http://dx.doi.org/10.1590/1678-4499.0093

CO_2 emission from soil after reforestation and application of sewage sludge

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Received: *March 19, 2014;* ***Accepted:*** *June 2, 2014*

Soil and Plant Nutrition | Article

Abstract

This study aimed to quantify the carbon dioxide emissions from an Oxisol under degraded pasture located in Sorocaba, São Paulo State, Brazil. The treatments were: sewage sludge (LE), sewage sludge compost (CLE), mineral fertilizer (AM) and no fertilization (T0). The experiment was conducted in a completely randomized block design with analysis of the effect of the four treatments (CLE, LE, and AM T0) with four replications. The application of sewage sludge, sewage sludge compost, mineral fertilizer and no fertilizer was statistically significant for the variables of height increase and stem height of Guanandi seedlings (*Calophyllum brasiliense* Cambessèdes - Calophyllaceae). Treatments showed significant differences in terms of CO_2 emissions from soil. The CLE exhibited the highest CO_2 fluxes, reaching a peak of 9.33±0.96 g C m^{-2} day^{-1} ($p<0.0001$), as well as the LE with a maximum CO_2 flux of 6.35±1.17 C m^{-2} day^{-1} ($p<0.005$). The AM treatment (4.96±1.61 g C m^{-2} day^{-1}) had the same statistical effect as T0 (5.33±0.49 g C m^{-2} day^{-1}). CO_2 fluxes were correlated with soil temperature in all treatments. However, considering the period of 172 days of evaluation, the total loss of C as CO_2 was 2.7% for sewage sludge and 0.7% for the sewage sludge compost of the total C added with the application on soil.

Key words: GHG, organic waste, carbon.

Emissão de CO_2 do solo após reflorestamento e aplicação de lodo de esgoto

Resumo

O presente estudo teve como objetivo quantificar as emissões de gás carbônico a partir de um Latossolo Vermelho eutroférrico sob pastagem degradada localizada na região de Sorocaba. Os tratamentos avaliados foram: lodo de esgoto (LE), composto de lodo de esgoto (CLE), adubo mineral (AM) e ausência de adubação (T0). O experimento foi conduzido em blocos inteiramente casualizados, sendo analisado o efeito dos quatro tratamentos (CLE, LE, AM e T0) com quatro repetições. A aplicação de lodo de esgoto, composto de lodo de esgoto, fertilizante mineral e ausência de adubação apresentaram efeito estatístico quanto às variáveis de incremento em altura e a altura do coleto das mudas de Guanandi (*Calophyllum brasiliense Cambessèdes* - Calophyllaceae). Os tratamentos apresentaram diferença significativa quanto às emissões de CO_2 do solo. O CLE foi o tratamento de apresentou os maiores fluxos de CO_2, atingindo um pico de 9,33±0,96 g C m^{-2} dia^{-1} ($p<0,0001$), assim como o LE, com um fluxo máximo de CO_2 de 6,35±1,17 C m^{-2} dia^{-1} ($p<0,005$), já o tratamento AM (4,96±1,61 g C m^{-2} dia^{-1}) apresentou o mesmo efeito estatístico que o T0 (5,33±0,49 g C m^{-2} dia^{-1}). Os fluxos de CO_2 apresentaram correlação com a temperatura do solo em todos os tratamentos estudados. No entanto, considerando o período de 172 dias de avaliação do experimento, a perda total de C na forma de CO_2 foi de 2,7% do total de C adicionado com a aplicação dos resíduos no solo para o lodo de esgoto e de 0,7% do total de C adicionado com a aplicação dos resíduos no solo para o composto de lodo de esgoto.

Palavras-chave: gases do efeito estufa, resíduos orgânicos, carbono.

1. INTRODUCTION

Emissions of gases that contribute to Global Warming or gases that cause the greenhouse effect (GHG), mainly carbon dioxide (CO_2), have attracted broad interest of society given the many consequences of climate change (IPCC, 2007). The increase in concentration of GHGs in the atmosphere due to human activities raised the average temperature of the Earth by 0.6 °C in the last century, which currently shows a heating rate of 0.21°C per decade (IPCC, 2007). However, the increase is estimated at 5.8 °C for the next hundred years, impact that will affect all countries at different scales (IPCC, 2007). Among the consequences, it is possible to highlight the reduction in agricultural productivity, species extinction, desertification, rising sea levels and increase in disease vectors (IPCC, 2007).

Among the GHGs, carbon dioxide (CO_2) is recognized as the gas that contributes most to global warming, due to the large amount that is emitted, which represents approximately 55% of total emissions (Cerri et al., 2007).

The application of mineral fertilizers and organic residues to the soil can alter GHG emissions to atmosphere (Chiaradia et al., 2009). In the case of mineral fertilizers, the major concern is related to losses of nitrogen as N_2O from nitrogen fertilizers (Passianoto et al., 2004). CO_2 is more associated with soil tillage practices and addition of organic residues (Carmo et al., 2007).

Nevertheless, the application of sewage sludge to soil as organic fertilizer is an alternative to solve a serious problem of the final destination of this residue, since it consists mostly of nutrients required by plants (Jayasinghe, 2012). On the other hand, addition of sewage sludge or organic waste with high organic carbon content available can greatly enhance the emission of gases into the atmosphere (De Urzedo et al., 2013).

Soil management systems adding organic residues and incorporating carbon (C) are evaluated as important alternatives to increase the capacity of atmospheric C sink and mitigate global warming (Amado et al., 2001; Bayer et al., 2006). In this sense, sewage sludge has high potential to promote the return of organic carbon (C-org) and nutrients to the soil (Chiaradia et al., 2009). Soil conservation management practices contribute to the process of capturing carbon from the atmosphere, allowing its immobilization in soil and biomass, in the order of 0.65 – 1.30 t ha^{-1} $year^{-1}$ C (Bruinsma, 2003). Increasing amounts of C-org promotes improvements in soil physical, chemical and biological properties, usually resulting in better conditions for plant growth (Jayasinghe, 2012).

Given this context, one aspect of great prominence in studies of soil organic matter is the assessment of the loss of carbon dioxide due to the land use and management (D'Andréa et al., 2004). In this context, a more rigorous study on GHG emissions from the soil where organic wastes have been applied is important to assess the real benefits from its use and the potential of adding organic compound in carbon sequestration in tropical soils (Ajwa and Tabatabai, 1994; Fernandes et al., 2005; Jenkinson et al., 1991). Although studies have shown considerable increases in GHG emissions following the use of sewage sludge, these emissions may be negligible compared to the amount of remaining carbon in the soil (Paramasivam et al., 2008).

The study aimed to evaluate the emissions of carbon dioxide from an typical oxisol in Sorocaba, São Paulo State, Brazil, treated with sewage sludge, sewage sludge compost and mineral fertilizer, as well as to determine the emission rates in relation to soil temperature, and to measure the initial growth of guanandi seedlings (*Calophyllum brasiliense* Cambessèdes - Calophyllaceae) in different treatments.

2. MATERIAL AND METHODS

The experiment was conducted in an area of degraded pasture, located in the Region of Sorocaba, São Paulo State, at the geographic coordinates 23°34'40" S and 47° 31'17,8"W. According to Köeppen classification, the climate of the region is Cfa (warm subtropical), with average annual temperature of 21.4 °C, maximum in the summer of 30.1°C and minimum of winter of 12.2 °C, and 1,285 mm annual rainfall (Silva, 2007). The soil of the experimental area was classified as Oxisol, according to that described by Embrapa (2006).

The species used in the experiment was guanandi (*Calophyllum brasiliense* Cambessèdes - Calophyllaceae). Trees were planted in an area of degraded pasture, using spacing of 3.0×2.0 m. At planting, glyphosate herbicide was applied to eliminate sprouting of weeds. Cylindrical holes were manually open, with 30 cm deep and 20 cm diameter, and the fertilizers were incorporated into the soil by hand. Seedlings used in planting were acquired in the seedling nursery Tropical Flora Reflorestadora, in the municipality of Garças, São Paulo State. Plants had characteristics suitable for experimentation in the field, according to recommendations of Kalil et al. (2007). Further details about the plant used in the experiment can be found in De Urzedo et al. (2013).

The experiment was performed in a completely randomized block design, with analysis of effect of four types of soil fertilization with four replications. Treatments were: sewage sludge, sewage sludge compost, mineral fertilization and no fertilization.

The experiment consisted of 16 plots with 16 Guanandi seedlings in each, forming a single border, each plot covered 72 m^2 area, totaling 1,152 m^2 area reforested with Guanandi.

The definition of the doses of fertilizer was calculated according to the ideal N content for plants native to the Atlantic Forest (60 kg ha^{-1}) and applied as ammonium nitrate (NH_4NO_3), according to recommendations of Raij B. van et al. (1996). The treatments with sewage sludge and sludge compost received a supplement of KCl, since the potassium content in these residues is low; doses were calculated according to the levels recommended by Raij B. van et al. (1996). The calculations to reach the doses were similar to those performed by Lambais and Carmo (2008), considering 30% as the mineralization rate of nitrogen in the sewage sludge and 10% in the compost.

To quantify the carbon dioxide flux, we used the static chamber method, which is based on the variation of the gas concentration inside it, disposed over the ground surface over time, from the adaptation of the method of Davidson et al.

(2002). The chamber comprises a movable PVC frame, cylindrical shaped, with 22 cm high and 25 cm diameter, which allows the temporary installation of the chamber surrounding the plants.

For sampling gases inside the chamber, we used a 20 ml-nylon syringe, and then added into small glass vials sealed with rubber caps. For each chamber, four vials were collected during the average time of 30 minutes, with the first sample collected 1 minute after closing the chamber and the remainder at 10, 20 and 30 minutes after closing the chamber. The CO_2 fluxes were measured for one of the four plants forming the useful portion of each repetition, selected at random. Monitoring of CO_2 was carried out over the 172 days after planting and the percentages of C emitted as CO_2 were calculated according to the amount of C-CO_2 accumulated during this period.

Gas samples were analyzed with a gas chromatograph Shimadzu GC-20-14 comprising an electron capture detector operating at 280 °C (Bowden et al., 1990) and a flame ionization detector for the determinations with standard mixture, and with helium carrier gas.

Carbon loss of treatments where residues were added was calculated according to De Urzedo et al. (2013).

During the treatment of seedlings with different nutrient sources, data relative to shoot length, in centimeters, were collected monthly with the aid of a measuring tape.

Data analysis

Data obtained by calculating the fluxes were summarized in graphs, in which measurements of total C (carbon) emitted by the soil along the monitoring were performed by means of interpolation points and the integral of the emission curve using the Origin software.

For statistical analysis, data were subjected to Kolmogorov Smirnov and Levene's tests to check for homogeneity of variance. When detected normality and homoscedasticity, data were analyzed by analysis of variance (ANOVA) and means were compared by Tukey's test at 5% significance (Barbin, 2003). Data showing no homogeneity of variances and/or normality were analyzed by the nonparametric Kruskal-Wallis test (Campos, 1983) and medians were compared through analysis of the box plots. These calculations were run using the Statgraphics software.

3. RESULTS AND DISCUSSION

C-CO_2 fluxes quantified in the soil with sewage sludge, sewage sludge compost, mineral fertilizer and no fertilization is shown in figure 1. Generally, C-CO_2 fluxes were higher during the first 50 days after the installation of the experiment; lower fluxes near to those found in the control treatment were observed from the day 100 after the addition of mineral and organic fertilizers to the soil. This result indicates that after 100 days the effect of residues on CO_2 fluxes decreased and remained low until the end of the experimental period.

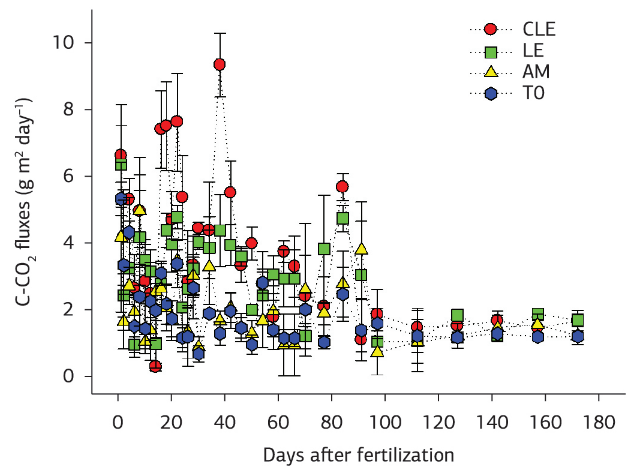

Figure 1. Emissions of carbon dioxide (g C m^{-2} day^{-1}) over the 172 days of monitoring soil treated with sewage sludge compost (CLE), sewage sludge (LE), mineral fertilizer (AM) and absence of fertilization (T0).

The treatment with sewage sludge compost had the highest emissions, reaching a peak of 9.33±0.96 g C m^{-2} day^{-1} ($p<0.0001$) after 38 days of planting. Similarly, treatment with sewage sludge exhibited significant emissions ($p<0.005$), with a maximum value of 6.35±1.17 C m^{-2} day^{-1} at the beginning of the experiment. The results showed that the application of sewage sludge and sludge compost increased CO_2 emissions from soil (Chiaradia et al., 2009; Fernandes et al., 2005; Lambais and Carmo, 2008), this process may be associated with increased amount of C available that increases the microbial activity and thus stimulate respiration of autotrophic and heterotrophic microorganisms in the soil (Ball and Smith, 1991). Thus, the application of residues in soil, possibly increased the organic matter content of the soil (Chiaradia et al., 2009; Carmo et al., 2013), which can be determined by the composition of the study materials (De Urzedo et al., 2013).

Moreover, the treatment with mineral fertilization showed the same effect that the control treatment, with a maximum emission rate of 4.96±1.61 g C m^{-2} day^{-1}. The period with the highest carbon dioxide emission from the treatment without fertilizer addition was the day of planting, corresponding to 5.33±0.49 g C m^{-2} day^{-1}. The result showed that the opening of the hole and soil mixing may have promoted carbon dioxide emissions, since the movement of the soil by mechanical action is one of the main factors responsible for raising CO_2 soil emissions (Reicosky and Lindstrom, 1993; Reicosky et al., 1997) with variations due to the intensity of tillage (La Scala Junior et al., 2001).

Peak emissions of CO_2 of all treatments were superior to the values of emission from the soil of the control treatment (0.976 - 1.955 g C m^{-2} day^{-1}), according to soil quality evaluated by the Soil Quality Kit Test in long-term experiments (Conceição et al., 2005). However, after 112 days of soil monitoring, we observed a stabilization of CO_2 emissions, with values within the ideal range for treatments with sewage sludge (1.07±0.91 g C m^{-2} day^{-1}), sewage sludge compost (1.48±0.24 g C m^{-2} day^{-1}), mineral fertilizer (1.04±0.30 g C m^{-2} day^{-1}) and no fertilizer (1 23±0.82 g C m^{-2} day^{-1}).

The average CO_2 emissions were positively correlated with average soil temperatures for all treatments (Figure 2). The treatments that received sewage sludge (R^2=0.93), sewage sludge compost (R^2=0.95) and mineral fertilizer (R^2=0.84) showed a high coefficient of determination between the variables, as well as mineral fertilizer that also showed a positive, although lower correlation (R^2=0.69). Correlations between CO_2 emissions and soil temperature are commonly found in the literature and the authors conclude that increases in soil temperature stimulate microbial activity and increases the respiration of plant roots. Furthermore, depending on the conditions of soil moisture, availability of nutrient and labile carbon, decomposition of soil organic matter can also be accelerated (Duiker and Lal, 2000; Janssens et al., 2001; Longdoz et al., 2000; Raich and Schlesinger, 1992).

In turn, the treatment with sewage sludge compost emitted the greatest amount of C over the 172 days of soil monitoring, totaling 502.39 g C m^{-2}, followed by sewage sludge that emitted 422.44 g C m^{-2} (Figure 3). These data show that the studied residues, sewage sludge compost and sewage sludge, respectively emitted approximately 1.90 times and 1.65 times more carbon dioxide when compared with the treatment without fertilization (263.92 g C m^{-2}). The use of mineral fertilizer (297.12 g C m^{-2}) increased about 1.12 times the carbon dioxide emission.

The cumulative C-CO_2 during the 172 days, in all treatments, was lower than that found in the literature. However, there is no data similar to this study in tropical ecosystems and planted forests. On the other hand, similar studies in boreal and temperate forests interpolated data obtained and estimated cumulative losses of C-CO_2 along a year. In this way, Russell and Voroney (1998) demonstrated that in a boreal forest, estimated emissions of carbon dioxide varied between 809 and 905 g C m^{-2} $year^{-1}$; and estimates of annual emissions for temperate forests are 438±140±68-870 g C m^{-2} $year^{-1}$ (Longdoz et al., 2000).

The loss of carbon as CO_2 from sewage sludge and sewage sludge compost were respectively 2.7% and 0.7%, thus it was possible to observe that while emissions from these materials were significant, most part of C-org (organic carbon) present in the material remained in the soil. In this sense, the application of sewage sludge and sewage sludge compost can be an alternative to increase the amount of carbon in tropical soils since long-term assessments confirm the results of the present study that

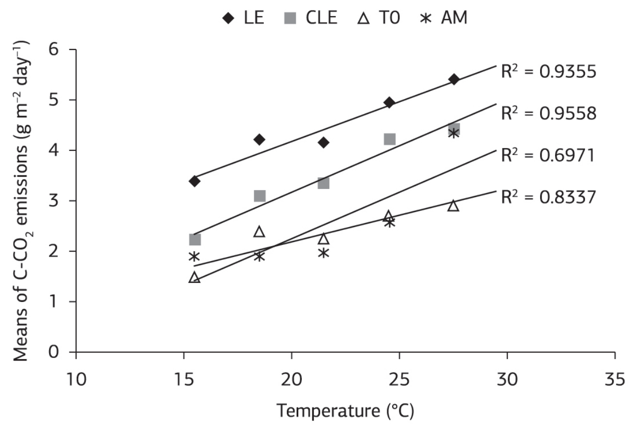

Figure 2. Regression between means of carbon dioxide emissions (g C m^{-2} day^{-1}) and means of temperature (°C) over the 172 days of monitoring, and the LE treatments: sewage sludge; CLE: Sewage sludge compost; T0: absence of fertilization; AM: mineral fertilizer.

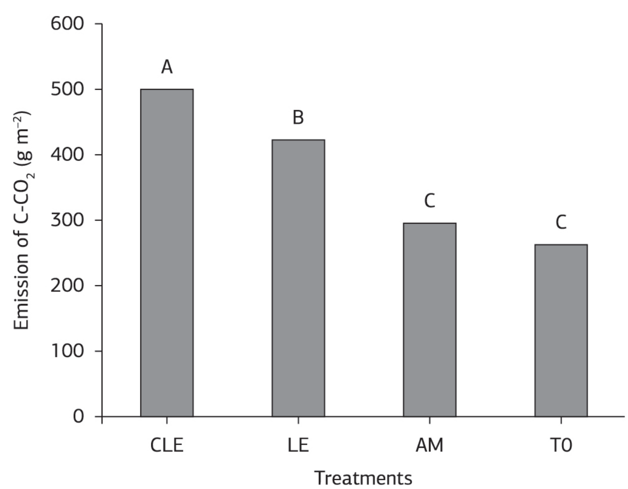

Figure 3. Emission of C-CO_2 (g C m^{-2}) over the monitoring of the experiment (172 days), with CLE: Sewage sludge compost; LE: sewage sludge; AM: mineral fertilizer; T0: no fertilization. Capital letters in the vertical bars indicate statistical difference between treatments by Tukey test at 5% significance level (n=4).

lasted only 172 days. The incorporation of C-org into the soil can be related both to the sludge production process and to its composition. The sewage sludge used in the study was stabilized in a process that contributed to a smaller biodegradable fraction with better recalcitrance and stability of the material. Thus, the residue has physico-chemical characteristics that confer resistance to microbial decay. The difficulties in the degradation also reflect the composition of the sewage sludge, including oils, greases and other recalcitrant molecules, which are of difficult biological degradation (Bertoncini et al., 2008). Besides these compounds, it is noteworthy the presence of humic substances, which are more stable and difficult to degrade, from a chemical point view, representing a reserve of C in

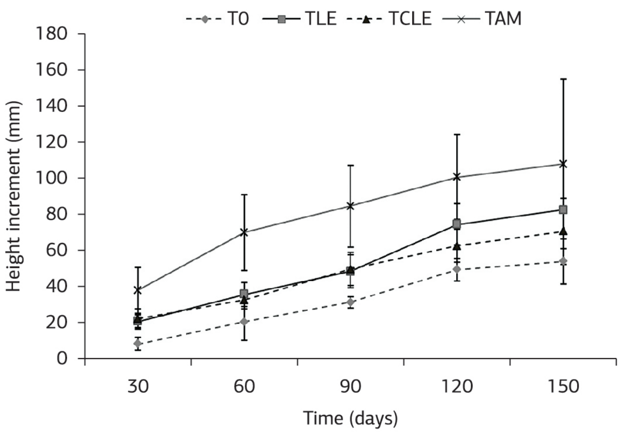

Figure 4. Height increment of C. brasiliense (n=16) for 150 days after seedlings plantation, were: TLE: Sewage sludge; TCLE: Sewage sludge compost; TAM: mineral fertilizer; T0: absence of fertilization.

the soil (Yang et al., 2004), considered the final stage of C compounds in the soil (Stevenson, 1994).

The results evidenced that the addition of sewage sludge and sewage sludge compost have the potential to increase the percentage of carbon in the soil, and its immobilization in the ecosystem functional dynamics (Bruinsma, 2003). With increasing levels of C-org, there will be processes of restoration of the degraded soil, since it enables improvements in physical, chemical and biological soil properties, and consequently resulting in gains in fertility (Bertoncini et al., 2008). Nevertheless, long-term studies become essential to characterize the dynamics of emissions, monitoring the process of stabilization of organic matter in the soil to thereby allow accurate estimates of the mechanism of C sequestration by soil. Additionally, it is necessary to evaluate the quality of organic matter and C present in the residues studied in order to check for the gains in terms of soil fertility and plant nutrition.

Seedlings of all treatments showed increased height growth in response to the application of sewage sludge, sewage sludge compost and mineral fertilization (Figure 4). The highest increase was registered for seedlings treated with mineral fertilization 108.20±47.08 mm, compared with the treatments with sewage sludge (82.87±21.37 mm) and sewage sludge compost (70.92±18.47 mm). The treatment with no fertilization showed the smallest increase (54.30±12.42). However, no significant difference was detected among treatments, possibly because the species is classified as late secondary, that is, the growth is considered slow (Carvalho, 2003), with seminal seedlings, which might have led to different responses within each treatment, as evidenced by the large standard deviation.

4. CONCLUSION

The application of residues to soil, sewage sludge and sewage sludge compost, significantly increased the emissions of carbon dioxide compared with the other treatments, with a strong correlation between soil temperature and CO_2 emissions, in all treatments. However, the loss of C-CO_2 from the soil treated with sludge and sludge compost, compared to the amount of carbon present in these residues, revealed that the high C-org content of these residues possibly remained stored in soil. Meanwhile, to better assess the stability of this carbon added to soil, long-term experiments are needed for a more reliable conclusion on the effect of applying sewage sludge and sludge compost in relation to potential increases of soil carbon.

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