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Short communication

CO_2 and N_2O flux balance on soybean fields during growth and fallow periods in the Argentine Pampas—A study case

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ABSTRACT

The estimation of the GHG balance of agroecosystems is essential to evaluate the impact of agriculture on the composition of the atmosphere. Cultivated soils may act as a sink or a source of CO_2 and usually emit N_2O. The aim of the present study was to assess the CO_2 and N_2O balances, and to analyze the relationships between N_2O fluxes and environmental variables for two soybean growing seasons and the fallow period between them, in an agricultural field in the Pampas region of Argentina. The fluxes of CO_2 and N_2O were measured by the eddy covariance and the static-chamber methods, respectively. The net ecosystem exchange from sowing to harvest was −2543 and −2307 kg CO_2-C ha^{-1}, for the first and second growing seasons, respectively. The N_2O net balance over the same periods was 1.45 and 0.96 kg N_2O-N ha^{-1}. A multivariate analysis showed that during the growing season the most important variable influencing N_2O emission was % water filled pore space (% WFPS), followed by nitrate content and soil temperature. During fallow, soil temperature was the main control factor, followed by % WPFS. The total balance (including CO_2 and N_2O) showed that the soil gained 753.5 kg Ceq ha^{-1} on average during cultivarion cycle. Taking into account the fallow period, the global balance resulted in a carbon loss of 1328.5 kg Ceq ha^{-1} over about one year. Our results clearly indicate the need to incorporate winter cover crops for improving the production system, as they can provide carbon to the soil and use the available stubble nitrogen from the previous crop.

1. Introduction

Agricultural ecosystems seem to play a major and increasing role in the balance of greenhouse gases (GHG) (Green et al., 2005; Salinger, 2007). Therefore, the estimation of the GHG balance of agroecosystems is essential to evaluate the impact of agriculture on the composition of the atmosphere (Rosenberg et al., 1998). It is important to gather regional-scale data because GHG emissions vary with climate condition, soil type, crop variety and management practices. The principal GHGs emitted from agricultural activities are CO_2 (associated with the balance between photosynthesis and respiration), N_2O (associated with soil nitrogen availability) and CH_4 (associated with flooded areas and livestock). The CO_2 balance is mainly controlled by solar radiation, temperature, phenological stage and vegetation type. N_2O emissions are primarily determined by the activity of soil microbes, carbon and nitrogen availability. Meta-analyses have shown that rates of fertilizer application and soil properties such as organic matter content, texture, drainage and pH, influence emission rates (Bouwman et al., 2002). These factors affect the source of processes of nitrification and denitrification (Dobbie and Smith, 2001), but agricultural management practices are of equal or greater importance (Rees et al., 2013). The multiplicity of factors that affect the balance of GHGs in the croplands may explain, in part, the wide disparity of results in the literature (Hénault et al., 2012).

In Argentina soybean has gained increasing importance since 1970, and currently occupies 60% of the total agricultural land, displacing other crops and activities such as livestock farming. This country is one of the major grain exporters in the world, particularly of soybean, maize and wheat. The objectives of this study were to quantify the CO_2 and N_2O balances in the Rolling Pampa region and to analyze the relationships between N_2O fluxes and environmental variables for two soybean growing seasons plus the winter fallow period between them. This region is the main

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cropland area of Argentina with the longest agricultural history of the country (Hall et al., 1992; Soriano et al., 1991; Viglizzo et al., 2001), and is among the world's most productive areas (Satorre and Slafer, 1999).

2. Materials and methods

2.1. Study site

The study area consisted of two adjacent private agricultural fields (34° 38′ 29.7″ S 59° 28′ 31.7″ W), 110 km west of Buenos Aires City (Argentina). This area is part of the Rolling Pampa region, within the phytogeographic district of the Pampa grasslands (Soriano et al., 1991). The landscape is almost flat (35 m asl) and the soil is classified as typical Argiudoll (Gouin series, INTA-SAGyP, 1990). The soil has a pH of 5.7 and contains 3.50% of mean organic matter, 2.03% of organic carbon and 0.19% of organic nitrogen. Mean annual rainfall is 978 mm and mean annual temperature is 16.5 °C (INTA-Pergamino database, 1967–2004). The fields occupied a total area of 39.6 ha and were managed under no-tillage for at least the last 15 years, with a typical crop rotation of soybean, maize, wheat and oat.

The study was performed between October 15, 2010 and June 30, 2012. There were two consecutive soybean growing seasons during this period. In the first season, soybean crop was sown on October 16, 2010 and harvested on April 15, 2011. Rows were spaced 40 cm apart and plant density was 38 plants m^{-2}. In winter 2011 both fields remained uncultivated. In the second season one field was sown with maize on September 19, 2011, while the other field was sown with soybean on November 12, 2011. The soybean field was harvested on April 14, 2012. We did not take into account fluxes in the maize field because our objective was to quantify GHG balance of soybean fields. Monthly mean air temperature was similar to historical records, between 9.3 and 23.9 °C. Precipitation was slightly lower than its historical mean in December 2010, October 2011 and early summer 2011/2012 (Fig. 1).

2.2. Measurement of CO_2 fluxes

Fluxes of CO_2 were obtained by the eddy covariance method (Aubinet et al., 2000; Lee et al., 2004; for details of the experimental set-up see Posse et al., 2014) and computed with standard procedures (Aubinet et al., 2012), such as 30-min block averaging, de-spiking, two-dimensional rotation for anemometer tilt correction and frequency response correction, using the EddyPro software (Li-Cor Inc., Lincoln, Nebraska, USA). Invalid data (e.g. night-time fluxes under non-turbulent conditions) were removed and gap filling was carried out applying the methodology of Reichstein et al. (2005). During the second growing season, when on one field was cultivated soybean and on the adjacent field maize, the CO_2 fluxes on the soybean field were determined by using a methodology proposed by Posse et al. (2014). By convention, positive flux values represent mass transfer into the atmosphere and away from the surface and negative values denote the reverse.

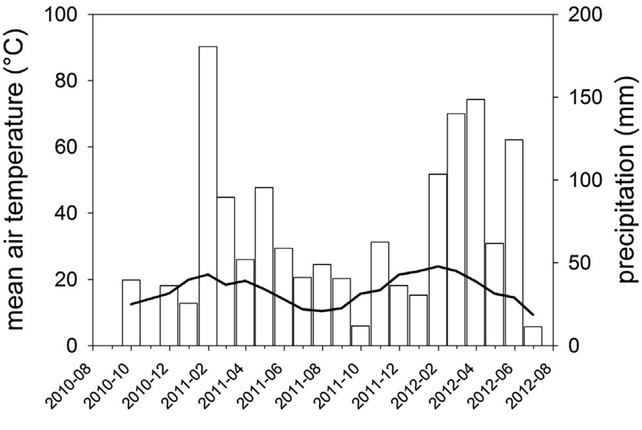

Fig. 1. Mean monthly temperature (lines) and monthly accumulated precipitation (bars) during the study period.

2.3. Static chamber measurements of N_2O fluxes

The N_2O fluxes were determined by the static chamber method using vented static chambers (Parkin and Venterea, 2010; Rochette and Bertrand, 2008) which were randomly placed on each soybean field (four per field). The chambers, covered with a reflective insulation, were 37 cm long, 25.5 cm wide and 14 cm high. Since we aimed at characterizing the entire ecosystem, plants (with their roots) had to be included in the study area. Therefore, we placed each chamber on a row also covering half of each side inter-row. After each sampling, the anchors were replaced into other sites of the field for the next measurement. Measurements were carried out from mid December 2010 to June 2012, once a month on average. Measurements have not been carried out between June 30 and November 23, 2011. When plant height exceeded that of the chambers, the stems were cut to less than 2 cm above the soil before installing the chamber on the anchor. On four different dates, we evaluated whether plant cutting affected N_2O flux rates. We compared the emission rates obtained from chambers including plants with those obtained from chambers without plants, and the results were not significantly different ($p = 0.5155$, data not shown).

On each sampling date, three 10 mL-air samples were collected at 15-min intervals (0, 15, 30 min) between 09.00 and 12.00 a.m. for all dates. Air temperature and soil temperature at 10 cm depth were recorded during each sampling date. As soon as possible, the N_2O concentration was measured using a gas chromatograph (Agilent Technologies 6890N) equipped with a 63 Ni electron capture detector (HP-Plot Molesieve, 30 m × 530 μm × 25 μm). The carrier gas was nitrogen (N_2). The injector, oven and detector temperatures were 100, 150 and 300 °C, respectively. Nitrous oxide fluxes were calculated by the linear regression method (Venterea, 2010) because our sampling dates reached the conditions to use this approach.

After gas sampling, two samples of soil from the area enclosed by the chamber were taken at 10 cm depth. One of these samples was used to estimate the soil bulk density (BD) by means of 0.05 m-diameter cylinders (98.17 cm^3), and the gravimetric water content (GWC) by oven-drying at 105 °C for 48 h. The percentage of water-filled pore space (% WFPS) was calculated according to the formula of Parton et al. (2001). The other soil sample was used to determine the NO_3^--N content by the steam distillation method (Bremner, 1965; Keeney and Nelson, 1982). Ammonium content was not determined due to economic constraints. To analyze the relationship between environment conditions and N_2O emission rates we used a decision tree analysis based on the procedure of Morgan and Sonquist (1963). N_2O emission was considered as the dependent variable and NO_3^--N content, % WFPS and soil temperature as the regressor variables (Di Rienzo et al., 2012). The crop growing season and the fallow period were analyzed separately.

The overall balance was calculated on the one hand by summing up daily values of carbon exchange from the eddy covariance method and on the other hand, by calculating a weighted time average between measurements of N_2O from the closed chambers. N_2O values were converted to gram-carbon equivalents taking into account their relative warming potential. For both gases, data from