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Effect of drip irrigation frequency, nitrogen rate and mulching on nitrous oxide emissions in a semi-arid climate: An assessment across two years in an apple orchard

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ABSTRACT

Micro-irrigation scheduling and mulch application can be used by orchardists to match water supply to plant demand and conserve water. There is little information on how these management practices affect nitrous oxide (N_2O) emissions from orchard soils, and most previous studies were short-term (<3 months during the growing season). We investigated (1) N_2O emissions across a 2 year cycle of orchard management and (2) seasonal N_2O emissions by analysing measurements taken before, during and after the growing season in an apple (*Malus domestica* Borkh) orchard under various managements in a semiarid climate. Treatments included drip irrigation frequency (every day or every 2nd day) delivering the same total amount of water, orchard floor management (bare soil or shredded bark and wood mulch) and nitrogen application rate applied as calcium nitrate by fertigation (20 or 40 g N tree^{-1}). Over a period of two complete years, irrigation every 2nd day reduced area-scaled N_2O emissions by 27% and application of shredded bark and wood mulch reduced area-scaled N_2O emissions by 19%, suggesting that reduced drip irrigation frequency and mulching may provide an opportunity for suppressing N_2O emissions from drip irrigated orchards. Treatment effects on N_2O emissions were variable across seasons and years and a significant portion (17–51%) of the annual N_2O emissions occurred during the pre-growing season particularly during freeze-thaw cycles, affirming the importance of year round monitoring when assessing the effect of managements on N_2O emissions.

1. Introduction

Agriculture is responsible for 84% of the global anthropogenic N_2O and 52% of methane (CH_4) emissions (Smith et al., 2008). Crop production is believed to contribute only small net emissions of carbon dioxide (CO_2) since crop fields act both as sources and sinks for CO_2 (Carlisle et al., 2010 and Smith et al., 2008). There are limited data on N_2O emissions from apple orchards (Pang et al., 2009), yet these systems cover more than 25 million ha worldwide (FAO, 2013). In Canada, apple orchards cover 15,000 ha (FAO, 2013), with over 3,200 ha located in the semi-arid Okanagan region of British Columbia (Seymour, 2015). To improve water-use efficiency, many apple orchards in the Okanagan have converted from overhead and under-tree sprinklers to under-tree micro-irrigation (micro-sprinkler, micro-spray or drip). This trend is expected to continue as demand for irrigation water increases due to climate change. When using under-tree micro-irrigation, nitrogen (N fertilizer) can be applied through the irrigation system (fertigation) during the period of high tree N demand in order to increase N use efficiency. However, fertigation also increases the localized concentrations of N and water, especially in drip-irrigated systems (Smart et al., 2011), and may increase the potential for N_2O emissions (Smart et al., 2011 and Zebarth et al., 2008). The effects of under-tree micro-irrigation and fertigation on N_2O emissions are not well known.

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Orchardists employ various irrigation frequencies, N application rates, organic amendments and orchard floor managements (e.g.: geotextile or mulch ground covers) to increase water and nutrient-use efficiency and improve fruit quality and productivity. These management practices influence soil moisture and nutrients (C and N) dynamics which in turn affect N_2O production via nitrification and denitrification. Higher N application rate usually results in higher N_2O emissions (Shcherbak et al., 2014). In contrast, varying irrigation frequency and applying organic amendments has been shown to have inconsistent effects on N_2O emission. Rolston et al. (1982) found the greatest total N_2O emission from perennial ryegrass occurred under the most frequent irrigation while Abalos et al. (2014) found no relationship between irrigation frequency and N_2O emissions for melons. Organic matter addition resulted in decreased N_2O emission (Livesley et al., 2010; Lopez-Fernández et al., 2007; Nyamadzawo et al., 2014; Sanchez-Martin et al., 2010; Steenwerth and Belina, 2010) while in other studies increased N_2O emission (Cochran et al., 1997; Laidlaw, 1993; Pelster et al., 2012). Most of these prior studies either measured N_2O emissions over a short period during the growing season or used manure as the source of organic matter (Fentabil et al., 2016). A 2 year study of the use of shredded bark and wood mulch applied as ground cover in a grape (*Vitis vinifera* L.) vineyard reduced cumulative N_2O fluxes by 28% (Fentabil, 2016; Fentabil et al., 2016); however, further work is needed to substantiate these results over a wider range of experimental conditions and crops.

We assessed the impacts of two frequencies of drip irrigation, two N application rates and two orchard floor managements (bare soil or shredded bark and wood mulch) on N_2O emissions and soil characteristics in an apple orchard. We hypothesized that higher irrigation frequency and higher N application rate would result in greater N_2O emissions due to increased soil moisture and N while application of a shredded bark and wood mulch as a soil cover would result in a decrease in N_2O emissions due to higher microbial immobilization of mineral N in the presence of a labile carbon source. Our objectives were to assess (1) seasonal N_2O emissions before, during and after the growing season and (2) cumulative N_2O emissions over a 2 year cycle of orchard management.

2. Materials and methods

2.1. Study site and experimental design

The study was conducted at the Summerland Research and Development Centre (SRDC) of Agriculture and Agri-Food Canada (Lat. 49°34′N and Long. 119°38′W), located in the Okanagan Valley near Summerland, BC, Canada. The site has a 30-year average (1981–2010) annual precipitation of 346 (±25) mm, and daily average temperature of 9.6 (±2.4) °C with a minimum daily average of around −2 °C in January and a maximum daily average of around 28 °C in July. (Environment Canada 2014a; 2014b). The soil is classified as an Osoyoos loamy sand (Wittneben, 1986), which is glacio-fluvial in origin, had a low water-holding capacity, a cation exchange capacity (CEC) of 7.9 meq (100 g) $^{-1}$, a pH of 6.6, and a C:N ratio of 7.9 before treatment initiation. The soil at the site is typical of apple orchards in the Okanagan Valley.

The experiment was conducted in an Ambrosia apple orchard planted in 2003. The apple trees were arranged in eight 53.1 m long rows with a 0.9 m tree spacing within rows and a 3.5 m spacing between rows. The outer row on each side of the planting were 'guard rows', used to eliminate edge effects and were not directly involved in the experiment. Each row (block) consisted of twelve 5-tree plots with dimensions of 4.50 m × 2 m. The trees on each end of the individual plots were 'guard trees' and the middle three trees were 'experimental trees'. A common orchard grass mix was grown in the 1.5 m wide inter-row (alley). The 'row' part of each plot was kept weed-free via the use of herbicides (primarily glyphosate).

The treatments for this study were established in 2012 as a split-plot experiment; the main plot units had a 2 × 2 factorial design with two irrigation frequencies and two N application rates. The split-plot units within each main plot consisted of three randomly assigned orchard floor management treatments: herbicide treated bare soil (Clean), shredded bark and wood mulch (Mulch) and black plastic woven geotextile (Geotextile). The whole experiment was a randomised complete block experiment with all treatment combinations replicated in six blocks; only three of the six blocks were used for greenhouse gas study in the present study, with the other three in use by other parallel experiments. Irrigation was designed to deliver 100% of the water lost to evapotranspiration via drippers (4 L h^{-1}) located 0.30 m on either side of each tree and suspended approximately 0.3 m above the soil surface. An atmometer (ETGage Co, Loveland, CO) measurement of potential evapotranspiration and a crop coefficient model was used to estimate actual evapotranspiration (Neilsen et al., 2015); the system was controlled automatically by a CR10X datalogger (Campbell Scientific, Logan, UT). The irrigation treatments consisted of irrigating twice a day (morning and afternoon) every day, or irrigating twice a day (morning and afternoon) every second day. The irrigation season extended from May through October and all plots received the same quantity of water. Plots were fertigated with $Ca(NO_3)_2$ for six weeks, from around mid-May to the end of June between 2012 and 2014; irrigation and fertigation were timed to coincide with apple development. Treatments were 20 N g $tree^{-1}$ or 63 kg N ha^{-1} (Low N, LN) and 40 N g $tree^{-1}$ or 127 kg N ha^{-1} (High N, HN).

The Clean and Mulch orchard floor management treatments were assessed in this study. The Geotextile treatment was excluded. Mulch was applied on a 2-m wide strip centered on the apple tree row. It was composed of shredded bark and woodchips (primarily from *Pinus contorta* var *latifolia* and *Picea glauca*) generated as waste from local sawmills. It was surface applied in late May of every second year (2012, 2014) to maintain a full mulch with a depth of approximately 10 cm. New mulch was topped up on existing mulch without disturbing the underlying material. Mulch was not applied in 2013 because it was still sufficiently thick to suppress weed growth.

2.2. Soil sampling and analyses

Soil sampling was conducted in May, June, August, and October in 2013, and every month from April to August, and October in 2014 for a total of 10 soil sampling rounds over two years. At each soil sampling time, soil cores from nine locations to a depth of 15 cm were collected in each of the row and in the alley using a 2-cm diameter auger (Fig. 1). Samples were separately composited for the row and the alley part of each plot. Soil samples were kept frozen until extraction and analysis. Determination of available nitrate-N and nitrite-N (hereafter referred to as NO_3^--N because concentrations of NO_2^--N were minimal) and ammonium-N (NH_4^+-N) on soil extracts used 2 M KCl in a 1:5 soil to extractant ratio with a 1-h shaking time, followed by filtration through Whatman No. 40 filter paper. The concentrations of NO_3^--N and NH_4^+-N in the extracts were determined using a segmented flow analyzer (SFA, Model 305D, Astoria Pacific International, Clackamas, OR). Salt-extractable organic C (SEOC) was extracted in the same way as NO_3^--N and NH_4^+-N but a 0.45-μm membrane filter (Millipore Corp, USA) was used for filtration (Chantigny et al., 2008), and an Aurora 1030W OI Analytical TOC analyzer (OI Analytical, USA) was used to determine concentration of SEOC.