Research article

Temperature Sensitivity (Q_{10}) of Organic Carbon in Red-yellow Soils and Its Conservation Strategies

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Abstract Soil respiration (SR) is the second largest flux of carbon in most terrestrial ecosystems after photosynthesis. Research indicates that a slight change in climate conditions induces a variation of the SR that could be equal to the release of CO_2 by fossil fuel emissions. For this reason, it is important to study what conditions control the variation of SR. Soil temperature is an important predictor of SR when there is no severe drought stress. The estimation of SR rates by the effect of temperature has been expressed with the Q_{10} relationship. This study aims to determine the Temperature Sensitivity (Q_{10}) coefficient of the red-yellow soil organic carbon and estimate its conservation strategy using biochar. To analyze temperature sensitivity, each treatment was kept under 25ºC and 35ºC for 150 days, and the soil respiration ratio (SRR) as well as soil organic carbon (SOC) content were measured by the spectrophotometry method. Lastly, a treatment of biochar at 5% was added as a carbon conservation mechanism. The experimental results showed a significant difference in SOC content between different temperature conditions. After 150 days under treatment, 35ºC treatment had a significant reduction of SOC in contrast with 25ºC treatment (3.65 and 6.02 mg C/g respectively). The addition of biochar resulted in higher values of SOC at the same temperature, relative to non-biochar treatments. The Q_{10} value was higher in soil without biochar (1.82), while the addition of biochar reduces the coefficient to 1.12. The SRR was reduced gradually with higher values at 35ºC, however, the biochar reduced the emission at 25ºC lower than other treatments. The results indicated that the Q_{10} value of red-yellow soil can be affected by the addition of biochar, which works as a carbon source to maintain and increase SOC content and reduce the release of CO_2 in the short term.

Keywords soil organic carbon, soil respiration rate, temperature sensitive, biochar

INTRODUCTION

The soil organic carbon is part of the organic matter in more than 50% of the content. This fulfills an important role in plant feeding, stabilization of soil structure, soil fertility, and most important, climate change effects mitigation. The soil carbon is dynamic by the interaction of the ecosystem; however, human activity impacts can destabilize SOC into either a net of carbon or a source of greenhouse gases (GHG) in the atmosphere (Trivedi et al., 2018).

The alteration of climate has a considerable effect on the SOC stocks, although it is variable depending on the type of soil and location, Changes in temperature lead to an increase in extreme drought events, followed by the loss of carbon in the soil. Efforts towards a better understanding of the SOC dynamic have indeed been made, however, the mechanism of stabilization and conservation of SOC stocks are still complicated to apply and understand. Further research must focus on the variation of soil and temperature, as well as conservation strategies (Pribyl, 2010).

According to De Oliveira Marques et al. (2017), the Red-yellow soil (Udults soil taxonomy), mainly located in the Amazon area, represents an important amount of global soil carbon, making this area vulnerable to deforestation activities and land uses.

The conservation of carbon stocks in the Amazon area has had an impact on the political decision of governments to act on reforesting rather than permitting deforestation. However, deforestation has been accelerated and the fragmentation process of the Amazon area is resulting in significant changes in carbon stock, as well as biomass soil (Barros and Fearnside, 2016).

Lloyd and Taylor (1994) remarked that the increase of microorganism activity in soil is stimulated by the increase in temperature, leading to an augment of microbial CO_2. This process reduces the SOC, which contributes to the global warming problem. In a short period (one year), the increase in temperature results in a considerable change in microbial activity and decomposition rate.

It has been demonstrated that the decomposition of SOC is higher as the temperature increases, with the biggest proportional increase observed at low temperatures. Are important issue is to estimate in detail to what extent the rising temperature could destabilize SOC and make it available for the decomposition process. The proportion of SOC stored in the world's soils is still argued and it is vulnerable to the impacts of warming of this century (Crowther et al., 2016).

In this study, we model approaches of changes in carbon availability by microbial activity that are needed to have a better understanding of the Red-yellow soil carbon. The Amazon area has an ecological function connected with the SOC, respiration rate, decomposition of organic matter, and estimation of conservation strategies that must be investigated.

OBJECTIVE

This study aims to determine the Temperature Sensitivity (Q_{10}) coefficient of the Red-yellow soil organic carbon, under different conditions of temperature (25 and 35ºC) and estimate its conservation strategy using biochar. The present research provides a new mechanism of climate change mitigation and a better understanding of soil and biochar.

METHODOLOGY

Soil Sample Source and Preparation

The current investigation involved sampling and analyzing three different sites of Red-yellow soil to measure parameters such as SOC and SRR. The sites were selected from Miyako Island, which is located in Okinawa Prefecture, south of Japan. The soil sample was collected from a non-disturbed forested area with four repetitions at each site (Carter and Gregorich, 2008). 1000g of soil was sampled, after that, air-dried soil was sieved and weighed into a labeled tray followed by adding 5% (w/w) of biochar as a biochar treatment and 0% of biochar for control. Samples were kept at approximate field capacity moisture conditions. Each treatment was divided into soil at ambient conditions (25ºC) and warm conditions (35ºC), and biochar rate (0% and 5%).

Soil Organic Carbon Determination

Each one of the treatments and repetitions was analyzed by the spectrophotometric procedure of organic carbon contents of soil (Wallinga et al., 1992). 50 mg (±0.5 mg) of soil was weighed and it was transferred carefully to a dry 100 mL volumetric flask. 10.0 mL of 0.333 M potassium dichromate solution ($K_2Cr_2O_7$) was added to each flask. 16.0 mL of concentrated sulfuric acid was added followed by putting the flasks in a boiling water bath for 45". The samples were cooled in the sink and made up to the volume with distilled water. The samples were centrifuged for 10" at 1000 g force.

For the preparation of the standard series, 100 mL flasks containing 1000 mg sodium oxalate with volumes of 0, 25.0, 50.0, 75.0 and 100.0 mL were used as standard into the volumetric flask. These standard series worked as 0, 5, 10, 15, and 20 mmol Cr^{+3} per liter of solution of standard series.

The absorbance of spectrophotometer Beam 4 nm was measured in a 1 cm cuvette at a wavelength of 590 nm within 2 hours after oxidation. SOC percentages were calculated by multiplying the Cr^{+3} concentrations found by 0.2250/w, where "w" is the weight of the air-dry soil sampled.

Soil Respiration Rate Determination

10 g of air-dried soil was weighed from each treatment into a 450 mL glass bottle followed by adding 3 mL of distilled water. The soil and water were mixed in the bottles and then covered with perforated films to reduce evaporation. The SRR was determined by using the infrared gas analyzer IR400 at time zero and measured again at the end of 1-h incubation (Sparda et al., 2016). The soil respiration rate (SRR, μL CO_2/h/g air-dried soil) was calculated using Eq. (1),

$$SRR = \left(CO_{2f} - CO_{2i}\right) * V * \frac{1000}{S} \tag{1}$$

where CO_{2i} and CO_{2f} are the initial and final CO_2 concentrations (ppm) of the 1-h incubation, respectively, and V is the space volume of the bottle with the soil sample (450 mL). The number of soil (S) was 10.0 g. Four repetitions were measured for each one of the treatments.

Temperature Sensitivity (Q_{10})

The temperature response of SR was estimated through a Q10 function using Eq. (2),

$$Q_{10} = \left(\frac{C_{i35ºC} - C_{f35ºC}}{C_{i25ºC} - C_{f25ºC}}\right)^{\frac{10}{TR-TW}} \tag{2}$$

where Q_{10}, the dependent variable, is the temperature sensitivity of SOC (carbon fluctuation coefficient at one temperature over the flux of a temperature 10º higher), *Ci* and *Cf* are the initial and final carbon respectively (at 25ºC and 35ºC), and finally, TR is the temperature at the regular condition and TW is the warmer temperature of soil (Meyer, et al., 2018).

Statistical Analysis

The comparison of the average of each one of the treatments was analyzed using the Shapiro-Wilk Normality and Levene Homogeneity test. The one-way ANOVA tests were performed to determine if there were differences through variance analysis. Then, the Tukey test was applied to determine the differences between treatments. In addition, a Box-Cox transformation was performed to fit the ANOVA test. All the tests were performed using RStudio (version 1.2.5042) for statistical analyses of the data. Analyses were performed at the significant level of $p \leq 0.05$.

RESULTS AND DISCUSSION

The fluctuation of SOC in a period of 150 days at different treatments of temperature and biochar is shown in Fig. 1. The SOC started at similar conditions, with a value of around 10 mg/g in all treatments. However, values of SOC were decreasing gradually for different rates. Firstly, the result of soil at 25ºC vs. 35ºC with no biochar (Fig. 1a) showed a significant effect of the temperature in the loss of carbon. At day 150, the 35ºC was 3.65 mg/g, considerably lower than 25ºC soil with 6.02 mg/g ($p<0.05$). This difference was described by McTiernan et al. (2003), where the decomposition rate of carbon components increased as temperature rose and was faster in tropical systems.

The addition of biochar kept the carbon content slightly constant. This is shown in Fig. 1b, where the values of treatments started at just over 10 mg/g and decreased just above 7 mg/g. The addition of biochar can increase the SOC (Singh et al., 2012) with the carbonized biomass having a slower decomposition process than fresh plant residues that are kept in the soil for longer periods depending on the amendment type, type of soil, soil conditions and plants, values even in warm conditions kept constant most of the experiment time. Figure. 1c compares treatments in ambient conditions (25ºC) for 150 days. As expected, the reduction of soil carbon was lower than treatment at warmer conditions, moreover, the addition of biochar increased values of soil carbon by 1 mg/g.

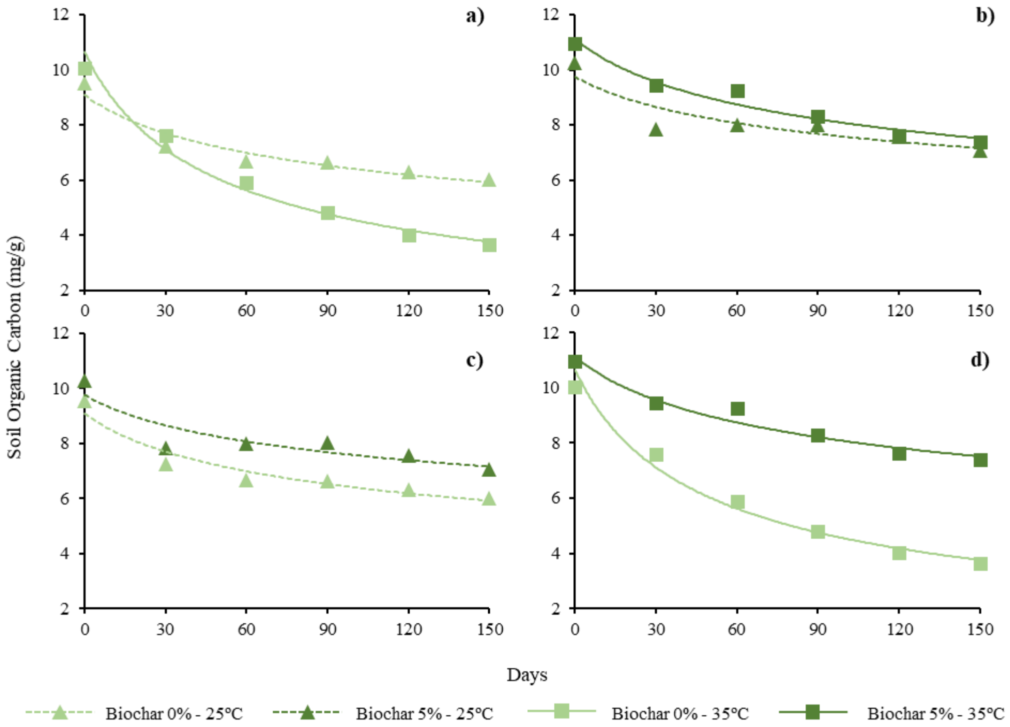

Fig. 1 Soil organic carbon decomposition in 150 days in different conditions

a) no biochar addition at 25ºC vs 35ºC; b) biochar addition at 25ºC vs 35ºC
c) 25ºC with biochar vs no biochar; and d) 35ºC with biochar vs no biochar.

The most remarkable outcome was the contrast of treatments at higher temperatures. Figure 1d provides information about the effect of temperature in soil with biochar addition. As with the previous experiment, values of SOC started above 10 mg/g, followed by a considerable reduction after 150 days. The 0% biochar sample drastically reduces the SOC amount from 10.05 mg/g at day 0 to 3.65 mg/g at day 150. This reduction is explained clearly in different experiences regarding carbon and organic matter degradation by the effect of temperature (Xu et al., 2019).

On the other hand, the addition of biochar showed a significant difference in the rate of degradation and soil organic carbon amount. This value started just below 11 mg/g (10.97 mg/g at day 0) and decreased gradually to 7.39 mg/g at day 150. This value represents more than double the 0% biochar sample at day 150. The action of biochar seems to have several features that preserve and increase the organic carbon amount in the soil. According to Zimmerman et al. (2011), the high surface area and porosity of biochar can increase the nutrient retention capacity of soil and improve the stability of SOC, as well as increase little inputs with higher C: N that will favor the growth and protection of SOC stocks. Nevertheless, Zimmerman reports the enhanced mineralization of existing soil carbon in response to biochar addition as found in the soil respiration rate (Fig. 2).

The action of biochar protects the original soil's organic carbon by reducing carbon emissions. This protection is mainly caused by the variety of aryl functional structures that are derived from aromatic rings (Atkinson et al., 2010). These two main features make the biochar recalcitrant and stable. First, the structure and porosity that physically avoid leaching and enzymatic breakdown of organic material and the chemical structure of biochar that relates to the type of biochar and temperature of production (Kasozi et al., 2010). In this case, the O/C ratio is the essential feature of the recalcitrance, which keeps the soil organic carbon at a higher level.

The soil respiration showed different rates per month. It can be seen in Fig. 2a that the effect of temperature was slightly higher at the beginning of the experiment, yet there were no significant differences at day 150. Values started over 8 μL CO_2/h/g and decreased just over 2 μL CO_2/h/g. The addition of biochar had a different effect on SRR, showing a higher release of CO_2 at 35ºC. In the last three months of the analysis, there was a significant effect between the biochar application and no application (Fig. 2b).

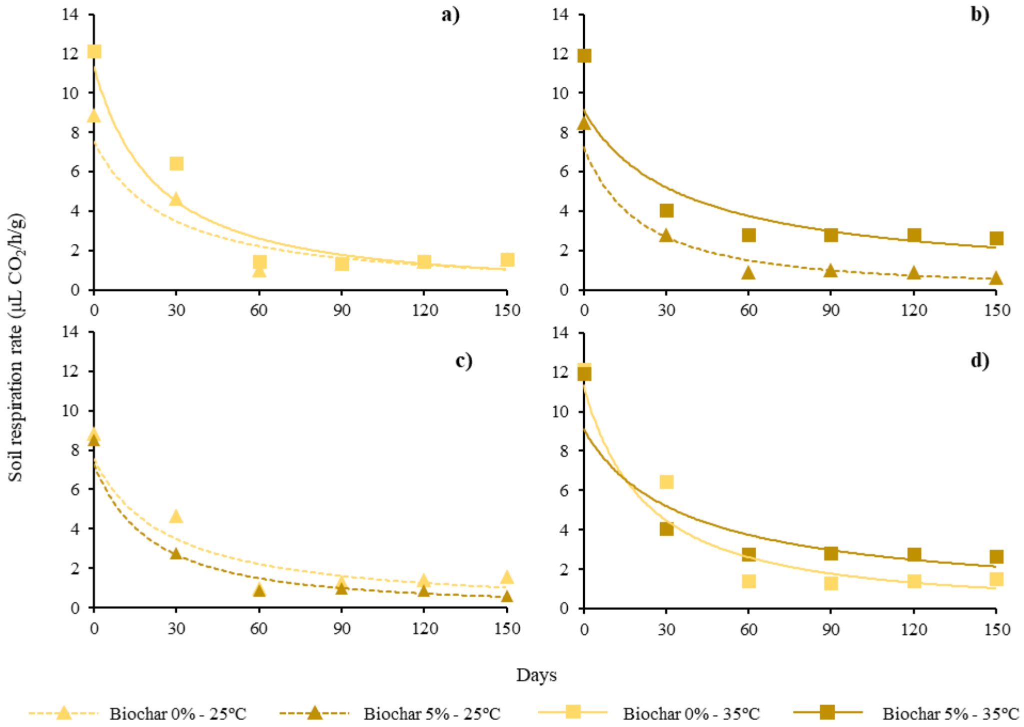

Fig. 2 Soil respiration rate in 150 days in different conditions

a) no biochar addition at 25ºC vs 35ºC; b) biochar addition at 25ºC vs 35ºC
c) 25ºC with biochar vs no biochar; and d) 35ºC with biochar vs no biochar

At ambient conditions (25ºC), the SRR did not show significant changes to the effect of biochar. Values kept constant, starting just over 8 μL CO_2/h/g and dropping just below 2 μL CO_2/h/g as shown in Fig. 2c. On the other hand, Fig. 2d shows the increase of SRR with the addition of biochar in the last period of analysis. By the addition of biochar, values started around 12 μL CO_2/h/g and dropped to 4 and 2 μL CO_2/h/g at 35ºC and 25ºC respectively. The increase in temperature in soil reflects a significant change in microbial activity in the short term. The addition of biochar in soil has affected the SOC amount but the effect on SRR does not show a stabilization in the short-term, as this depends on temperature and microbial activity (Xu et al., 2019). Additionally, Xu et al. (2019) describe the activation and stabilization of carbonized material over a longer period (more than one year), which increases the amount of soil carbon and reduction of CO_2 emission.

Finally, the temperature sensitivity (Q_{10}) described as a coefficient of the effect of temperature in soil organic carbon showed a positive effect of the biochar action. As described in Eqs. (3) and (4), the values of initial SOC were 9.53 and 10.05 mg/g for treatment without biochar and with biochar respectively at 25ºC and 10.97 and 10.27 mg/g for treatment without and with biochar respectively at 35ºC. After 150 days, final values are 3.65 and 6.02 mg/g for treatment without biochar, and 7.39 and 7.07 mg/g when biochar is applied.

$$Q_{10} = \left(\frac{C_{i35^\circ C} - C_{f35^\circ C}}{C_{i25^\circ C} - C_{f25^\circ C}}\right)^{\frac{10}{TR-TW}} = \left(\frac{10.05-3.65}{9.53-6.02}\right)^{\frac{10}{35-25}} = 1.82 \qquad (3)$$

$$Q_{10} = \left(\frac{C_{i35ºC} - C_{f35ºC}}{C_{i25ºC} - C_{f25ºC}}\right)^{\frac{10}{TR-TW}} = \left(\frac{10.97-7.39}{10.27-7.07}\right)^{\frac{10}{35-25}} = 1.12 \quad (4)$$

The outcome of Eq. (3) provides information on the coefficient value of Red-Yellow soil organic carbon with no addition of biochar. This coefficient (1.82) represents a higher dependency of SOC and microbial activity by the effect of temperature. In contrast, the Eq. (4), the addition of biochar reduced this coefficient to 1.12, which represents a reduction of this dependency and an increase in resilient carbon amount. According to Yang Liu and Zhang (2017), the rate of Q_{10} reaction value increases in a certain degree of temperature dependence, thus, the more temperature-dependent the SOC, the higher the value will be Q_{10}.

CONCLUSIONS

It is demonstrated that Red-Yellow soil is highly affected by the effect of temperature, and it can be reduced significantly and so, degraded the soil. Although this type of soil has low organic carbon content, this reduction can be covered by biochar. This black material fulfills a role as a carbon source to maintain and increase SOC content. Connected to this, the addition of biochar not only affects the carbon content but increases the amount of recalcitrant carbon in the soil over longer periods. Due to the high content of Aryl Groups and higher O/C rate, the recalcitrant carbon reduces the mineralization and the degradation of carbon, this allows a higher concentration of SOC even in warm conditions of temperature. It seems to be that biochar works as an important conservation strategy by reducing temperature sensitivity (Q_{10}). Although studies over a longer period must be considered, this outcome represents an alternative for Red-yellow soil in climate change impact and conservation of carbon in the soil.

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