N_2O and CO_2 Emission from Mine Soil Reclaimed with Organic Amendments

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Abstract
Surface coal mining causes drastic soil disturbance leading to serious degradation of inherent soil characteristics and productivity. The primary objective of mined land reclamation is to restore soils capacity to support vegetation and other essential ecosystem services. Organic amendments such as bio-solids, manure, composted manure and industrial by-products are effective in restoring soil productivity; however there has been little investigation of the potential for these amendments to give rise to potential green house gases such as nitrous oxide (N_2O) and carbon dioxide (CO_2). This laboratory incubation study compared N_2O and CO_2 fluxes from non-amended mine soil (control) and mine soil amended with lime and fertilizer, a manure (1.6g dry weight per 100g soil), composted poultry manure (7.1g dry weight per 100 g soil) and fresh poultry layer manure (1.6g dry weight per 100g soil) mixed with four rates of paper mill sludge (PMS) (0, 6.6, 9.9 and 13.2g dry weight per 100g soil) to achieve C: N ratios of 7:1,14:1, 21:1 and 28:1. The amount of N added with the compost and with all manure + PMS treatments was constant. The experiment was carried out at soil moisture contents of 60% and 80% water filled pore space (WFPS). The impacts organic amendments had on N_2O and CO_2 emissions were very short-lived. Combined application of fresh manure and PMS caused an increase in the N_2O and CO_2 emissions during the first 3 days of incubation. No differences were observed in emissions among the fertilizer, compost and only manures treatments.

Key Words
Nitrous oxide emission, mined land reclamation, manure, denitrification.

Introduction
Surface coal mining results in degradation of soil physical properties, significant loss of organic matter and nutrients and hence diminishes soil productivity (Akala and Lal 2001). Restoring the soil productivity and the establishment of sustained vegetative cover are primary objectives of mine soil reclamation. Use of post-mining landscapes for biomass production requires development of highly productive soils which can be achieved by large additions of organic amendments including agricultural manure. However, addition of large amounts of organic amendments results in significant nutrient loss unless measures are taken to stabilize the amendments and sequester the nutrients (Cravotta 1998; Sopper 1993; Stehouwer *et al.* 2006). Previous research has demonstrated that these leaching losses of manure N can be largely avoided either by composting the manure or by mixing the manure with high carbon materials such as paper mill sludge (PMS). However, these amendments could also create conditions conducive for nitrous oxide (N_2O) and carbon dioxide (CO_2) emission because of the presence of large amounts of organic carbon and nitrogen and thus increased microbial activity. Release of CO_2 and N_2O to the atmosphere represents loss of essential nutrients from soil and also emission of two major greenhouse gases. Nitrous oxide is a greenhouse gas 300 times more effective than CO_2 (Ramaswamy *et al*. 2001). To assess the potential for these amendments to cause such gaseous emissions, we conducted a laboratory incubation experiment using mine soil treated with various manure-based amendments.

Methods
Soil sampling
Soil for this study was collected from the surface layer (0-15 cm) of an active mine site in Clearfield Co., PA. Soil material was passed through a 2 cm screen to remove large rock fragments before being brought back to the laboratory. Soils were analysed for gravimetric moisture by drying for 48h at 105°C. Then the soils were sieved to 2 mm, were characterized for physico-chemical properties such as pH, acidity, Ca, Mg, K, P cation exchange capacity (CEC) and then they were stored at 4°C for further analysis.

Incubation experiment-Measurement of N_2O and CO_2 emission from soil
An incubation experiment was set up using 1L clear glass mason jars each containing 100 gm soil mixed with the amendments described in Table 1. Soils were adjusted at 60% and 80% water filled pore space

(WFPS). Soil oxygen (O_2) level is difficult to measure directly; therefore, changes in soil O_2 levels are usually described using a surrogate, such as water-filled pore space (WFPS) (Lemke *et al.* 1998; Davidson and Verchot 2000). Nitrification occurs at up to 60% WFPS (Davidson and Verchot 2000). Denitrification becomes dominant at WFPS 60% (Lemke *et al*. 1998) and at 80% WFPS, O_2 diffusion is restricted to the point where N_2O is used as an electron acceptor and reduced to N_2 (Veldkamp *et al.* 1998). However, these WFPS values are not exact limits for nitrification and denitrification, because O_2 availability is a combination of O_2 diffusion rate and O_2 consumption by heterotrophic activity (Ma *et al.* 2008). Moreover, maintaining the soils at these two constant moisture levels ensured that the soil does not become too dry or too wet because both these conditions can impede microbial activity. Each treatment at each moisture level was replicated 3 times for gas sampling and one extra replicate for measuring ammonium (NH_4^+) and nitrate (NO_3^-) concentrations in soil using KCl as an extractant. The jars were incubated at 20±2°C, were aerated on a regular basis and were checked for water content by weighing the jars one day before each gas sampling. Gas samples were collected at 0, 1, 3, 6, 10, 28 and 37 days and were analyzed for N_2O and CO_2 using a Gas Chromatograph (Varian CP-3800). The treatment effects were analyzed by using two -way ANOVA and single degree of freedom contrasts were used for planned comparisons using SAS (Statistical analysis software).

Table1. Quantities of amendment material, C and N added to mine soil

Treatment	Material added (g/100 g soil)	Total C added (g C/ 100 g soil)	Total N added (mg N/100 g soil)
Control	-	-	-
Lime and fertilizer	0.5 g lime + 0.07 g ammonium nitrate	0.6	24
Compost	7.1 g compost	2.45	121
Manure	1.6 g manure	0.65	121
Manure and PMS(14:1)	1.6 g manure + 6.6 g PMS	1.68	121
Manure and PMS(21:1)	1.6 g manure + 9.9 g PMS	2.52	121
Manure and PMS(28:1)	1.6 g manure + 13.2 g PMS	3.36	121

Results

Physico-chemical properties of soil

The physico-chemical characterictics of soil such as pH, acidity was measured. Soil pH was 4.5 and acidity 20.7. Also soils samples were analyzed for Ca, Mg, K, P and CEC. The CEC of the soil was found to be 17 meq/100 g of soil and Ca (190 ppm),Mg(106 ppm), K(67 ppm), P(7 ppm).

Nitrous oxide (N_2O)emission results

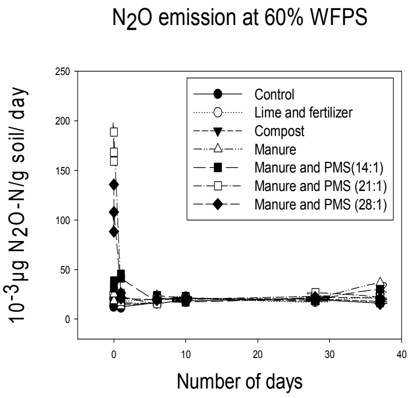

Figure1. Effect of organic amendments on N_2O emission from mine soil at 60% water filled pore space (WFPS)

Carbon dioxide (CO_2)emission results

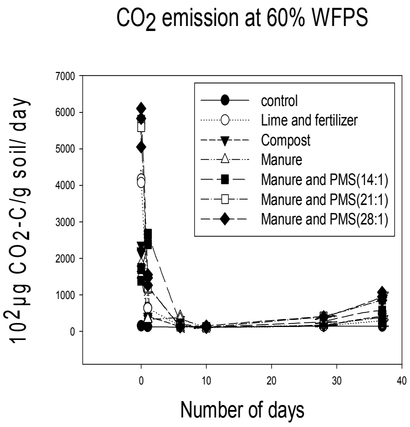

Figure2. Effect of organic amendments on CO_2 emission from mine soil at 60% water filled pore space (WFPS)

Discussion

Results indicated the effect of amendments and soil moisture content on N_2O and CO_2 emissions from reclaimed mined soils. Organic treatments, especially, the higher ratios of manure and PMS treatments (14:1 and 21:1 C: N ratios) gave rise to larger N_2O and CO_2 emissions from mined soils compared to untreated soil and soil amended with inorganic fertilizer. But the effect was limited to only first 3 days of incubation (Figure 1 and Figure 2). This increase of emission can be attributed to increased heterotrophic activity right after application of amendments. Increase of moisture content from 60 to 80% caused statistically significant increase in N_2O emission from manure based amendments (Figure not shown). In another study by Ciarlo *et al.* (2007), the greatest N_2O emission occurred at 80% WFPS where the conditions were not reductive enough to allow complete reduction to N_2. The NH_4^+ content in the KCl extract of soil remained high in all organic amendments but the level of NO_3^- was found to be low in all treatments except for the soil treated with lime and fertilizer. This can be due to lower level of nitrification conversion of NH_4^+ to NO_3^- by the nitrifying population in soil. The reason why nitrifiers were not active in soil could be related to soil pH (pH below 5) because in soil, autotrophic nitrifying bacteria grow best at neutral pH (Principles and applications of soil microbiology, 2nd edition). Therefore it can be summarized from the laboratory results that organic amendments have the potential to cause increased CO_2 and N_2O emissions. However, since these effects persisted only for a very brief period under controlled laboratory conditions, these results should be further tested *in situ*.

Conclusion

Over the past century, global average surface temperature has warmed by about 0.75ºC (Solomon *et al.* 2010). Much of the warming occurred in last half-century largely due to anthropogenic increases in well-mixed greenhouse gases (IPCC 2007). Therefore, care should be taken to avoid any human activity that would cause potential green house gas emissions capable of causing rise in earth's temperature to the environment. Hence, mine reclamation study needs to incorporate methods and develop strategies to come up with restoration mechanisms that are environmentally safe and at the same time are economically efficient. This study attempted to quantify and compare the emissions from mine systems reclaimed with different organic amendments. Once the results of this study are tested *in situ*, this study will be a useful addition to the growing body of literature focusing on restoration of degraded ecosystems. Data from this research coupled with studies focusing on biomass production in degraded lands will help develop a reclamation strategy that ensures optimum productivity while minimizing the emissions to the environment. Recommendations will be made to land managers on the basis of these research evidences to help them achieve specific reclamation targets with minimum environmental and economic costs.

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