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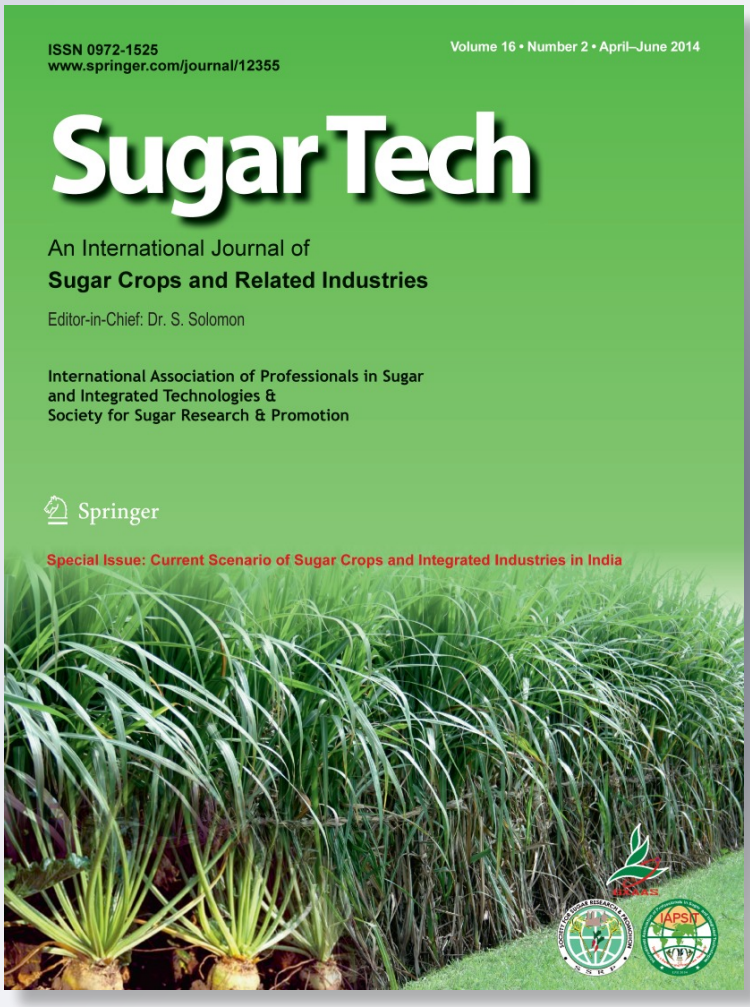

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RESEARCH ARTICLE

Greenhouse Gas Emissions from Green-Harvested Sugarcane With and Without Post-harvest Burning in Tucumán, Argentina

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Abstract Concentrations of greenhouse gases (GHG) in the atmosphere are increasing due to anthropogenic actions, and agriculture is one of the most important contributors. This study quantified GHG emissions from green-cane harvested sugarcane with and without post-harvest burning in Tucumán (Argentina). A field trial was conducted in Tucumán during the 2011/2012 season using a randomised complete-block design with four replications. Treatments were: (a) harvest without sugarcane burning (neither before nor after), and (b) harvest with trash burnt after harvest. The method used to capture gases (CO_2, CH_4 and N_2O) in the crop cycle was based on closed-vented chambers, while quantification was by gas chromatography. There were significant emission rates of CO_2 and N_2O during the sugarcane cycle in Tucumán, but no evidence of CH_4 emissions or uptakes. N_2O and CO_2 emission rates were higher in the no-burning treatment than in the burnt, but only in part of the crop cycle. The former is apparently associated with the application of nitrogen fertiliser, while the higher CO_2 emissions seem to be associated with trash retention. There were no significant correlations between environmental factors and emission rates. Although these results seem pessimistic, in the context of an entire crop GHG balance (including the emissions due to burning before or after harvest) green-cane harvesting without burning could effectively lead to a reduction of total GHG emissions during the crop cycle.

Keywords Carbon dioxide · Nitrous oxide · Methane · Emission rates · Sugarcane

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Introduction

Concentrations of greenhouse gases (GHG) have been increasing through anthropogenic action since the Industrial Revolution at annual rates of 0.4, 0.6 and 0.25 % for CO_2, CH_4 and N_2O, respectively (IPCC 1996). These gases are characterised by their long persistence in the atmosphere, generating increased radiation and higher temperatures that destroy the ozone layer and lead to Earth's global warming (Mosier et al. 1998). Thus, there is great interest in the international community in determining and quantifying the main sources of GHG in order to reduce their emissions and prevent their accumulation in the atmosphere.

One of the most important sources of anthropogenic GHG emissions is agriculture, producing 12–14 % of the total GHG generated by humans (IPCC 2006). Estimates for 2005 show that this sector produced about 50 and 60 % of the total anthropogenic emissions of CH_4 and N_2O, respectively, whilst the CO_2 balance was neutral if electricity and fuel CO_2 emissions associated with agricultural production are not counted. Both CH_4 and N_2O are potent

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GHG, with global warming potentials 25 and 298 times higher than CO_2, respectively (IPCC 2007).

Argentinean agricultural and livestock sectors produce 44 % of the total GHG emissions generated in country (Fundación Bariloche 2005). However, these estimates were calculated using the international global factors proposed by the Intergovernmental Panel on Climate Change (IPCC), not with specific local ones. The United Nations Framework Convention on Climate Change has encouraged parties to communicate their GHG (CO_2, CH_4 and N_2O) emissions from different sectors (e.g. energetic, industrial, agricultural, etc.). In Brazil, sugarcane burning represents 98 % of agricultural GHG emissions (Lima et al. 1999), and Correa de Campos (2003) showed a reduction of about 5 t C-CO_2/ha/year when sugarcane was managed without burning.

Burning is a traditional practice in Argentinian sugarcane, either before and/or after harvesting (Digonzelli et al. 2006; Scandaliaris et al. 2002). As burning biomass emits considerable amounts of GHG to the atmosphere, it affects the balance between emission and capture of GHG (Lima et al. 1999). Hence, it is important to determine the local sugarcane GHG emission factors in Tucumán, the main sugarcane area of Argentina. Better GHG estimates would allow the industry to compete better in the international biofuel market where requirements for environmental sustainability are growing continuously. If the Argentinian sugar and alcohol industry expects to take part in future international markets, it must adjust to those requirements. It is also probable that, in the near future, these international standards will be required for accessing even the domestic market.

We aimed to quantify GHG emissions from sugarcane in Tucumán, taking account of the traditional burning practice and alternatives for sustainable crop management.

Materials and Methods

A field trial was conducted in Tucuman during 2011–2012 on a typical Apludol soil characterized as silty clay loam. The area has a mean annual precipitation of 1,250 mm and the mean temperatures in January and July are 24.8 and 11.9 °C, respectively. Treatments were: (a) no burning before or after harvest; and (b) trash burning after harvest. All plots were harvested mechanically. Plots (each six rows by 20 m long) were arranged in a randomized complete-block design with four replications. Nitrogen fertilizer (as urea) was band-applied near the crop row at a rate of 101 kg N/ha.

Two close-vented chambers (Hutchinson and Livingston 2001; Parkin et al. 2003) per plot (one in the crop row and the other in the inter-row) were used to capture gases (CO_2, CH_4 and N_2O) throughout the crop cycle. Chambers, composed of non-reactive PVC, had a volume of 3 L and a diameter of 15 cm. These chambers allowed the collection of gases emitted by soil and trash over constant periods of time. Gases were always collected, between 10:30 am and 12:30 pm to minimize diurnal variations, by means of vacuum pumps, and were stored in evacuated 10 mL vials. Time periods used in this study were 0, 20 and 40 min.

Emissions of GHG were measured monthly over the course of the growing season, beginning after the harvest of the preceding crop (15 September 2011) and ending at the following harvest (15 July 2012). At each sampling, soil moisture and soil nitrate contents, and temperatures at 15 cm depth were determined. Air temperature at canopy level was also measured. Soil-moisture content was determined by a gravimetric method by drying samples to a constant weight at 110 °C for 72 h. Soil-nitrate contents were determined using the nitracheck reflectometer methodology (Merckoquant nitrate strips, Merck KGaA, Germany). The soil solution was extracted from each soil sample by adding 100 mL of KCl solution to each 100 g of sampled soil. After vigorous shaking for 40 min, the soil solution was filtered.

GHG concentrations were quantified by gas chromatography. CO_2 and CH_4 determinations were made by means of a flame-ionization detector (using a methanizer in the case of CO_2), while N_2O concentrations were obtained using an electron-capture detector.

Gas fluxes were calculated from the rate of change of the concentration of the compound of interest in the chamber headspace. We used a linear regression between GHG concentration and sampling time (Parkin et al. 2003), and results were expressed in micrograms of trace gas per square meter and hour ($\mu g/m^2/h$).

Results

There were different GHG emissions through the sugarcane cycle in Tucumán for the three analyzed gases (CO_2, N_2O and CH_4) and for both treatments (no burning and burning after harvest).

CO_2 emission rates increased from about 63,000 $\mu g/m^2/h$ at the post-harvest sampling to about 114,000 $\mu g/m^2/h$ at tillering in the no-burning treatment (Fig. 1).In the same period, the burnt treatment decreased its emission rates to about 30,000 $\mu g/m^2/h$ following the burning but then increased to about 80,000 $\mu g/m^2/h$ at tillering. At tillering, the no-burning treatment emitted 43 % more CO_2 than the burnt one. After tillering, emission rates in both treatments decreased to about 26,000 $\mu g/m^2/h$ at canopy closure. From then, emission rates decreased in both treatments up until harvest (about 10,000 $\mu g/m^2/h$).

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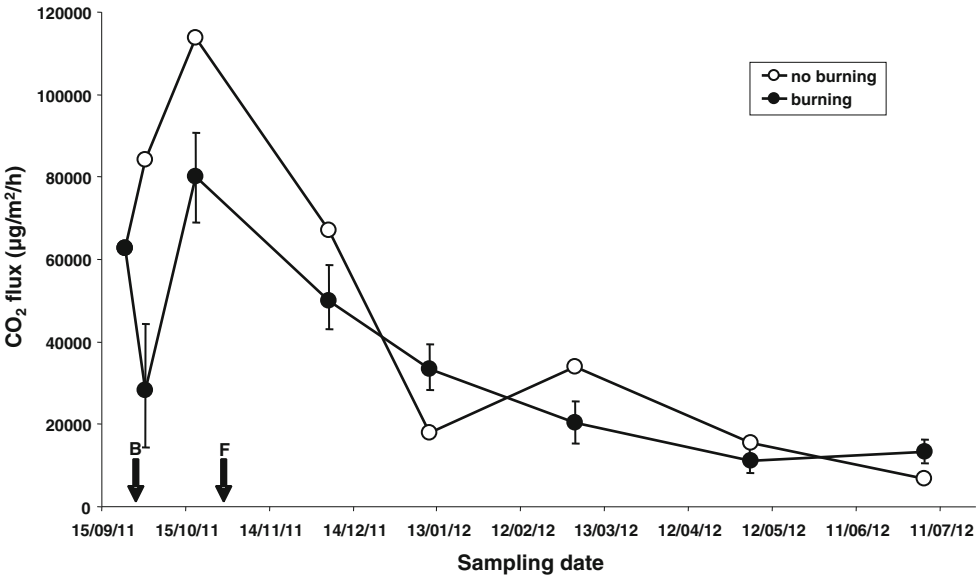

Fig. 1 CO_2 flux along the crop cycle in Tucumán for sugarcane harvested with (*closed symbols*) and without (*open symbols*) post-harvest burning. *Arrows* indicate burning (*B*) and fertilization (*F*) dates. *Bars* stands for the standard error of the means for each sampling date

Initially, N_2O emission rates decreased in a similar way in both treatments from about 228 µg/m^2/h at the post-harvest sampling to about 26 µg/m^2/h at tillering (Fig. 2). However, emission rates in the no-burning treatment increased greatly after nitrogen fertilization to about 222 µg/m^2/h, while the burnt treatment only slightly increased its emission rates to about 39 µg/m^2/h. This emission trend continued to the sampling at the maximum growth phase, when both treatments had similar emission rates of about 31 µg/m^2/h. Similar emission rates continued until harvest. During the period from post-fertilization to the maximum growth phase, the no-burning treatment emitted 247 % more N_2O than the burnt one.

There were no significant CH_4 emissions or uptakes during the crop cycle, with the trends being similar for both treatments through the crop cycle and ranging from −0.0085 to 0.0052 µg/m^2/h.

In general, there were no significant correlations during the crop cycle between environmental factors and emission rates for any of the gases analyzed. However, CO_2 emission rates were significantly correlated with (i) soil temperature in the burnt treatment ($r = 0.53$; $p \leq 0.051$; $n = 48$), and (ii) air temperature in both treatments ($r = 0.58$; $p \leq 0.028$; $n = 48$ for the burnt treatment and $r = 0.63$; $p \leq 0.019$; $n = 48$ for the no-burning treatment).

Discussion

Our results represent the first measurements of GHG sugarcane emissions in Tucumán. They showed significant CO_2 and N_2O emission rates during the crop cycle, but no evidence of CH_4 emissions or uptakes.

CO_2 emission rates ranged between about 10,000 and 114,000 µg/m^2/h over the entire crop cycle. These emissions are significantly lower than those reported by Brazilian (São Paulo area) studies (Correa de Campos 2003; La Scala Jr et al. 2006; Rachid et al. 2012). We explain this partially by the lower precipitation and temperatures in Tucumán (1,250 versus 1,500 mm and 19.1 versus 23.1 °C for Tucumán and Brazil, respectively).

Our results showed much higher CO_2 emissions during the pre-tillering period in the burnt treatment than in the no-burning treatment, an increase in the rate by as much as 43 %. Correa de Campos (2003) and Rachid et al. (2012) reported similar CO_2 emission rates during the sugarcane cycle for no-burning and burnt treatments. We attribute the significant difference to the effect of fire on soil microorganisms and on the availability of decomposable carbon.

N_2O emission rates varied through the crop cycle from about 26 to about 228 µg/m^2/h. This variation through the season was apparently associated with the application of nitrogen fertiliser. These emission values are higher than the range of 30–85 µg/m^2/h during the sugarcane cycle reported by Correa de Campos (2003) and Rachid et al. (2012) Brazil. These differences could be associated with the higher rates of fertiliser used in Tucumán (110 versus 73 kgN/ha for Tucumán and Brazil, respectively). Weier (1999), who fertilised sugarcane in Australia with 73 kgN/ha, reported N_2O emission rates of 37–590 µg/m^2/h during the 104 days after the harvest. However, in that case, measurements were made with a different sampling regimen,

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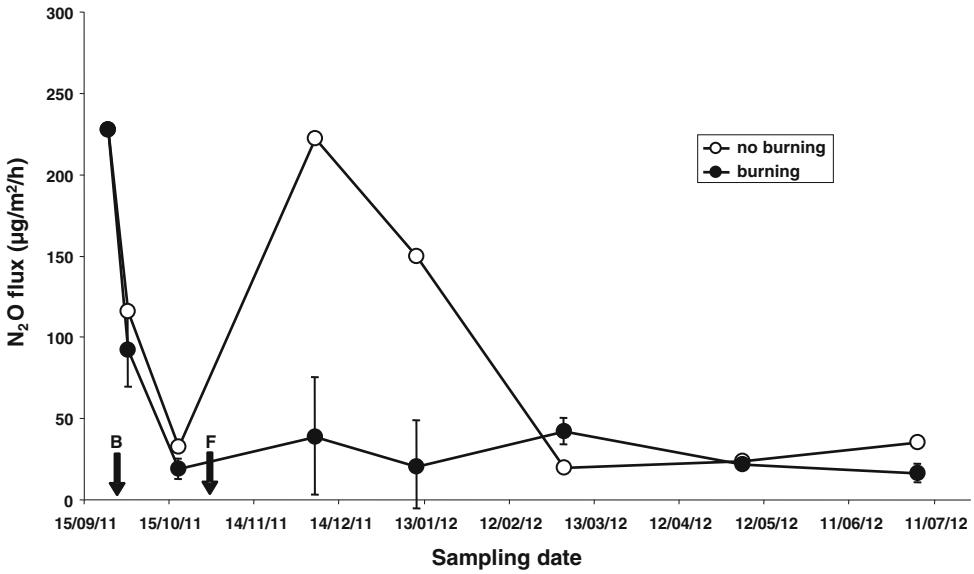

Fig. 2 N_2O flux along the crop cycle in Tucumán for sugarcane harvested with (*closed symbols*) and without (*open symbols*) post-harvest burning. *Arrows* indicate burning (*B*) and fertilization (*F*) dates. *Bars* stands for the standard error of the means for each sampling date

and were on a soil with 80 % of water-filled pore space where denitrification losses could be expected to be high.

Our burnt crop generated 247 % lower N_2O emission rates than the no-burning treatment in Tucumán. This trend started at fertiliser application, so could be associated with the effect of fire on soil microorganisms. Although there are differences in the magnitude of rates, these results agree with Rachid et al. (2012) in that burning decreased N_2O emission rates. However, they differed from Correa de Campos (2003) who reported similar N_2O emission rates for both burnt and no-burning treatments.

We found no significant CH_4 emissions or uptakes during the sugarcane cycle in Tucumán in both treatments (no-burning and burnt). These results differed from those obtained in Brazil by Correa de Campos (2003) and Rachid et al. (2012) who reported CH_4 emission rates of 43 and 10 µg/m^2/h, respectively. Moreover, Correa de Campos (2003) reported that his burnt treatment resulted in uptakes of CH_4 at rates of 66 µg/m^2/h. Although there were differences between this study and the Brazilian ones, CH_4 emission rates were meaningful if compared with those reported for the other gases. However, Weier (1999) in Australia reported CH_4 emission rates of 333 µg/m^2/h, probably because their soil was water-logged with up to 80 % of water-filled pore space.

Surprisingly, we found no important correlations between environmental factors and emission rates, although those factors are usually reported to be associated with GHG emissions (e.g. Fang and Moncrieff 2001; Huttunen et al. 2003; Kosugi et al. 2007; de Figueiredo Brito et al. 2009). By contrast, Jantalia et al. (2008) reported no correlations between gas flux and environmental factors. However, all of the studies showing significant correlations between environmental factors and GHG emissions were carried out over more than 1 year of field study, unlike our study that reports the results of only 1 year. We consider that more years of research under the sugarcane area of Tucumán are probably needed to make definitive conclusions about GHG emissions and the environmental factors related to them.

Conclusions

Although our results are based on 1 year data, they have considerable value as they are the first measurements of GHG sugarcane emissions in Tucumán. There were significant emission rates of CO_2 and N_2O during the sugarcane cycle in Tucumán, while there was no evidence of CH_4 emissions or uptakes. N_2O and CO_2 emissions were higher in the no-burning treatment than in the burnt one during part of the crop cycle. The former is apparently associated with the application of nitrogen fertiliser, whilst the higher CO_2 emissions seem to be associated with trash retention. There were no important correlations between environmental factors and emission rates.

Although these results seem pessimistic, in the context of an entire crop GHG balance (including the emissions due to burning before or after harvest) green-cane harvesting could effectively lead to a reduction of total GHG emissions during the crop cycle.

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