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N_2O and CO_2 emissions following repeated application of organic and mineral N fertiliser from a vegetable crop rotation

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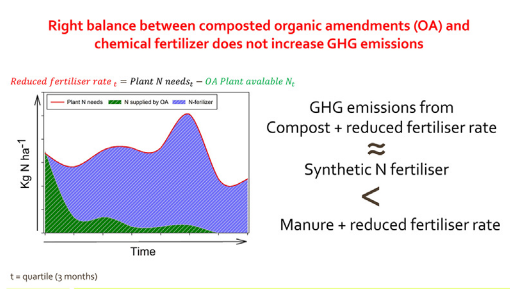
HIGHLIGHTS

- The repeated application of composted manure did not increase GHG emissions.
- The incorporation of organic matter was the main factor controlling GHG emissions.
- Accounting for the N released from organic amendments can sustain crop production.
- A refined N_2O emission factor for the land application of OA is proposed.
- The continuous synthetic N-fertiliser only application leads to soil health decline.

GRAPHICAL ABSTRACT



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ABSTRACT

Accounting for nitrogen (N) release from organic amendments (OA) can reduce the use of synthetic N-fertiliser, sustain crop production, and potentially reduce soil borne greenhouse gases (GHG) emissions. However, it is difficult to assess the GHG mitigation potential for OA as a substitute of N-fertiliser over the long term due to only part of the organic N added to soil is being released in the first year after application. High-resolution nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions monitored from a horticultural crop rotation over 2.5 years from conventional urea application rates were compared to treatments receiving an annual application of raw and composted chicken manure combined with conventional and reduced N-fertiliser rates. The repeated application of composted manure did not increase annual N_2O emissions while the application of raw manure resulted in N_2O emissions up to 35.2 times higher than the zero N fertiliser treatment and up to 4.7 times higher than conventional N-fertiliser rate due to an increase in C and N availability following the repeated application of raw OA. The main factor driving N_2O emissions was the incorporation of organic material accompanied by high soil moisture while the application of synthetic N-fertiliser induced only short-term N_2O emission pulse. The average annual N_2O emission factor calculated accounting for the total N applied including OA was equal to 0.27 ± 0.17%, 3.7 times lower than the IPCC default value. Accounting for the estimated N release from OA only enabled a more realistic N_2O emission factor to be defined for organically amended field that was equal to 0.48 ± 0.3%. This study demonstrated that accounting for the N released from repeated application of composted rather than raw manure can be a viable pathway to reduce N_2O emissions and maintain soil fertility.

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1. Introduction

The increase in emissions of the greenhouse gases (GHG) nitrous oxide (N_2O) into the atmosphere and carbon dioxide (CO_2) through the decomposition of soil organic matter contribute to regional and global scale environmental issues associated with the depletion of the stratospheric ozone layer and climate change (Smith et al., 2007). The principal source of N_2O emissions is related to the activity of denitrifying and nitrifying soil microorganisms under anoxic conditions (Butterbach-Bahl et al., 2013). The magnitude of soil-borne N_2O emissions is correlated to the amount of soil available nitrogen (N) (Shcherbak et al., 2014). Agricultural soils receiving high N inputs through the application of N rich synthetic fertilisers used to sustain crop production are responsible for 60% of global anthropogenic N_2O production (Smith et al., 2007).

Intensively cultivated agricultural soils for vegetable crop production are characterised by high N-fertiliser application rates and are often combined with manure application leading to an annual total N application rates ranging from 220 to 1145 kg N ha^{-1} y^{-1} (Diao et al., 2013; Rezaei Rashti et al., 2015; Porter et al., 2017). Due to these high N inputs and frequent irrigation, vegetable systems are highly susceptible to N losses and extraordinarily high N_2O emissions have been reported (up to 240 kg N_2O-N $ha^{-1}y^{-1}$, Jia et al., 2012). Additionally, the numerous inter-annual tillage events required for the relatively short cycle (2–3 months) of vegetable crops exacerbate soil borne CO_2 emissions, an indicator of soil C degradation. In this context, the application of organic amendments (OA) such as composted and raw animal manures to vegetable cropping soils can potentially promote soil C storage (Vanden Nest et al., 2014) while also providing a valuable source of N. Replacing part of the synthetic N-fertiliser with OA will also reduce the environmental costs associated with industrial N fixation by recycling a large source of readily available N (Ceotto, 2005).

There is currently no consenus on whether the land application of OA increases or reduces soil-borne GHG emissions (Graham et al., 2017), depending strongly on soil properties, climatic conditions, the biochemical quality (C to N ratio, C/N) of the OA and the rate at which OA are applied in proportion to crop needs (Thangarajan et al., 2013; Charles et al., 2017). Hayakawa et al. (2009) observed that the application of OA increased N_2O emissions by two to seven times in an Andisol, while reductions in N_2O emissions were observed when composted OA were added to a Vertisol (Dalal et al., 2010; De Rosa et al., 2016b). Generally, high N_2O emissions following application of OA were observed when OA with low C to N ratios (C/N) are applied (Dalal et al., 2010) and when application rates result in soil inorganic N levels exceeding crop N demand (VanderZaag et al., 2011). Accordingly, De Rosa et al. (2016b) in an annual vegetable crop rotation demonstrated that avoiding excess nutrients to crop needs by accounting for the plant available N (PAN) supplied from composted rather than raw OA did not increase N_2O emissions. However, it is difficult to assess the GHG mitigation potential for OA as a substitute of N-fertiliser over the long term due only about 25% (Pettygrove and Heinrich, 2009) of the organic N added to soil is being released in the first year after application (Diacono and Montemurro, 2010). In addition, the land application of OA would not be likely to result in short-term changes in soil physical and chemical characteristics (Graham et al., 2017). To date, little information is available on the GHG mitigation potential of OA in intensively cultivated horticultural soils and even less under subtropical conditions. Furthermore, N dynamics in the soil after repeated applications of OA and the effect this has on temporal GHG emissions in a horticultural rotation is poorly understood.

The hypothesis of this research is that the repeated annual application of OA could promote GHG emissions depending on the quality (composted or raw manure) and amount of OA applied to the vegetable cropping system due to an increase in C and N availability. In addition, we hypothesise that the continuous conventional N-fertiliser strategy will lead to soil C decline under intensive cultivation. Therefore, the objective of this study was to assess the GHG mitigation potential of repeated annual applications of composted or raw OA combined with a reduced N-fertiliser strategy for an intensively cultivated vegetable crop rotation.

2. Materials and methods

2.1. Site description

A field experiment was conducted from September 2013 to February 2016 at Gatton Research Station in the Lockyer Valley, a major vegetable producing region in southeast Queensland, Australia (latitude 27°32′56″S, longitude 152°19′39″E; 100 m a.s.l.). The area is characterised by a humid subtropical climate, with warm to hot summers and mild to cool winters. Annual average temperature is 20 °C with an average daily maximum of 27 °C and a minimum of 13 °C. Summer rainfall accounts for nearly 60% of the total average annual rainfall of 750 mm (Bureau of Meteorology, Australia). The alluvial soil of the study area is classified as a Black Vertisol (FAO, 1998) with 600 g clay kg^{-1}, 220 g silt kg^{-1}, 180 g sand kg^{-1} and soil bulk density of 1.15 g cm^{-3}. The uppermost soil layer (0–20 cm) contained 15 g organic C kg^{-1}, 1.2 g total N kg^{-1} (analysed with a Leco Trumac CNS Analyser,LECO Corporation, USA), had a pH (H_2O) of 7.8, and cation exchange capacity (CEC) 43.9 $cmol_c$ kg^{-1}. A barley (*Hordeum vulgare*) cover crop grown prior to the experiment was cut and removed to minimise any residual N from the cultivation of previous crops.

2.2. Field management and experimental set-up

The details of the experimental design and N management strategies can be found in De Rosa et al. (2017). In brief, the crop rotation under investigation was a succession of three crop cycles of seven vegetable crops grown in raised beds from September 2013 to February 2016. The crop rotation (Table S1) included green beans (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*) as a catch-crop, broccoli (*Brassica oleracea* var. *italica*) and lettuce (*Lactuca sativa*) in first crop cycle (September 2013 to September 2014); sweet corn (*Zea mays* var. *saccarina*), broccoli, and lettuce for second crop cycle (September 2014 to September 2015), and finally sweet corn for the last crop cycle (September 2015 to February 2016).

Six fertiliser treatments were arranged in a randomised block design with four replicates (1.5 × 10 m with 1.5 m buffer):

i) A conventional N-fertiliser rate applied as urea (CONV, 770 kg of N-fertiliser ha^{-1} for the entire rotation) based on local farm management;
ii) Zero N input treatment (0N) was used to account for background soil GHG emissions.

Four treatments of OA were derived from the factorial combination between (i) two organic amendments: raw (Ma) layer chicken manure and aerated turned composted (Co) chicken manure and (ii) two levels of chemical N-fertiliser: reduced (+Rd) and a conventional (+CONV) N-fertiliser rate. The experimental plots of OA that received the full amount of N-fertiliser in the first crop cycle (Ma + CONV and Co + CONV), only received OA in the second and third crop cycles. The factorial combination between OA and different N-fertiliser rates resulted in:

iii) Composted chicken manure plus conventional N-fertiliser rate (Co + CONV) for the first crop cycle, and composted chicken manure only in the second and third crop cycle (Co);
iv) Composted chicken manure plus reduced N-fertiliser rate (Co + Rd);