Effect of rice husk biochar on nitrous oxide emission from decomposing hairy vetch in two soils under high-soil moisture condition

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Abstract
Hairy vetch (*Vicia villosa* Roth) plants are widely used as green manures. They fix nitrogen (N) and provide a fraction of the fixed N to other crops when they decompose. Thus, green manuring with legumes is considered as an alternative to chemical N fertilizer application. However, N-rich plant residue is also a potential source for nitrous oxide (N_2O), a greenhouse gas. On one hand, rice husk biochar is widely used as a soil conditioner in Japan and has been reported as a tool to reduce N_2O emissions. The interaction between biochar and N rich composting materials on N_2O emission has not been studied well. We conducted a soil core incubation experiment under high soil moisture (~100% WFPS) to investigate the N_2O emissions from two soils, i.e., an Andosol and a Fluvisol after application (0.8 kg m^{-2}) of ^{15}N labelled (0.49 atom %) hairy vetch. Additionally, the experiment contains a biochar treatment. The N_2O emissions and inorganic-N in soils were monitored for 1.5 month. Generally, the use of biochar suppressed soil NH_4^+-N concentrations in the Andosol whereas the effect of biochar on NH_4^+-N was not significant in the Fluvisol. Biochar application did not influence the cumulative N_2O emissions but increased the contribution of hairy vetch-N to the cumulative N_2O emissions, according to the analyses of N_2O-^{15}N. Our study suggests that rice husk biochar is not a good option to mitigate N_2O emissions during the decomposition of surface applied hairy vetch, although this study was performed under a laboratory condition without plants. However, the trends of the inorganic-N concentration changes following the addition of hairy vetch and biochar were markedly different between the two soil types. Thus, factors behind the differences need to be further studied.

Key Words
N_2O, N_2, Andosol, Fluvisol, soil type

Introduction

The use of legume green manures is receiving heightened attention as an alternative to chemical N fertilizer. Hairy vetch is used as a green manure legume and is often grown during the pre-growing season to supply N to the succeeding crop through decomposition (Cherr et al. 2006). However, previous studies reported that the decomposition rates of plant residues varied due to soil types. Thus, to improve the efficiency of the use of green manure legume derived-N by the subsequent crop, studies that investigate the factors controlling the availability of N during the decomposition of green manure legumes are needed, particularly focusing on the effect of soil types.

The decomposition of plant residues is also an important contributor of global nitrous oxide (N_2O) emission (Baggs et al. 2000). Therefore, studies investigating the contribution of decomposing green manure to N_2O emission are needed.

In recent years, charcoals made from biological materials, known as “biochar”, have been shown to retain inorganic-N in soils (Clough et al. 2013). Rice husk biochar made from agricultural wastes has traditionally been used as a soil conditioner in Japan. The addition of rice husk biochar to soils may change inorganic-N concentrations in soils during the decomposition of legumes and subsequently can influence N_2O emissions from soil.

Currently there is little information available on the interaction between the application of biochar and soil types on the decomposition of surface applied legume plants, including hairy vetch, in relation to N dynamics. We believe further studies are needed in this area to improve the use of hairy vetch as an alternative to chemical fertilizers, for sustainable N supply. The N dynamics under high soil moisture may particularly be important due to the risk of high N_2O emissions. Also, ^{15}N labeled legume leaves can be used to identify the different N sources (N from surface applied residue and N from soil organic matter) for N_2O production.

Methods

Soils

Two major types of Japanese soils were used, namely, an Andosol and a Fluvisol. The soils were sampled from two experimental fields at the National Institute for Agro-Environmental Sciences, Japan (36°01'N, 140°07'E). In general Andosol is often used for crop production whereas Fluvisol is used as rice paddies and has lower water permeability.

Treatments

The soils (100 g dry weight per core) were packed into PVC pipe cores (inner diameter = 5.5 cm). Then, the cores received one of the four treatments (with/without biochar × with/without hairy vetch). For the cores with biochar, commercially available rice husk biochar (Green tech Inc., Japan, Niigata, 42%C, 0.5%N) was mixed into the soil before packing (2.1 kg biochar m^{-2} soil). For the cores with hairy vetch, dried and finely cut hairy vetch (0.8 kg hairy vetch m^{-2} soil surface) was applied on the soil surface after we packed the soils into the cores. The hairy vetch used in the experiment was ^{15}N-labelled (0.49 Atom% ^{15}N), by growing them with $^{15}NO_3^-$. Compared to the cores without biochar, the cores with biochar had less bulk densities but the same amount of the soil per core. The cores were maintained at a room temperature. Soil moisture contents were maintained at around 100% WFPS. The experimental period was 45 days.

Measurement of inorganic-N

For the inorganic-N measurements, 96 cores were used in total (2 soil types × ± biochar × ± hairy vetch × 4 sampling timings × 3 replicates). At each sampling time (8, 15, 22, and 44 d after the application of hairy vetch), the ammonium (NH_4^+-N) and nitrate (NO_3^--N) concentrations were measured by destructively sampling the cores with three replicates for each treatment. Each soil core was separated into two depths (0–1 cm ("top") and below ("bottom") and they were separately measured for the inorganic-N concentrations to investigate the diffusion of N from the surface applied hairy vetch. Soil inorganic-N was extracted from these soils with 10% potassium chloride (KCl) (4 g soil to 20 ml KCl solution) and determined colorimetrically using a flow injection auto-analyser system (AquaLab, Japan).

Measurement of soil N_2O emissions, cumulative N_2O emissions, ^{15}N enrichment and N_2 emissions

A separate set of cores with the same treatments was used for this part of the experiment. Nitrous oxide (N_2O) emissions were measured 2–3 times a week using a gas chromatograph (GC) equipped with an electron capture (ECD) detector (GC-2014, Shimadzu). The ^{15}N enrichment of N_2O was measured using a Delta V isotope ratio mass spectrometer (Thermo Electron Corporation) after being concentrated using an automated Trace Gas Pre-Concentrator (Thermo Scientific) (Uchida et al. 2014). The cumulative recovery of the applied hairy vetch-N, as N_2O-N, was calculated based on the cumulative emissions of N_2O-^{15}N per the amount of ^{15}N applied as hairy vetch-^{15}N. The acetylene block method was used to measure N_2 emission rates from soils. The N_2 emissions were destructively measured using separate soil cores at four times, day 8, 15, 22, and 45.

Statistical analysis

Analysis of variance (ANOVA) was performed to investigate the effects of soil type, biochar and hairy vetch application on inorganic-N concentrations. For the cumulative gas emission data (soil N_2O emissions, N_2 emissions, and the recovery of HV-^{15}N as N_2O-^{15}N) and the soil bulk density data, the ANOVA was also performed to investigate the effects of soil type, biochar and hairy vetch application. For soil pH data, the ANOVA was performed to observe the effect of biochar and soil types. When significant effects of the treatments were observed, means were compared using the Tukey's multiple comparison tests.

Results and discussion

Soil inorganic-N

Only the top layer results were shown here and the bottom layer showed the similar trend but in smaller scale. The hairy vetch treatment significantly increased NH_4^+-N concentrations, with and without the presence of biochar in the two soil types (Fig 1a and b). The biochar treatment decreased soil NH_4^+-N in the hairy vetch treatments in the Andosol (Fig. 1a) but not in the Fluvisol (Fig. 1b). Biochar treatment increased the NO_3^--N concentrations in the top layer in both the Andosol and the Fluvisol (Fig. 1c and d).

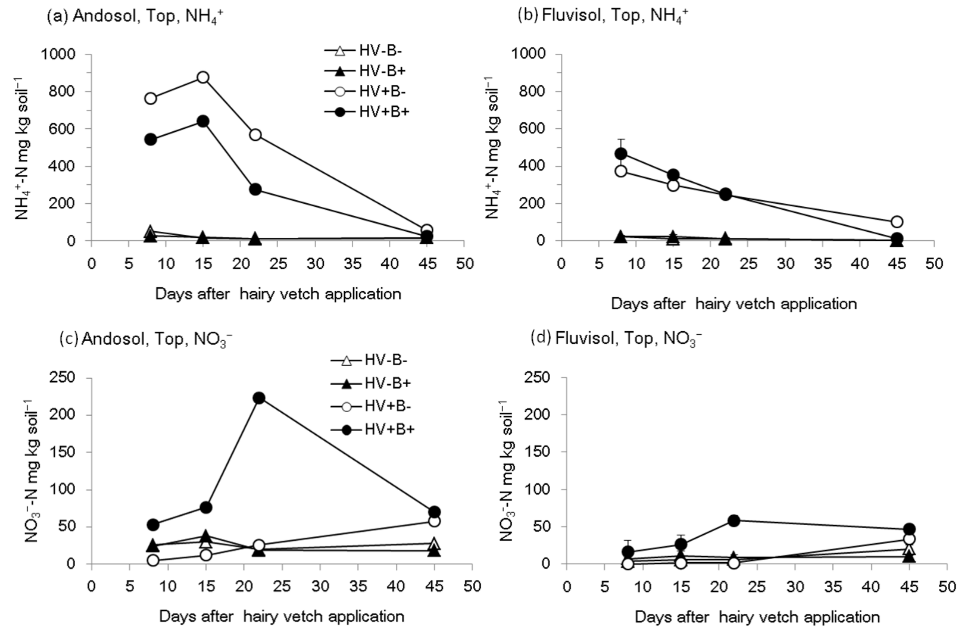

Figure 1. Changes in soil ammonium-nitrogen (NH_4^+-N) concentration at 0–1 cm "Top" layer in (a) the Andosol and (b) the Fluvisol, and in soil nitrate-nitrogen (NO_3^--N) concentration in (c) Top layer soil in Andosol and (d) Top layer soil in Fluvisol. Triangles and circles are without hairy vetch (HV−) and with hairy vetch (HV+) treatment, white marks and black marks are without biochar (B−) and with biochar (B+) treatment, respectively. The error bars were standard deviations (n = 3).

N_2O, N_2 emissions and the recovery of HV-^{15}N as N_2O-^{15}N

The application of hairy vetch on the soil surface immediately increased N_2O emissions in both the Andosol (Fig. 2a) and Fluvisol (Fig. 2b). In the Andosol, the peaks of N_2O emissions for the soils with hairy vetch occurred (i) immediately after the application of hairy vetch, and (ii) 20–22 days after the application of hairy vetch. Between the two peaks (day 6–15), the Andosol with hairy vetch and biochar showed relatively higher N_2O emissions, when compared to the Andosol with hairy vetch without biochar. In the Fluvisol, the N_2O emission patterns after the addition of hairy vetch were similar to those of the Andosol. However, the second peak of N_2O emissions in the Fluvisol with hairy vetch appeared relatively slower (day 37) when compared to the second N_2O emission peak from the Andosol with hairy vetch (day 20–22).

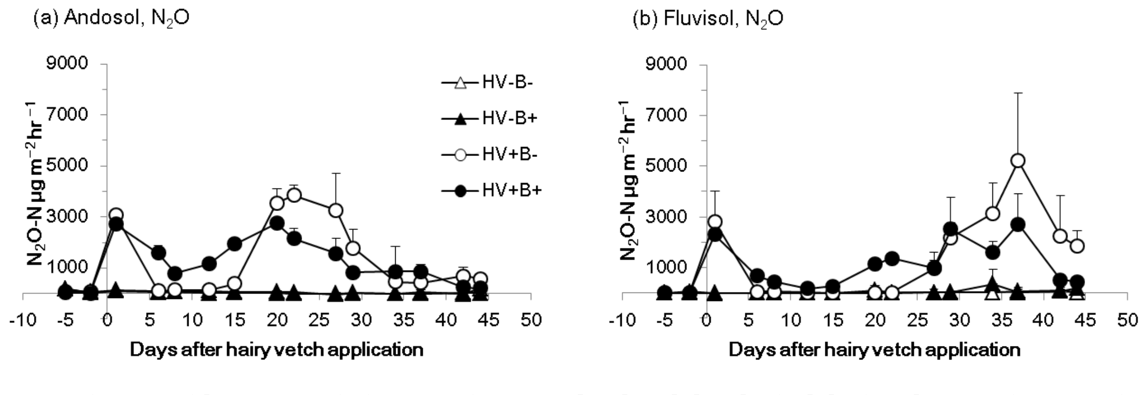

Figure 2. Nitrous oxide (N_2O) emission rates in (a) Andosol and (b) Fluvisol during the experiment. Triangles and circles are without hairy vetch (HV−) and with hairy vetch (HV+) treatment and white marks and black marks are without biochar (B−) and with biochar (B+) treatment, respectively. The errors were standard deviations (n=3). The negative values were the days before the application of hairy vetch.

The biochar did not influence the cumulative N_2O-N emissions for either the Andosol or Fluvisol (Table 1). However, for the soils with hairy vetch, cumulative recovery of applied hairy vetch-N as N_2O-N was significantly increased due to the addition of biochar (Table 1). The addition of hairy vetch also increased the N_2 emissions in both the Andosol and the Fluvisol (Table 1). The addition of biochar decreased the N_2 emissions in both the Andosol and Fluvisol, in soils with hairy vetch. .

Table 1. Cumulative N_2O emissions, cumulative recovery of applied hairy vetch-N as N_2O-N, and N_2 emissions. The data are the average of three replicates and the errors are standard deviations.

Soil types	Treatments		Cumulative N_2O emission (μg N m^{-2})	Cumulative recovery of applied hairy vetch-N as N_2O-N (%)	N_2 emission (μg N m^{-2})
	Hairy vetch	**Biochar**			
Andosol	–	–	0.24 ± 0.09		0.04 ± 0.03
		+	0.10 ± 0.04		0.01 ± 0.01
	+	–	3.09 ± 0.04	1.73 ± 0.05	3.51 ± 1.11
		+	2.96 ± 0.45	2.63 ± 0.50	2.06 ± 0.58
Fluvisol	–	–	0.10 ± 0.01		0.07 ± 0.05
		+	0.29 ± 0.26		0.08 ± 0.11
	+	–	3.56 ± 0.82	2.34 ± 0.24	2.06 ± 0.49
		+	2.87 ± 0.39	2.90 ± 0.29	0.70 ± 0.34

Conclusion

The effect of the surface applied legume residue, hairy vetch, on inorganic N concentration, N_2O, and N_2 emission were influenced by the presence of rice husk biochar. Under saturated soil moisture conditions, the addition of biochar reduced the amount of soil NH_4^+-N in an Andosol but the effect of biochar on NH_4^+-N was not significant for a Fluvisol. The effect of biochar on N-related microbial processes has to be investigated further in detail. The cumulative emission of N_2O was not significantly different with and without biochar both in an Andosol and a Fluvisol. However, the cumulative recovery of applied hairy vetch-N as N_2O-N was higher with biochar.

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