TREES IMPROVE SOIL CARBON STOCKS IN INTEGRATED CROP-LIVESTOCK-FORESTRY (ICLF) SYSTEMS

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ABSTRACT
Soil organic carbon (SOC, determined with dichromate oxidation) accumulation was evaluated at three ICLF sites of different ages (2, 4 and 11 years) and soil textures (469, 198, 632 g kg^{-1} clay) in southern Goiás state of Brazil. SOC stocks were accessed at 0-30, 30-100 and 0-100 cm soil layers under the tree-rows and between tree-rows. SOC stocks were calculated based on equivalent soil mass, using pasture, in which the ICLFs were implemented, as reference. Our objective was to investigate the potential of trees in accumulating SOC in ICLFs. Dunnett's test was applied to check the effect of trees on soil C stocks within each location using the linear mixed model. More SOC was measured under tree-rows at all sites and all soil layers, compared to the alley between the tree-rows, except for the youngest site (Morrinhos) at 0-30 cm. Trees, therefore, are important to maximize SOC accumulation in ICLFs. Further studies are, however, necessary to expand the database to support more robust analysis and to conclude on SOC sequestration (immobilization).
Key words: soil organic carbon; neotropical savanna; Cerrado

INTRODUCTION

Mixed farming systems with trees, annual crops and pasture can be efficient in soil carbon sequestration of clayey Ferralsols in Brazil in a very short term (OLIVEIRA et al., 2018).

ICLF is recommended practices for pasture restoration (MUNIZ et al., 2011; ASSIS et al., 2015; LOSS et al., 2011), improvements in animal welfare (KARVATTE et al., 2016) and higher crop yields (SILVEIRA et al., 2011) with simultaneous reductions on land use impacts such as loss of soil C and net GHG emissions (LEMAIRE et al., 2014). Important C accumulation capacity is associated with ICLF systems due to larger assimilation of atmospheric C in the biomass (MÜLLER et al., 2009) compared to conventional agriculture, and some forestry (monocultures) systems (Tsukamoto Filho et al., 2004) including other integrated systems without trees. Soil C dynamics under ICLF may be very different from that observed in systems without trees. The wood component can directly influence soil C accumulation by the arrangement and density of trees and by the tree species (KUNHAMU et al., 2011). The horizontal stratification of the area, in which rows of trees are alternated with pasture strips or rows of annual crops in the alleys, can efficiently be combined with the use of machinery for grain crops. Indirect effects of the tree component may manifest themselves through its influence on the alley crops (MENDES et al., 2013; FRANCHINI et al., 2014) or pasture (PACIULLO et al., 2011). This zoning effect may alter soil organic C (SOC) spatial distribution. Besides, trees affect the vertical distribution of SOC fractions (HEILE et al., 2010).

The aim of this study was to assess soil C stocks at incremental depths up to 1.0 m in three ICLF sites as affected by the presence of eucalyptus trees. This study, part of the Integra-Carbono Project, is expected to provide relevant baseline data on soil C accumulation of agricultural lands highlighting management practices to increase C sequestration at depth aiming at long-term mitigation of atmospheric CO_2.

MATERIAL AND METHODS

ICLF systems consisted of Eucalyptus tree rows alternated with pasture *Urochloa* sp. grass and were evaluated in three sites in the southern part of the Goiás State of Brazil. In Cachoeira Dourada at the Boa Vereda Farm the ICLF system was 11 years old, while in Quirinópolis at the Santa Bárbara Farm it was 4 years old and in Morrinhos at the Experimental Farm of the Goiano Federal Institute it was 2 years old at the date of sampling. Apart from Cachoeira Dourada in the Atlantic Forest biome, the two other sites were in the savanna (Cerrado) (Figure 1). Between November 2019 and February 2020, soil samples were collected from under the tree-rows and in the middle of the pasture alley. At Cachoeira Dourada sampling was done in five and in Quirinópolis and Morrinhos in four replicates. Horizontally, soil sampling was done in a manner to respect the structure of the sites in terms of the disposition of the tree lines to be able to infer on tree-line effects. Vertically, the soil was sampled to 1 m depth, divided into seven sampling layers (0-10, 10-20, 20-30, 30-40, 40-60, 60-80, 80-100 cm) to be able to study the vertical stratification of soil carbon stocks. The relatively deep sampling of the soil was necessary because even with low C concentration, soil layers below 30 cm can account for over 50% of the total C (e.g. OLIVEIRA et al., 2018). Therefore, it is important to take at least a layer of 1.0 m into account when assessing the effect of soil management and agriculture production systems on SOC stocks, especially when tree species and deep-rooting grasses are grown.

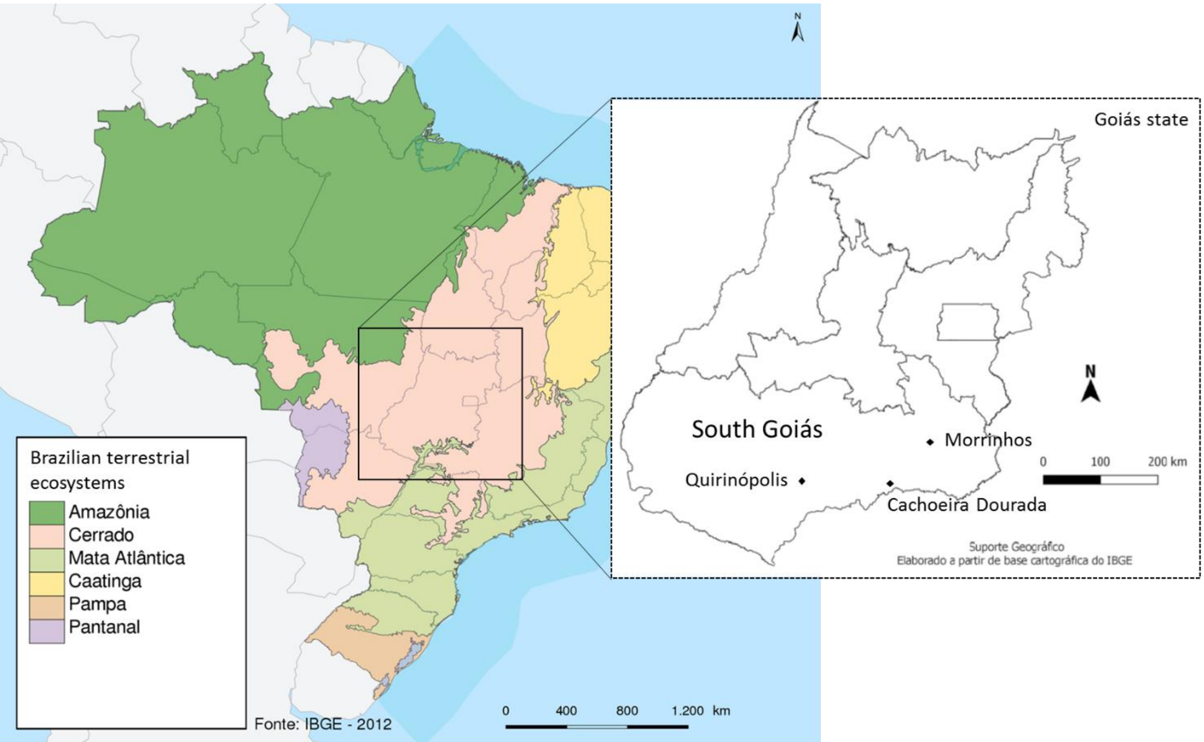

Figure 1. Location of the study sites in South Goiás, Brazil.

SOC was determined by wet dichromate combustion with external heating (we used the data without correcting for soil organic matter, that is, without multiplying the result of the carbon determination by 1.724) modified by Souza et al. (2016), soil texture using the densitometric method (Embrapa 2017), and soil bulk density was measured with the soil core method using Kopecky rings with known volume (EMBRAPA, 2017). Three replicates were taken for each measurement. The samples were taken in the middle of each soil layer. SOC stocks were calculated based on equivalent soil mass, using pasture, in which the ICLFs were implemented, as reference. SOC mas was expressed in Mg ha^{-1}.

Dunnett's test was applied to check the effect of tree position on soil C stocks by soil depth (0-30, 30-100 and 0-100 cm), within each location. Analyses were performed using the linear mixed model procedure (Proc Mixed) in SAS/STAT (SAS Institute Inc., 2008). Tree position was considered as fixed effect and replicates as random effect.

RESULTS AND DISCUSSIONS

The soil texture at the three evaluated sites were remarkably different. The soil in Cachoeira Dourada featured very clayey texture both in the upper, 0-30 cm (632 g kg^{-1} clay; 221 g kg^{-1} sand), and lower, 30-100 cm (672 g kg^{-1} clay; 170 g kg^{-1} sand), layer. In Quirinópolis the soil was a loamy sand at 0-30 cm (198 g kg^{-1} clay; 770 g kg^{-1} sand) and sandy clay loam at 30-100 cm (247 g kg^{-1} clay; 722 g kg^{-1} sand). In Morrinhos both layers had clay texture (0-30 cm: 469 g kg^{-1} clay, 364 g kg^{-1} sand; 30-100 cm: 475 g kg^{-1} clay, 354 g kg^{-1} sand. Soil texture plays an important role in SOC accumulation.

SOC stocks are shown in Figure 2. Between 35% (Morrinhos) and 50% (Quirinópolis) of SOC was in the top 30 cm layer. In the 1.0 m layer SOC ranged between 77,66 (Quirinópolis) and 133.56 (Morrinhos) Mg ha^{-1}.

Trees affected SOC stocks at almost all depths and all sites, nominal significance levels were between $p \leq 0.3121$ and $p \leq 0.0196$, except at Morrinhos site at 0-100 cm, where no effect was observed ($p \leq 0.9393$). Soil carbon stocks were larger under the tree-rows at different significance levels, independently of soil texture and the age of the ILCF system, however nominal significance level within 5% ($p \leq 0.05$) was detected only at the oldest site in Cachoeira Dourada at 0-100 cm. In Morrinhos, at 0-30 cm the soil under tree-rows contained less SOC than under the pasture alley between tree-rows. There is limited information on subsurface C accumulation under trees in ICLF systems under tropical climate. Accumulation of SOC at the top 0.1 or 0.2 m soil layers was observed in cacao–rubber (MONROE et al., 2016) and coffee-agroforestry systems worldwide (TUMWEBAZE; BYAKAGABA, 2016; THOMAZINI et al., 2015; NOPONEN et al., 2013); however, positive effects of the trees were not observed (or studied) in deeper (>0.2 m) soil layers. Most literature on integrated systems report results obtained from integrated crop-livestock (ICL) systems that lack the presence of the forestry component. However, similar results to ours were observed by Oliveira et al. (2018) for the 30-100 and 0-100 cm layers under the tree-rows and the pasture component between the trees in Nova Canaã do Norte in Mato Grosso state, also with *Eucalyptus sp*., but they reported no difference at 0-30 cm. They attributed the higher accumulation rate under the tree-rows to the root system of the trees.

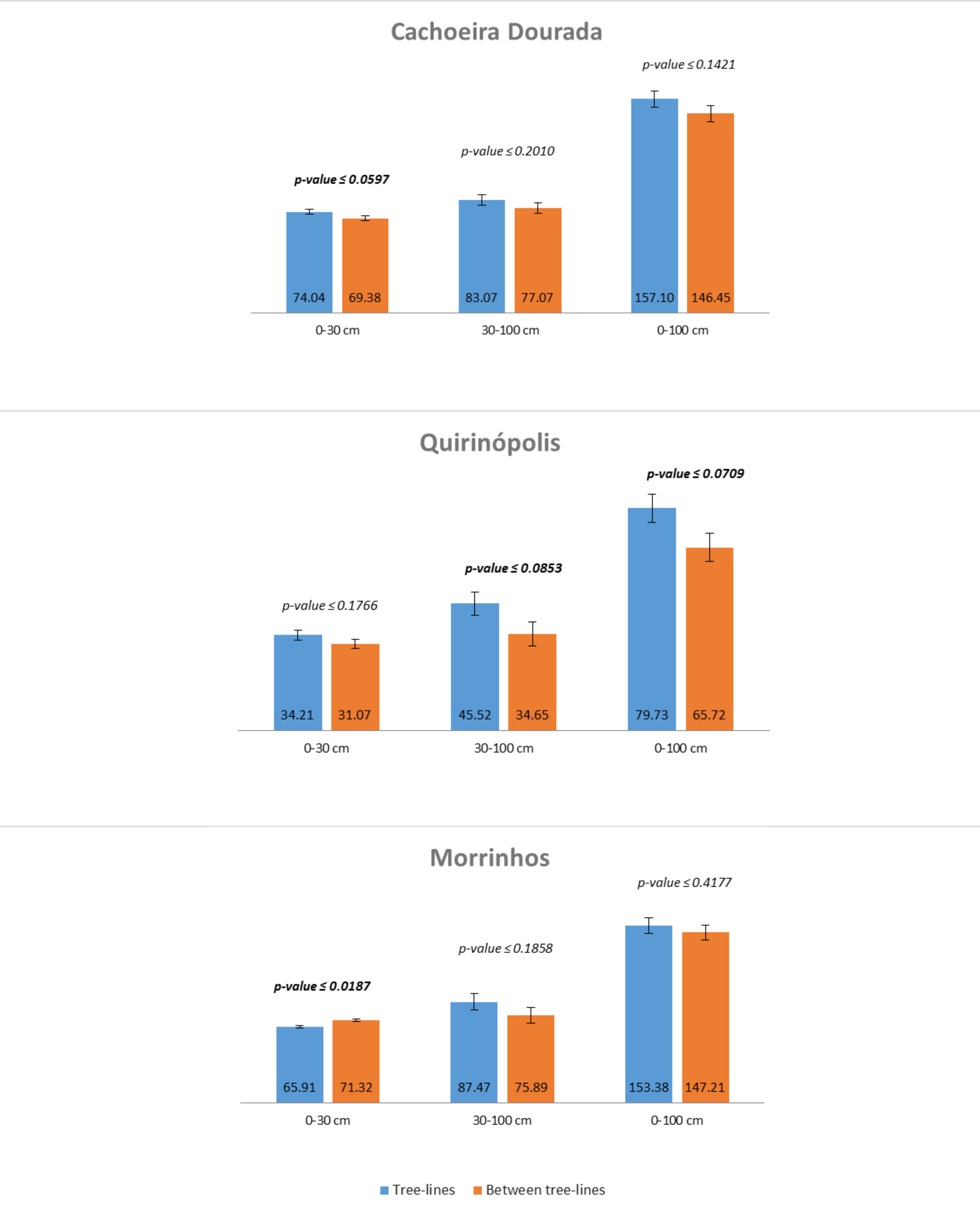

Figure 2. Soil organic carbon stocks (Mg ha^{-1}) under the tree-rows and between tree-rows in three soil depths (0-30, 30-100 and 0-100 cm) at the sites Cachoeira Dourada, Quirinópolis and Morrinhos in southern Goiás state, Brazil. Error bars are standard errors of mean (n=4). Nominal significance level (p-value) of F-tests for the effect of tree-rows by soil depth.

CONCLUSIONS

Trees played a significant role in the increase of SOC stocks in ICLF systems. Trees promoted SOC accumulation, compared to the alley, at 30-100 cm at the two oldest sites within $p\leq 0.15$ significance level and at $p\leq 0.05$ at the oldest site at 0-100 cm. In this work we did not aim to calculate the weighted SOC stock of the ICLFs, but rather compare SOC accumulation as affected by tree-rows versus alley. Further studies are, however, needed to expand the database to support more robust analysis in combination with aboveground C accumulation, greenhouse gas emissions and to identify more conclusive processes involved in SOC sequestration (immobilization).

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REFERENCES

ASSIS, P. C. R.; STONE, L. F.; MEDEIROS, J. C.; MADARI, B. E.; OLIVEIRA, J. M.; WRUCK, F. J. Atributos físicos do solo em sistemas de integração lavoura-pecuária-floresta. **Revista Brasileira de Engenharia Agrícola e Ambiental**, Campina Grande, v.19, n.4, p.309-316, 2015.

EMBRAPA. Empresa Brasileira de Pesquisa Agropecuária. **Manual de métodos de análises de solo**. 3 ed. Brasília: Embrapa, 2017. 574p.

FRANCHINI, J. C.; BALBINOT JUNIOR, A. A.; SICHIERI, F. R.; DEBIASI, H.; CONTE, O. Yield of soybean, pasture and wood in integrated crop–livestock–forest system in Northwestern Paraná state, Brazil. **Revista Ciência Agronômica**, v.45, n.5, p.1006-1013, 2014. Available at: <http://www.scielo.br/pdf/rca/v45n5spe/16.pdf>. Accessed on: 01 Mar.2021.

HEILE, S. G.; NAIR, V. D.; RAMACHANDRAN NAIR, P. K. Contribution of trees to carbon storage in soils of silvopastoral systems in Florida, USA. **Global Change Biology**, v.16, n.1, p.427-438, 2010.

KARVATTE JÚNIOR, N.; KLOSOWSKI, E. S.; ALMEIDA, R. G.; MESQUITA, E. E.; OLIVEIRA, C. C.; ALVES, F. V. Shading effect on microclimate and thermal comfort indexes in integrated crop–livestock–forest systems in the Brazilian Midwest. **International Journal of Biometeorology**, v.60, n.1, p.1933–1941, 2016.

KUNHAMU, T. K.; KUMAR, B. M.; SAMUEL, S. Does tree management affect biomass and soil carbon stocks of *Acacia mangium* Willd. Stands in Kerala, India? In: KUMAR, B. M.; NAIR, P. K. R. (Ed.). **Carbon sequestration potential of agroforestry systems**: Opportunities and challenges. Dordrecht: Springer, 2011. p.217-228.

LEMAIRE, G.; FRANZLUEBBERS, A.; CARVALHO, P. C. D. F.; DEDIEU, B. Integrated crop-livestock systems: Strategies to achieve synergy between agricultural production and environmental quality. **Agriculture, Ecosystems & Environment**, v.190, p.4-8, 2014.

LOSS, A.; PEREIRA, M. G.; GIÁCOMO, S. G.; PERIN, A.; ANJOS, L. H. C. Agregação, carbono e nitrogênio em agregados do solo sob plantio direto com integração lavoura-pecuária. **Pesquisa Agropecuária Brasileira**, Brasília, v.46, n.10, p.1269-1276, 2011.

MENDES, M. M. S.; LACERDA, C. F.; CAVALCANTE, A. C. R.; FERNANDES, F. E. P.; OLIVEIRA, T. S. Desenvolvimento do milho sob infuência de árvores de pau-branco em sistema agrossilvipastoril. **Pesquisa Agropecuária Brasileira**, v.48, n.10, p.1342-1350, 2013.

MONROE, P. H. M.; GAMA-RODRIGUES, E. F.; GAMA-RODRIGUES, A. C.; MARQUES, J. R. B. Soil carbon stocks and origin under different cacao agroforestry systems in Southern Bahia, Brazil. **Agriculture, Ecosystems & Environment**, v.221, n.1, p.98-108, 2016.

MÜLLER, M. D.; FERNANDES, E. N.; CASTRO, C. R. T.; PACIULLO, D. S. C.; ALVES, F. F. Estimativa de Acúmulo de Biomassa e Carbono em Sistema Agrossilvipastoril na Zona da Mata Mineira. **Pesquisa Florestal Brasileira**, v.60, n.1, p.11-17, 2009.

MUNIZ, L. C.; MADARI, B. E.; TROVO, J. B. F.; CANTANHÊDE, I. S. D. L.; MACHADO, P. L. O. A.; COBUCCI, T.; FRANÇA, A. F. S. Soil biological attributes in pastures of different ages in a crop-livestock integrated system. **Pesquisa Agropecuária Brasileira**, v.46, n.10, p.1262-1268, 2011.

NOPONEN, M. R. A.; HEALEY, J. R.; HAGGAR, G. S. J. P. Sink or source-the potential of coffee agroforestry systems to sequester atmospheric CO2 into soil organic carbon. **Agriculture, Ecosystems & Environment**, v.175, n.1, p.60-68, 2013.

OLIVEIRA, J. M. O.; MADARI, B. E.; CARVALHO, M. T. M. How soil carbon and nutrient availability in an integrated crop-livestock-forest system are related? In: WORLD CONGRESS OF SOIL SCIENCE, 21, 2018, Rio de Janeiro. **Resumos…** Rio de Janeiro: IUSS/SLCS/BSSS. p.1-1.

PACIULLO, D. S. C.; GOMIDE, C. A. M.; CASTRO, C. R. T.; FERNANDES, P. B.; MÜLLER, M. D.; PIRES, M. F. Á.; FERNANDES, E. N.; XAVIER, D. F. Características produtivas e nutricionais do pasto em sistema agrossilvipastoril, conforme a distância das árvores. **Pesquisa Agropecuária Brasileira**, v.46, n.10, p.176-1183, 2011.

SAS. SAS Institute Inc. **SAS/STAT ® 9.2**: User’s Guide. Cary-NC: SAS Institute Inc., 2008. 7886p.

SILVEIRA, P. M.; SILVA, J. H.; LOBO JUNIOR, M.; CUNHA, P. C. R. Atributos do solo e produtividade do milho e do feijoeiro irrigado sob Sistema integração lavoura-pecuária. **Pesquisa Agropecuária Brasileira**, v.46, n.10, p.1170-1175, 2011.

SOUZA, D. M.; MORAIS, P. A. O.; MATSUSHIGE, I.; ROSA, L. A. Development of Alternative Methods for Determining Soil Organic Matter. **Revista Brasileira de Ciência do Solo**, v.40, n.e0150150, p.1-17, 2016. Available at: <http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100-06832016000100419&lng=en&nrm=iso>. Accessed on: Mar. 2021.

THOMAZINI, A.; MENDONÇA, E. S.; CARDOSO, I. M.; GARBIN, M. L. SOC dynamics and soil quality index of agroforestry systems in the Atlantic rainforest of Brazil. **Geoderma Regional**, v.5, n.1, p.15-24, 2015.

TSUKAMOTO FILHO, A. A.; COUTO, L.; NEVES, J. C. L.; PASSOS, C. A. M.; SILVA, M. L. Fixação de Carbono em um sistema agrossilvipastoril com eucalipto na região do cerrado de Minas Gerais. **Agrossilvicultura**, v.1, n.1, p.29-41, 2004. Available at: <http://www.sbag.org.br/03-SBAG-v1-n1-2004-29-41.pdf>. Accessed on: 28 Jan. 2021.

TUMWEBAZE, S. B.; BYAKAGABA, P. Soil organic carbon stocks under coffee agroforestry systems and coffee monoculture in Uganda. **Agriculture, Ecosystems & Environment**, v.216, n.1, p.188-193, 2016.