Reduction of soil nitrogen losses from a Vertisol with organic waste amendments under subtropical conditions

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Abstract

A high concentration of soil mineral nitrogen (N) in intensive horticulture can lead to environmental pollution such as eutrophication and greenhouse gas emissions. Organic waste amendments were chosen for two soil incubation experiments based on biochemical evidence, such as a total carbon (C) to total N ratio of >25:1(White 1997), <1% tissue N (Parton and Silver 2007), that they would initiate N immobilisation, thus reducing the soil mineral N pool. The preliminary incubation evaluated whether green waste and a composted green waste, at 3 t C/ha, could manipulate the N transformations in a horticultural soil, with and without fertilisation. Soil NO_3-N was reduced with addition of either amendment regardless of fertilisation with the green waste having a stronger initial immobilisation of NO_3-N. However, the reduction in mineral N, particularly in the fertilised treatments was approximately 15% and not substantial enough to warrant field application. The second incubation was designed to evaluate a range of organic waste amendments for reduction of soil mineral N, specifically targeting post harvest conditions where the crop has been removed and the risk of N loss is elevated. The organic waste amendments were incorporated at 6 t C/ha and included wheat straw, sugarcane trash, Agrichar™ (green waste biochar), rice husk biochar and mineral fibre from the paper and cardboard recycling industry. The mineral fibre, wheat straw and sugarcane trash all reduced soil NO_3-N by greater than 75% in the first 7 days; these amendments may be suitable for post harvest field incorporation to reduce occurrence of environmental pollution.

Introduction

Worldwide, waste production is increasing exponentially in conjunction with the escalating population; a landfill shortage crisis is imminent. Issues such as lack of space, environmental pollution and increasing cost of landfill are forcing waste producers to seek different disposal mechanisms such as returning biodegradable waste to the land (Rahn *et al.* 2003). Currently, cities consume energy, food, water and other raw materials and release wastes. Horticulture is ideally situated, generally in close proximity to urban areas, to re-use waste materials and offset some of our cities waste production. At present, horticulture is a contributor to environmental pollution through over-fertilisation followed by loss of nutrients from the cropping system leading to eutrophication, coastal contamination and greenhouse gas emissions. While, organic waste amendments have long been used for soil fertility and structure (De Neve *et al.* 2004), there is limited data on their use to reduce soil N losses, particularly in the subtropics (Khalil 2005). The addition of high C amendments of specific biochemical characteristics has the potential to reduce off-site N loss, with the associated benefit of reducing pressure on landfill.

Key Words

Nitrogen, immobilisation, incubation, organic waste amendments, greenhouse gas, biochar

Materials and methods

Soil and amendment characterisation

All the amendments were milled to 8 mm and air-dried, with the exception of the rice husk and green waste biochar's which were uniform in size and had dried during production. The soil (0-15 cm depth) was air dried and sieved to 2 mm for uniformity. The mineral N in the soil and amendments was extracted with 2 M KCl (ratio 1:10) (Bremner 1965) and the extract was analysed colorimetrically for nitrate (NO_3^-), ammonium (NH_4^+) and nitrite (NO_2^-) (Bremner 1965) with an automated discrete analyser (Seal AQ2). The lignin, cellulose and solubles were measured using the acid digestible fibre (ADF) method. Sub-samples of the amendments and soil were dried for gravimetric water content analysis and for total C and N using a CNS elemental analyser (Leco).

Incubation experiment
The ground, air-dried soil was weighed into re-sealable plastic bags (1100 g oven-dry equivalent). In the first incubation the sieved, air dried, green waste and compost were applied at 3 t C/ha to relevant bags and mixed evenly into the soil. In the second incubation an application rate of 6 t C/ha was used. The soil and amendments were added to poly-vinyl-chloride (PVC) incubation columns (internal diameter = 85 mm, height = 300 mm, filling height = 150 mm, bulk density = 1.25 g cm^{-3}). The preliminary incubation was used to evaluate whether amendments could reduce off-site N losses in both a low (no fertiliser) and high (200 kg/N/ha) available N environment. The second incubation was designed to mimic high N post harvest horticultural soils; all treatments received 200 kg/N/ha. Lids, with a hole in the centre were sealed onto the columns with silicon grease. The hole was unplugged when analysis was not occurring to ensure aeration and to minimise moisture loss. The preliminary study proceeded for 28d; the second incubation ran for 84d. Columns were maintained at 24°C, in the dark, and moisture maintained at 55% water holding capacity for both experiments.

For the determination of N_2O emissions, the incubation columns were aerated to ensure an oxygenated environment before the lid was sealed for 60 min after which the headspace was sampled. Gas samples were injected into pre-evacuated exetainers and analysed using gas chromatography, as described by Allen (2007). Gas sampling was conducted at 12 intervals in the preliminary experiment and 16 intervals in the second experiment. Cumulative gas emissions over both incubation periods were calculated based on daily emissions by integrating the area under the curve. In both incubations linear gas release was determined during peak emission timings to ensure N_2O emissions were linear over the sampling period. Destructive sampling was conducted to determine soil mineral N analysis (described above).

Results and discussion

Soil N transformations
Organic N is not available to plants or microbiota until it is mineralised via microbial decomposition (Moss 2002) ultimately to simple inorganic molecules of NH_4^+ (White 1997). Ammonium ions can be converted by specific microbes to NO_3^- in an oxidative process known as nitrification. Therefore, $NH_4^+$and NO_3^- ions, soil mineral N, can be present in soil due to organic matter decomposition as well as fertiliser application. However, anions (negatively charged particles), such as NO_3^-, are subject to loss from the cropping system via leaching and run-off due to their high solubility and repulsion from net negatively charged soil colloids. This problem can be exacerbated in intensive subtropical horticulture where N application rates are high and irrigation and rainfall events are frequent due to the climate and intensive nature of the system. A high concentration of soil mineral N can also enhance soil emissions of the greenhouse gas, N_2O.

Many studies have shown soil microbes assimilate available N into their mass (immobilisation) when soil is amended with a high C organic material (Gobat 2004; Taylor 1989), typically those with a total carbon to total nitrogen (C:N) above the critical ratio of 25:1(White 1997). Another key indicator is a <1% total N of an organic amendment (Parton and Silver 2007), as more N is required for microbial growth during decomposition than what is provided by the substrate (Ambus 1997). To a lesser extent residue cellulose and lignin percentages can also influence mineralisation rates. These materials are difficult for microbes to decompose resulting in a reduction in net N mineralisation rate (Rahn *et al.* 2003).

The preliminary trial reviewed a green waste and green waste compost, both common waste products of urban areas, and their influence on soil N transformations and N_2O emissions. Each amendment had a C:N above the critical value and an initial tissue N of <1%, thus, it was hypothesised that microbes would immobilise N with their soil incorporation. Both amendments decreased soil mineral N, particularly soil NO_3^- (Figure 1a). The results from the preliminary incubation indicated that green waste and green waste compost, if incorporated into a horticultural field post harvest, when available N is high, could reduce available N. However, the immobilisation period was short-lived and weak. Waste amendments which result in a more rapid immobilisation of mineral N would be more suitable for field conditions.

Amendments in the second incubation were chosen as they are waste products likely to be in proximity to horticulture sites. These amendments had a wider range of C:N ratio's than those evaluated in the preliminary experiment, and were <1% in total N. The wheat straw, sugarcane trash and mineral fibre all exhibited a strong initial immobilisation of N, reducing NO_3-N by >70% compared to the control by Day 7 (Figure 1b).

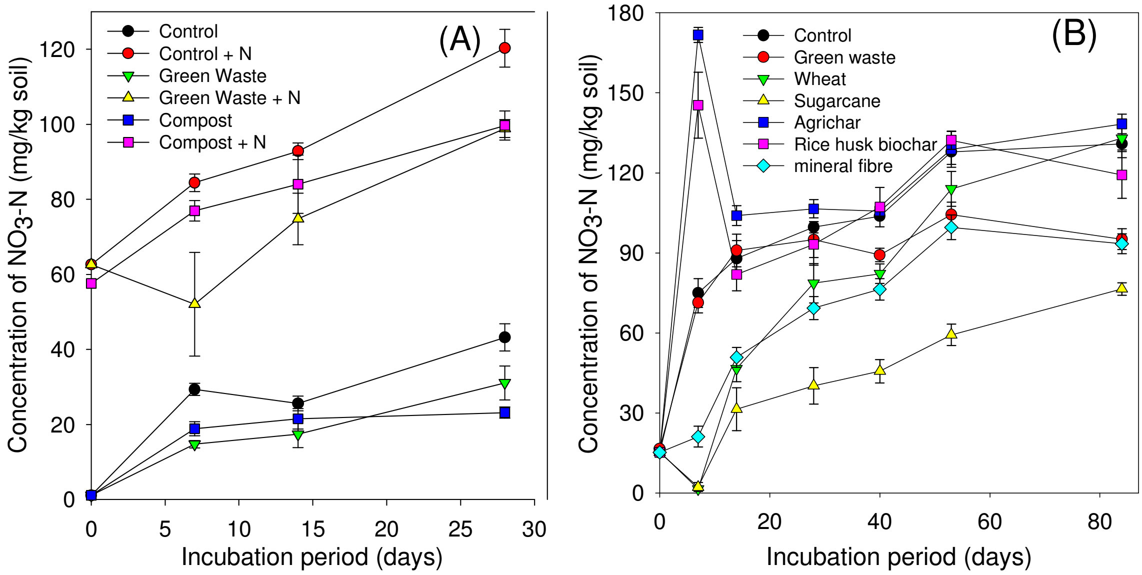

Figure 1. Concentration of soil NO_3-N in a vertisol. (A) Soil amended with green waste or compost, with or without fertilisation over 28d incubation. (B) Soil with 200 kg/N/ha amended with various organic waste amendments over 84d incubation. Error bars depict standard error of the mean.

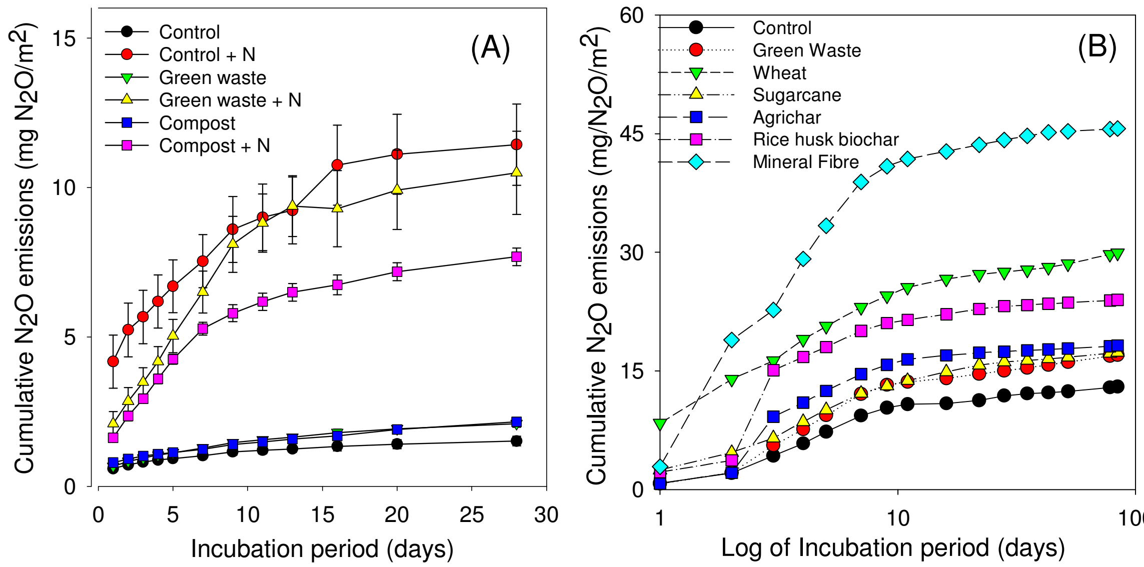

Figure 2. Cumulative soil emitted N_2O from a vertisol (A) Soil amended with green waste or compost and with and without fertilisation over 28d incubation period. (B) A high N vertisol with and without organic amendments across an 84d incubation period. Error bars depict standard error of the mean.

Soil based N_2O emissions

There are two main processes for N_2O production: nitrification and denitrification. Aerobic conditions were created in both incubations to ensure nitrification was the main contributor; although denitrification can occur due to anaerobic micro-sites in an aerobic soil (Müller 2004). As mineral N is the substrate for N_2O production, elevated mineral N is generally associated with higher emissions. In the preliminary incubation where there was a fertilisation factor, N fertiliser addition increased cumulative N_2O emission by 6 fold (Figure 2a). There were no clear differences in cumulative N_2O emissions between unfertilised treatments where emissions were due to low soil mineral N. However, in fertilised treatments, cumulative N_2O emissions were decreased by addition of green waste (18%) and compost (40%). In the second incubation all amendments increased soil cumulative N_2O emissions compared to the unamended control, although the increase was minimal for several treatments (Figure 2b). Rice husk biochar, wheat straw and mineral fibre all increased soil emitted N_2O by approximately two fold mainly due to an increase in the soil mineral N during peak emission, or because an increase in microbial metabolism reduced the availability of oxygen creating anaerobic conditions.

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Conclusions

Intensive horticultural uses large inputs of N fertiliser to optimise yields. Soil mineral N can be leached from the cropping system during irrigation and rainfall events, resulting in detrimental impacts on the environment, such as eutrophication, coastal pollution and increased soil greenhouse gas emissions, such as N_2O. Two incubations were conducted where organic waste amendments, selected for their biochemical characteristics, were evaluated for their potential to immobilise soil mineral N. Mineral fibre, sugarcane trash and wheat straw have potential to reduce N losses for post harvest application in subtropical horticulture.

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