Greenhouse gas emissions from soils under sugarcane for ethanol production in Brazil

Carlos E. P. Cerri[A], Carlos C. Cerri[B], Marcelo V. Galdos[B], Brigitte J. Feigl[B] and Martial Bernoux[C]

[A]Universidade de São Paulo (USP) – Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Piracicaba, São Paulo, Brazil, Email cepcerri@esalq.usp.br
[B]Universidade de São Paulo (USP) – Centro de Energia Nuclear na Agricultura (CENA), Piracicaba, São Paulo, Brazil, Email cerri@cena.usp.br, mvgaldos@cena.usp.br, beduardo@cena.usp.br
[C]Institut de Recherche pour le Développement (IRD), UMR EcoandSols "Functional Ecology and Soil Biogeochemistry", Montpellier, France, Email martial.bernoux@ird.fr

Abstract
This paper includes both an integrative view of global patterns on the distribution and trends in SOM as well as research in South America, specially in Brazil, focusing on the impact of land use change and management practices on SOM. Finally, this work presents the potential effects on SOM due to the cultivation of biofuel crops, especially ethanol from sugarcane in Brazil. Future directions are briefly discussed here. For instance, ethanol can be produced from cellulose and hemicelluloses that are present in feedstocks including fast-growing hays like switchgrass, short-rotation woody crops like poplar and also from crop residues.

Key Words
Carbon dioxide, methane, nitrous oxide, soil, carbon footprint.

Introduction
The interactions of land use, management and environment create a varied picture of SOM dynamics across the globe. Globally, the amount of organic matter in soils, commonly represented by the mass of carbon, is estimated to be about 1500 Pg C (1 Pg C = 10^{15} g carbon) in the top 1 m of soil, which is three times the amount present in the vegetation and twice the amount found in the atmosphere (IPCC 2007). The amount of carbon stored in soil is determined by the balance of two biotic processes-the productivity of terrestrial vegetation and the decomposition of organic matter. Each of these processes has strong physical and biological controlling factors. These include climate; soil chemical, physical, and biological properties; and vegetation composition.

Methods
This paper includes both an integrative view of global patterns on the distribution and trends in SOM as well as research in South America, especially in Brazil, focusing the impact of land use change and management practices on SOM. Land use change, mainly for previous agricultural practices, has often decreased in soil organic carbon (SOC) stocks due to enhanced mineralization of soil organic matter (mainly to CO_2). A significant fraction of the ~32% increase in atmospheric CO_2 over the last 150 years stems from the breakdown of soil organic matter after forests and grasslands were cleared for farming. This process increases greenhouse gas concentrations in the atmosphere, exacerbating global warming. Conversely, adoption of "best management practices", such as conservation tillage, can partly reverse the process – they are aimed at increasing the input of organic matter to the soil and/or decreasing the rates at which soil organic matter decomposes. This mechanism has been called "soil carbon sequestration" and can be defined as the net balance of all greenhouse gases (e.g., CO_2, CH_4 and N_2O), expressed in C-CO_2 equivalents or CO_2 equivalents, computing all emission sources and sinks at the soil-plant-atmosphere interface. It must be noted that CO_2 fluxes are evaluated trough C stock changes in the different compartments and CH_4 and N_2O fluxes directly measured, or estimated with the best available estimates.

Results and discussion
Finally, this work presents the potential effects on SOM due to the cultivation of biofuel crops, especially ethanol from sugarcane in Brazil (Figure 1). Depleting fossil fuel sources and the increasing demand for energy is currently worldwide fuelling the use of biomass as a renewable energy (IEA 2007). In Brazil, the largest exporter of ethanol in the world, the current trend is for growth in this sector, mainly due to geopolitical, economic and environmental issues further forcing the use of ethanol as alternative to fossil fuel. However, up to know it is not well understood how large scale intensive production of biomass for

energy purposes and/or changes in agricultural management will feedback on the biogeochemical cycles of carbon, nitrogen and water. For instance, possible negative effects include enhanced greenhouse gas (GHG) emissions, especially of the potent GHG N_2O, due to an increasing application of synthetic fertilizer to maximize biomass production. On the other hand a series of positive environmental consequences might result, e.g. if soil C and N stocks could be increased due to adaptation of agricultural management e.g. improved treatment of crop residues. Thus, biofuel production is/ will be an important component in any sustainable regional management strategy, requiring the balancing of ecological demands.

0	CO_2: soil accumulation	-1.62
0.46	N_2O: harvesting and annual cycle	0.45
0.19	CH_4: harvesting and annual cycle	-0.01
0.65	Total	-1.18
	Difference	-1.83

Figure 1. Carbon balance (Mg Ceq/ha/y) for sugarcane production with different harvesting systems (with or without burning sugarcane leaves).

Future directions are briefly discussed here. For instance, ethanol can be produced from cellulose and hemicelluloses that are present in feedstocks including fast-growing hays like switchgrass, short-rotation woody crops like poplar and also from crop residues. While not cost-competitive today, already observed advances in technology lead us to believe that in the next few years, ethanol made from these feedstocks, called second generation ethanol, will become commercially feasible. Taking into account the scarcity of arable land available to meet an increasing energy demand, it is expected that crop residues will be totally or partially removed from the field for ethanol production (Cerri *et al.* 2007). On the other hand, in the case of sugarcane, partial removal of litter may even be beneficial, since in some soil and climate conditions, excessive mulch might hinder planting, fertilizer application and irrigation operations, increase disease and pest occurrence (e.g. *Mahanarva fimbriolata*) and delay ratoon emergence resulting in lower crop yields. There might be a compromise in leaving part of the residues on the field while processing the other part into bioethanol, which would still be beneficial to the soil and to the crop, and allow for the production of renewable energy (Galdos *et al.* 2010).

While the negative impacts of complete litter removal are foreseeable, the impact of partial removal on soil organic carbon, soil physical quality, and crop productivity has not been fully resolved. It is well known that crop residues applied to soil are important for soil organic carbon, which is an important determinant of soil fertility and within limits; crop productivity is positively related to the soil organic matter content. More information about the maximum permissible rates of sugarcane litter removal under different soil and climate conditions is highly needed. Furthermore, it is essential to develop decision support systems for a judicious management of crop residue for essential but competing uses, since a potential reduction of carbon levels in soils can contribute to increased levels of greenhouse gases in the atmosphere.

Conclusions

Considering the increase in demand for alternative energy sources, and pressing issues such as global warming and the depletion of natural resources, there is a need for sustainable biofuel production. There are currently several initiatives for the establishment of specific criteria for environmentally sound biofuel production, including government standards and regulations. However, most sets of criteria for the agricultural phase of biofuel production focus primarily on greenhouse gas emissions and energy use. Taking into account the issues discussed here, soil quality should definitely be included in the sustainability assessments for bioethanol.

References

Cerri CEP, Sparovek G, Bernoux M, Easterling WE, Melillo JM, Cerri CC (2007) Tropical agriculture and global warming: impacts and mitigation options. *Scientia Agricola* **64**, 83-99.

Galdos MV, Cerri CC, Lal R, Bernoux M, Feigl BJ, Cerri CEP (2010) Net greenhouse gas balance in Brazilian Ethanol Production Systems. *Global Change Biology- Bioenergy* (in press)

IPCC (2007) Intergovernmental Panel on Climate Change, United Nations Environment Programme. Assessment report 4. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.

IEA (2007) 'CO_2 Emissions from Fuel Combustion: 2007 edition'. http://data.iea.org/ieastore/statslisting.asp?

1 – 6 August 2010, Brisbane, Australia. Published on DVD.