Agricultural and Forest Meteorology 150 (2010) 748–756

Contents lists available at ScienceDirect

Agricultural and Forest Meteorology

journal homepage: www.elsevier.com/locate/agrformet

Emissions of methane and nitrous oxide from Australian sugarcane soils

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ARTICLE INFO

Article history:
Received 22 November 2008
Received in revised form 15 June 2009
Accepted 25 June 2009

Keywords:
Flux-gradient techniques
Automatic chambers
Fourier transform infrared spectroscopy
Acid sulfate soils

ABSTRACT

Climatic conditions and cultural practices in the sub-tropical and tropical high-rainfall regions in which sugarcane is grown in Australia are conducive to rapid carbon and nitrogen cycling. Previous research has identified substantial exchanges of methane (CH_4) and nitrous oxide (N_2O) between sugarcane soils and the atmosphere. However, that research has been mostly short-term. This paper describes recent work aimed at quantifying exchanges of CH_4 and N_2O from fertilised sugarcane soils over whole growing seasons. Micrometeorological and chamber techniques provided continuous measurements of gas emissions in whole-of-season studies in a burnt-cane crop on an acid sulfate soil (ASS) that was fertilised with 160 kg nitrogen (N) ha^{-1} as urea in the south of the sugarcane belt (Site 1), and in a crop on a more representative trash-blanketed soil fertilised with 150 kg urea-N ha^{-1} in the north (Site 2). Site 1 was a strong source of CH_4 with a seasonal emission (over 342 days) of 19.9 kg CH_4 ha^{-1}. That rate corresponds to 0.5–5% of those expected from rice and wetlands. The many drains in the region appear to be the main source. The net annual emission of CH_4 at Site 2 over 292 days was essentially zero, which contradicts predictions that trash-blankets on the soil are net CH_4 sinks. Emissions of N_2O from the ASS at Site 1 were extraordinarily large and prolonged, totalling 72.1 kg N_2O ha^{-1} (45.9 kg N ha^{-1}) and persisting at substantial rates for 5 months. The high porosity and frequent wetting with consequent high water filled pore space and the high carbon content of the soil appear to be important drivers of N_2O production. At Site 2, emissions were much smaller, totalling 7.4 kg N_2O ha^{-1} (4.7 kg N ha^{-1}), most of which was emitted in less than 3 months. The emission factors for N_2O (the proportion of fertiliser nitrogen emitted as N_2O–N) were 21% at Site 1 and 2.8% at Site 2. Both factors exceed the default national inventory value of 1.25%. Calculations suggest that annual N_2O production from Australian sugarcane soils is around 3.8 kt N_2O, which is about one-half a previous estimate based on short-term measurements, and although ASS constitute only about 4% of Australia's sugarcane soils, they could contribute about 25% of soil emissions of N_2O from sugarcane. The uptake of 50–94 t CO_2 ha^{-1} from the atmosphere by the crops at both sites was offset by emissions of CH_4 and N_2O to the atmosphere amounting to 22 t CO_2-e ha^{-1} at Site 1 and 2 t CO_2-e ha^{-1} at Site 2.

1. Introduction

Sugarcane is produced on 430,000 ha in sub-tropical and tropical high-rainfall regions on the east coast of Australia. The current farming practice in a large part of the industry is to employ a system of trash-blanketing whereby the green foliage is separated from the cane stalks during the harvesting operation and returned as a trash mulch to the soil surface at a rate of 15–20 t dry matter (ca. 6–8 t C) ha^{-1}. Around 30% of the industry employs a burnt-cane system in which the foliage is removed by burning before harvesting the cane stalks.

The high soil temperatures, high soil moisture regimes, high levels of available C and the high rates of mineral N fertiliser commonly used in the industry (ca. 150 kg N ha^{-1} y^{-1}) can all be expected to intensify the normal processes of carbon and nitrogen cycling in sugarcane soils. Research over the last decade has shown that there can be substantial exchanges of CH_4 and N_2O between sugarcane crops and the atmosphere. Weier (1998), for instance, used the results of experiments where urea was applied to microplots to estimate that fertilised sugarcane soils without a trash cover on the soil emit 17 kg N_2O ha^{-1} y^{-1} and soils with a trash blanket emit 20 kg N_2O ha^{-1} y^{-1} (13 kg N ha^{-1} y^{-1}). Applying

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doi:10.1016/j.agrformet.2009.06.018

these rates to the total Australian sugarcane crop resulted in an estimated production from sugarcane soils of 7.1 kt N_2O y^{-1}. From similar experiments and calculations, Weier (1998) estimated that trash-blanketed sugarcane soils might consume around 0.8 kg CH_4 ha^{-1} d^{-1}. Denmead et al. (2005) measured emissions of CH_4 and N_2O from an acid sulfate soil (ASS) producing sugarcane in the south of the sugar belt and found emissions of CH_4 that were comparable with those from rice and wetlands and emissions of N_2O that were several times higher than those usually reported for other agricultural soils. However, those and other estimates of greenhouse gas exchange by sugarcane soils are based on short-term studies covering only a few days and do not represent the whole of the growing season or the range of soil and climatic conditions encountered over the sugar growing areas. Both Weier (1998) and Dalal et al. (2003) have pointed to the need for a project entailing comprehensive, multi-season measurements made with state of the art technology.

This paper describes recent work aimed at quantifying exchanges of CH_4 and N_2O from sugarcane soils over whole growing seasons and identifying driving factors. It was conducted at 2 sites in sub-tropical and tropical Australia: one a fertilised ASS producing sugarcane with a burnt-cane system on the coastal lowlands of northern New South Wales (Site 1) which occupy around 4% of the cane-growing lands, and the other a fertilised, sandy loam (Chromosol) with a trash-blanketed system at Mackay, Queensland (Site 2), considered to be more representative of soils and cultural practices in the industry. The studies employed both micrometeorological and chamber techniques. Both systems provided continuous measurements over the whole growing seasons (342 days at Site 1 and 292 days at Site 2) with some missing periods due to equipment breakdown and adverse weather conditions. The research permits a re-evaluation of emissions of CH_4 and N_2O from Australian sugarcane soils and provides data for assessing the greenhouse consequences of increased sugarcane production for biofuels. Various aspects of the research described here have been published previously in conference proceedings (Denmead et al., 2006, 2007, 2008; Wang et al., 2008). The present paper draws them together to provide an overview of the project and its findings.

2. Methods

2.1. Sites and crop management

2.1.1. Site 1

The area is an estuary flood plain and is under extensive sugarcane production. The soils on the farm where the measurements were made are sulfuric and are classified formally as Sulfaquets and Humaquets (Soil Survey Staff, 1998), commonly referred as acid sulfate soils (ASS). During periods of high rainfall, they are often inundated. They are characterised by a surface organic horizon 0.2–0.3 m deep (a clay loam with 9.8% organic carbon and pH $\sim$ 5), a strongly acidic A2 horizon (pH < 4) extending to around 0.5 m, a reduced B horizon and often, a water table at depths of 0.5–0.7 m. The acidic A2 horizon is formed from the oxidation of pyrite. An extended description of the soil has been given by Wilson et al. (1999).

Sugarcane is harvested annually and regenerates vegetatively (ratoons) for $\sim$5 years. Emission measurements were made in a block of first-ratoon cane that had been burnt before harvest. Measurements commenced on 14 October, 2005 just prior to the application of urea fertiliser on 18 October. The application rate was equivalent to 160 kg N ha^{-1} and the fertiliser was applied in slits cut to a depth of 10–15 cm on each side of the plant row and then covered with soil. At that time, the mean height of the plants was 0.4 m. The measurements reported here are for the 342 days between 14 October, 2005 and 20 September, 2006. By the end of the investigation, the cane had grown to a height of 4 m. Rainfall for the period was 1879 mm and the mean air temperature was 20.8 °C.

2.1.2. Site 2

Emissions were measured in a block of trash-blanketed fifth-ratoon cane. The soil is a sandy loam (Chromosol) with 1.7% organic carbon and pH 4.7 in the top 0.3 m. It is described locally as a Pioneer non-calcic brown soil. The rate of fertiliser application was 150 kg N ha^{-1}, just less than that at Site 1, but fertiliser was applied in only one band instead of two as at Site 1. Measurements commenced on 8 November, 2006 and fertiliser was applied on 19 November, 2006. At the start of the measurement period, the plants were 0.4 m high. Measurements continued until 7 September, 2007 when the plants were 4.1 m high, and the block was harvested on 5 October, 2007. Rainfall over the measurement period of 292 days totalled 2142 mm and the mean air temperature was 22.4 °C.

2.2. Emission measurements

Both micrometeorological and chamber techniques were employed.

2.2.1. Micrometeorological

Micrometeorological techniques can provide continuous measurements of gas exchange between crop and atmosphere. The advantage of these approaches is that they measure average gas fluxes over areas of hundreds of m^2 to a few ha, depending on the measurement height, thereby reducing the point to point variability which bedevils chamber flux measurements. A commonly used flux-gradient technique was employed at Site 1 to measure emissions of both N_2O and CH_4. Recent descriptions of this approach for measuring emissions on a landscape scale have been provided by Prueger and Kustas (2005). Specific applications to N_2O emissions have been given by Pattey et al. (2007) and Phillips et al. (2007), and applications to CH_4 emissions by Laubach and Kelliher (2004) and Pattey et al. (2006). The method uses measurements of aerodynamic properties, atmospheric stability and the change with height of the mean atmospheric densities $\bar{\rho}_g$ of the gases of interest in the air layer above the crop. The emission rate of the gas, F_g, is calculated from the relationship

$$F_g = \frac{k u_* (\bar{\rho}_{g,1} - \bar{\rho}_{g,2})}{\ln[(z_2 - d)/(z_1 - d)] - [\psi(z_2 - d) - \psi(z_1 - d)]}, \tag{1}$$

where k is the von Karman constant, u_* is the friction velocity, z_1 is the lower height of measurement and z_2 the upper, d is the height of the zero-plane displacement, and ψ is a correction for atmospheric stability. For ψ, we have followed Paulson (1970) in using integrated forms of stability functions. For unstable atmospheric conditions, we have used the function proposed by Dyer and Hicks (1970) and for stable conditions, the function given by Webb (1970). These lead to $\psi = 2\ln\{(1 + x^2)/2\}$ for the unstable case, where $x = \{1 - 16(z - d)/L\}^{1/4}$, and $\psi = -5(z - d)/L\}$ for the stable case. In the foregoing, L is the Obukhov length $(= -\bar{\rho}_a c_p u_*{}^3 \bar{\theta}/kgH$, $\bar{\rho}_a$, being the mean density of air, c_p the specific heat of air at constant pressure, $\bar{\theta}$ the mean potential temperature, g the acceleration due to gravity and H the sensible heat flux).

In our studies, z_1, was set initially at 1 m above the top of the cane and z_2 at 1.5 m above that. As the crop grew, z_1 and z_2 were shifted incrementally to maintain a height of 1 m above the crop with z_2 still at 1.5 m above that. A three-dimensional sonic anemometer (Campbell Scientific CSAT3) mounted at 1.5–2 m