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Assessing drivers of N_2O production in California tomato cropping systems

Taryn Kennedy [a,*], Charlotte Decock [a,b], Johan Six [a,b]

[a] Department of Plant Sciences, University of California, One Shields Avenue, Davis, CA, USA
[b] Department of Environmental Systems Sciences, Institute of Agricultural Sciences, Swiss Federal Institute of Technology, Zurich, Switzerland

HIGHLIGHTS

- We assessed drivers of N2O production in two different tomato-cropping systems.
- Both management systems exhibited carbon limitation on denitrification rates.
- Denitrification is likely an important source of N2O in the conventional system.

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ABSTRACT

Environmental conditions and agricultural management events affect the availability of substrates and microbial habitat required for the production and consumption of nitrous oxide (N_2O), influencing the temporal and spatial variability of N_2O fluxes from soil. In this study, we monitored for diurnal and event-related patterns in N_2O emissions in the field, evaluated how substrate availability influenced denitrification, and assessed N_2O reduction potential following major events in two tomato (*Lycopersicon esculentum*) management systems on clay loam soils: 1) conventional (sidedress fertilizer injection, furrow irrigation, and standard tillage) and 2) integrated (fertigation, subsurface drip irrigation, and reduced tillage). Potential denitrification activity, substrate limitation, and reduction to N_2 were measured with an anaerobic slurry technique. In the field, we found no consistent diurnal patterns. This suggests that controlling factors that vary on an event-basis overrode effects of diurnally variable controls on N_2O emissions. The lack of consistent diurnal patterns also indicates that measuring N_2O emissions once per day following major events is sufficient to adequately assess annual N_2O emissions in those systems. Nitrous oxide emissions varied per event and across functional locations in both systems. This illustrates that mechanisms underlying N_2O emissions vary at relatively small temporal and spatial scales and demonstrates the importance of studying N_2O emissions in the context of events and functional locations. In the conventional system, N_2O fluxes were high [74.2 ± 43.9–390.5 ± 90.1 μg N_2O-N m^{-2} h^{-1}] and N_2O reduction potential was significant. Both management systems exhibited carbon limitation on denitrification rates; and rates were N limited in the third fertigation event in the integrated system. Our findings suggest that denitrification is strongly contributing to high N_2O emissions in conventional tomato cropping systems in California. Hence, management practices that reduce the conditions that favor denitrification, such as subsurface drip irrigation, are promising strategies for N_2O reduction.

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1. Introduction

Produced primarily during the microbially mediated processes of nitrification and denitrification, N_2O is a potent greenhouse gas related to agricultural activities, such as soil fertility management and irrigation. Nitrous oxide emissions increase with increased N fertilization rates (Bouwman et al., 2002; Cole et al., 1997; Halvorson et al., 2008) and when N availability exceeds plant demand (Chantigny et al., 1998), although the response is not always linear (Hoben et al., 2011; McSwiney and Robertson, 2005). Yet, it is not fertilizer rate alone that determines the production of N_2O, other factors also play a role. Crop N uptake (Linquist et al., 2012), the rate and timing of fertilizer application (Burger et al., 2005; Hao et al., 2001; Hultgreen and Leduc, 2003), and irrigation strategy (Sánchez-Martín et al., 2010) also influence the availability of substrates required for N_2O production. Lower N_2O emissions have been observed in subsurface drip *versus* furrow-irrigated tomato systems in California (Kallenbach et al., 2010; Kennedy et al., 2013) and were attributed to the improved use of fertilizer and water through subsurface drip irrigation with N fertigation. More precise N management resulted in better matching of N availability and crop demand and reduced N loss *via* N_2O emissions. It remains to be tested,

* Corresponding author at: 1700 Wilson Court, Eugene, OR 97402, USA. Tel.: +1 928 830 2563.
E-mail addresses: tlkennedy@ucdavis.edu (T. Kennedy), charlotte.decock@usys.ethz.ch (C. Decock), jsix@ethz.ch (J. Six).

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however, for those tomato systems whether 1) diurnal variations of N_2O fluxes are a potential source of error when calculating annual losses and 2) if denitrification plays an important role in N_2O production and consumption during major management events and at specific locations across the seedbed.

The biochemical production of N_2O is highly temperature-dependent, increasing exponentially with increasing temperatures following the Arrhenius equation (Focht, 1974; Maag and Vinther, 1996). In field experiments, N_2O fluxes have been found to vary diurnally following the pattern of surface soil temperature (3–10 cm) with production peaking in late afternoon (Maljanen et al., 2002; Williams et al., 1999). Maximum nitrification rates have been observed at 20 °C and decrease with further increases in temperature (Maag and Vinther, 1996). Gross N_2O production from denitrification has been shown to increase up to temperatures of 60–65 °C, however the ratio of N_2 to N_2O produced also increased (Keeney et al., 1979; Maag and Vinther, 1996). In the Central Valley of California, summer soil temperatures measured at 15 cm depth often exceed 20–25 °C and air temperatures vary 20–30° diurnally, which may cause the production of N_2O to vary diurnally. Short-term variation in N_2O fluxes can lead to an over- or underestimation of daily, seasonal, and annual N_2O emissions when fluxes are measured once daily with manual static chambers (Maljanen et al., 2002; Smith and Dobbie, 2001). A profound understanding of the temporal variability in N_2O fluxes is crucial to select an appropriate sampling frequency for accurately capturing cumulative N_2O emissions.

Within each event, fluxes are different at specific locations within the field (Garland et al., 2011; Kallenbach et al., 2010; Zebarth et al., 2008), referred to here as functional locations. Within each type of management event and at each functional location, different mechanisms may play a role in determining the size of a N_2O pulse. Therefore, understanding which microbial processes are occurring within each event and at each functional location could help to better strategize management practices to reduce N_2O emissions and harmful N loss.

In the following study, we measured diurnal and event-related N_2O emissions, investigated the controls on denitrification rates, and evaluated N_2O reduction potential in semi-arid tomato cropping systems of California under two different management regimes: 1) conventional (sidedress fertilizer injection, furrow irrigation, and standard tillage) and 2) integrated (fertigation, subsurface drip irrigation, and reduced tillage). We focused on the management events that produced the largest N_2O fluxes in the previous growing season (see Kennedy et al., 2013) and made measurements of gas fluxes from the field and laboratory incubations, with the intent to:

1. Determine whether N_2O fluxes vary diurnally.
2. Make comparisons within each management system between events and functional locations, based on field N_2O fluxes.
3. Perform laboratory incubations to determine whether denitrification or N_2O reduction to N_2 are major loss pathways for these two systems.
4. Evaluate whether the incubation data can explain the differences observed in field N_2O fluxes between events and functional locations, by providing additional information on C and N limitation and N_2O reduction to N_2.

2. Materials and methods

2.1. Site descriptions and study design

Our field study was conducted at two farms in Winters, CA (Lat. 38°34′ N; Long. 121°56′ W) from 25 April to 21 June 2011. The Yolo County region has a semi-arid Mediterranean climate where most of the precipitation falls as rain between October and April. Precipitation was 490 mm in 2011 (Fig. 1); average precipitation from 2001 to 2011 was 597 mm (Agriculture and Natural Resources, 2012). The soil at both sites is classified as Brentwood silty clay loam (fine, montmorillonitic, thermic Typic Xerochrept) by the National Cooperative Soil Survey; however textural analyses of soil samples collected from both field sites (0–15 cm) indicated that the topsoils had a clay loam texture. Processing tomatoes (*Lycopersicon esculentum*) were grown in both fields during the 2011-growing season.

The two sites were under two different management regimes. Extensive field operations, including tillage passes, bed cultivation, seedling transplant, and harvest, were conducted in both fields and are listed in Table 1. The conventional field was fertilized two times over the course of the study period with a total of 181 kg N ha^{-1}. The bulk of the fertilizer (24–8–0–2) was applied as a sidedress injection on 25 April 2011, prepared as a liquid and shanked into each shoulder of the seedbed to a depth of 15 cm, approximately one month after transplanting. The second fertilization occurred during an irrigation event; CAN-17 was dripped into the head ditch of the surface irrigation system and delivered to the beds through the

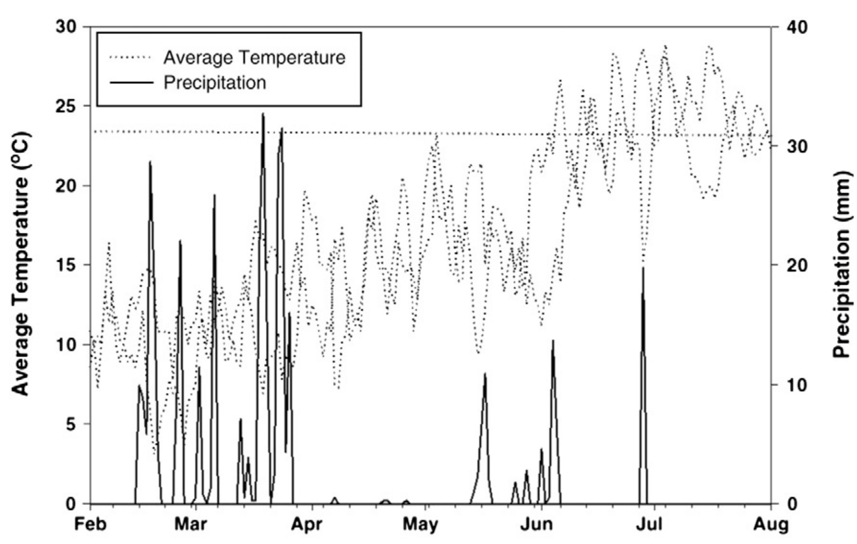

Fig. 1. Temperature and precipitation data from 1 February to 1 August 2011 recorded at a University of California Integrated Pest Management weather station in Winters, CA.