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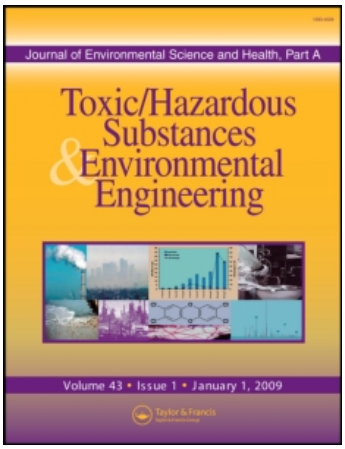


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# Evaluation of emission of greenhouse gases from soils amended with sewage sludge

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Increase in concentrations of various greenhouse gases and their possible contributions to the global warming are becoming a serious concern. Anthropogenic activities such as cultivation of flooded rice and application of waste materials, such as sewage sludge which are rich in C and N, as soil amendments could contribute to the increase in emission of greenhouse gases such as methane ($CH_4$) and nitrous oxide ($N_2O$) into the atmosphere. Therefore, evaluation of flux of various greenhouse gases from soils amended with sewage sludge is essential to quantify their release into the atmosphere. Two soils with contrasting properties (Candler fine sand [CFS] from Florida, and Ogeechee loamy sand [OLS] from Savannah, GA) were amended with varying rates (0, 24.7, 49.4, 98.8, and 148.3 Mg $ha^{-1}$) of 2 types of sewage sludge (industrial [ISS] and domestic [DSS] origin. The amended soil samples were incubated in anaerobic condition at field capacity soil water content in static chamber (Qopak bottles). Gas samples were extracted immediately after amending soils and subsequently on a daily basis to evaluate the emission of $CH_4$, $CO_2$ and $N_2O$. The results showed that emission rates and cumulative emission of all three gases increased with increasing rates of amendments. Cumulative emission of gases during 25-d incubation of soils amended with different types of sewage sludge decreased in the order: $CO_2 > N_2O > CH_4$. The emission of gases was greater from the soils amended with DSS as compared to that with ISS. This may indicate the presence of either low C and N content or possible harmful chemicals in the ISS. The emission of gases was greater from the CFS as compared to that from the OLS. Furthermore, the results clearly depicted the inhibitory effect of acetylene in both soils by producing more $N_2O$ and $CH_4$ emission compared to the soils that did not receive acetylene at the rate of 1 mL $g^{-1}$ soil. Enumeration of microbial population by fluorescein diacetate (FDA) and most probable number (MPN) procedure at the end of 25-d incubation demonstrated a clear relationship between microbial activity and the emission of gases. The results of this study emphasize the need to consider the emission of greenhouse gases from soils amended with organic soil amendments such as sewage sludge, especially at high rates, and their potential contribution to global warming.

**Keywords:** Denitrifier, greenhouse gases, global warming, methanogens, organic waste, sewage sludge.

## Introduction

Land disposal of various organic by-products is becoming a major problem due largely to their potentially harmful constituents. Among the organic products, sewage sludge (SS) also known as biosolids, is produced by the wastewater treatment plants in cities around the globe. Sewage sludge accounts for a very large volume, which evidently continues to increase. Application of SS to agricultural land is a common practice around the world and currently gaining increased attention due to the fact that SS characteristically contains high levels of major plant nutrients N and P and is enriched in organic materials therefore; application of SS could help to improve physical, chemical and biological fertility of soils.[1] In Europe, between 3 to 80% of the sludge produced is applied to land, with an average of 39%, while in the USA the average is 33%.[2] It is important to note that, application of low-quality sludge at high quantity to agricultural soils may adversely affect soil fertility, threaten ground water quality, and lead to food chain contamination.

Aerobic or anaerobic decomposition of nitrogen containing organic matter in solid waste and refuse generates various gases consisting methane ($CH_4$), carbon dioxide ($CO_2$), nitrous oxide ($N_2O$) and ammonia ($NH_3$). Furthermore, it has been recognized that a large number of previously unevaluated sources such as SS and animal

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manures may be contributing to the increase of greenhouse gases in atmosphere.[3,4] This has stimulated further studies into agriculture's share of the emission. It is believed that agriculture is responsible for 80% of anthropogenic $N_2O$ emissions[5] but current reports have suggested that animal wastes, or manures are important underestimated source of $N_2O$.[6]

Similarly, availability of information regarding the contribution of land applied SS to emission of various greenhouse gases ($CH_4$, $CO_2$, and $N_2O$) during the decomposition process is currently limited. As a result, the current study was initiated to evaluate the effect of: (i) soil type; (ii) rates and types of SS amendment on the emission of $CH_4$, $CO_2$, and $N_2O$ from two soils amended with varying rates of SS during a 25-day incubation period at their respective field soil water capacity.

## Materials and methods

### *Setup of incubation study*

Twenty grams of each portion of soils CFS (pH = 6.8) from Lake Alfred, Florida, and OLS from Savannah, Georgia (pH = 5.2) were placed in 250 mL Qopak bottles (Fisher Scientific Co., Newark, NJ). Two sets of triplicate soil samples were amended on area basis with either 0.00, 0.225, 0.450, 0.900, or 1.350 g (equivalent to 0, 24.7, 49.4, 98.8, or 148.3 Mg $ha^{-1}$) of dried and ground SS obtained from 2 water quality control plants in Savannah, GA [representing domestic (DSS) and industrial sources (ISS)]. Characteristics of the soils and sewage sludge materials used in the study are presented in Table 1.

The soil in each bottle was mixed thoroughly with respective amendments and appropriate amounts of deionized water to attain field capacity soil water content. The bottles were then sealed with 22 mm Mininert Caps (Precision Sampling, Baton Rouge, LA) fitted with gas sampling ports. The bottles were repeatedly evacuated and flushed with helium to maintain anaerobic conditions. Subsequently, 10% (by volume) of the head space gas, in one triplicate set of Qopak bottles was replaced with purified $C_2H_2$ to stop the final step of the denitrification process so that $N_2O$ could be sampled and analyzed along with $CH_4$ and $CO_2$.

Samples were incubated at room temperature (25°C) for 25-days, at field capacity soil water content. Moisture content of soil-sludge mixture in incubation bottle was adjusted by checking the change in weight differences on weekly basis. Gas samples (10 mL) were taken at every other day interval for the determination of composition and quantity of various greenhouse gases. The volume of sampled gas

**Table 1.** Selected properties of domestic sewage sludge (DSS), industrial sewage sludge (ISS) and soils used in this study

| *Properties*[a] | *Units* | *DSS*[b] | *ISS*[c] | *CFS*[d] | *OLS*[e] |
|---|---|---|---|---|---|
| pH (1:1 water:soil) | | 6.00 | 6.20 | 6.80 | 5.20 |
| C | % | 39.50 | 25.77 | 0.50 | 1.20 |
| N | % | 4.57 | 3.65 | 0.04 | 0.06 |
| S | % | 1.11 | 1.18 | 0.01 | 0.02 |
| P | mg $kg^{-1}$ | 13250.00 | 18540.00 | 1130.00 | 206.00 |
| K | mg $kg^{-1}$ | 1206.00 | 1785.00 | 285.00 | 3270.00 |
| Ca | mg $kg^{-1}$ | 15980.00 | 18890.00 | 369.20 | 3284.30 |
| Mg | mg $kg^{-1}$ | 1655.00 | 2571.00 | 562.40 | 262.20 |
| Mn | mg $kg^{-1}$ | 191.20 | 303.20 | 14.50 | 14.10 |
| Fe | mg $kg^{-1}$ | 10420.00 | 17210.00 | 591.40 | 661.50 |
| Cu | mg $kg^{-1}$ | 219.50 | 246.90 | 38.40 | 1.20 |
| Zn | mg $kg^{-1}$ | 542.50 | 597.10 | 92.60 | 7.40 |
| Pb | mg $kg^{-1}$ | 37.10 | 2.50 | 20.90 | 4.90 |
| Cd | mg $kg^{-1}$ | 4.10 | 10.41 | 0.40 | 0.60 |
| Ni | mg $kg^{-1}$ | 16.60 | 19.59 | <1.00 | <1.00 |
| Cr | mg $kg^{-1}$ | 24.70 | 27.40 | 7.40 | 4.30 |
| Al | mg $kg^{-1}$ | 10170.00 | 8547.60 | 1216.00 | 1383.00 |
| Sand | g $kg^{-1}$ | — | — | 967.00 | 860.00 |
| Silt | g $kg^{-1}$ | — | — | 8.00 | 100.00 |
| Clay | g $kg^{-1}$ | — | — | 25.00 | 40.00 |
| CEC | cmol $kg^{-1}$ | | | 2.20 | 3.90 |
| Texture | | | | fine sand | loamy sand |

[a]Total Elemental compositions were determined on acid digest by ICP-OES.
[b]Collected from President street water quality control plant, Savannah, Georgia [Domestic source (DSS)].
[c]Collected from Travis field water quality control plant, Savannah, Georgia [Industrial source (ISS)].
[d]Collected near Lake Alfred in Polk County (Candler fine sand), Florida [CFS].
[e]Collected near Savannah in Chatham county (Ogeechee loamy sand), Georgia [OLS].

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from the bottle was compensated with a similar amount of helium at each sampling event.

## Determination of greenhouse gases

Concentrations of $CH_4$, $CO_2$, and $N_2O$ in the samples were measured by injecting 10 mL of gas sample using a gas-tight syringe into a specialized and dedicated greenhouse gas chromatograph equipped with Porapak Q column (1 m length; 1/8" diameter; pore size is 80/100) and operated isothermally at 60°C and with $^{63}Ni$ electron capture detector (ECD to detect $CO_2$ & $N_2O$) and flame ionization detector (FID to detect $CH_4$) (Shimadzu GC-14A, Shimadzu Inc., Columbia, MD). Each gas analysis (area measurements under each peak) was calibrated using gas certified standards (1000 ppm $CO_2$, 1 ppm $N_2O$ and 5 ppm $CH_4$) from Scott Specialty Gases, Plumsteadville, PA.

## Measurement of microbial response

### *Heterotrophic microbial activity*

The effects of SS amendment on heterotrophic microbial activity and their impact on the emission of various greenhouse gases were investigated by measuring the rate at which fluorescein diacetate (FDA) was hydrolyzed as proposed by Schnrer and Rosswall.[7] Fifty mL of 60 mM phosphate buffer (pH 7.6) and 0.5 mL FDA (2 g $L^{-1}$ of ethanol) were added to a 250-mL Erlenmeyer flask containing 2 g of wet soil sample at the end of 25-d incubation. The flasks were stoppered, incubated for 60-min at 25°C on a rotary shaker (200 rpm). Fifty mL acetone was added to the soils and the flasks were swirled to stop further microbial activity. A 25-mL aliquot was centrifuged (1800 *g*; 5 minutes), clarified using disposable syringe filter (0.45 $\mu$m) and absorbance at 490 nm measured.

### *Denitrifying bacteria population*

Most probable number (MPN) technique was used to estimate denitrifying bacteria population.[8] Sterile Hungate tubes containing 5 mL nutrient broth were inoculated with dilutions of soils. Nutrient broth was prepared by mixing two solutions: i.e., (i) containing 1 g $KNO_3$, 1 g asparagines, 5 mL 1% alcoholic solution of bromothymol blue, in 500 mL deionized water; and (ii) containing 8.5 g of Na citrate, 1 g $KH_2PO_4$, 1 g $MgSO_4.7H_2O$, 0.2 g $CaCl_2.6H_2O$, 0.05 g $FeCl_3.6H_2O$, in 500 mL deionized water. The soil dilutions were prepared by vigorously shaking 1 g of moist soil in 99 mL of saline solution (0.85% [wt/wt] NaCl) with 3 drops of Tween 80 (Fisher Scientific Inc.). A series of 100-fold dilutions were used to inoculate 5 tubes for each dilution level. These tubes were incubated for 2-wks anaerobically at 25°C. The presence of denitrifying microbial population was identified by the color change of nutrient medium from green to deep blue with mild frothing and denitrifier population was estimated by MPN calculation.

### *Statistical analysis*

Means and standard errors of emission flux (concentrations) for $CH_4$, $CO_2$, and $N_2O$ gases were computed at each sampling events. In addition, regression analyses were carried out to see possible relationships between the cumulative emissions of measured greenhouse gases and total heterotrophic microbial population estimated by fluorescein diacetate (FDA) hydrolytic activity technique.

## Results and discussion

### *Emission patterns of major greenhouse gases*

The laboratory incubation study evaluated the effect of soil type, rates and types of sewage sludge application and the influence of addition of $C_2H_2$ on the emission $CH_4$, $CO_2$, and $N_2O$ from soils incubated at their respective field capacity soil water content. Among the greenhouse gases investigated, $CO_2$ was the most prominent gas released from soils irrespective of soil type, amendment type or rates on the basis of emission flux per gram of soil per day (Figures 1, 2, and 3). In contrast, emission flux of $N_2O$ was the smallest most of the incubation period, except for a rapid flux at the early stage of incubation. Rapid initial denitrification was also observed by several researchers when air dried soils were remoistened during incubation.[9–11]

This observation was probably due to low availability of mineral N present in SS material and possible slow decomposition and mineralization of organic-N present in SS under simulated anaerobic condition of this study. It is important to note that $N_2O$ flux was substantially greater from the soils that received DSS than those that received ISS. This could be, in part, due to the presence of greater N in the DSS as compared to that of in the ISS (Table 1). Emission flux of $CH_4$ was somewhat moderate with more fluctuation through out the incubation period.

In general, emission flux of $CH_4$ varied very little with soil type, type and rate of SS. Effect of soil water content and its adjustment to field capacity level on weekly basis had a substantial effect on the emission pattern of $CO_2$ and $CH_4$, but not on $N_2O$ (Figures 1, 2, and 3). This trend was possibly due to the presence of more water soluble organic carbon (WSOC) and not much water soluble N (WSN) when the soils were remoistened. However, no information is currently available on WSOC and WSN from this study to support this observation.

### *Effect of $C_2H_2$ addition on emission flux of greenhouse gases*

Acetylene is generally used in denitrification studies to inhibit the final step of the denitrification process so that $N_2O$

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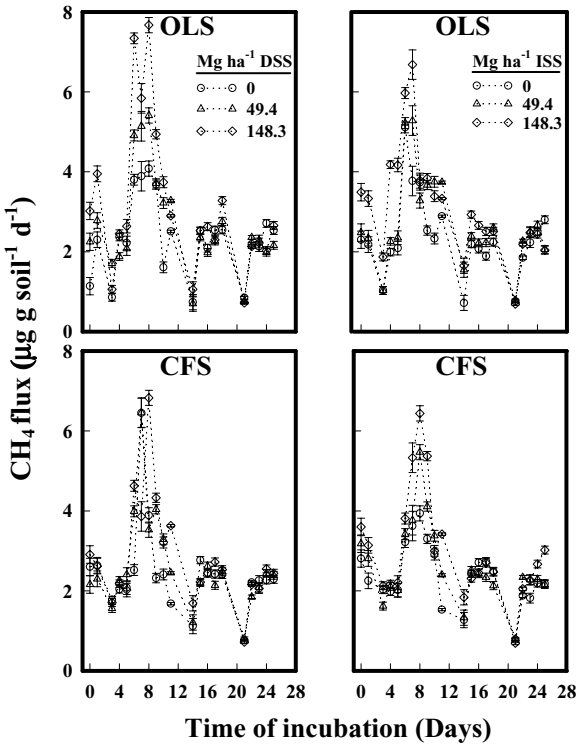
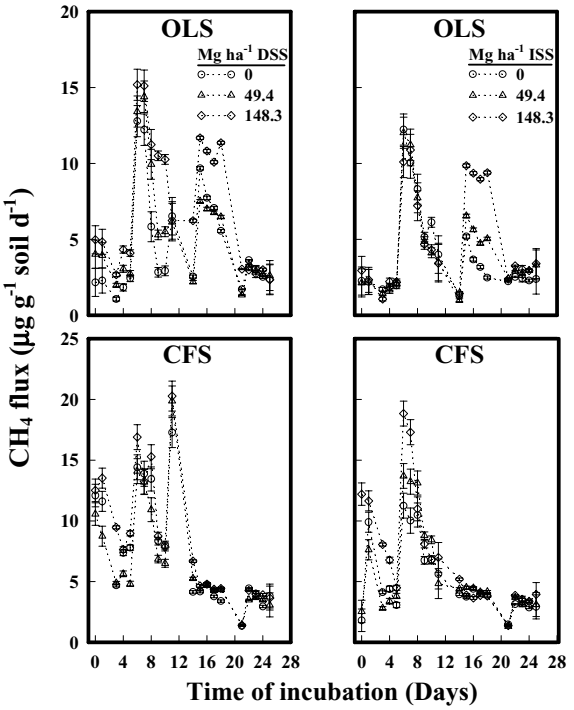
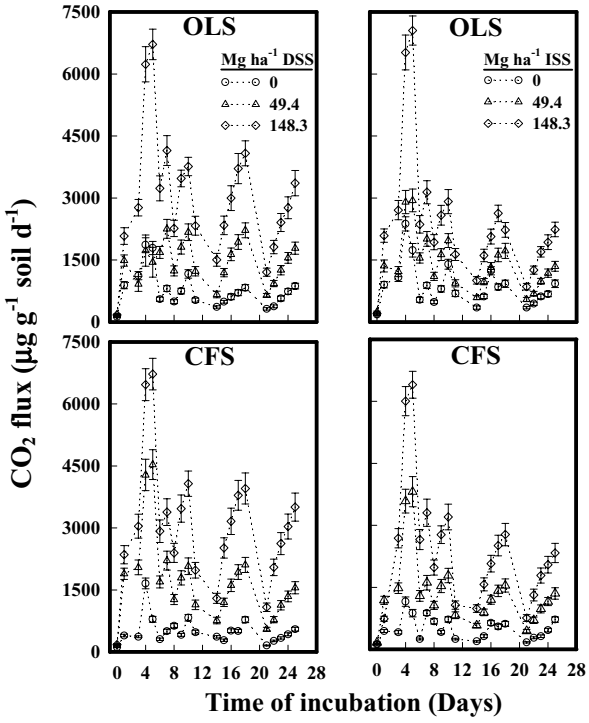



(a)

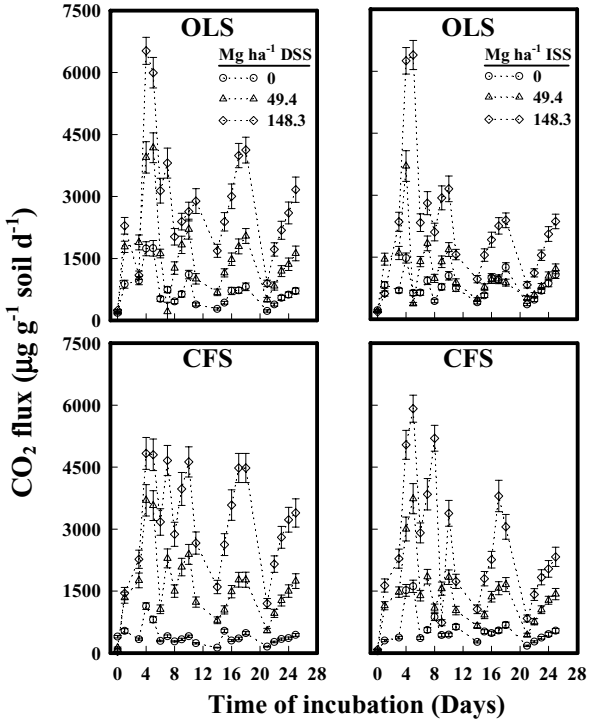



(b)

**Fig. 1.** Emission patterns of $CH_4$ in a 25-d laboratory study with 2 soils [Candler fine sand (CFS) and Ogeechee loamy sand (OLS)] amended and incubated at their respective field capacity moisture with various rates of domestic (DSS) and industrial (ISS) sewage sludge in the absence [Fig. 1a] and presence [Fig. 1b] of 1 mL of $C_2H_2$. All the data points show mean and standard error of values from triplicate measurements.




(a)




(b)

**Fig. 2.** Emission patterns of $CO_2$ in a 25-d laboratory study with 2 soils [Candler fine sand (CFS) and Ogeechee loamy sand (OLS)] amended and incubated at their respective field capacity moisture with various rates of domestic (DSS) and industrial (ISS) sewage sludge in the absence [Fig. 2a] and presence [Fig. 2b] of 1 mL of $C_2H_2$. All the data points show mean and standard error of values from triplicate measurements.

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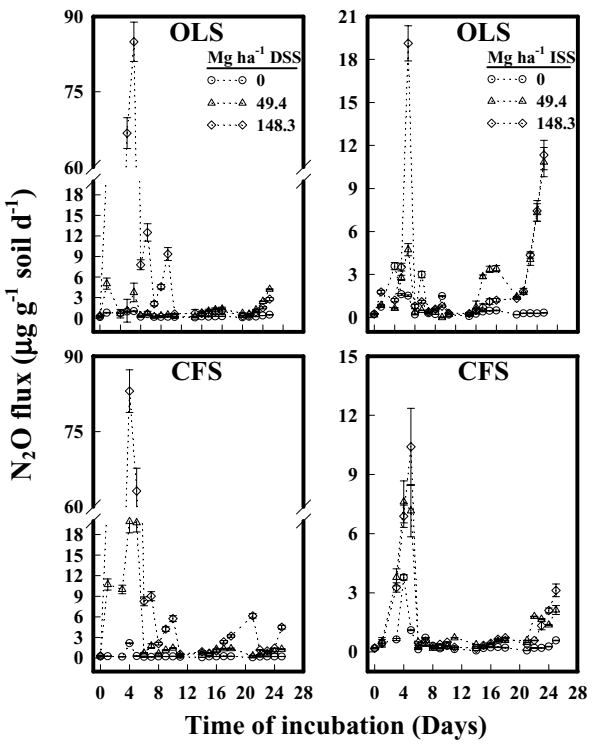
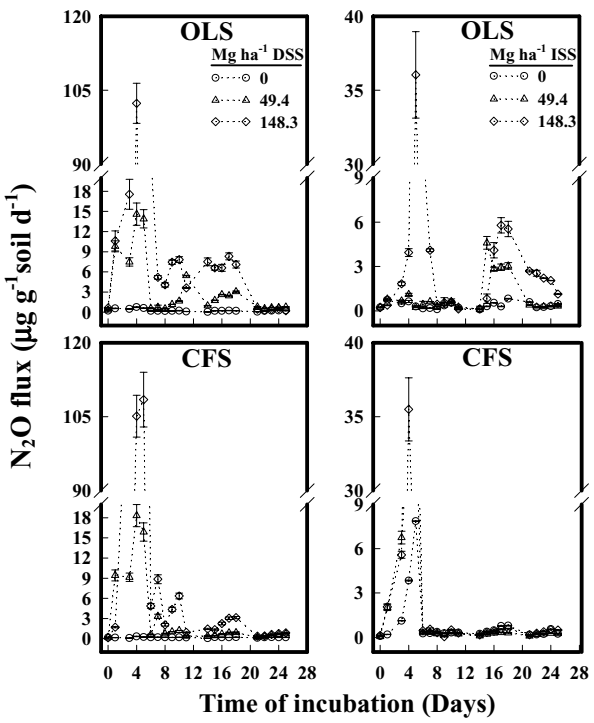



(a)




(b)

**Fig. 3.** Emission patterns of $N_2O$ in a 25-d laboratory study with two soils [Candler fine sand (CFS) and Ogeechee loamy sand (OLS)] amended and incubated at their respective field capacity moisture with various rates of domestic (DSS) and industrial (ISS) sewage sludge in the absence [Fig. 3a] and presence [Fig. 3b] of 1 mL of $C_2H_2$. All the data points show mean and standard error of values from triplicate measurements.

could be sampled and analyzed.[12,13] Nitrous oxide flux from various treatments which received 1 mL $C_2H_2$ $g^{-1}$ soil was almost one and a half times greater than that of the set of treatment that did not receive $C_2H_2$ irrespective of soil type, rates and type of amendments. Thus, the the effect of $C_2H_2$ on the emission of $N_2O$ was clearly evident. It is also important to note from the observation that, the flux of $N_2O$ varied substantially with type of sludge and soil. This observation is in close agreement with generally observed influence of various soil chemical, physical and biological properties on the denitrification activity in soil and its subsequent effect on $N_2O$ flux[10,11,14,15] as well as the influence of properties of the type of amendments.[16,17]

Acetylene which was added to inhibit further reduction of $N_2O$ to $N_2$ gas had substantial influence on $CH_4$ flux. Our experimental results indicated that addition of 1 mL of $C_2H_2$ $g^{-1}$ soil increased $CH_4$ flux by 1.5- to 3-fold. It is generally accepted by various researchers that methane is oxidized by methane mono-oxygenase (MMO) representing the key enzyme for methanotrophic bacteria.[18,19] Acetylene has an inhibitory effect on MMO, thereby, reducing the activity of methanotrophic bacteria and subsequently increases the net $CH_4$ production. The oxidation of $CH_4$, net $CH_4$ production, and other possible inhibitors of $CH_4$ oxidation were the subject of various researchers since this is an important natural process of reducing $CH_4$ emission.[17,20]

Different types of $CH_4$ consuming bacteria present in soils tend to reduce the amount of net $CH_4$emission to atmosphere by oxidizing $CH_4$ into various other compounds such as $CO_2$, acetate, and formate.[22] Therefore, the presence of methanotrophic microbial populations in soils would not necessarily result in increased production of $CO_2$. However, it is important to note that inhibitory effect of $C_2H_2$ on methanotrophic bacterial activity would increase the net $CH_4$production in soils. Unlike $CH_4$ and $N_2O$, the effect of addition of $C_2H_2$was not significant with respect to $CO_2$ emission in this study.

### *Cumulative emission of major greenhouse gases*

Cumulative emissions of $CO_2$, $CH_4$, and $N_2O$ estimated per gram of soil are presented in Table 2. At each sampling time, head space gases were flushed out upon the completion of measuring the concentrations of $CO_2$, $CH_4$, and $N_2O$ in 10 mL sample injected into specialized GC-14A gas chromatograph. This step facilitated the estimation of concentrations and rates of emission of gases between 2 sampling time periods. Cumulative emissions of $CO_2$, $CH_4$, and $N_2O$ increased with increasing rates of SS. However, the type of soil, the type of SS, and the presence or absence of $C_2H_2$ had significant effects on the cumulative emissions of $CH_4$ and $N_2O$ but not on $CO_2$.

### *Cumulative emission of $CO_2$*

Cumulative emissions of $CO_2$ increased with increasing rates of either type of SS across both soils (Table 2). It

**Table 2.** Cumulative emissions of $CO_2$, $CH_4$, $N_2O$ and number of denitrifier population per gram of soil for Candler fine sand and Ogeechee loamy soil amended with various rates of two different types of sewage sludge

| | | | *Presence of $C_2H_2$* | | | | *Absence of $C_2H_2$* | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | *Cumulative emission $g^{-1}$ soil (Mean values)* | | | | *Cumulative emission $g^{-1}$ soil (Mean values)* | | | |
| *Soil* | *SS type* | *SS application rates Mg $ha^{-1}$* | *$CO_2$ mg* | *$CH_4$ $\mu g$* | *$N_2O$ $\mu g$* | *Number of denitrifiers $10^6 g^{-1}$ soil* | *$CO_2$ mg* | *$CH_4$ $\mu g$* | *$N_2O$ $\mu g$* | *Number of denitrifiers $10^6$ $g^{-1}$ soil* |
| CFS | DSS | 0.0 | 9.44 | 159.84 | 6.27 | 3.3 | 12.08 | 59.42 | 4.19 | 2.3 |
| | | 24.7 | 25.19 | 168.96 | 51.19 | nd† | 27.60 | 60.18 | 39.20 | nd |
| | | 49.4 | 38.37 | 169.35 | 216.21 | 4.9 | 40.71 | 62.19 | 76.28 | 4.9 |
| | | 98.8 | 57.49 | 175.70 | 244.72 | nd | 58.15 | 62.75 | 227.42 | nd |
| | | 148.3 | 72.74 | 191.25 | 349.57 | 17.0 | 71.77 | 65.18 | 280.51 | 14.0 |
| | ISS | 0.0 | 12.72 | 110.17 | 27.40 | 1.7 | 11.59 | 56.94 | 11.08 | 2.3 |
| | | 24.7 | 23.02 | 124.12 | 40.97 | nd | 24.29 | 58.12 | 29.78 | nd |
| | | 49.4 | 32.92 | 127.40 | 44.62 | 3.3 | 32.10 | 58.62 | 34.76 | 3.3 |
| | | 98.8 | 41.41 | 141.94 | 45.19 | nd | 47.61 | 62.10 | 37.74 | nd |
| | | 148.3 | 59.25 | 168.93 | 60.71 | 4.9 | 54.37 | 63.96 | 50.71 | 4.9 |
| OLS | DSS | 0.0 | 16.81 | 112.89 | 8.67 | 4.9 | 18.30 | 55.59 | 6.08 | 2.2 |
| | | 24.7 | 31.58 | 115.04 | 44.24 | nd | 26.13 | 55.69 | 29.60 | nd |
| | | 49.4 | 37.06 | 120.92 | 66.52 | 11.0 | 33.48 | 60.12 | 47.50 | 2.7 |
| | | 98.8 | 52.65 | 129.23 | 217.31 | nd | 53.00 | 60.21 | 159.68 | nd |
| | | 148.3 | 65.06 | 152.71 | 270.90 | 13.0 | 71.54 | 69.78 | 218.72 | 14.0 |
| | ISS | 0.0 | 18.30 | 86.69 | 29.20 | 2.0 | 20.49 | 54.58 | 9.72 | 2.3 |
| | | 24.7 | 25.84 | 87.59 | 29.95 | nd | 26.00 | 58.62 | 28.90 | nd |
| | | 49.4 | 27.30 | 102.05 | 31.52 | 4.9 | 30.43 | 59.13 | 31.36 | 3.1 |
| | | 98.8 | 46.41 | 102.74 | 50.31 | nd | 45.65 | 59.38 | 46.16 | nd |
| | | 148.3 | 53.68 | 118.66 | 69.21 | 7.0 | 55.07 | 75.50 | 51.16 | 6.2 |

†nd: not determined.

was interesting to note that the Candler fine sand received DSS produced greater amount of cumulative $CO_2$ compared to that from Ogeechee loamy sand received DSS. It is probably due to sandy texture, which facilitated more aeration in sandy soil from Florida than that of in loamy sand from Georgia. In addition, the presence of $C_2H_2$ did not increase the amount of $CO_2$. This may be due to oxidation of $CH_4$ by different type of methanotrophic bacteria which in turn might have produced other by products such as acetate, and formate etc, as explained by Dassonville and Renault.[22]

### *Cumulative emission of $CH_4$*

Cumulative emission of $CH_4$ increased with increasing rates of either type of SS across both soils. Addition of acetylene had significant impact on the cumulative emission of $CH_4$ irrespective of type of soil or SS. Addition of acetylene increased the cumulative amount of $CH_4$ by 1.5- to 3-fold, depending on the soil type and SS used. Acetylene effect was somewhat lower in soils that received ISS. This may be due to the presence of some harmful materials in the ISS which may have interfered with the activity of methanogenic bacteria.

### *Cumulative emission of $N_2O$*

Cumulative emission of $N_2O$ increased with increasing rates of either type of SS across both soils in the presence or absence of $C_2H_2$. However, the increase varied from ~2–200% in soils with acetylene. The increase in $N_2O$ was greater in soils that received DSS as compared to that with ISS. This could be attributable to the presence of greater quantity of soluble C and other nutrients in the DSS as compared to those in the ISS. Likewise, the former may contain lower amounts of harmful materials as compared to the latter. The $N_2O$ emission was greater in sandy soils (CFS) amended with DSS. The availability of electrons in organic compounds is one of the factors controlling the heterotrophs, which comprise the majority of denitrifiers. The denitrification and other N transformation processes are controlled by several other factors such as soil pH, temperature, oxygen content, soil moisture content, soil texture, forms of available N and presence of inhibitors.[13]

### *Microbial influence on emission of major greenhouse gases*

Microbial influence on the emission of major greenhouse gases was evaluated by using Fluorescein diacetate (FDA)

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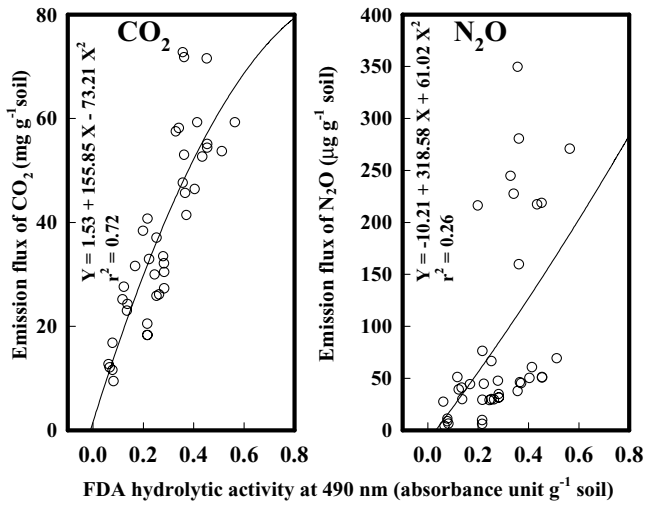


**Fig. 4.** Regression relationship between the cumulative emissions of measured greenhouse gases ($CO_2$ and $N_2O$) and total heterotrophic microbial population estimated by fluorescein diacetate (FDA) hydrolytic activity technique.

hydrolytic activity, and most probable number (MPN) technique. FDA hydrolytic activity was consistently greater upon incubation of soils containing larger amounts of SS irrespective of types of soils or amendments. Similarly, greater amount of sludge amended soils produced greater amount of emission of gases (Table 2). FDA hydrolytic activity is an indicator of total heterotrophic microbial population.[7] Most of the organic N and organic C present in soils amended with SS undergo aerobic or anaerobic decomposition mainly by heterotrophic microorganisms which result in emission of various gases ($CO_2$, $CH_4$, and $N_2O$). Regression analysis indicated a significant positive relationship ($r^2 = 0.72$) between the cumulative $CO_2$ emission and heterotrophic microbial activity (Fig. 4). Similar regression analysis indicated a very weak relationship for cumulative $N_2O$ and $CH_4$ emission with heterotrophic microbial activity.

Denitrifier population in soils amended with various rates of SS as determined by MPN was different for various treatments. Denitrifier count varied by about one order of magnitude between the minimum and maximum values (Table 2). Denitrifier population increased with increasing rates of SS amendments which in turn reflected an increase in cumulative $N_2O$ emission. However, methanogenic microbial population estimated by means of emission of $CH_4$ gas in the head space of culture tubes which were incubated with 1mL of soil dilutions ($10^{-2}$, $10^{-4}$ and $10^{-6}$) in Baker methanogenic medium did produce only a weak relationship.

## Conclusion

The emission of greenhouse gases such as $CH_4$, $CO_2$, and $N_2O$ from land applied sewage sludge (SS) could pose a great threat to environment, since the above gases contribute to global warming. Evaluation of emission of these gases from soils amended with various rates of domestic and industrial types of SS indicated that emission rates and cumulative emission of all three gases increased with increasing rates of amendments. The cumulative emission of gases during our 25-d incubation of soils amended with different types of SS decreased in the order: $CO_2 > N_2O > CH_4$. The emission of gases from both soils was greater with amending SS from domestic origin compared to that from soils amended industrial origin. This could be attributable either to lower C and N content or to the presence of greater harmful chemicals in ISS as compared to those that in the DSS.

Furthermore, the emission of gases was greater from a sandy soil (CFS) amended with SS than from a loamy sand soil (OLS). Results also clearly depicted the inhibitory effect of acetylene in both soils by producing more $N_2O$ and $CH_4$ emission compared to the soils not receiving acetylene. Enumeration of microbial population by FDA and MPN procedure at the end of 25-d incubation period demonstrated a clear relationship between the microbial activity and the emission of gases. This study suggested the need to understand the potential for emission of greenhouse gases from soils when organic soil amendments such as sewage is applied at high (disposal) rates.

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