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Gaseous emissions from an intensive vegetable farm measured with slant-path FTIR technique

Mei Bai[a,*], Helen Suter[a], Shu Kee Lam[a], Rohan Davies[b], Thomas K. Flesch[c], Deli Chen[a]

[a] School of Agriculture and Food, Faculty of Veterinary and Agricultural Sciences, The University of Melbourne, Parkville, VIC 3010, Australia
[b] BASF Australia Ltd., Southbank, VIC 3006, Australia
[c] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB T6G 2R3, Canada

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ABSTRACT

A recently developed slant-path flux gradient (FG) technique, combined with open-path Fourier transform infrared (OP-FTIR) spectroscopy, was deployed to concurrently measure gas emissions of ammonia (NH_3), nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4) from an intensive vegetable farm in Australia. Gas fluxes were continuously measured for three weeks following chicken manure application to a celery crop, followed by intermittent measurements for three days a week for another three weeks. The average flux measured over the 41 day measurement period for NH_3 and N_2O, was 5.2 and 2.9 $mg\,N\,m^{-2}\,h^{-1}$, respectively, CH_4 was 1.1 $mg\,C\,m^{-2}\,h^{-1}$, and CO_2 was 0.7 $C\,g\,m^{-2}\,h^{-1}$. Manure and fertilizer application substantially increased the emissions of these gases, by providing carbon (C) and nitrogen (N) substrates to the soil. The cumulative N losses as NH_3 and N_2O following fertilizer application were 6.7% and 3.7% of total N applied, respectively. Using this FG/OP-FTIR technique, we demonstrated that the N_2O emission factor for this vegetable farm is much higher than the IPCC default emission factor for manure applied to managed lands. These results highlight the need for large-scale measurements to quantify multiple gas losses from intensive agricultural systems.

1. Introduction

Nitrogen (N) fertilizers are applied to croplands to increase food production, but more than half of the applied N can be lost to the atmosphere as ammonia (NH_3) and the greenhouse gas (GHG) nitrous oxide (N_2O) (Chen et al., 2008; Mosier, 1994). This results in financial loss to the producer and can cause environmental pollution. Increased atmospheric N_2O concentrations contribute to stratospheric ozone depletion (Hutchinson and Mosier, 1979) and global warming (Forster et al., 2007). Ammonia in the atmosphere worsens air quality and deposition of NH_3 onto land may subsequently lead to indirect N_2O emission (de Klein et al., 2006). Furthermore, fertilized soils are hotspots of other GHGs (Smith et al., 2007b), such as carbon dioxide (CO_2) through stimulating heterotrophic microbial activities (Jezierska-Tys and Frąc, 2007) and methane (CH_4) through methanogenesis under anaerobic conditions (Dalal et al., 2008). In intensive agricultural systems such as vegetable farms, animal manures (in addition to chemical fertilizers) are commonly surface broadcast on the vegetable growing beds during plant growth. This practice would likely increase the emissions of NH_3, N_2O and CH_4 (Chadwick et al., 2011; Heller et al., 2010; Sommer and Hutchings, 2001).

Accurate measurement of NH_3, N_2O, CO_2 and CH_4 emissions in situ is vital to develop inventories of regional and national emissions. Whilst numerous studies have examined the emissions of individual gas species (Bouwman et al., 2002; Denmead et al., 1977; Mosier, 1994; Norman et al., 1997; Smith et al., 2007a; Sommer et al., 2004b), studies looking simultaneously at a suite of important GHGs are lacking. Measurements are complicated by the reactive nature of NH_3 (a "sticky" gas, readily absorbs to surfaces) (McGinn and Janzen, 1998), by the large temporal and spatial variability in N_2O emissions (Neftel et al., 2010; Turner et al., 2008), and by the cost of multiple sensors needed for continuous emission measurements of multiple gases.

Various techniques have been used to quantify gaseous emissions from agricultural farmlands. For example, the chamber method used in conjunction with gas chromatography has been used extensively to measure fluxes from soil (Mosier and Mack, 1980). However, this technique interferes with the soil microclimate and has low temporal and spatial resolution, although some chamber studies are conducted over many months to provide a longer temporal coverage. Ammonia emissions from fertilized soils can also be estimated by cumulative absorption on an acidic medium (Ferm, 1979), or by using a passive sampler/denuder to absorb diffused NH_3 when air is pumped through a

* Corresponding author.
E-mail address: mei.bai@unimelb.edu.au (M. Bai).

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sampler over a period of time (Leuning et al., 1985). Using these passive techniques, the horizontal flux of NH_3 can be obtained by integration of absorbed NH_3 and the air flow rate associated with wind speed and direction. These techniques are labour intensive (McGinn and Janzen, 1998). Micrometeorological techniques can provide a real-time integration of trace gas emissions with a large measurement footprint. Nevertheless, some of these micrometeorological techniques require expensive fast-response concentration sensors (e.g. quantum cascade lasers), while others require complex configurations (e.g. heated sample inlet, pumps) in the field, and the measurement of background concentration (needed with some techniques) can be problematic. For example, Bai et al. (2014) measured the fluxes of NH_3 and N_2O from an intensive celery farm using an inverse-dispersion micrometeorological technique combined with open-path Fourier transform infrared (OP-FTIR) spectroscopic technique, but uncertainty was introduced to the flux calculation when the background concentrations were not well-defined (Lam et al., 2015).

In this study, we utilized a recently developed slant-path flux gradient (FG) technique (Flesch et al., 2016) combined with OP-FTIR spectroscopy to measure emissions of NH_3, N_2O, CO_2, and CH_4. Instead of using a traditional FG calculation based on measuring point concentration at two or more heights, the slant-path FG calculation uses open-path concentrations measured over vertically separated paths. This allows emissions to be measured with a single open-path sensor paired with an aiming system to direct the sensor to high and low measurement paths. The objective of this study was to quantify gaseous emissions following manure application to a vegetable crop by simultaneously measuring the fluxes of NH_3, N_2O, CO_2, and CH_4 using the slant-path FG/OP-FTIR technique.

2. Materials and methods

2.1. Experimental site

The experiment was conducted at a commercial vegetable farm at Clyde (38°07'38''S, 145°19'53''E), Victoria, Australia, from 24 March to 6 May 2014. The experimental site (220 × 248 m) was open and flat (Fig. 1), with a fetch (the distance between the upwind source edges and the OP-FTIR system) greater than 90 m. During this study, there were no other emission sources nearby that could contribute to the measurements. The soil was classified as a Chromosol (Isbell, 1996), with a sandy loam topsoil (0–15 cm) with a pH ($CaCl_2$) of 6.2, cation exchange capacity (CEC) of 15.0 meq (100 g)$^{-1}$, organic C content of 2.2% and total N of 0.24%. During the experimental period the average minimum and maximum temperatures were 6 and 33 °C, respectively. The daily-average wind speed (at 3.0 m above ground) ranged from 0.2 – 5.5 m s^{-1} and the total precipitation (rainfall and irrigation) was 186 mm.

Celery plants at the 4 – 5 leaf stage were transplanted to the site on 24 February prior to starting the experiment. On 28 March, chicken manure (4.3% N, $NH_4{}^+$–N: 4633 mg kg^{-1}, $NO_3{}^-$–N: 313 mg kg^{-1}, dry matter content: 77%, pH: 6.8) was surface broadcast on the celery growing beds at a total rate of 353 kg N ha^{-1} (8.2 Mg manure ha^{-1}). On 1 April, fertilizer, Cal-Gran (a mixture of calcium ammonium nitrate and ammonium sulphate, total 23.9% N), was topdressed on the beds at total 38 kg N ha^{-1} on 1April. The application rates and methods of manure and fertilizer followed the commercial farm practices in this region. On each sampling day, fifteen soil sample cores were collected at 0 – 15 cm depth (2.5 cm diameter) in each quadrant of the paddocks following a transect path, from both the bed and furrow areas. There were total of 10 sampling days. Subsamples (20 g, < 2 mm, dried at 40 °C) were extracted with 100 mL 2 M potassium chloride for the analysis of $NH_4{}^+$ and $NO_3{}^-$ by a segmented flow analyzer (Skalar SAN + +). Background emission measurements were conducted for three days prior to the manure application. Continuous emission measurements following the manure application began on 28 March and continued until 16 April when the daily flux dropped to background levels, and thereafter measurements were made over three days each week up to 6 May to identify any residual NH_3 flux. The timeline of the study (measurements, crop management and N application) is summarized in Table 1.

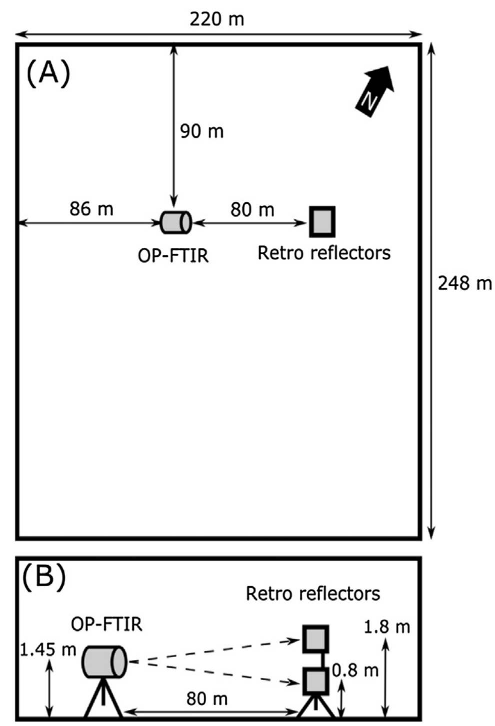

Fig. 1. The design of the study (A), and the slant-path OP-FTIR system configuration (B). The arrows (A) show the distance between the OP-FTIR and the retro reflector (80 m), and between the OP-FTIR and the boundaries of experimental site (86 and 90 m). The height of the OP-FTIR (B) was measured relative to the celery bed surface. Figure is not to scale.

2.2. Flux measurements

Following Flesch et al. (2016), gas fluxes of NH_3, N_2O, CO_2 and CH_4 were measured with a modified FG technique. A single OP-FTIR sensor with an aiming motor was deployed to give line-average gas concentrations from two vertically offset slant-paths, measured by sequentially aiming the OP-FTIR at high and low retro reflectors. The emission rates (Q_{FG}) were calculated from the vertical difference in gas concentration and atmospheric stability and turbulence parameters (Flesch et al., 2016; Wilson and Flesch, 2016):

$$Q_{FG} = (k_v \rho_a \, u_*/S_c)(M_s/M_a) * \kappa * \Delta C_L \quad (1)$$

Table 1
Timeline of the study including measurements, crop management, and N applications.

	Measurements	Crop management	N application
24 Feb		Celery transplanted	
25 – 27 March	Background emission flux measurement		
28 March – 16 April	Measurement		28 March: chicken manure 353 kg N ha^{-1} 1 April: Cal-Gran 38 kg N ha^{-1}
22 – 24 April	Measurement		
27 – 29 April	Measurement		
4 – 6 May	Measurement		