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Research paper

Greenhouse gas emission responses to sugarcane straw removal

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ABSTRACT

Sugarcane straw has been identified as an important feedstock to increase bioenergy production. However, changes in greenhouse gas (GHG) emissions due to straw removal are not yet understood. We hypothesized that partial straw removal changes decomposition rates and could change GHG fluxes. We performed a field experiment within the largest sugarcane-producing region of Brazil (São Paulo state) to assess GHG fluxes and straw decomposition. The treatments were: no-removal – 12 Mg ha^{-1} left on soil surface; medium removal – 6 Mg ha^{-1}; high removal – 3 Mg ha^{-1}; and total removal – bare soil. Static chambers were used to quantify GHG fluxes, and straw decomposition was measured using bottomless plastic boxes over a period of 180 days. Our findings showed that GHG were affected by the straw removal, although daily emissions were highly variable. Cumulative CO_2 and N_2O emissions were 35–45% lower under bare soil compared to other removal; however under no removal the CH_4 uptake was 40% higher compared to bare soil. High straw decomposition was found in the no-removal, which decreased with the removal intensity. C released by straw decomposition was estimated between 0.5 and 3.1 Mg ha^{-1}. By analyzing the C balance in C equivalent (Ceq) between decomposition and emissions we estimated that about 3.5 Mg ha^{-1} of straw are necessary to neutralize GHG emissions from soil and straw decomposition. Finally, we suggest that medium straw (~6 Mg ha^{-1}) maintenance would be a suitable strategy to increase bioenergy production and preserves adequate soil cover, as well as offsetting losses in soil C stocks.

1. Introduction

In recent decades, global energy demand and concerns about climate change have led to a significant increase in the production of bioenergy [1]. This demand has boosted the cultivation of sugarcane in Brazil, which is considered one of the best raw-materials, which is both economically and environmentally sustainable, for bioenergy (bioethanol and bioelectricity) production in the world [2].

Brazil accounts for 35% of the world's sugarcane production, and 657 million tons of stalks were harvested from 9 million hectares in 2017/2018 [3]. Considering that 10–20 Mg ha^{-1} (dry mass) of aboveground crop residues (straw) are produced each year [4], it is possible that part of this residue may be left on the soil surface and the rest harvested as raw-material for other industrial uses (i.e., bioenergy production).

The maintenance of sugarcane straw in the field can promote soil carbon accumulation [5,6], nutrient cycling [6,7], improvement of soil structural quality [5], erosion protection and reduction of soil losses [8,9], biological activity [10], reduction in soil temperature variations [11] and an increase in soil moisture [12]. On the other hand, the increase in bioelectricity co-generation from biomass (bagasse and straw) burning and, more recently, cellulosic-bioethanol production (i.e., second-generation bioethanol) has increased the interest of the sugarcane industry in using the straw remaining in the field as a potential bioenergy feedstock [4]. Hence, Brazilian governmental projections indicate a potential for the production of about 10 billion liters of cellulosic bioethanol from sugarcane straw by 2025 [13] and that 17% of the domestic electric energy production will be provided by sugarcane biomass by 2023 [14].

Although sugarcane straw has the potential to be used as a bioenergy feedstock, the effects of straw removal management on field GHG fluxes are still unknown. In the literature, investigations of GHG emissions related to crop residue management are not conclusive with respect to an increase or reduction of fluxes [15–18]. The high variability of the GHG data makes it difficult to determine the specific interaction between the factors that can influence these emissions

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[19,20]. However, changes in GHG emissions could be linked to soil conditions due to the amount of straw left on the soil surface (i.e., covering surface, decomposition rates, C and N added, maintenance of soil moisture and others), favoring soil biota activity and, consequently, altering GHG fluxes [17,21].

Therefore, we hypothesized that the partial removal of the sugarcane straw changes soil conditions as well as straw decomposition rates and, consequently, could change GHG fluxes. Besides, this straw removal management could modify the relative proportion of each gas in the total emissions, reducing the contribution of N_2O and CH_4 in relation to CO_2. To test this hypothesis, we conducted a field experiment aiming to quantify the GHG fluxes and straw decomposition under different intensities of sugarcane straw removal in south-central Brazil.

2. Material and methods

2.1. Site description and sampling strategy

This study was conducted in an area cultivated with sugarcane near Piracicaba city, São Paulo state (22° 41′ 55″ S, 47° 33′ 33″ W). The climate is classified as Cwa - humid subtropical (Köppen classification), with dry mild winters and rainy summers. The mean annual rainfall is approximately 1400 mm, and the average annual temperature is 22.9 °C. February is the hottest month, averaging 24.7 °C, and July is the coldest month, averaging 17.7 °C. The soil is a Typic Acrudox [22] with 34% clay, bulk density of 1.38 Mg m^{-3}, pH (water) of 5.8, 23 g kg^{-1} of organic matter, 27 mg dm^{-3} of available phosphorus and 52% base saturation.

This area was cultivated with the sugarcane variety SP 80–3280, which was planted in September 2014 and harvested in December 2015 (i.e., at the end of the sugarcane-harvesting season in this region). The experiment was initiated by quantifying the sugarcane straw on the soil surface immediately after harvesting. Straw was collected from five 1-m^2 quadrants randomly distributed within the area. A straw sample was also collected in raffia bags and stored in a cold chamber (~7 °C) for 12 days, until the experiment was installed in the field. The straw was composed of approximately 40% tops and green leaves and 60% dried leaves in a heterogeneous shredded mixture with pieces ranging from 7x1 to 22 × 5 cm. All the material collected inside the quadrants was dried at 60 °C until it reached a constant weight. Total C and N were determined using an elemental analyzer (LECO© TrusPec®, Michigan, USA). The total amount of straw left on the soil surface postharvest was about 12 Mg ha^{-1} of dry matter (with ~40% moisture content), with total C and N contents of 420 g kg^{-1} and 8.2 g kg^{-1}, respectively.

The field experiment was installed on January 4, 2016 in order to (i) quantify the GHG fluxes from the soil and the straw and (ii) evaluate the decomposition of the straw placed in the space between the rows of regrown sugarcane. To isolate only the response of straw decomposition on the GHG fluxes, no input (mineral or organic fertilizer, lime or agrochemicals) was applied to the sugarcane regrowth during the experiment.

The experimental design was completely randomized with four replications of four intensities of straw removal (treatments): i) no-removal (NR, 12 Mg ha^{-1} of dry matter maintained on the soil surface), ii) medium removal (MR, 6 Mg ha^{-1} of dry matter maintained), iii) high removal (HR, 3 Mg ha^{-1} of dry matter maintained) and iv) total removal (TR, bare soil). Measurements were made between January and July 2016, over a period of 180 days.

2.2. GHG sampling and analysis

The chambers used to collect GHG fluxes consisted of a base and a lid. The chamber measured 30 (ø) x 10 (H) cm and was buried in the soil 2–3 cm deep leaving an approximate volume of 5.5 L (discounting the straw volume). Pre-weighed straw was added into the sampling chamber: 217.6, 108.5 and 54.3 g (wet mass), equivalent to 12, 6 and 3 Mg ha^{-1} of dry matter, respectively. In addition, a total removal treatment was included, i.e., 0 Mg ha^{-1} of dry matter. For each intensity of straw removal (treatment) four chambers were installed (totaling 16 chambers) that remained in the field throughout the experimental period. Around the chambers (~1-m^2), an amount of straw equivalent to the treatments was added to maintain a similar soil cover.

GHG sampling started on January 5, 2016. Air samples from within the chambers were taken with a 20 mL nylon syringe (Becton Dickinson Ind. Surgical Inc.) at four sampling times (0, 10, 20 and 30 min) counted from the closing of the chambers. All GHG sampling was performed in the morning, between 10:00 and 11:00 h. During the sampling, environmental temperature, atmospheric pressure and precipitation were monitored.

GHG concentrations were measured by gas chromatography (SRI-GC-110®, Torrance, USA) with a HAYESP™ packed column (80–100 mesh) maintained at 82 °C to separate molecular gases. N_2O concentration was quantified using an electron capture detector (ECD) operating at 325 °C, and CO_2 and CH_4 concentrations were determined by a flame ionization detector (FID).

GHG fluxes were calculated by the linear change in the amount of each gas in the chambers (obtained by the Clapeyron equation) as a function of incubation time (30 min). Cumulative (integral) GHGs were calculated by linear interpolation of the daily gas fluxes (after extrapolation from hourly to daily fluxes) between two successive samples by the trapezoidal rule [23], with the numerical integration considering the days after the start of sampling until the end of the experiment. To calculate the N_2O emission factor (N_2O_{EF}) from the N released by straw decomposition, the difference in the cumulative N_2O from the treatments with increasing straw removal intensity after discounting the value for bare soil was used, according to the methodology described in Guidelines for National Inventories of Greenhouse Gases [24]. The CH_4 and N_2O fluxes were converted into CO_2 and C-equivalent (CO_2e and Ceq) according to their global warming potentials (GWP_{100}) of 25 and 298, respectively [25].

2.3. Straw decomposition: sampling and analysis

The straw decomposition experiment also started on January 4, 2016. To plastic bottomless boxes measuring 35 (W) x 55 (L) x 20 (H) cm, 591.4, 295.7 or 147.8 g (wet mass) of straw was added, equivalent to 12, 6 or 3 Mg ha^{-1} of dry matter, respectively, with four replications. Around the boxes (~1-m^2), an amount of straw equivalent to the treatments was placed in order to maintain the same soil cover. Destructive straw samples (four boxes for each treatment/sampling time) were collected on the 30th, 70th, 120th and 180th days after the installation of the experiment. Therefore, the total number of boxes evaluated was 64 (i.e., 4 treatments x 4 sampling times x 4 replications). All material inside the boxes was collected and taken to the laboratory to be dried at 60 °C until a constant weight was reached. The dry matter results were corrected by the ash content in order to exclude the effect of straw contamination by soil at the sampling time. Straw ashes were measured for each site by calcining 1 g of straw dry matter aliquot in a muffle furnace at 550 °C for 2 h [26].

The dynamics of the straw decomposition was modeled using equation (1) [26]:

$$R = I.e^{-kt} \quad (1)$$

Where: R is the remaining fraction in the dry matter at time t in days; I is the potentially decomposable fraction in dry mass and, k is the constant of decomposition.

Using the k value the half-life ($T_{1/2}$) of residues was estimated using equation (2) [27]:

$$T_{1/2} = (\ln 2)/k \quad (2)$$