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Carbon dioxide enrichment effects on the decomposition of sugarcane residues

Nilza Patrícia Ramos[1], Thiers Alves Vidal[2], Rebeca Ramos[3], Raffaella Rossetto[4] and Kátia de Lima Nechet[1]

[1]Brazilian Agricultural Research Corporation – Environmental Unit, Jaguariúna, São Paulo State, Brazil; nilza.ramos@embrapa.br
[2]Faculdade de Jaguariúna, Jaguariúna, São Paulo State, Brazil
[3]Pontifícia Universidade Católica, Campinas, São Paulo State, Brazil
[4]Agência Paulista de Tecnologia dos Agronegócios, Piracicaba, São Paulo State, Brazil

Abstract The aim of this study was to determine the decomposition dynamics of sugarcane residue under conditions of enriched atmospheric CO_2 concentration using a FACE facility (Free-Air Carbon Dioxide Enrichment). The experiment, conducted in Jaguariúna, São Paulo State, Brazil, using the ClimapestFACE facility, received two treatments: elevated CO_2 (550 ± 100 µmol mol^{-1}) and ambient CO_2 (400 µmol mol^{-1}), for a single amount (5 t ha^{-1}) of straw (cane trash), in a randomized-block design with six replications. Decomposition was determined by using litter bags with sampling at 0, 14, 36, 60, 90, 119, 179, 291 and 362 days after commencement and determining the remaining biomass (kg ha^{-1}), decomposition rate (%), constant *k* (kg.day^{-1}) and half-life (t½) of decomposition (calculated by first-order exponential model). Results showed significant statistical interaction among treatments, mainly from 90 to 179 days after the beginning of the experiment when the region had high precipitation and, coincidently, the highest straw decomposition rate (4%) at the ambient CO_2 concentration (400 µmol mol^{-1}). After that, there were no statistical differences. Small differences between treatments were not significant to affect the overall behavior of the decomposition dynamic, which followed an exponential behavior, with the same *k* (0.002929 kg $days^{-1}$) for both treatments. Decomposition ratio was high (33%) during the first 36 days, but t½ was 237 days. Final decomposition was 69% with 1.5 t $ha^{-1}$of remaining biomass. We concluded that the increase of atmospheric CO_2 concentration (from 400 to 550 ± 100 µmol mol^{-1}) does not change the dynamic of sugarcane residue decomposition, which is exponential and has its highest biomass loss in the first 36 days after field deposition.

Key words Decomposition, sugarcane residue, climate change, sustainability, FACE

INTRODUCTION

Earth's atmospheric carbon dioxide (CO_2) concentration has increased substantially since the beginning of Industrial Revolution, with a current concentration estimated to be 390-µmol mol^{-1} (Ciais and Sabine 2013). Considering different climate change scenarios, a concentration of 500-1000 µmol mol^{-1} of CO_2 has been estimated for 2100, leading to an increase of up to 4°C in the global temperature (IPCC 2014). These changes in atmospheric CO_2 concentration have reportedly influenced agroecosytems at various scales. Examples are the effects of elevated CO_2 on the physiology of cultivated plants (Chakraborty *et al.* 2008) and interactions of crops and pests (Ghini *et al.* 2011). However, there are few reports on the effect of elevated CO_2 concentration on soil attributes specifically the decomposition and nutrient cycling from crop residues, including those from sugarcane. This is probably due to the difficulty in easily elevating the ambient CO_2 concentration in natural ecosystems by the addition of pure CO_2.

Most of the studies were carried out by using growth chambers or open-top chambers that change other environmental factors, such as luminosity and temperature, and interfere with the real response to applied CO_2. We used Free Air Carbon-Dioxide Enrichment (FACE) experiments to improve this type of investigation under more realistic conditions. FACE facilities allow the exposure of plants to elevated CO_2 under field condition without any enclosure (Leakey *et al.* 2004). In Latin America, the first FACE facility, the ClimapestFACE, is located at Embrapa Environment, in Jaguariúna, São Paulo, Brazil and has been operational since 25 August 2011 (Ghini *et al*. 2015).

In Brazil, sugarcane is widely harvested as green cane, supplying large amounts of sugarcane residue that can exceed 20 t ha^{-1} $year^{-1}$ of dry biomass (Vitti *et al.* 2008). The residue cover promotes the increase of physical (Sparovek and Schnug 2001; Graham *et al.* 2002), chemical (Six *et al.* 2002; Galdos *et al.* 2009; Trivelin *et al.* 2013) and biological (Pankhurst *et*

al. 1999; Moody *et al.* 2009) soil components. Hence, any alteration of the residue decomposition environment can result in a significant change in these parameters.

Litter decomposition is defined as a process resulting from the activity of decomposer micro-organisms on plant litter and it is strongly influenced by environmental conditions (Cotrufo *et al.* 2009) and the chemical composition of the litter (Swift *et al.* 1979). Kutsh *et al*. (2009) reported that studies on interactions of climate change with soil carbon stocks, organic matter decomposition, and microbial respiration are still not conclusive. However, given climate-change scenarios, especially increase in atmospheric CO_2 concentration, some effects on the decomposition process are expected. Therefore, our work aims to determine the decomposition dynamics of sugarcane residue under conditions of increased atmospheric CO_2 concentration, using a FACE experimental facility.

MATERIALS AND METHODS

The experiment was conducted in the ClimapestFACE facility, located in a coffee plantation, at Embrapa Environment, in Jaguariuna, São Paulo, Brazil (latitude 22º42'21 S, longitude 46º59'10 W; altitude of 581 masl). The climapestFACE was laid out in a randomized complete-block design with two treatments (different CO_2 concentrations) and six replications. Each experimental plot consisted of a 10-m-diameter octogonal ring. Six rings represented the control (ambient CO_2 of 400 µmol mol^{-1}) and the other six the elevated-CO_2 treatment (550 ± 100 µmol mol^{-1}) obtained by the injection of pure CO_2 to achieve the target CO_2 concentration (Torre Neto *et al.* 2014). The experimental field was classified as a clayey dystroferric red latosol soil (47% clay, 47 g kg^{-1} sand, 63% silt). The climate is humid subtropical according to the Köppen-Geiger classification. Precipitation and air temperature data over the period of the experiment (Fig. 1) were collected from the ClimapestFACE meteorological station.

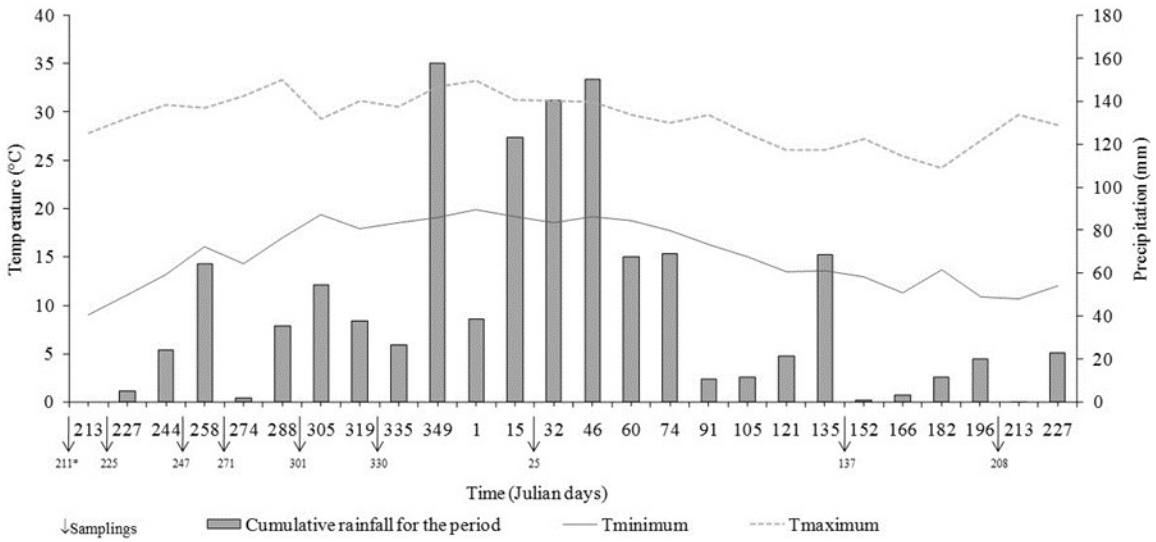

Fig. 1. Precipitation and minimum and maximum air temperatures for August 2014 to August 2015 (in days of the year) at the ClimapestFACE facility.

Decomposition of sugarcane residue (25% of green and 75% of brown leaves, without stalks pieces and with C:N ratio of 101) was assessed between 30 July 2014 and 30 August 2015 (simulating the period between sugarcane harvests). The CO_2 injection occurred during the daylight hours (06:00 to 18:00). The frequency of CO_2 around the target levels for each treatment [400 µmol mol^{-1} (CO_2env) and 550 µmol mol^{-1} (CO_2+)] for each month during the 1- year of evaluation is given in Figure 2.

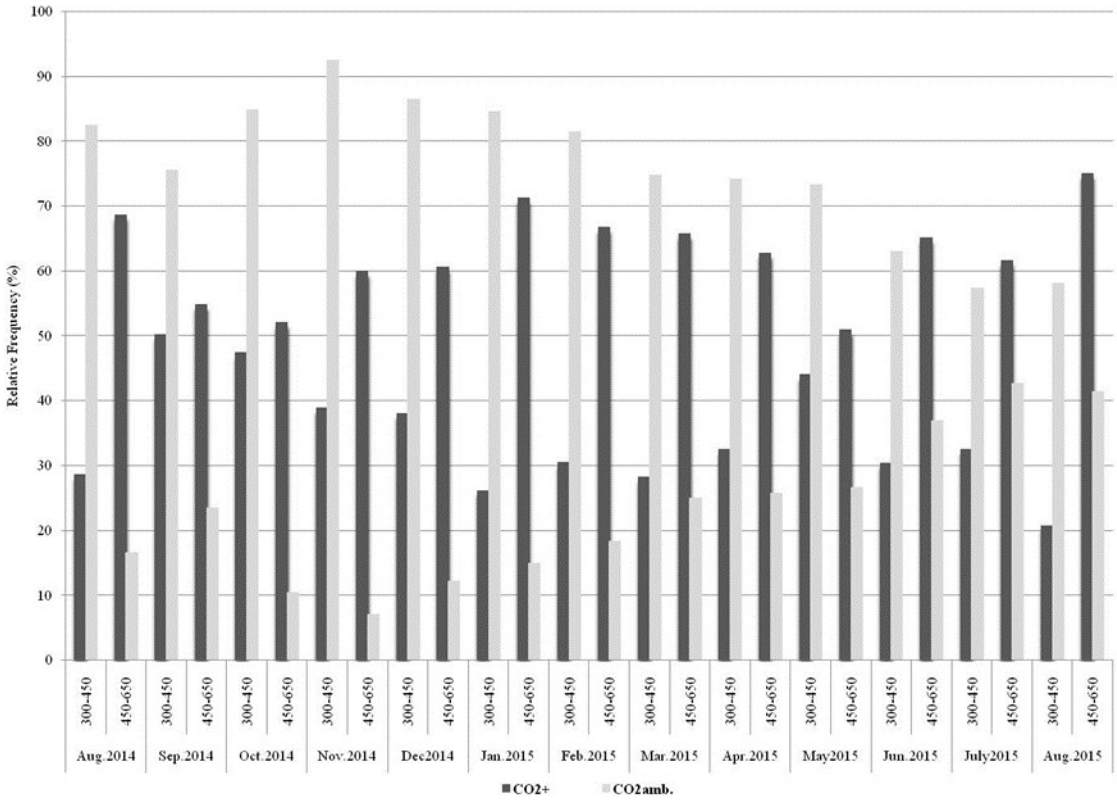

Fig. 2. Frequency of CO_2 levels within 300-450 and 450-650 µmol mol^{-1} (corresponding to a maximum variation of 20% around the target levels of 400 µmol mol^{-1} (CO_2env) and 550 µmol mol^{-1} (CO_2+)) for each month of the experiment in the ClimapestFACE facility.

Sugarcane residue of cv. RB86-7515 was obtained from a commercial area where sugarcane is harvested mechanically. The residue was dried in the shade, with ambient temperature (about 28-30ºC) and homogenized. We monitored the dynamics of residue decomposition using litter bags (20 x 20 cm and 35 mesh size) according to the Bocok and Gilbert (1957) methodology. This involved distributing 24 of these bags containing 20 g dry residue matter (an equivalent of 5 t ha^1 of residue), in each plot between rows of previously established coffee trees. Three bags were randomly collected at 0 (30 July 2014), 14, 36, 60, 90, 119, 179, 291 and 362 days after the trial was established. The collected residue samples were sieved, dried in an air oven at 50ºC for 7 days, and the dry matter determined by precision weighing.

The decomposition dynamic was determined by calculating dry remaining biomass (B_{remain} = y_{final} in kg ha^{-1}) and decomposition rate [$rate_{decomp}$= 100 – (B_{remain}*100/ y_{begin})]. The B_{remain} was also used within the adjusted kinetic equation (Y_{final} = y_{begin}*$exp^{(-k*time)}$) to determine the kinetic constant (*k)* and half-life (t½) of the decomposition process (Thomas and Asakawa 1993). Statistical analysis was performed using the SISVAR v.5.6 statistical software (Ferreira 2014). Significant differences among means were estimated by analysis of variance (ANOVA) followed by t-tests.

RESULTS AND DISCUSSION

The interaction of CO_2 enrichment and time of decomposition resulted in a statistical significant effect on the amount of remaining dry biomass of the residue and its decomposition rate, mainly from 90 to 179 days after the experiment was established (Fig. 3). After and before this period, there were no statistical differences. The sugarcane residue decomposition rate (33%) was highest during the first 36 days of the trial and represented more than 47% of the 69% final dry biomass mineralized over the full 362-day period.

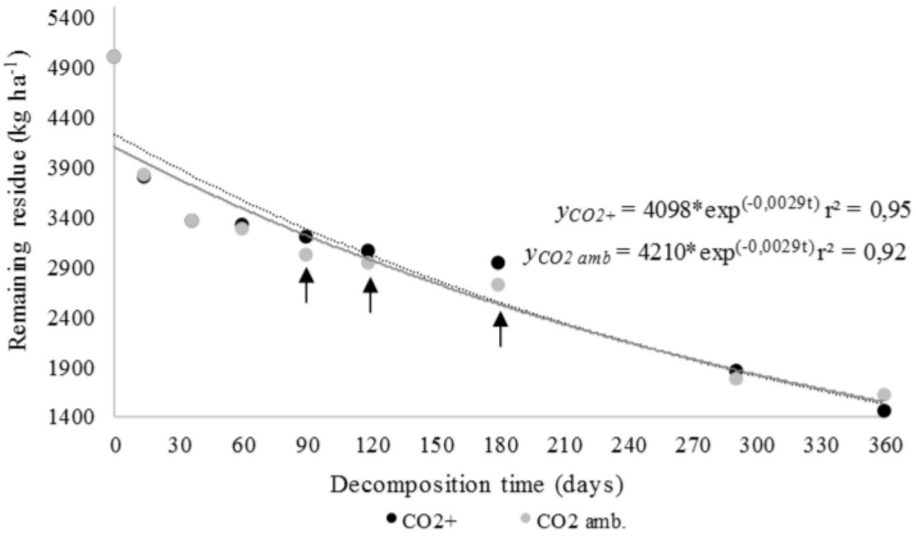

Fig. 3. Remaining residue dry biomass (kg ha^{-1}), represented by first order exponential model, and samplings () with significant differences between CO_2 treatments in the ClimapestFACE facility.

In line with exponential mathematical models that represent the decomposition process of agricultural residues (Thomas and Asakawa 1993), the results confirm the existence of two phases: an accelerated and a slow phase (Fig. 3). The initial accelerated phase is thought to be characterized by the mineralization of less complex compounds (cellulose and hemicellulose) and the second phase by the leaching of recalcitrant elements, such as lignin (Jenkinson and Ayanaba 1977; Fengel and Wegener 1989). However, the decomposition dynamic represented by the exponential model and the constant of decomposition (*k*) were similar in both treatments. Our results showed that the CO_2 enrichment over time does not change the decomposition dynamic of sugarcane residues.

The half-life of the residue decomposition (237 days) was similar in the two CO_2 treatments. The high value (237 days) of this parameter confirmed that decomposition is slow. This was confirmed by the long time (326 days) to mineralize just 69% of the initial residue biomass. Part of this period matches the period of significant statistical differences (90 to 179 days of experimentation) for decomposition rates. The ambient CO_2 treatment had 4% more mineralized biomass than the CO_2 enriched (CO_2+) treatment over this period.

Residue composition, environmental temperature, humidity, and microbial activity are factors that affect the decomposition process (Cotrufo *et al*. 2009), and in our study, only the microbial activity was not controlled. Thus, the differences observed were attributed to changes in the microbial activity in CO_2+ treatment associated with a high precipitation, 538 mm in only 89 days (Fig. 1). In this context, Bardgett *et al.* (2008) claim there is an uncertainty due to climate change (CO_2 and temperature) acting on microbial breakdown of soil organic matter. On the other hand, Kutsh *et al.* (2009) concluded that climate change, in the short-term and mainly through atmospheric temperature, must lead to an adjustment of the soil microflora, which could result in changes of the physiology of particular species and changes of species composition. This change in soil microflora could be harmful for decomposer microbiota, especially the recalcitrant ones that break lignin and act during the slow phase of decomposition process. This was shown in our study where there was an accelerated phase during the first 36 days of the residue decomposition process (Figure 3).

Understanding decomposition dynamics is considered essential for decision making about agricultural residue management during crop cycles, including sugarcane fertilization and nowadays, residue extraction. The main factor contributing to soil quality is the final quantity of mineralized material, and in our study, this was not affected by the CO_2 treatments (Fig. 3). Thus, it is possible that atmospheric CO_2 enrichment will not change the final amount of decomposed sugarcane residue where 69% of the initial residue is decomposed after 1 year. This is in line with the findings of Abramo Filho (1995), Oliveira *et al.* (2002) and Fortes *et al.* (2012) who also found residue decomposition above 60% over one sugarcane cycle under Brazilian field conditions.

Our study adds to our knowledge the effect of climate change on the decomposition process of sugarcane residues. Further studies are required to identify relations between above-belowground microbial communities and the decomposition

process for agricultural residues. There are considerable gaps in our understanding of the response of soil respiration that involve complex interactions with soil microbes, symbionts and herbivores (Bardgett *et al.* 2008).

CONCLUSION

We conclude that the increase of atmospheric CO_2 concentration from 400 to 550 ± 100 µmol mol^{-1} does not change the dynamics of sugarcane residue decomposition, which is exponential and has its highest biomass loss in the first 36 days after placement in the field.

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Effet d'un enrichissement en dioxyde de carbone sur la décomposition des résidus de canne

Résumé. Le but de cette étude était de déterminer les dynamiques de décomposition des résidus de canne en utilisant une enceinte FACE (Free-Air Carbon Dioxide Enrichment) pour enrichir l'air en dioxyde de carbone**.** L'expérimentation conduite à Jaguariúna, état de São Paulo, au Brésil, en utilisant l'enceinte ClimapestFACE comportait deux traitements : atmosphère enrichie en CO_2 (550 ±100 µmol mol^{-1}) et atmosphère ambiante en CO_2 (400 µmol mol^{-1}), pour une même quantité de paille de canne (5 t ha^{-1}), selon un dispositif en blocs randomisés à six répétitions. La dégradation de la paille a été déterminée en utilisant des sachets contenant des résidus de canne échantillonnés à 0, 14, 36, 60, 90, 119, 179, 291 et 362 jours après le début de l'expérimentation, en déterminant la biomasse restante (kg ha^{-1}), le taux de décomposition (%), la constante *k* (kg.$jour^{-1}$) et la demi-vie (t½) de décomposition (calculée selon un modèle exponentiel de premier ordre). Les résultats ont montré une interaction statistiquement significative entre les traitements, principalement de 90 à 179 jours du début de l'expérimentation, pendant une période de forte précipitation, coïncidant avec le plus fort taux de décomposition de la paille (4%) à la concentration ambiante de CO_2 (400 µmol mol^1). Il n'y a pas eu d'autres différences statistiques**.** Les faibles différences entre les traitements n'étaient pas suffisamment significatives pour affecter le comportement global de la dynamique de décomposition qui a suivi une loi exponentielle, avec le même *k* (0.002929 kg $jour^{-1}$) pour les deux traitements. Le taux de décomposition était élevé (33%) les 36 premiers jours, pour une demi-vie de 237 jours. La décomposition finale a été de 69% avec une biomasse restante de 1.5 t ha^{-1}. Nous en avons conclu que l'augmentation de la concentration en CO_2 (de 400 to 550 ± 100 µmol mol^{-1}) ne modifie pas la dynamique de décomposition des résidus de canne, qui est exponentielle avec la plus importante chute de biomasse les 36 premiers jours du positionnement du paillis au champ.

Mots-clés: Décomposition, résidus de canne à sucre, changement climatique, durabilité, FACE

Efectos del incremento de dióxido de carbono en la descomposición de los residuos de caña de azúcar

Resumen. El objetivo del estudio fue determinar la dinámica de descomposición de residuos de caña de azúcar en condiciones de atmósfera enriquecida de CO_2, utilizando una instalación FACE (Free-Air Carbon Dioxide Enrichment). El experimento, realizado en Jaguariúna, São Paulo, Brasil, utilizo la instalación ClimapestFACE y recibió dos tratamientos: niveles elevados de CO_2 (550 ± 100 µmol mol^{-1}) y el CO_2 ambiente (400 µmol mol^{-1}), por un aporte único (5 t ha^{-1}) de la paja (bagazo de caña), en un diseño aleatorio de bloques con seis repeticiones. La descomposición se determinó mediante el uso de bolsas de follaje con el muestreo a los 0, 14, 36, 60, 90, 119, 179, 291 y 362 días después del inicio y la determinación de la biomasa restante (kg ha^{-1}), índice de descomposición (%), constante *k* (kg day^{-1}) y la media vida (t½) de la descomposición (que se calcula por el modelo exponencial de primer orden). Los resultados mostraron una interacción estadísticamente significativa entre tratamientos, principalmente de 90 a 179 días después del inicio del experimento, en que la región tenía alta precipitación y coincidentemente, la más alta tasa de descomposición de la paja de (4%) a la concentración de CO_2 ambiente (400 µmol mol^{-1}). Después de eso, no hubo diferencias estadísticas. Las pequeñas diferencias entre los tratamientos no fueron significativas para afectar el comportamiento general de la dinámica de descomposición, que siguió un comportamiento exponencial, con la misma k (0.002929 kg $día^{-1}$) para ambos tratamientos. El índice de descomposición fue alto (33%) durante los primeros 36 días, pero la t½ fue de 237 días. La descomposición final fue de 69% con biomasa de 1,5 t ha^{-1} de la restante. Llegamos a la conclusión de que el aumento de la concentración de CO^2 en la atmósfera (400 a 550 ± 100 µmol mol^{-1}) no cambia la dinámica de la descomposición de los residuos de caña de azúcar, que es exponencial y tiene su pérdida de biomasa más alta en los primeros 36 días después de la deposición de campo.

Palabras clave: Descomposición, residuos de caña de azúcar, cambio climático, sostenibilidad, FACE