# SEÇÃO IX - POLUIÇÃO DO SOLO E QUALIDADE AMBIENTAL

## $CO_2$, $CH_4$ AND $N_2O$ FLUXES IN AN ULTISOL TREATED WITH SEWAGE SLUDGE AND CULTIVATED WITH CASTOR BEAN[1]

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**ABSTRACT**

**Organic residue application into soil alter the emission of gases to atmosphere and $CO_2$, $CH_4$, $N_2O$ may contribute to increase the greenhouse effect. This experiment was carried out in a restoration area on a dystrophic Ultisol (PVAd) to quantify greenhouse gas (GHG) emissions from soil under castor bean cultivation, treated with sewage sludge (SS) or mineral fertilizer. The following treatments were tested: control without N; FertMin = mineral fertilizer; SS5 = 5 t $ha^{-1}$ SS (37.5 kg $ha^{-1}$ N); SS10 = 10 t $ha^{-1}$ SS (75 kg $ha^{-1}$ N); and SS20 = 20 t $ha^{-1}$ SS (150 kg $ha^{-1}$ N). The amount of sludge was based on the recommended rate of N for castor bean (75 kg $ha^{-1}$), the N level of SS and the mineralization fraction of N from SS. Soil gas emission was measured for 21 days. Sewage sludge and mineral fertilizers altered the $CO_2$, $CH_4$ and $N_2O$ fluxes. Soil moisture had no effect on GHG emissions and the gas fluxes was statistically equivalent after the application of FertMin and of 5 t $ha^{-1}$ SS. The application of the entire crop N requirement in the form of SS practically doubled the Global Warming Potential (GWP) and the C equivalent emissions in comparison with FertMin treatments.**

**Index terms: residue, nitrogen, carbon dioxide, nitrous oxide, methane.**

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**RESUMO**. *FLUXOS DE $CO_2$, $CH_4$ E $N_2O$ DE UM ARGISSOLO TRATADO COM LODO DE ESGOTO E CULTIVADO COM MAMONA*

*A aplicação de resíduos orgânicos no solo pode alterar a emissão de gases para atmosfera e dentre estes, $CO_2$, $CH_4$ e $N_2O$, podem contribuir para o aumento do efeito estufa. Este ensaio foi realizado com o objetivo de quantificar a emissão de gases do efeito estufa (GEE) de um Argissolo Vermelho-Amarelo distrófico (PVAd) tratado com lodo de esgoto (LE) e cultivado com mamoneira em área de reforma de canavial. Os tratamentos testados foram: Controle sem N; FertMin = fertilizante mineral; LE5 = 5 t $ha^{-1}$ de LE, equivalente a 37,5 kg $ha^{-1}$ de N; LE10 = 10 t $ha^{-1}$ de LE, equivalente a 75 kg $ha^{-1}$ de N; e LE20 = 20 t $ha^{-1}$ de LE, equivalente a 150 kg $ha^{-1}$ de N. A quantidade de lodo foi baseada na rate recomendada de N para a mamoneira (75 kg $ha^{-1}$), nas quantidades de N no LE e na fração de mineralização do N do lodo. As emissões de gases foram quantificadas durante 21 dias. A aplicação tanto de lodo como de fertilizante mineral alterou os fluxos de $CO_2$, $N_2O$ e $CH_4$ em comparação ao controle. A umidade do solo não alterou as emissões de GEE, e o fluxo desses gases no tratamento com fertilizante mineral não foi estatisticamente diferente do verificado com a aplicação de 5 t $ha^{-1}$ de LE. A aplicação de todo o N requerido pela cultura, na forma de lodo de esgoto, dobrou o Potencial de Aquecimento Global (PAG) e as emissões em equivalente-carbono, em comparação com o tratamento com fertilizante mineral.*

*Termos de indexação: resíduo, nitrogênio, dióxido de carbono, óxido nitroso, metano.*

## INTRODUCTION

The scientific community has paid considerable attention to the study of the balance of greenhouse gas (GHG) emissions (Lal et al., 1995). Increases in GHG concentrations in the atmosphere caused by human activity have led to a greater retention of solar radiation on the planet surface, reducing atmospheric losses and resulting in an increase in temperature or global warming. In this context, agricultural activities are responsible for around 30 % of the global GHG emissions (Norse, 2003), though this value increases to 50 % when considering only developing countries, mostly located in tropical and subtropical regions (IPCC, 2007).

Land use changes, above all the deforestation of tropical forests (IPCC, 2007), and improper application of organic and/or inorganic fertilizers have altered the GHG emission from soil into the atmosphere (Ajwa & Tabatabai, 1994). However, it is also known that conservationist agricultural practices can increase C capture from the atmosphere, immobilizing it in the soil and in biomass, in the order of 0.65 to 1.30 t $ha^{-1}$ $year^{-1}$ C (Bruinsma, 2003). The agronomic potential of organic residues such as sewage sludge (SS) is essentially based on returning organic C (C-org) and nutrients to the soil. An increase in the soil C-org level could improve the physical, chemical and biological proprieties, normally resulting in increased fertility (Oliveira, 2000). For soil in temperate climate conditions, increments in soil organic C have consistently been reported by different authors (Epstein et al., 1976; Doran & Parkin, 1994; Karlen et al., 1997; Logan et al., 1997; Reeves, 1997; Karlen et al., 2001). In tropical regions, however, the degradation rates of organic C may be higher (Oliveira, 2000) as a result of high temperature and moisture. In Brazil, studies carried out in the field with SS have demonstrated temporary effects on soil organic C content (Silva et al., 1998; Oliveira & Mattiazzo, 2001).

Carbon dioxide and $CH_4$ emitted from cultivated soils are a result of the C-org metabolism degradation (Moreira & Siqueira, 2002). Soil NOx emissions, in turn, are associated with the denitrification process in which anaerobic bacteria use $NO_2^-$ or $NO_3^-$ as a final electron acceptor, releasing $N_2O$ and $N_2$ (Moreira & Siqueira, 2002). The application of residues rich in decomposable C will therefore accelerate the aerobic metabolism of this substrate, consuming $O_2$, which would also favor the appearance of reduced soil environments (Hansen & Henriksen, 1989) and consequently, N losses to the atmosphere.

Studies on the contribution of soils treated with organic residues to the GHG fluxes in tropical climate as well as the potential C capture in these systems are rare (Jenkinson et al., 1991; Ajwa & Tabatabai, 1994; Fernandes, 2005), although some studies have already shown that SS application in agriculture significantly increases GHG emissions, proportionally to the applied rate (Paramasivam et al., 2008).

Based on the hypothesis that the application of sewage sludge as C and nutrient source to cultivated soils alters greenhouse gas emissions, the objective of this study was to quantify the fluxes of these gases in a dystrophic Ultisol under castor bean (*Ricinus communis* L.) cultivation, treated with different sewage sludge rates.

## MATERIALS AND METHODS

This study was carried out in an area of dystrophic Ultisol (PVAd), on which sugar cane (*Saccharum* *officinarum* L.) had been grown, in Capivari, State of São Paulo (lat 22 ° 55 ' 45 " S, long 47 ° 33 ' 58 " W; 550 m asl) with an average annual rainfall of 1,355 mm, classified by Köppen as Cwa, humid tropical, with dry winter and hot and humid summer (climate data of the experiment in figure 1). The following soil chemical properties were measured in the 0–20 cm layer: pH-$CaCl_2$ = 4.4; C-org. = 9.50 g $dm^{-3}$; P-resin = 7.0 mg $dm^{-3}$; K = 1.0 $mmol_c$ $dm^{-3}$; $Ca^{2+}$ = 6.0 $mmol_c$ $dm^{-3}$; $Mg^{2+}$ = 2.0 $mmol_c$ $dm^{-3}$; H + Al = 22.0 $mmol_c$ $dm^{-3}$; sum of bases = 9.0 $mmol_c$ $dm^{-3}$; cation exchange capacity = 31.5 $mmol_c$ $dm^{-3}$ and base saturation = 29.0 %.

Castor bean, cultivar IAC-Guarani, was chosen as rotational crop for the restoration of a plantation after 30 years of uninterrupted sugar cane cultivation. In September 2004, 4.5 t $ha^{-1}$ lime (PRNT = 63 %) and two herbicide rates (Glyphosate) were respectively applied for soil correction and to eliminate cane regrowth and weeds.

The sewage sludge (SS), consisting mainly of treated household sewage, had undergone a process called "aerated tanks of complete mixture, followed by decantation tanks", at the Jundiaí sanitation company in the state of São Paulo. At the end of the process, the sludge with around 2 % solids was removed from the decantation ponds after about one year. The sludge was conditioned with cationic synthetic polymers, centrifuged mechanically and air-dried under a plastic cover for 120 days, resulting in a material with around 40 % solids and low concentration of pathogens. The main physical-chemical properties of the SS are listed in table 1.

The rates of N and sludge were determined based on the quantity of N recommended for castor bean cultivation (75 kg $ha^{-1}$ N) (Raij et al., 1997) and the N Mineralization Rate (NMR) of the residue, so that the application of the SS rates would result in 0.5, 1.0 and 2.0 times this quantity. To calculate NMR, a preliminary laboratory trial was carried out using the method described by Eaton et al. (1995) to determine the N mineralization fraction of the residue. The following treatments were tested: Control - without N; FertMin - mineral fertilizer; SS5 - 5 t $ha^{-1}$ sludge; SS10 - 10 t $ha^{-1}$ sludge; and SS20 - 20 t $ha^{-1}$ sludge (dry base). In this case 37.5, 75 and 150 kg $ha^{-1}$ N were added as SS applications, respectively. The FertMin treatment supplied 75 kg $ha^{-1}$ N, 80 kg $ha^{-1}$ $P_2O_5$ and 40 kg $ha^{-1}$ $K_2O$ in the forms of ammonia nitrate, simple superphosphate and potassium chloride. These quantities were based on official fertilizer recommendation for the crop in the State of São Paulo (Raij et al., 1997).

**Table 1. Some chemical[1] properties of sewage sludge applied to soil**

| Characteristic | Unit | Value |
|---|---|---|
| pH | -- | 5,80 |
| Moisture [2] | g $kg^{-1}$ | 583,30 |
| Total-N[3] | g $kg^{-1}$ | 27,08 |
| $NH_4^+$-N | g $kg^{-1}$ | 1,04 |
| $NO_3^-$-N + $NO_2^-$-N | g $kg^{-1}$ | 0,79 |
| Organic-N | g $kg^{-1}$ | 25,25 |
| Organic carbon[4] | g $kg^{-1}$ | 289,10 |
| C/N Ratio | -- | 10,68 |
| NMR[5] | % | 28 |

[1] Determined by EPA method SW-846-3051. [2] Moisture: loss of mass at 60 °C. [3] Total-N: Kjeldahl. [4] $C_O$: Walkley & Black. All concentration values based on dry material. [5] NMR: N mineralization rate.

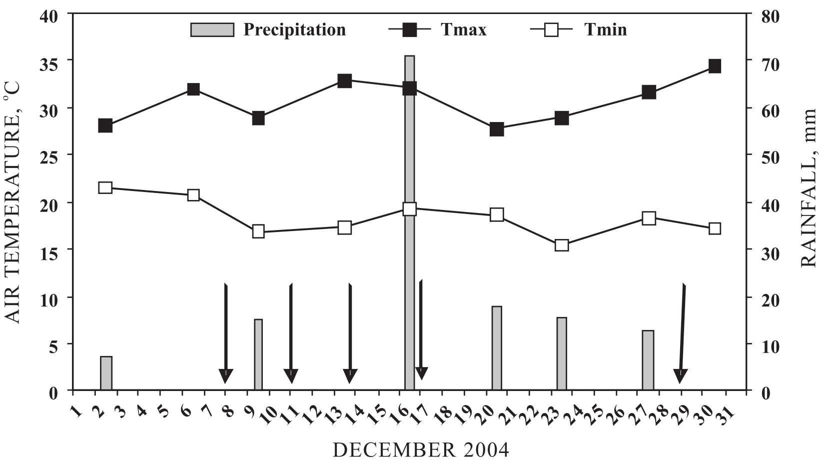


**Figure 1. Average daily precipitation and maximum and minimum temperature observed during the gas sampling period (December 2004). Vertical arrows indicate gas collections, on December 8, 2004 = time 0; December 11, 2004 = time 3 days after application (DAA) of SS and fertilizers; December 14, 2004 = 6 DAA; December 17, 2004 = 9 DAA and December 29, 2004 = 21 DAA.**

The experimental plots were each 112 $m^2$ (14 x 8 m) and were distributed using a randomized block design with three blocks, totaling 15 plots. Sewage sludge and fertilizer rate were calulcated to supply the area covered by the gas collection chamber (0.057 $m^2$). The treatments were applied by hand, incorporating SS and fertilizers in the 0–10 cm layer with a garden hoe. Immediately after the treatments, the gas collection chambers were installed. These chambers, two per plot, were made of seamless stainless steel (20 height x 32 cm width, internal diameter 27 cm) and were installed at a depth of about 3 cm.

The experiment was initiated on 8 December 2004, with castor bean sowing and the first gas sample collection. The gas was always collected 0, 5, 10 and 15 min after the chamber had been closed, as in the procedure described by Bowden et al. (1990). At time zero (i.e. on 8 December 2004), sampling took place immediately after installation, when the chambers were still open. A 60 mL syringe was used, and the collected gas was transferred to an evacuated flask and hermetically sealed. Immediately after sampling at time zero, the chamber was closed with a lid that had a central bore, to which a three-way valve was attached linked to a syringe coupled with the manual vacuum pump and a collector flask. For each sample collection, after gas suction from within the chamber, the gas was transferred from the flask using a 70 cm Hg vacuum.

Gas was sampled 3, 6, 9 and 21 days after application (DAA) of SS and fertilizer. During the collections, the temperature of the air, soil at the surface and at depths of 5 and 15 cm was measured at the beginning and the end of the sample collection by thermometers installed in each plot. In addition, on the sampling days, the gravimetric soil moisture was measured by weighing a composite sample of 20 sub-samples per plot after oven-drying at 105 C for 72 h. The gases were analyzed at the CENA/USP Isotopic Ecology Laboratory by gas chromatography (Shimadzu, model GC-14A), equipped with an electron capture $^{63}$Ni detector (ECD) and a flame ionization detector (FID) (Steudler et al., 1991).

The gas fluxes data of the 21 days were analyzed based on an average reliability interval at a significance level of 5 %, understanding that repeated measurements over time did not satisfy the assumed causality required by variance analysis (ANOVA).

To make the treatment results comparable, the fluxes values were transformed into global warming potential (GWP) and C emission equivalence (CEE) of the gases, using $CO_2$ as a reference (IPCC, 2001; Costa et al., 2006). GWP represents the cumulative radioactive force from a pre-determined time in the past until the present caused by emission of a mass unit of the gas. This index is useful in comparisons of relative efficiency of each GHG in trapping heat, using a standard gas as reference, which, to simplify matters, was $CO_2$. For the calculation, it was assumed that in a 100 year period GWP is 21 for $CH_4$, 310 for $N_2O$ and 1 for $CO_2$ (Bathia et al., 2005). GWP of the different treatments was calculated as in equation 1 (Robertson, et al., 2000; Bathia et al., 2005):

$$GWP = (CH_4 \times 21) + (N_2O \times 310) + CO_2 \quad (1)$$

Carbon equivalent emissions (CEE) were calculated using equation 2:

$$CEE = (GWP \times 12)/44 \quad (2)$$

GWP and CEE data were transformed to log ($x$), to homogenize variances and normalize frequency distribution. For presentation, original units were transformed using the inverse operation. Data were subjected to descriptive statistical analysis, normality testing (Shapiro-Wilk), variance homogeneity testing (Levene), linear correlation analysis, variance analysis (ANOVA) and when pertinent, the means of the treatments were compared by the Tukey test. All statistical tests and comparison of means were performed at a significance level of 5 %.

## RESULTS AND DISCUSSION

### Gas fluxes and soil moisture

There was no significant correlation between GHG fluxes and soil moisture considering the five gas collections together (Table 2). A positive correlation is generally expected between $N_2O$ and $CH_4$ emission and soil moisture since the production of this gas is favored in anaerobic environments. The low rainfall volume in the period was probably not enough to significantly alter $N_2O$ and $CH_4$ production. It must be restated that in addition to soil moisture, other variables may be limiting for the occurrence of these emissions, for example: N availability in the system, labile C and presence of denitrifying and methanogenic microorganisms (Carmo et al., 2005).

**Table 2. Linear correlation coefficients between $CH_4$, $CO_2$ and $N_2O$ fluxes and soil moisture considering average value of treatments and collections**

| | $CH_4$ (1) | $CO_2$ | $N_2O$ | Moisture(1) |
|---|---|---|---|---|
| $CH_4$ (1) | - | 0.4206* | 0.8760** | -0.0468 |
| $CO_2$ | - | - | 0.6047** | 0.3938 |
| $N_2O$ | - | - | - | -0.0314 |

(1) Values used in correlations, expressed as fluxes averages for each day sampled and average moisture percentage. * and **: Significant at 5 and 1 %, respectively.

However, when the emissions of these gases are considered separately in each sample, significant positive correlations are verified between soil moisture and respective $CH_4$ and $N_2O$ fluxes 21 DAA. $CO_2$ emissions did not correlate with soil moisture in any sample collection period (Table 3).

The application of SS to soils could increase the organic matter content used as energetic substrate by microorganisms. The biodegradable fraction is related to protein compartment and makes up from around 20 to 60 % of the total organic matter in sewage sludge or less than 20 % if the sludge is composted (Andrade, 2004). Sewage sludge used in this study had been stabilized in a process that contributed to a smaller biodegradable fraction with better recalcitrance and stability. Probably the more labile soil C applied with SS was used as an energy source for metabolic processes for soil microbiota and was exhausted 21 DAA, so that from this point on moisture became more limiting. It should be noted that the enrichment with N via SS could also have stimulated C immobilization in the microbial biomass and reduced losses in the form of $CO_2$. In laboratory conditions using SS from CSJ, Andrade (2004) observed that 50 % of total $CO_2$ emission over a 70 day period took place in the first 10 days after incubation.

**Table 3. Linear correlation coefficient (r) of average $CH_4$, $CO_2$ and $N_2O$ fluxes and moisture in the soil for each collection**

| | Days after application (DAA) | | | | |
|---|---|---|---|---|---|
| | 0 | 3 | 6 | 9 | 21 |
| $CH_4$[(1)] | -0.467 | 0.529 | 0.846 | 0.469 | 0.942* |
| $CO_2$ | -0.300 | 0.652 | 0.0875 | -0.056 | 0.590 |
| $N_2O$ | -0.621 | 0.759 | 0.205 | -0.241 | 0.920* |

[(1)] Values used in correlations, expressed as average fluxes on each sampling day and average moisture percentage. * Significant at 5 %.

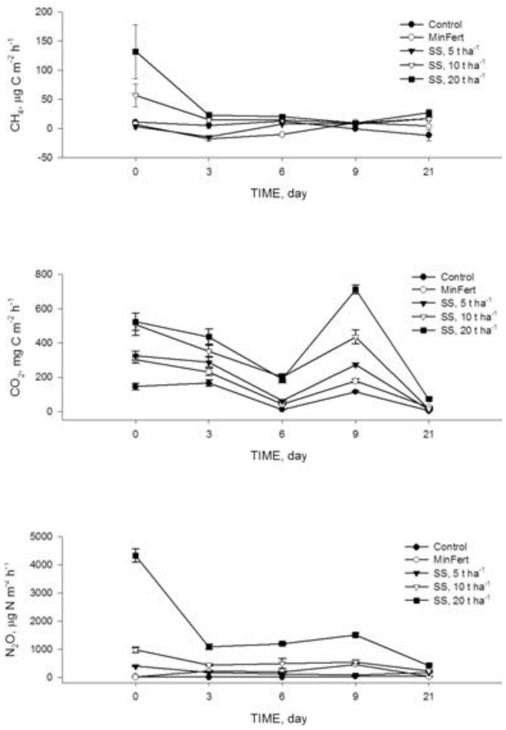


**Figure 2. $CH_4$, $CO_2$ and $N_2O$ fluxes in Ultisol treated with sewage sludge and mineral fertilizer planted with castor beans. MinFert = Mineral fertilizer application, SS = Sewage-Sludge application. Vertical bars represent average standard deviation (n = 6).**

## $CH_4$, $CO_2$ and $N_2O$ fluxes

The GHG fluxes quantified in soil under castor bean treated with sewage sludge and mineral fertilizers is shown in figure 2. Generally, there was a decrease in gas fluxes over time, which differed in function of the treatment. The fluxes were highest after the application of 20 t ha$^{-1}$ SS, for time zero (0 DAA), followed by gradual reduction until 21 DAA. The fluxes of all GHG had the same behavior (Figure 2), independent of the treatment.

For $CH_4$, there were no statistical differences between the treatments tested. Two differentiated pulses were observed 0 DAA, between the 10 and 20 t ha$^{-1}$ SS treatments. These pulses appear to be related to the presence of anaerobic microorganisms in sewage sludge, mainly methanogenic bacteria that were still active immediately after SS incorporation into the soil. After this sample collection, values diminished to 0.015 and 0.020 μg m$^{-2}$ h$^{-1}$ $CH_4$–C with the application of 10 and 20 t ha$^{-1}$ SS, respectively (Figure 2). In the treatments control, FertMin and 5 t ha$^{-1}$ SS, negative methane fluxes values were measured, indicating methane consumption in these treatments.

According to Steudler et al. (1996), tropical upland soils are considered methane sinks. Methane can be consumed by methanotrophic bacteria and also by the reaction of methane with hydroxyl present in the atmosphere. It should however be noted that $CH_4$ dynamics in soils depend on anaerobic soil conditions as well as the presence of organic matter and methanogenic microorganisms. However, many studies have reported that changes in land use cause a considerable increase in methane emission; positive values and/or values closer to zero have been observed, i.e., less negative (Keller et al., 1986; Keller & Reiners, 1994; Carmo et al., 2006).

In general, the greater the sludge rate applied, the higher were the $CO_2$ emission values, mainly 9 DAA, probably in function of higher C content added to soil via sludge application. It was also verified that there was practically no difference between treatments for $CO_2$ fluxes 21 DAA, with exception of the treatment supplied with the highest SS rate; despite much lower than in the evaluation 9 DAA, the value was significantly higher than in the other treatments (Figure 2). This agrees with results reported by Fernandes et al. (2005) and Lambais & Carmo (2008), who also verified increases in $CO_2$ emission with SS application.

Nevertheless, divergences in this type of study are expected for different experimental conditions, that is, the quality and rate of material applied as well as climatic conditions in the experimental area are certainly decisive for the gas emissions analyzed (Chiaradia, 2005).

For the rate of sewage sludge estimated to provide the N quantity required by castor bean, there were no difference in $CO_2$ emissions between the treatments FertMin and 10 t ha$^{-1}$ SS. Twenty one DAA, the $CO_2$ fluxes for all treatments was statistically equal. The biodegradable fraction of SS organic matter, which is predominantly recalcitrant, might have been exhausted within few days after application, slowing down the second part of the decomposition process of the material in comparison with the first and consequently reducing $CO_2$ emission to the atmosphere (Pires et al., 2002).

Observing only average values, $N_2O$ emissions, similarly to $CO_2$, differed in the different treatments tested and increase in emissions was verified with SS application. The $N_2O$ emissions from treatments that supplied 10 and 20 t ha$^{-1}$ SS were highest; the greatest fluxes was observed at the highest SS rate (Figure 2). At the end of 21 days of sampling, the emissions in all treatments tested were below 1,000 μg m$^{-2}$ h$^{-1}$ N-$N_2O$.

According to Teixeira et al. (2004), emissions in the order of 1,000 μg m$^{-2}$ h$^{-1}$ N-$N_2O$ are considered very high and the authors only observed emissions of this magnitude 180 days after applying 40 t ha$^{-1}$ SS. Fernandes et al. (2005) also verified emissions of 2,000 μg m$^{-2}$ h$^{-1}$ N-$N_2O$ after applying 100 kg ha$^{-1}$ N via SS. In this study, $N_2O$ emission values (mean of six replications ± standard deviation) were equal to: 31.36 ± 2.80; 189.73 ± 31.23; 195.99 ± 22.01; 543.94 ± 59.68 and 1,713.90 ± 255.98 μg m$^{-2}$ h$^{-1}$ N-$N_2O$, for Control, FertMin, SS5, SS10 and SS20 treatments, respectively. These values are lower than those reported by other authors (Teixeira et al., 2004; Fernandes et al., 2005) even when considering a complete supply of N demand via sludge, as in the treatment SS10. The maximum SS rate resulted in nitrous oxide emission similar to that reported by Fernandes et al. (2005).

It was therefore concluded that the application of nitrogen mineral fertilizer as well as SS altered the mineralization rate of soil organic matter and consequently $N_2O$ emission. Similar results were also observed by Fernandes et al. (2005); Teixeira et al. (2004) and Paramasivam et al. (2008), who also observed higher GHG emissions with increasing rates in the following sequence: $CO_2 > N_2O > CH_4$. Nitrogen dioxide is predominantly produced in soil by biological processes such as nitrification and more frequently denitrification, and the values of atmospheric emission depends as much on available $NH_4^+$ and $NO_3^-$ concentrations as on factors such as soil temperature, pH, texture and moisture (Firestone & Davidson, 1989). Soils fertilized with N are sources with significant contribution to the total $N_2O$ emission (Harrison & Webb, 2001). Even methane and $CO_2$ emissions could be increased with N application as fertilizer (Chu et al., 2007), offering better conditions for the soil microbiota development as well as diminishing the C/N ratio of the medium and increasing oxygen consumption, leading to the formation of anaerobic microsites in the soil.

A comparison of the treatments FertMin and SS10, which theoretically represent applications of the same N quantity (75 kg ha$^{-1}$), shows that SS application resulted in a marked increase of around 2.8 times in nitrous oxide emission. This result could be an indication that the N mineralization fraction of sludge in experimental conditions was higher than estimated under laboratory conditions. It is suggested that more research be undertaken to quantify sludge N mineralization in field conditions. However, SS application greatly increases potential $N_2O$ as well as methane emissions into the atmosphere, which is even more worrying. In this sense, studies on this issue are necessary and urgent, particularly of methods that help minimize N losses in the form of $N_2O$.

## Global warming potential and carbon equivalent

Global warming potential (GWP) and C equivalent emissions (CEE) varied from 5,340 to 22,555 kg ha$^{-1}$ $CO_2$ and from 675 to 6,151 kg ha$^{-1}$ C, respectively (Table 4). There was a significant difference ($p < 0.05$) between and among treatments. The application of 20 t ha$^{-1}$ SS resulted in the greatest GWP and CEE in comparison with the others. There was no statistically significant difference ($p > 0.05$) between the treatments SS5 and FertMin, since in both cases the value of GWP as well as of CEE was about half of that of SS10.

Application of total N required by castor bean through sludge practically doubled GWP and CEE. These results agree with those reported by Bathia et al. (2005), who verified that substitution of mineral fertilizer by organic fertilizer increased methane emissions by 60 % and GWP by 28 % in a rice-maize rotation.

In a long term study (9 years) of GWP in conventional agricultural systems, Robertson et al. (2000) verified far lower GWP values than Bathia et al. (2005) with 161 g day$^{-1}$ $CO_2$-equivalent m$^{-2}$. These results reinforces the potential of use of these organic residues to increase GHG emissions, mainly those rich in N.

**Table 4. Global warming potential (GWP) and carbon emission equivalent (CEE) for an Ultisol treated with sewage sludge (SS) and mineral fertilizer (FertMin)**

| Treatment | GWP | CEE |
|---|---|---|
| | kg $ha^{-1}$ $CO_2$ | kg $ha^{-1}$ C |
| Control | 2,474 d | 675 d |
| FertMin | 5,340 c | 1,456 c |
| SS, 5 t $ha^{-1}$ | 6,305 c | 1,720 c |
| SS, 10 t $ha^{-1}$ | 11,690 b | 3,188 b |
| SS, 20 t $ha^{-1}$ | 22,555 a | 6,151 a |
| CV (%) | 8,63 | 10.11 |
| ANOVA – value F | 365.85* | 365.81* |

Consecutive averages with the same letter in the same column did not differ statistically by the Tukey test 5 %. CV: coefficient of variation; *: significance of 5 %.

## CONCLUSIONS

1. Greenhouse gas fluxes ($CO_2$, $CH_4$ and $N_2O$) were increased by the application of 10 and 20 t $ha^{-1}$ sewage sludge (SS) until 21 days after application to the soil.

2. Sewage sendge application in agriculture has a great potential to increase methane emissions into the atmosphere, shortly after the SS is applied *in natura*.

3. If all N required by castor bean is supplied in SS, potential global warming and C equivalent emissions can increase significantly.

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