative CO_2-C emission showed that there were statistical differences ($p < 0.01$) for all comparisons, including comparisons between different temperatures (Table 3). Based on angular coefficients (β_1), there was a greater soil respiration under native vegetation areas, which occurred in eight of the ten possible comparisons, with the mean increase of 22% at both temperatures, and emphasizes the comparison between EpNV and EpPa10 where soil respiration in the native vegetation area was 56.7% greater than the managed system (Table 3). The exceptions were only the comparative with UlCr30 under 33°C and EqCr4 under 28°C. Nevertheless, the complete analysis of the latter situation (EqCr4) indicates a tendency for an increase in the native vegetation area (Figure 1).

In contrast to results for CO_2 emission, the statistical differences for the decomposition rates were less pronounced, both between the systems of land use, as well as between temperatures (Table 4). This is probably due to the large variation in decomposition rate during the incubation period (Figure 2), rather than the differences between the averaged data, since in some cases substantial differences were observed, such as the systems EqNV and EpCr4 where the temperature increase resulted in 17.8% and 16.4% greater decomposition rates, respectively.

According to the parameters presented in Figure 1, the exponential model presented a high level of adjustment to describe the cumulative CO_2-C curves for both temperatures, since the coefficients of determination (R^2) varied between 0.993 (EpNV- 28°C) and 0.999 (EpNV-33°C). Additionally, the angular coefficients varied only between 0.967 and 1.014, indicating that the variation between the observed and modelled data ranged from −3.3% to + 1.4%, (see Figure 1), indicating that there was no difference between the observed and modelled data according to the *t* test. The exceptions were only the EpNV and EpPa10 systems at 28°C, where significant differences were observed, suggesting that for these situations the exponential model did not achieve the best fit for the relationship between CO_2-C emission and time.

Overall, the mean values of Q_{10} for the labile and recalcitrant components of soil carbon were, 1.51 ± 0.17 and 3.04 ± 0.7, respectively. When grouped by land use system, native vegetation areas had an average Q_{10} of 2.19 for labile and 2.24 for recalcitrant C components, respectively, whereas in managed systems the results were 1.11 ± 0.11 and 3.52 ± 0.28, for these components, respectively (Table 5). The analysis by each soil type showed that the Entisol Psamments (Ep) had greater sensitivity to temperature increase for both SOM pools, however, the system managed over 10 years as pasture (EpPa10) presented Q_{10} indices, significantly smaller than the other systems. The Ultisol (Ul) presented the smallest values of Q_{10} for both SOC components compared to the other soils, although it presented the largest relative difference between labile and recalcitrant Q_{10} (Table 5).

TABLE 3 Angular coefficients of the regression analysis and their respective results of *t* test for the cumulative C-CO_2 emission from different soil types and land use systems at the two temperatures (28 and 33°C), and the comparison of 33 × 28°C within the same land use system

	28°C		**33°C**		**33 × 28°C**		
	EqCr4	**EqCr15**	**EqCr4**	**EqCr15**	**EqNV**	**EqCr4**	**EqCr15**
EqNV	0.957**	1.037**	1.029**	1.105**	1.179**		
EqCr4		1.083**		1.072**		1.098**	
EqCr15							1.107**
	UlCr30		**UlCr30**		**UlNV**	**UlCr30**	
UlNV	1.162**		0.896**		0.927**		
UlCr30						1.198**	
	EpCr4	**EpPa10**	**EpCr4**	**EpPa10**	**EpNV**	**EpCr4**	**EpPa10**
EpNV	1.207**	1.474**	1.208**	1.567**	1.236**		
EpCr4		1.222**				1.163**	
EpPa10				1.296**			1.234**

**Significant at $p < 0.01$ according to the *t* test.

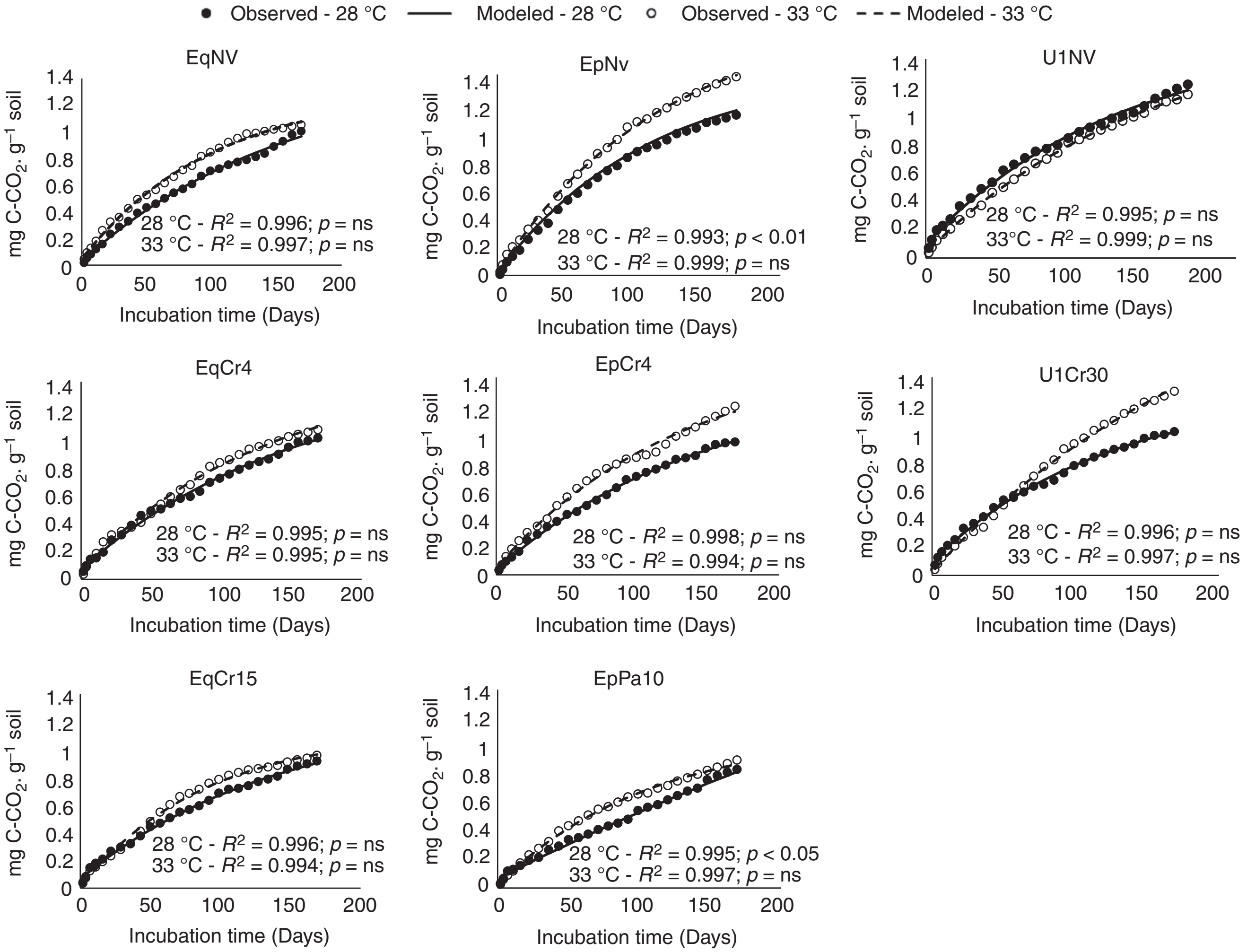

FIGURE 1 Observed and modelled cumulative CO_2-C emissions from different soil types and land use systems at 28 and 33°C in the exponential model. Not significant according to the t test, and the p values are used to evaluate the goodness of fit

TABLE 4 Angular coefficients of the regression analysis and their respective results of t test for the decomposition rates from different soil types and land use systems at the two temperatures (28 and 33°C), and the comparison of 33 × 28°C within the same land use system

	28°C		33°C		33 × 28°C		
	EqCr4	**EqCr15**	**EqCr4**	**EqCr15**	**EqNV**	**EqCr4**	**EqCr15**
EqNV	0.693**	0.762**	0.958^{ns}	1.072^{ns}	1.178^{ns}		
EqCr4		1.006^{ns}		1.09^{ns}		0.916^{ns}	
EqCr15							0.915^{ns}
	UlCr30		**UlCr30**		**UlNV**	**UlCr30**	
UlNV	1.073^{ns}		0.897*		0.704**		
UlCr30						0.816*	
	EpCr4	**EpPa10**	**EpCr4**	**EpPa10**	**EpNV**	**EpCr4**	**EpPa10**
EpNV	0.976^{ns}	0.967^{ns}	1.1^{ns}	1.446**	1.263**		
EpCr4		0.953^{ns}		1.28**		0.873^{ns}	
EpPa10							1.164^{ns}

**Significant at $p < 0.01$; *significant at $p < 0.05$; ^{ns}not significant according to the t test.

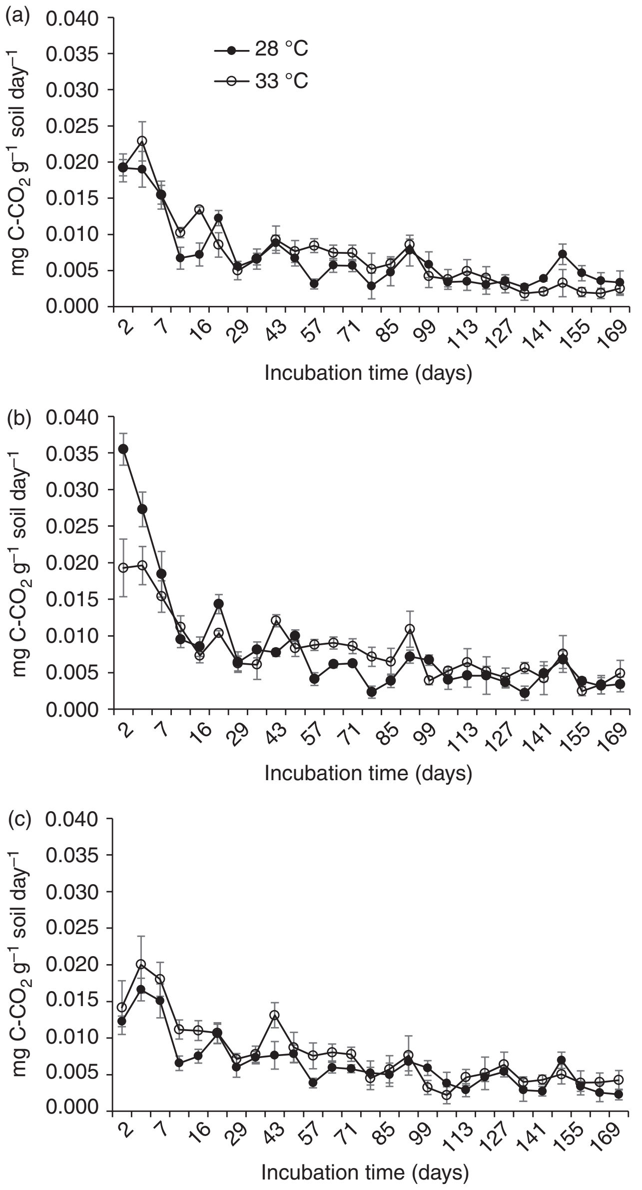

FIGURE 2 SOC decomposition rates at different soils. (a) Entisol Quartzipsamments; (b) Ultisol; and (c) Entisol Psamments; and temperatures of 28 and 33°C. Error bars represent standard deviation of the mean (n = 15 for Entisols and 10 for Ultisol)

TABLE 5 Results of Q_{10} values of different carbon components for different soils and land use systems

Soil/Land use systems	$Q_{10\text{-Labile}}$	$Q_{10\text{-Recalcitrant}}$
EqNV	3.24 (0.13)[a]	0.81 (0.08)
EqCr4	0.76 (0.01)	4.46 (0.52)
EqCr15	1.00 (0.05)	5.06 (0.39)
Mean	1.67 (0.06)	3.44 (0.33)
UlNV	0.39 (0.02)	1.05 (0.12)
UlCr30	0.39 (0.02)	2.60 (0.23)
Mean	0.39 (0.02)	1.82 (0.18)
EpNV	2.94 (0.24)	4.87 (0.43)
EpCr4	2.86 (0.10)	5.16 (0.72)
EpPa10	0.51 (0.04)	0.31 (0.03)
Mean	2.10 (0.13)	3.45 ± 0.38
Native vegetation	2.19 (0.12)	2.24 (0.22)
Agricultural systems	1.11 (0.05)	3.52 (0.37)
Overall mean	1.51 (0.08)	3.04 (0.31)

[a]Values within brackets represent the standard error (n = 5).

4 | DISCUSSION

Our results clearly indicate that Brazilian semi-arid soils are considerably sensitive to temperature increases. Such sensitivity may gradually compromise maintenance of soil quality and the sustainability of agriculture in this region. We have also found evidence of differences in sensitivity between soil types and land use systems. SOM, a fundamental component of soil quality and productive systems, especially in semi-arid regions, can be at least partially restored, since there is a continuous input of organic material in agroecosystems. Nevertheless, maintenance will certainly be hampered. Soil respiration and CO_2 release are generally expected to increase with temperature and, as our results show, soils are quite reactive, with an average increase in CO_2 emissions of 12.0% and up to 28.1%. These results corroborate those reported in literature (Bol, Bolger, & Little, 2003; Ise & Moorcroft, 2006; Zheng et al., 2010), which support the hypothesis that temperature is an important factor in SOM decomposition rate and that CO_2 emission will likely increase with increasing temperature.

The texture differences between the soil types did not result in logical responses to the increase in temperature. For example, the Ultisol which had the larger clay content (18.2%) was the only soil where CO_2-C emission decreased with increased temperature was observed (UlNV), but was also the soil type in which the largest increase in CO_2 emission was found (28.1% in the cultivated area – UlCr30). That is, a very significant increase compared with the Entisol Quartzipsamments, which had a clay content of 7.9% but had an emission increase similar to that of Entisol Psamments, mainly the EpNV and EpCr4 with an average clay content of 4.9%.

Several studies have suggested that clay may protect SOM from the decomposition process, and this protection has been attributed to different mechanisms (Six & Paustian, 2014; Von Lützow et al., 2006). One mechanism is physical protection such as afforded by the presence of a large proportion of micropores, that hinder the access of microorganisms to part of the organic matter. There is also chemical protection, which is based on the ability of clays to form organomineral complexes (Krull, Baldock, & Skjemstad, 2003; Von Lützow et al., 2006). However, recent studies have found results indicating that the clay content may not be as decisive in relation to SOM decomposition (Dilustro, Collins, Duncan, & Crawford, 2005; Fissore et al., 2008; Wei et al., 2014). According to Wei et al. (2014), other mechanisms such as microbial adaptation may be important for SOM stabilization and destabilization processes, but this aspect is less studied than physical and chemical mechanisms (Cotrufo, Wallenstein, Boot, Denef, & Paul, 2013). Moreover, the effects of clay on SOM decomposition may interact with other factors, such as temperature. The adsorption of SOM on clay minerals is an exothermic reaction, whereas desorption is endothermic. According to Le Chatelier's principle, an increase in temperature favours the preservation of more reactants in exothermic reactions and may generate more products in endothermic reactions in clayey soils (Wei et al., 2014). This means that temperature increases can stimulate desorption of organic materials and retard their adsorption to clay surfaces, thus enhancing substrate availability (Conant et al., 2011). Consequently, due to this interaction, SOM decomposition in clay soils may be more sensitive to changes in temperature.

The C decomposition in all soil types followed the same pattern as shown in Figure 2. We found that the decomposition rates had declined dramatically by day 40, remaining small and relatively constant up to day 169. As described by Xu et al. (2010), the rapid decline in decomposition rate was probably driven by the progressive depletion of labile C in the SOC being incubated. Since the incubated soil samples were removed from the plant-soil system, the LC pool decomposed rapidly and had no replacement mechanism. With the increased contribution of RC in decomposition of SOC (Fang et al., 2005; Vanhala et al., 2007; Xu et al., 2010), the decomposition rates decreased and stabilized.

Q_{10} is the proportional change in soil respiration for a 10°C increase in temperature and may be used as an important approach to enhance our understanding of SOC dynamics. It allows the evaluation of different aspects, such as the role of the SOM lability, the temperature impact on the sequence in which organic material compounds are decomposed (Conant et al., 2008), the activity of soil microorganisms (Hou et al., 2016) and of soil texture (Wei et al., 2014). Our findings for the Q_{10} index are consistent with studies that have addressed similar topics (Conant et al., 2008; Plante et al., 2010; Xu et al., 2010), where the most studied situations gave larger values of Q_{10} for more resistant soil carbon. The greater sensitivity to temperature increases in the RC is in agreement with basic thermodynamic chemistry described by the Arrhenius equation (Conant et al., 2008; Davidson & Janssens, 2006), according to which, the most resistant C has more activation energy and increases in temperature help increase or stimulate this activation energy and could thus make C-resistant compounds more sensitive to temperature increase (Conant et al., 2008; Vanhala et al., 2007; Xu et al., 2010). However, the differences between the soils types, as well as the land use systems were large, with the systems EqNV, EpNV and EpCr4 having values of Q_{10} much greater than the other systems. Moreover, the variables contemplated in this study such as soil texture, soil carbon and microbial carbon, were not sufficient to explain the differences. Thus, in future studies other variables, such as soil mineralogy, organic matter fractionation and characterization, and organic substrates (litter) should be taken in account to improve the understanding of soil respiration dynamics faced with the temperature increase in the Brazilian semi-arid region.

Finally, in general, the labile carbon component of soils under native vegetation presented greater respiration rates and greater sensitivity to temperature than under other land uses. These results differ from those found in other studies (Birge et al., 2015; Plante et al., 2010), which found that cropland or pasture resulted in greater CO_2 emissions, and attributed this response to the greater lability of particulate organic matter of areas under cultivation. However, in the present study, cultivated areas were subject to grazing after harvest (the usual practice in the Brazilian semi-arid regions), resulting in a reduction in the organic matter input and leaving only the more lignified material on the soil, which is more exposed to decomposition and may contribute to the explanation of the greater sensitivity of the recalcitrant carbon component in the managed systems. Another aspect that could be considered is that native vegetation areas are more favourable to microbial activity because they are environments with less disturbance, resulting in faster rates of decomposition. However, this hypothesis is not reflected in data of microbial C, where it can be observed that microbial population in native areas is not enhanced.

5 | CONCLUSIONS

Our findings showed that a temperature increase of 5°C substantially increased the respiration rate of soils, and consequently increased CO_2 emission in all situations studied. More specifically, we observed that the most recalcitrant organic matter component was more sensitive to temperature increase. Considering that the recalcitrant component contains most of the soil C (e.g., on average 80%), the response of recalcitrant C to changes in temperature can accelerate soil organic C losses, resulting in positive feedback to global warming. Greater soil respiration in native vegetation areas and a trend of higher temperature sensitivity of labile component in these areas in comparison with areas under anthropogenic influence was observed. These results indicate that in the conditions of the Brazilian semi-arid region, it is necessary to think of alternatives to mitigate the effects of global warming, not only for agroecosystems but also for areas of native vegetation (Caatinga). However, the Brazilian semi-arid region is a mosaic of soil types, climatic conditions and management; therefore, further studies contemplating other situations and improving the understanding of the effects of global warming on soils of such regions are needed.

ACKNOWLEDGEMENTS

This research was funded by the Foundation for Research Support of the State of Alagoas (FAPEAL) and the National Council for Scientific and Technological Development (CNPq). We also thank the Federal Institute of Alagoas for providing the vehicle for field trips and farmers of the semi-arid state of Alagoas for their support during collection of soil samples.

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How to cite this article: Maia SMF, Gonzaga GBM, Silva LKDS, Lyra GB, Gomes TCDA. Soil organic carbon temperature sensitivity of different soil types and land use systems in the Brazilian semi-arid region. *Soil Use Manage*. 2019;35:433–442. https://doi.org/10.1111/sum.12508