Soil carbon stocks in Southwest Goiás, Brazilian Cerrado: land use impact and spatial distribution

Fabiano de Carvalho Balieiro[A], Rachel Bardy Prado[A], Heitor Luiz da Costa Coutinho[A], Vinícius de M. Benites[A], Elaine C.C. Fidalgo[A], Carlos Eduardo Gonçalves Ferreira[B], Silvio Marcos Ferreira Filho[C] and Marconi Betta[C]

[A]Embrapa Solos, Rua Jardim Botânico, 1,024; Jardim Botânico, Rio de Janeiro, RJ, Brazil, Email balieiro@cnps.embrapa.br; rachel@cnps.embrapa.br
[B]Universidade Estadual do Rio de Janeiro, R. São Francisco Xavier, 524 - Maracanã - Rio de Janeiro – RJ, Brazil - Cep 20550-900, Email carlosed.gf@hotmail.com
[C]Universidade de Rio Verde, Fazenda Fontes do Saber - Caixa Postal 104 - CEP: 75.901-970, Rio Verde - Goiás, Brazil.

Abstract
Soil Organic Matter (SOM) conservation is essential for environmental services maintenance, mainly in the tropics, where this component is essential for soil fertility, structure and biological activity. Although the Brazilian Cerrados presents the largest area available for cultivation and livestock production, contrasting findings have been reported on the impact of land use on soil carbon stocks and dynamics. This work aimed at evaluating how the prevailing land use types impact Cerrado soil carbon stocks and at presenting the spatial variability of this attribute in great part of Southwest Goiás, Brazil. The mean estimated soil carbon stock values obtained from land under agricultural use indicated that, although some cultivated areas showed higher C stocks than native vegetation, in general, conversion to agriculture, under the major management practices in use in Southwest Goiás, result in partial loss of the original soil carbon stocks. On average the Eucalyptus and pasture areas are those with lowest carbon emission potential to the atmosphere. Most of the soil carbon is stored under the native vegetation. Considering the fact that it occupies only 1/3 of the mapped region, policy makers should direct efforts to the conservation of these fragments, their vulnerability, and to their potential as greenhouse gas emitters if converted to agriculture, without soil management practices that lead to conservation. Greater effort is needed to generate a larger spatially explicit dataset, expanding the existing knowledge on carbon dynamics under different crops and soil management scenarios.

Key Words
Remote sensing, mapping, soil organic matter; land use and land cover.

Introduction
Soil Organic Matter (SOM) conservation is essential for environmental services maintenance, mainly in the tropics, where this component is essential for soil fertility (source of nutrients and providing most of its cationic exchange capacity), structure and biological activity. Despite Brazil being the largest contributor to Greenhouse Gas (GHG) emission derived from land use changes and deforestation, the emission reduction potential of the agricultural sector is significant and not yet sufficiently explored. Agroforestry systems, reduced tillage, fertilizer management, mixing or rotating crops with nitrogen fixing species, and improved feeding strategies for livestocks, can help in mitigating nitrous oxide, carbon dioxide, and methane emissions (Sisti *et al.* 2004; Silva *et al.* 2004, Bayer *et al.* 2006). These issues were addressed by the agenda of the 15th Conference of Parties on the UN Framework Conservation on Climate Change negotiations, in Copenhagen in December 2009 (Nelson 2009).

According to Nelson (2009) several countries have reduced their funding for national statistical programs and some tools like remote sensing systems are still inadequate to the task of monitoring global change in a workable scale. Therefore, any effort directed to data collection related to land use and its effects at the local scale, and dissemination of this information in a spatially explicit framework should be encouraged. Geographic Information Systems (GIS) and other geotechnologies could be used to support the decision makers (Burrough and McDonnel 1998). Although the Brazilian Cerrados extend throughout more than 200 million hectares (Goedert 1980), and presents the largest area available for cultivation and livestock production, contrasting findings have been reported on the impact of land use on soil carbon stocks and dynamics. This high variability could be related to different management practices applied to the soil combined with the spatial heterogeneity of the land use pattern, as well as local and regional edaphoclimatic conditions. Sano *et al.* (2008) reported that 80 million hectares of the biome Cerrado are under different uses, which correspond to 39.5% of total area. The most representative land use types reported in this work were cultivated pasture and agricultural crops, occupying 26.5 and 10.5% of the Cerrado, respectively. A higher dynamics could be observed in its southern portion and most of the natural vegetation is located in its northern region. As data on the spatial distribution of C stocks in these "hotspots" areas are scarce, this work aimed at evaluating how the prevailing land use types impact Cerrado soil carbon stocks and at presenting the spatial variability of this attribute in great part of Southwest Goiás, Brazil.

Methods

Description of the study area

The case study area includes six municipalities (Rio Verde, Montividiu, Santa Helena de Goiás, Santo Antônio da Barra e Acreúna) of Southwest Goiás State (SW). This area comprises 1.63 million ha inserted in the central part of the Cerrado biome (Brazilian Savanna). It is located between geographic coordinates 14º09'S, 19º27'S and 48º31'W, 53º12'W. This area was selected because it is one of the most productive agricultural areas of Brazil, mainly for the production of grain crops. The climate of this region is humid tropical, typical of savanna regions, with a strong dry season from May to September. The mean annual rainfall is approximately 1,600 mm, the mean annual temperature is 21.3 ^{o}C and the mean temperatures in the warmest and coolest months are 27.6 ^{o}C and 16.2 ^{o}C, respectively. The annual mean relative humidity is approximately 71%. According to the Brasil (1981) database, the predominant soil orders in this region are Oxisols ("Latossolos Vermelhos") and Quartzipsamments ("Neossolos quartzarênicos", (Embrapa 1999). The natural vegetation includes different vegetation physiognomies like open Cerrado (dominated by grasses) and Cerrado *stricto sensus* (with an expressive arboreal component).

Soil sampling and analysis

Sixty nine sites under different land uses (14 sites under agriculture, 15 under pasture, 25 under silviculture, and 15 under natural vegetation - Cerrado) were sampled in the study area. Under each site, soil samples were collected from three pits in a virtual square of ~50 x 50 m. Samples for chemical and physical analyses were collected from depths of 0-5, 5-10, 10-20 and 20-40 cm and from each depth a pooled sample was prepared. All soil samples were air dried and sieved through a 2 mm mesh to remove stones and root fragments, before analyses. In the same pits and for the same depths, soil bulk density was determined by use of a steel ring with a known volume (Kopecky rings). Soil organic carbon (SOC) content (oxidisable carbon) was analysed according to Walkey (1954) in the Department of Soil Science of Rio Verde University (FESURV) at Goiás State. Soil particle size measurements, comprising sand (2.00-0.05 mm), silt (0.05-0.002 mm) and clay (<0.002 mm) were estimated by the hydrometer method using Na-hexametaphosphate as a chemical dispersant, as described by Embrapa (1997).

Soil C stocks calculation

The total soil C stock was estimated as the total C concentration multiplied by the weight of soil present in samples from 0 to 40 cm depth, under each system. Several studies reported differences in soil bulk densities under agricultural and natural vegetation, suggesting that a correction factor should be applied to the calculations considering a reference value for the soil mass present in the target soil depth. This was not applied in this case because of the large distances between sampled sites, which could result in errors in the estimation of land use effects on soil carbon stocks, per unit area. The mean bulk density values for the different land use types showed an increase of 16.4%, 5.7% and 4.2% in soils under pasture, agriculture and silvicultural systems, in comparison with those under natural vegetation. To calculate the potential of soil C sequestration or emission by specific land uses it is needed to take the soil C stock values under the natural vegetations as baseline data. The significance ($p<0.05$) of land use effects on organic C stocks was obtained using the Student t-test.

Soil C stocks mapping considering land use

Initially, the land use map of the study area was obtained by processing Landsat 5 satellite images (30 m resolution). These images were georreferenced using a cartographic base at a scale of 1:250,000, available in SIEG (2008). Image processing was done using the SPRING software, version 4.3.3, applying the segmentation tool (thresholds: similarity, 13; area, 70) followed by supervised classification. In the classification step, the Bhattacharya Distance algorithm was applied to allocate areas to one of four land use classes: natural vegetation, silviculture, pasture and agriculture. Algorithm training was done using ground truth data collected from 70 field spots. The mapping units were the polygons obtained from the land use map. The sum of the soil C stocks values, from 0 to 40 cm depths, was associated to each land use type, using ARCGIS 9.3 tools (ESRI). The mean value was used for mapping and interpretation. The land use class "agriculture" included mainly soybeans, sugar cane and cotton crops. The class "Other uses" was created, related to urban areas and areas covered by shadows and clouds. This step allowed the calculation of the total C stocks associated with each land use type present in the study area, using ARCGIS 9.3 tools.

Results

Soil carbon content

Agricultural land use, in average, reduces the soil C concentration in relation to native vegetation (NV). Soil organic carbon contents (SOC) under NV were 15.4 ± 2.2 g/kg (means ± *SE*) and under eucalyptus, agriculture and pastures were, respectively, 13.2 ± 1.1, 12.6 ± 2.5 and 8.7 ± 1.1 g/kg in the 0-5 cm layer; showing the same trend in deeper layers. Our results should be analyzed with concern because these values represent the arithmetic means. In fact, some sites were characterized by a trend to an enhanced C sequestration activity, in other words, the C stocks in these areas were higher than NV. On other hand, while several authors observed an increase in soil organic carbon content, stocks and fertility of soil Cerrados, under different land uses, we observed a reduction tendency on SOC under agri- and silvicultural uses.

Effect of land use on soil C stocks

In despite of a large variability in soil C stocks data obtained from each of the other land uses sampled, the results are consistent with several studies because they suggest that soil management could influence markedly on soil C stocks. For NV, soil C stocks (0-40 cm) ranged from 11.75 to 83.28 Mg/ha, with the average (± *SE*) value about 48.36 ± 5.31 Mg /ha. The mean soil C stock values obtained from soils under eucalyptus, pasture and agriculture were 42.22 ± 3.74, 37.8 ± 2.67 and 36.04 ± 6.32 Mg/ha, respectively. Using the mean value and the NV as a reference or baseline, these results show that land use stimulated degradation of both old and recently fixed soil C, suggesting that conservation agriculture practices were not generally adopted in Southwest Goiás and need to be improved, to reduce C emissions and stabilize the C sequestered.

Soil C stocks map

Pastures and agricultural areas prevail in the mapped region, occupying 13.3 and 57.5%, respectively, of the total area (Figure 1). Even though, the native vegetation represents approximately 28.1% of the area. It is very much fragmented, present in both pasture (Paraúna Municipality and part of Rio Verde Municipality) and agricultural (Acreúna, Montividiu, Santa Helena de Goiás, Santo Antônio da Barra and the southwest of Rio Verde Municipality) landscapes. This represents a threat to biodiversity conservation and indicates a condition of vulnerability of the ecosystems that should be investigated. Total soil carbon stocks in the studied area was estimated in 69,830.24 Mg. Distribution of the total soil C stock value through the land use classes is: 22.029,43 Mg for native vegetation, 39,438.64 Mg for agriculture, 8,149.55 Mg for pasture and 212.62 Mg for silviculture.

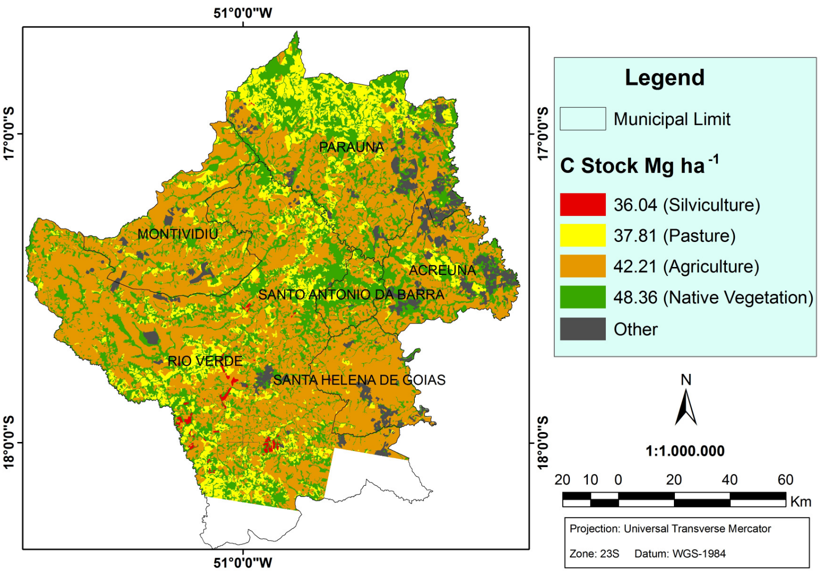

Figure 1. Soil carbon stocks (Mg /ha) map by land use classes.

Conclusions

(i) Most areas sampled under agriculture use showed a reduced level of conservation of soil carbon stocks, when compared with natural vegetation areas. Those occupied by Eucalyptus and pasture (and five sites under agricultural use) showed the lowest potential of soil carbon loss to the atmosphere;

(ii) Most of the soil carbon is stored under the native vegetation. Considering the fact that it occupies only 1/3 of the mapped region, policy makers should direct efforts to the conservation of these fragments, considering their vulnerability, and their potential as greenhouse gas emitters if converted to agricultural land use under conventional soil management strategies;

(iii) The results reveal trends of soil carbon stocks status under different land uses that could aid in the description of future scenarios, and in the proposal of novel agricultural management techniques, such as integrated crop-livestock-forestry systems, aiming to enhance carbon conservation and sequestration to the soils. Greater effort is needed to generate a larger spatially explicit dataset, expanding the existing knowledge on carbon dynamics under different crops and soil management scenarios.

Acknowledgment

This research received funding from Internacional Potash Institute (IPI) through the "Aduba Brasil Project"; from the Inter-American Institute for Global Change Research (IAI), through the CRN II Program (Project 2031), which is supported by the US National Science Foundation (Grant GEO-0452325) and from the IAI Project 104358, supported by the International Development Research Centre (IDRC).

References

Bayer C, Martin-Neto L, Mielniczuk J, Pavinato A, Dieckow J (2006) Carbon sequestration in two Brazilian Cerrado soils under no-till. *Soil and Tillage Research* **86**, 237-245.

Brasil (1981) Ministerio das Minas e Energia. Folhas SE-22-VD (Jataí), SE-22-X-A (Inhúmas), SE.22-X-C (Rio Verde), SE-22-Y-B (Caçu) e SE-22-Z-A (Quirinópolis): Geologia, Geomorfologia, Pedologia, Vegetacao, Uso potencial da terra. Mapas escala 1: 250.000. Levantamento de Recursos Naturais, v.25, Projeto Radambrasil. (Rio de Janeiro).

Burrough PA; Mcdonnel RA (1998) Principles of geographical information systems: spatial information systems and geostatistics. (Oxford: Clarendon).

Corbeels M, Scopel E, Cardoso A, Bernoux M, Douzet JM, Siqueira Neto M (2006) Soil carbon storage potencial of direct seeding mulch-based cropping systems in the Cerrados of Brazil. *Global Change Biology* **12**, 1773-1787.

Empresa Brasileira De Pesquisa Agropecuária (1999) 'Sistema Brasileiro de Classificação de Solos'. (Rio de Janeiro).

Sá JCM, Cerri CC, Lal R, Dick W, Piccolo MC, Feigl BE (2009) Soil organic carbon and fertility interactions affected by a tillage chornosequence in a Brazilian Oxisol. *Soil and Tillage Research* **104**, 56-64.

Nelson G (2009) Agriculture and climate change: na agenda for negotiation in Copenhagen. *Focus* **16**,.

Sieg. (2008) Sistema Estadual de Estatística e de Informações do Estado de Goiás. Base Cartográfica Digital (Drenagem, Mapa Político Rodoiviário - Escala 1:250.000). http://www.sieg.go.gov.br/. Acesso em 21 de Julho de

Silva JE, Resck DVS, Corazza EJ, Vivald L (2004) Carbon storage in clayey Oxisol cultivated pasture in the "Cerrado" region, Brazil. *Agriculture, Ecosystems and Environment* **103**, 357-363.