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Assessment of N_2O emissions from a fertilised vegetable cropping soil under different plant residue management strategies using ^{15}N tracing techniques

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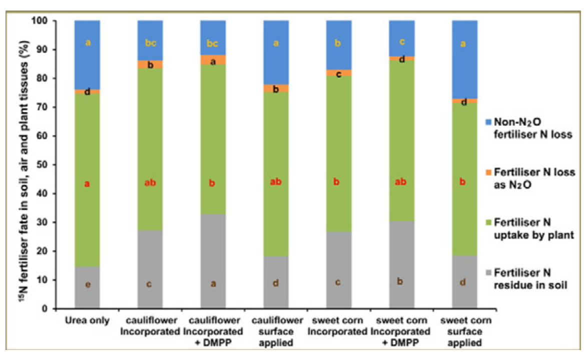
HIGHLIGHTS

- We evaluated N_2O sources in combined plant residue and ^{15}N fertiliser application.
- Residue application lead to net N mineralisation and higher N_2O flux than ^{15}N only.
- Soil incorporation of residues increased microbial immobilisation of applied ^{15}N.
- Mulching of sweet corn, contrary to cauliflower reduced N_2O than its incorporation.
- DMPP reduced emitted N_2O in sweet corn but increased it in cauliflower application.

GRAPHICAL ABSTRACT



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ABSTRACT

Combined application of plant residues and N fertilisers strongly affect soil mineral N dynamics and N_2O emissions depending on the quality of the plant residues, their application methods and other management strategies. We investigated the effect of combined application of two vegetable plant residues (cauliflower and sweet corn) and ^{15}N fertiliser on N dynamics and N_2O emission in a glasshouse pot study. The experiment was conducted under two residue management practices (soil incorporation vs surface mulching) over 98 days with growing basil (*Ocimum basilicum*) plants. We also assessed the efficacy of applying the nitrification inhibitor, 3,4-dimethylpyrazole phosphate (DMPP) to the plant residues, for reducing N loss and mitigating N_2O emissions. Application of plant residues, both on the soil surface or into soil, resulted in net N mineralisation and increased cumulative N_2O emission compared with the application of N fertiliser alone. Soil surface mulching of sweet corn decreased total and residue-induced cumulative N_2O emission compared with the incorporation method, while it showed opposite effect on N_2O emissions from cauliflower residue. The application of DMPP with sweet corn residue reduced total, residue- and fertiliser-induced N_2O emissions; however its application with cauliflower residue did not show any mitigating effect on the N_2O emissions. The residue application methods and the use of DMPP did not significantly affect ^{15}N recovery by the basil plants. In contrast, soil incorporation of these residues doubled the microbial immobilisation of applied ^{15}N into soil organic matter. Linear regression analysis of N_2O emission during the experimental period indicated that in the treatments without DMPP

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application, soil NO_3^--N concentration was the most important factor in controlling the magnitude of N_2O emissions, while the application of DMPP changed the dominant regulating factor from NO_3^--N to NH_4^+-N concentration.

1. Introduction

Agricultural lands are the major source of anthropogenic N_2O, which has a significant role in global warming and destruction of the ozone layer (IPCC, 2013). Intensive vegetable cropping systems are generally characterised by heavy fertiliser N applications to maintain productivity, and consequently high N_2O emissions occur through microbial nitrification and denitrification (Pang et al., 2009; Rezaei Rashti et al., 2015; Scheer et al., 2014). Therefore, reduction in N_2O emissions from these cropping systems could potentially make a significant contribution to the mitigation of global anthropogenic N_2O emissions.

Agricultural activities provide nearly 4 billion metric tons of plant residues per year at the global scale (Lal, 2005). Returning of these residues to cropping lands can sustain soil organic matter and enhance soil fertility by increasing microbial activity and nutrient availability (Ma et al., 2010; Smith et al., 1993) as well as reducing water loss and limiting weed growth. It has been reported in previous studies that residue application may increase or decrease N_2O emission depending on the quantity and quality (nutrient content, biochemical composition and physical features) of the applied residues (Baggs et al., 2003; Chen et al., 2013; Garcia-Ruiz and Baggs, 2007; Rezaei Rashti et al., 2016), while denitrification is considered as the primary source of N_2O emissions in plant residue amended soils (Kong et al., 2017; Li et al., 2016). Vegetable residues can release up to 150 kg N ha^{-1} through mineralization (De Neve and Hofman, 1998), and different management practices of the harvested vegetable residues (such as soil incorporation or surface mulching) may affect N_2O emissions differently in these cropping systems. Generally, plant residues applied as a surface mulch have a slower decomposition rate than soil incorporated residues due to the greater fluctuations in soil moisture content and temperature, lower availability of soil nutrients and limited contact of applied residues with soil in this application method (Schomberg et al., 1994; Thonnissen et al., 2000). Huang et al. (2004) and Zhu et al. (2013) reported that decomposition of soil incorporated plant residues provided more bioavailable carbon and nitrogen sources for soil microbial activities. The enhancement of soil microbial respiration may also facilitate the development of anaerobic micro-sites which favour the denitrification process.

Combined application of plant residues and chemical N fertilisers has been reported to be beneficial in increasing N use efficiency of applied fertilisers (Mohammad et al., 2012). This may occur through enhancing the microbial immobilisation of applied mineral N, in the early days after application, and synchronising soil N dynamics with N demands of the cultivated crop. However, studies by Garcia-Ruiz and Baggs (2007) and Gentile et al. (2008) indicated that soil incorporation of plant residues in combination with N fertilisers may increase N_2O emissions. Carmo et al. (2013) and Wang et al. (2016) also reported increases in N_2O emissions after surface application of sugarcane residue. It has been suggested that mineral N application may increase the decomposition rate of labile carbon compounds in applied plant residues (Jiang et al., 2015). The increase of soluble organic carbon in the presence of high levels of soil mineral N would consequently increase N_2O emissions by stimulating the denitrification process (Paul and Beauchamp, 1989; Lan et al., 2017).

In order to reduce N losses and increase fertiliser N use efficiency, nitrification inhibitors have been introduced to agricultural soils (Boeckx et al., 2005; Di and Cameron, 2003; Pereira et al., 2010). Nitrification inhibitors can delay the conversion of NH_4^+ to NO_3^- and provide more opportunities for plant uptake and microbial immobilisation of NH_4^+ within the soil profile. The inhibition of O_2 consumption by the nitrification process may also improve soil O_2 status and reduce N_2O loss through denitrification (Zhu et al., 2015). The 3,4-dimethylpyrazole phosphate (DMPP) is one of the most popular forms of such inhibitors, which has been widely used over the past years (Hatch et al., 2005; Zerulla et al., 2001). This nitrification inhibitor is effective at low application rates of 0.5–1.5 kg ha^{-1}. DMPP has a low water solubility, a slow degradation rate and can reduce the risk of NO_3^- leaching and N_2O emission (Li et al., 2009; Menendez et al., 2006; Zerulla et al., 2001). Menendez et al. (2012) reported that the addition of DMPP to mineral N fertilisers can significantly reduce N_2O emissions, but the efficacy of this nitrification inhibitor strongly depends on the environmental conditions. The effect of DMPP on reducing N_2O emissions from fertilised vegetable fields has been investigated recently by Pfab et al. (2012) and Scheer et al. (2014), but to our knowledge no published data are currently available on the mitigating effects of DMPP in combined application of vegetable residues and N fertilisers.

The main objectives of the present study were to: (1) monitor the dynamics of soil mineral N and N_2O emissions following the application of two contrasting vegetable residues with ^{15}N-labelled fertiliser, in the presence of growing plants; (2) evaluate the effect of different plant residue management strategies (incorporation vs. surface mulching) on N_2O emission and N use efficiency of the applied N sources; (3) determine the effects of DMPP application on reducing N losses and N_2O emissions following plant residue application; (4) assess the effect of moisture fluctuations on soil N dynamics and N_2O production from combined applications of vegetable residues and ^{15}N-labelled fertiliser. The underlying hypotheses were: (a) Vegetable residue quality and its application method would affect soil N dynamics and N_2O emissions; (b) DMPP application onto vegetable residues before incorporation into soil may increase N use efficiency and consequently reduce N_2O emissions.

2. Materials and methods

2.1. Plant materials and biochemical analysis

Two common crop residues in Australian sub-tropical vegetable cropping systems with substantial differences in N content and chemical/biochemical characteristics, namely cauliflower (*Brassica oleracea ver. Botrytis L.*) and sweet corn (*Zea mays L.*), were selected. The plant residues were dried at 60 °C for two days and then cut into 2 cm pieces for application to pots and ground to <1 mm for chemical and biochemical analyses (Table 1). Total carbon (TC) and nitrogen (TN) contents of plant materials were determined by dry combustion using a LECO CN analyser (TruMac NO. 830–300-400, USA). Lignin and cellulose contents were determined sequentially with the acid detergent pre-treatment method (Wang et al., 2004). Total polyphenol contents in residue samples were determined using 50% methanol extractant followed by the Folin Ciocalteau colorimetric method calibrated with gallic acid (Waterman and Mole, 1994). The results are reported on an oven-dry weight basis.

The chemistry of each plant material was also assessed with solid state ^{13}C–cross-poralization magic angle spinning (CPMAS) nuclear magnetic resonance (NMR) spectroscopy using a Varian Unity Inova 400 spectrometer (Varian Inc., Palo Alto, CA) operating at a frequency of 100.6 MHz. A measured mass of each plant material (250 mg) was packed into a silicon nitride rotor (7 mm OD) and spun at 5 kHz at the magic angle. A standard cross-polarization pulse sequence was applied