Biochar and soil nitrous oxide emissions

Carlos Francisco Brazão Vieira Alho[(1)], Abmael da Silva Cardoso[(1)],
Bruno José Rodrigues Alves[(2)] and Etelvino Henrique Novotny[(3)]

[(1)]Universidade Federal Rural do Rio de Janeiro, BR 465, Km 7, CEP 23890-000 Seropédica, RJ, Brazil. E-mail: alhojunior@gmail.com, abmael2@gmail.com [(2)]Embrapa Agrobiologia, BR 465, Km 7, CEP 23890-000 Seropédica, RJ, Brazil. E-mail: bruno@cnpab.embrapa.br [(3)]Embrapa Solos, Rua Jardim Botânico, nº 1.024, Jardim Botânico, CEP 22460-000 Rio de Janeiro, RJ, Brazil. E-mail: etelvino@cnps.embrapa.br

Abstract – The objective of this work was to evaluate the effect of biochar application on soil nitrous oxide emissions. The experiment was carried out in pots under greenhouse conditions. Four levels of ground commercial charcoal of 2 mm (biochar) were evaluated in a sandy Albaqualf (90% of sand): 0, 3, 6, and 9 Mg ha^{-1}. All treatments received 100 kg ha^{-1} of N as urea. A cubic effect of biochar levels was observed on the N_2O emissions. Biochar doses above 5 Mg ha^{-1} started to mitigate the emissions in the evaluated soil. However, lower doses promote the emissions.

Index terms: lignocellulosic residues, greenhouse gases, pyrolysis.

“Biochar” e emissões de óxido nitroso pelo solo

Resumo – O objetivo deste trabalho foi avaliar o efeito da aplicação de “biochar” nas emissões de óxido nitroso pelo solo. O experimento foi conduzido em vasos, sob condições de casa de vegetação. Quatro níveis de carvão vegetal moído a 2 mm (“biochar”) foram avaliados em um Planossolo Háplico arenoso (90% de areia): 0, 3, 6 e 9 Mg ha^{-1}. Todos os tratamentos receberam aplicação de 100 kg ha^{-1} de N, na forma de ureia. Observou-se efeito cúbico dos níveis de “biochar” sobre as emissões de N_2O. Doses de “biochar” acima de 5 Mg ha^{-1} começaram a mitigar as emissões no solo avaliado. No entanto, doses inferiores promovem as emissões.

Termos para indexação: resíduos lignocelulósicos, gases de efeito estufa, pirólise.

Brazilian timber production results in high waste, which commonly does not have an appropriate destination, creating environmental problems, such as silting and water and air pollution, caused by the usual burning of the disposed wood. This residue can be used for other purposes, such as raw material for several industrial purposes, including the production of energy, solvents, paints, fibbers, and paper. The alternative use of lignocellulosic residues can contribute to the efficient use of forest resources, as economic and environmental strategies, adding value to by-products, helping to solve problems of environmental liabilities and creating jobs.

Biochar is the term used for the solid product obtained from pyrolysis of lignocellulosic materials that concentrate carbon in a stable form, in order for it to be deliberately applied to soils, increasing their carbon storage and providing agronomic benefits. Specific physical and chemical properties of biochar, such as high porosity (Liang et al., 2006), contribute to water retention (Lehmann et al., 2003). Its particulate nature (Skjemstad et al., 1996), combined with a specific chemical structure (Baldock & Smernik, 2002), provides great resistance to microbial degradation in soils (Cheng et al., 2008).

Among the many alternative uses of lignocellulosic wastes, the utility as feedstock for pyrolysis processes, producing chemicals, fuels (bio-oil or syngas), and biochar for soil application, has only recently been studied, mainly because of the increasing preoccupation regarding climate change. Besides the potential for positive effects on soil fertility, when applied to agricultural soils, biochar may contribute to reduce nitrous oxide (N_2O) emissions, a potent greenhouse gas (Bruun et al., 2011).

At the meeting under the United Nations Framework Convention on Climate Change (UNFCCC) held in Bonn, Germany, in May 2009, the agricultural use of pyrolyzed materials (biochar), as a strategy to mitigate emissions of greenhouse gases, was included in the final document, to be discussed in Copenhagen, Denmark, in December 2009. However, political aspects were prioritized in this last meeting and the discussions on the topic and, especially, on the strategies and practices to mitigate the emissions of greenhouse gases were not debated.

Nitrous oxide, as well as carbon dioxide and methane, have an important contribution to the anthropogenic influences on the greenhouse effect. Although CO_2 is emitted in greater quantities than the last two, N_2O and CH_4 have higher global warming potential (GWP) than CO_2. Considering a period of 100 years, the GWP of N_2O is 296 times higher than the GWP of CO_2 (Forster et al., 2007).

Another important aspect is the increase of the atmospheric concentration of N_2O, which is in the order of 0.2 to 0.3% per year due to the growth of emissions caused primarily by human activities. It is estimated that 80% of the emissions are derived from agriculture (Beauchamp, 1997), caused by the intensive use of nitrogen fertilizers. Several authors have proposed practices to mitigate the industrial emissions of N_2O (Sänger et al., 2001), but for agro-forestry, studies are still incipient.

The objective of this work was to evaluate the effect of biochar application on soil nitrous oxide emissions.

The experiment was carried out during the summer of 2008/2009, at Embrapa Agrobiologia, RJ, Brazil, under controlled conditions (greenhouse), using a sandy Albaqualf and commercial charcoal grounded at 2 mm. Five kilogram pots were used in a completely randomized experimental design, with five replicates. Four doses of biochar were evaluated: 0 (control), 3, 6, and 9 Mg ha^{-1}. Biochar was incorporated into soil by careful mixing, and the soil water content was adjusted to 80% of field capacity, being corrected periodically during the experiment.

The soil in the pots was left to rest during the initial seven days. Then, all treatments received 100 kg ha^{-1} of N, in urea form.

Gas sampling was performed using two overlapping sealed compartments. The lower compartment contained the treatments and the upper one the controlling valve for the entrance and exit of gases. A vacuum pump (pressure difference of -80 kPa) was used for collecting gas aliquots.

The sampling for N_2O fluxes was performed daily for 17 days, between 9h30 and 10h30 in the morning, representing the average daily flow (Alves et al., 2012).

The analyses of N_2O concentrations were carried out at Embrapa Agrobiologia using a gas chromatograph equipped with a Porapak Q column and an electron capture detector. The N_2O emissions were calculated by integrating the flows measured during the evaluation period.

Data were subjected to analysis of variance and linear regressions. Residual analysis was performed by graphical methods.

The highest N_2O fluxes were observed at the beginning of the experiment, when the availability of mineral nitrogen was higher because of the recent fertilizer application (Figure 1). Afterwards, the N_2O fluxes showed successive peaks with decreasing intensities (e.g.: peaks on January 11th, January 17th, and January 20th). These peaks were probably due to the water applications for moisture correction, a factor that stimulates chemical reactions in the soil. Yanai et al. (2007) had already reported that biochar effects on soil N_2O emissions were dependent on the initial soil moisture content.

Data significantly fitted to a cubic regression model (Figure 2). Experimental error was normally distributed and independent, without heteroscedastic. The 6 and 9 Mg ha^{-1} levels showed a mitigating effect on N_2O soil emissions, with values 29 and 49% lower than the control, respectively. According to the regression model, it was possible to assume that doses greater than 5 Mg ha^{-1} would probably mitigate N_2O soil emissions. However,

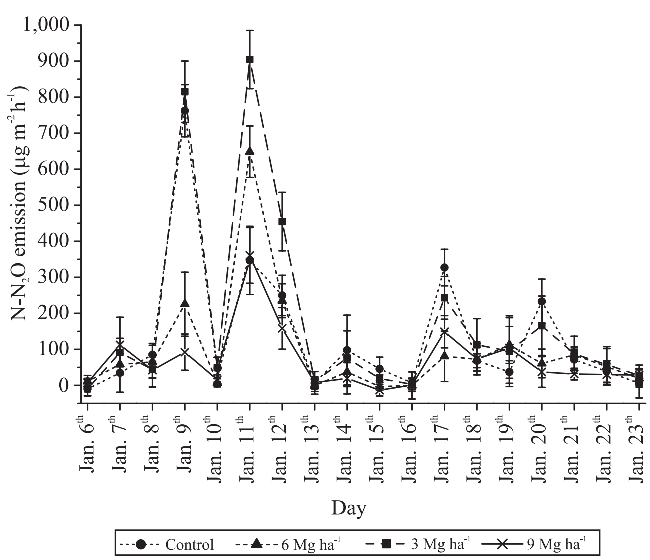

Figure 1. Daily N-N_2O soil emissions in consequence of the application of biochar doses (Mg ha^{-1}) on soil during the experiment. Bars indicate standard deviation.

the treatment with 3 Mg ha^{-1} showed an increase of 32% of N_2O emission compared to the control, which can be attributed to the increase in water retention. According to Yanai et al. (2007), there is no direct evidence to link biochar addition with N_2O suppression. The authors assumed that biochar addition led to water absorption and improved soil aeration, reducing denitrification at 73% water-filled pore space (WFPS), while at 83% WFPS enhanced N_2O fluxes were thought to result from insignificant improvement in soil aeration and stimulation of N_2O-producing activity. Biochar application might also decrease N_2O emissions by increasing soil pH (Wang et al., 2012) and soil aeration (Cavigelli & Robertson, 2001).

Bruun et al. (2011) found that the effect of biochar on N_2O soil emissions depends on the used dose, with a low dose (1% w w^{-1}) resulting in an increase of the emission and a high dose (3% w w^{-1}) in a mitigation effect in the order of 47% of the total flow. Wang et al. (2012) reported that biochar application decreased N_2O emissions up to 54 and 53% during rice and wheat seasons. However, Clough et al. (2010) found that biochar application had no effect on N_2O emission.

Under the tested conditions, doses of biochar above 5 Mg ha^{-1} started to mitigate N_2O emissions from the soil, although lower doses promote the emissions. Therefore, the use of biochar may be an alternative to mitigate N_2O soil emissions from soil. However, considering that N_2O emissions have often depended on the inherent characteristics of biochar, on the addition of exogenous nitrogen, and on soil properties (Clough et al., 2010), the

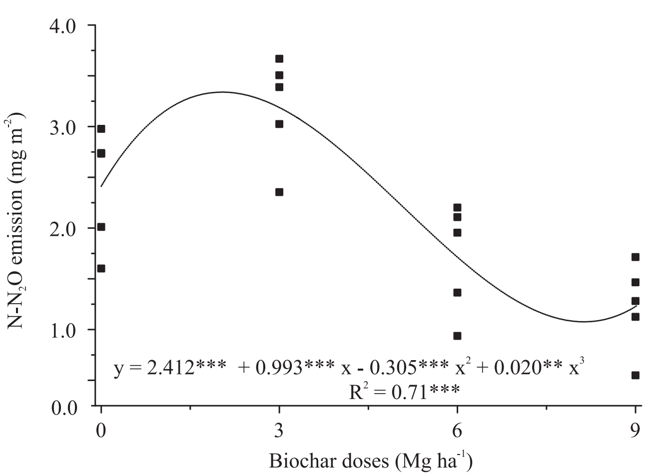

Figure 2. Cumulative N-N_2O soil emissions for the different biochar doses. ** and ***Significant at 1 and 0.1% probability, respectively.

mechanisms by which biochar mitigates N_2O emissions still have to be elucidated.

Acknowledgements

To Embrapa and to Fundação de Amparo à Pesquisa do Estado do Rio de Janeiro, for financial support; to Conselho Nacional de Desenvolvimento Científico e Tecnológico, for the scholarships granted; and to Jasmin Lemke, for the assistance with proofreading of the text.

References

ALVES, B.J.R.; SMITH, K.A.; FLORES, R.A.; CARDOSO, A.S.; OLIVEIRA, W.R.D.; JANTALIA, C.P.J; URQUIAGA, S.; BODDEY, R.M. Selection of the most suitable sampling time for static chambers for the estimation of daily mean N_2O flux from soil. **Soil Biology and Biochemistry**, v.46, p.12-19, 2012.

BALDOCK, J.A.; SMERNIK, R.J. Chemical composition and bioavailability of thermally altered *Pinus resinosa* (Red pine) wood. **Organic Geochemistry**, v.33, p.1093-1109, 2002.

BEAUCHAMP, E.G. Nitrous oxide emission from agricultural soils. **Canadian Journal of Soil Science**, v.77, p.113-123, 1997.

BRUUN, E.W.; MÜLLER-STÖVER, D.; AMBUS, P.; HAUGGAARD-NIELSEN, H. Application of biochar to soil and N_2O emissions: potential effects of blending fast-pyrolysis biochar with anaerobically digested slurry. **European Journal of Soil Science**, v.62, p.581-589, 2011.

CAVIGELLI, M.A.; ROBERTSON, G.P. Role of denitrifier diversity in rates of nitrous oxide consumption in a terrestrial ecosystem. **Soil Biology and Biochemistry**, v.33, p.297-310, 2001.

CHENG, C.H.; LEHMANN, J.; THIES, J.E.; BURTON, S.D. Stability of black carbon in soils across a climatic gradient. **Journal of Geophysical Research Biogeosciences**, v.113, 2008.

CLOUGH, T.J.; BERTRAM, J.E.; RAY, J.L.; CONDRON, L.M.; O'CALLAGHAN, M.; SHERLOCK, R.R.; WELLS, N.S. Unweathered wood biochar impact on nitrous oxide emissions from a bovine-urine-amended pasture soil. **Soil Science Society of America Journal**, v.74, p.852-860, 2010.

FORSTER, P.; RAMASWAMY, V.; ARTAXO, P.; BERNTSEN, T.; BETTS, R.; FAHEY, D.W.; HAYWOOD, J.; LEAN, J.; LOWE, D.C.; MYHRE, G.; NGANGA, J.; PRINN, R.; RAGA, G.; SCHULZ, M.; VAN DORLAND, R. Changes in Atmospheric Constituents and in Radiative Forcing. In: SOLOMON, S.; QIN, D.; MANNING, M.; CHEN, Z.; MARQUIS, M.; AVERYT, K.B.; TIGNOR, M.; MILLER, H.L. (Ed.). **Climate Change 2007**: the physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University, 2007. p.131-217.

LEHMANN, J.; DA SILVA, J.P.; STEINER, C.; NEHLS, T.; ZECH, W.; GLASER, B. Nutrient availability and leaching in an archaeological Anthrosol and a Ferralsol of the Central Amazon basin: fertilizer, manure and charcoal amendments. **Plant and Soil**, v.249, p.343-357, 2003.

LIANG, B.; LEHMANN, J.; SOLOMON, D.; KINYANGI, J.; GROSSMAN, J.; O'NEILL, B.; SKJEMSTAD, J.O.; THIES, J.; LUIZÃO, F.J.; PETERSEN, J.; NEVES, E.G. Black carbon increases cation exchange capacity in soils. **Soil Science Society of America Journal**, v.70, p.1719-1730, 2006.

SÄNGER, M.; WERTHER, J.; OGADA, T. NO_x and N_2O emission characteristics from fluidised bed combustion of semi-dried municipal sewage sludge. **Fuel**, v.80, p.167-177, 2001.

SKJEMSTAD, J.O.; CLARKE, P.; TAYLOR, J.A.; OADES, J.M.; MCCLURE, S.G. The chemistry and nature of protected carbon in soil. **Australian Journal of Soil Research**, v.34, p.251-271, 1996.

WANG, J.; PAN, X.; LIU, Y; ZHANG, X.; XIONG, Z. Effects of biochar amendment in two soils on greenhouse gas emissions and crop production. **Plant and Soil**, 2012. Doi: 10.1007/s11104-012-1250-3.

YANAI, Y.; TOYOTA, K.; OKAZAKI, M. Effects of charcoal addition on N_2O emissions from soil resulting from rewetting air-dried soil in short-term laboratory experiments. **Soil Science and Plant Nutrition**, v.53, p.181-188, 2007.

Received on January 31, 2011 and accepted on April 5, 2012