Greenhouse gas emissions from intensive pasture on ferrosol in Northern NSW, Australia: Impact of biochar amendment

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Abstract
An intensive field campaign was performed from April to June 2009 to assess the effect of biochar amendment on the emission of soil-borne GHGs from a sub-tropical pasture on acidic ferrosol. Over the whole measurement period high emissions of N_2O and high fluxes of CO_2 could be observed, whereas a net uptake of CH_4 was measured. Only small differences in the fluxes of N_2O and CH_4 from the biochar amended plots (35.33 ± 4.83 µg N_2O-N/m^2/h, -6.76 ± 0.20 µg CH_4-C/m^2/h) vs. the control plots (31.08 ± 3.50 µg N_2O-N/m^2/h, -7.30 ± 0.19 µg CH_4-C/m^2/h) could be observed, while there was no significant difference in the fluxes of CO_2. However, it could be observed that N_2O emissions were significantly lower from the biochar amended plots during periods with low emission rates (< 50 µg N_2O-N/m^2/h). Only during an extremely high emission event following heavy rainfall N_2O emissions from the biochar amended plots were higher than from the control plots. Our results demonstrate that pastures on ferrosols in Northern NSW are a significant source of GHG and that the amendment of biochar can alter those emissions. However, more field and laboratory incubation studies covering prolonged observation periods are needed to clarify the impact of biochar amendment on soil microbial processes and the emission of soil-borne GHGs.

Key Words
Greenhouse gas emissions, biochar amendment, Northern NSW, Australia.

Introduction
Land-use and agricultural practices affect the soil microbial carbon (C) and nitrogen (N) turnover and hence the biosphere-atmosphere exchange of greenhouse gasses (GHG), namely N_2O, CH_4 and CO_2. In Australia, the agricultural sector contributes to 15.7% of of the total emissions of GHGs and the agriculture produces about 59.5% of all CH_4 emissions (67.2 Mt CO_2−eq.) and 85.3% of all N_2O emissions (20.7 Mt CO_2−eq.) (AGO 2007). When land-use changes involving biomass burning, soil degradation and deforestation are included in this estimate, the overall emissions account for one-third of the total national GHG release. At the same time agriculture is considered to have the highest GHG mitigation potential by reducing GHG emissions from soil and sequestering carbon in soils via modified land-use and management.
A promising new mitigation approach of is the application of biochar to soils, which offers the potential of securely sequestering carbon in the soil since charcoal generally is protected from rapid microbial degradation (Lehmann *et al.* 2006). Moreover, it has been shown that biochar amendment to soils can significantly improve soil quality and plant growth (Chan *et al.* 2007; Chan *et al.* 2008) and at the same time reduce the emissions of GHG from soils (Yanai *et al.* 2007; Van Zwieten *et al.* 2009). However, to date only very few studies reported on the effect of biochar on soil soil-borne GHGs emissions and the impact of biochar amendment on soil microbial processes remains unclear. Therefore, this study aimed to investigate the effect of soil biochar amendment in pasture systems of Northern NSW upon the emissions of N_2O, CH_4 and CO_2 over a 2 month intensive field campaign using a fully automated closed chamber monitoring system

Methods
Continuous trace gas flux measurement
The soil–atmosphere exchange of N_2O, CH_4 and CO_2 was measured with a mobile fully automated measuring system. 6 acrylic measuring chambers (50cm x 50cm x 15cm; width x length x height) were fixed on stainless steel frames, which were driven approximately 10 cm into the soil. The lids of the chambers were opened and closed automatically with pneumatic devices. During the closing period air samples from each chamber were taken alternately and injected towards the analytical devices. Changes in N_2O and CH_4 concentration after chamber closure were measured with a gas chromatograph (Texas Instruments SRI 8610C, Torrance/USA) equipped with a ^{63}Ni electron capture detector (ECD) for N_2O analysis and a flame

ionisation detector (FID) for CH_4 analysis. In addition, an infrared gas analyser (LI-COR 820, LICOR, Lincoln/USA) was installed to allow measurements of CO_2 concentrations in air samples. N_2O, CH_4 and CO_2 fluxes were calculated from the linear increase or decrease in gas concentration, corrected for air temperature, atmospheric pressure and chamber volume to surface area ratio.

Study site

The study site at Wollongbar Agricultural Institute (28°50′S, 153°25′E) in north eastern NSW, Australia was decribed by Sinclair *et al.* (2009) as a factorial experiment assessing the impacts of two different biochars upon fertiliser use efficiency and pasture biomass production. This study examined one treatment within this factorial experiment and compared it to the corresponding controls. A cattle feedlot biochar (analysis in Table 1 below) was applied at 10t/ha in November 2006 and was incorporated to a depth of 100mm. The site had a combination of Amarillo pinto peanut and annual ryegrass. Over the annual ryegrass season (summer), the plots received an equivalent 50kg N/ha each month, and twice yearly applications of P (28 kg/ha) and K 50 (kg/ha). These quantities of N application are common for intensive pasture production. Sinclair *et al.* (2009) found a significant response to both N and P uptake from the biochar amendment, as well as a significant increase in pasture biomass yield over 2 seasons, 2007 and 2008.

Table 1. Summary analysis of cattle feedlot biochar used in field trial.

Total C	Total N	Total P	Total K	pH ($CaCl_2$)	$CaCO_3$ eq.	KCl NH_4-N	KCl NO_3-N	Bray 1 P	CEC
51%	0.43%	0.61%	1.8%	10.4	5.7%	0.16mg/kg	0.32mg/kg	61mg/kg	16cmol(+)/kg

Results

Basic soil analyses were conducted on the site at the commencement of the study period. These are shown in Table 2. It is clear from these analyses that there are no major differences in the soil properties, although as expected, soil C appears slightly higher in the biochar amended plots. The pH of the soil was 4.7 ($CaCl_2$) and the CEC of the soils was very low at 5.1 cmol (+)/kg.

Over the whole measurement period high emissions of N_2O and high fluxes of CO_2 could be observed, whereas a net uptake of CH_4 was measured. Only small differences in the fluxes of N_2O and CH_4 from the biochar amended plots vs. the control plots could be observed, but there was no significant difference in the fluxes of CO_2 (Table 3).

Table 2. Analysis of soil in plots (n=3) prior to commencement of study.

	Biochar	Std dev	Control	Std dev
Total N	0.44	0.02	0.45	0.02
Total C	4.6	0.12	4.4	0.17
KCl extractable NH_4-N	6.1	0.98	7.2	1.7
KCl extractable NO_3-N	5.2	0.23	4.0	0.64

In general, a great spatial and temporal variability of the fluxes could be observed. Soil CO_2 emissions ranged from 36 to 86 mg CO_2-C/m^2/h and a positive correlation with soil water filled pore space (WFPS) could be observed. Average methane uptake from the pasture site was found to be 6.76 mg CH_4-C/m^2/h for the biochar plots and 7.30 mg CH_4-C/m^2/h for the control plots with highest values up to 18 mg CH_4-C/m^2/h. Methane emissions up to 7.31 mg CH_4-C/m^2/h occurred after periods of heavy rainfall under saturated soil moisture conditions. Highest spatial and temporal variability was measured for the N_2O fluxes with emissions ranging from 1.9 to 502 µg N_2O-N/m^2/h. N_2O fluxes were strongly correlated to WFPS and highest emissions were measured after an extreme rainfall event with 157 mm of rain over one day (May 22, 2009). During periods with constant WFPS a strong diurnal pattern of N_2O emissions could be observed with highest fluxes occurring in the late afternoon, which was explained by the daily temperature pattern in the topsoil.

Table 3: Mean N_2O, CH_4 and CO_2 fluxes emissions from the biochar amended vs. the control treatments for measuring periods from April 19 to June 13, 2009.

	Biochar	Control
Mean CO_2 Flux [mg CO_2 /m^2/h]	67.70 ± 0.82	67.88 ± 0.99
Mean CH_4 Flux [mg CH_4 -C/m^2/h]	-6.76 ± 0.20	-7.30 ± 0.19
Mean N_2O Flux [µg N_2O-N/m^2/h]	35.33 ± 4.83	31.08 ± 3.50

Table4. N_2O emissions from the biochar amended vs. the control treatments for different measuring periods.

Time Period	N_2O emission biochar [µg N_2O-N/m^2/h]	N_2O emission control [µg N_2O-N/m^2/h]
19.5-15.5	15.94 ± 0.59	22.82 ± 0.79
20.5-26.5	132.28 ± 19.52	89.81 ± 15.71
1.6-13.6	7.05 ± 3.08	10.16 ± 2.80

During periods with low emission rates (< 50 µg N_2O-N/m^2/h) N_2O emissions were significantly lower from the biochar amended plots compared to the control plots. However, after the extreme rainfall event on May 22 significantly higher emissions were measured from the biochar treatment (Table 4).

Conclusion

Using a fully automated closed chamber monitoring system we could quantify emissions of N_2O, CH_4 and CO_2 from intensive pasture with a high temporal resolution. Our results demonstrate that pastures on acidic ferrosols in Northern NSW are a significant source of GHG. Although a small overall uptake of CH_4 was observed this could not offset the high emissions of N_2O and CO_2. The hypothesis that the application of biochar would lead to a reduction in emissions of GHG from soils was not supported in this field assessment. The overall GHG balance was slightly higher in the biochar amended treatment. However, our results demonstrate that biochar can alter those emissions. More field and laboratory incubation studies covering prolonged observation periods are needed to clarify and optimise the impact of biochar amendment on soil microbial processes and the emission of soil-borne GHGs.

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