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EUCALYPTUS DEVELOPMENT AND CARBON SEQUESTRATION IN AN INTEGRATED PRODUCTION SYSTEM IN SÃO DOMINGOS DO ARAGUAIA, PA

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ABSTRACT
Among the benefits of the Integrated Production System - ICLF is the reduction of CO_2 emission into the atmosphere and the consequent mitigation of climate change. This study aimed to evaluate the eucalyptus growth and estimate its carbon sequestration in a crop-livestock-forest integration system located in the southeastern region of Pará. The data were collected at *Fazenda Cristalina*, in the municipality of São Domingos do Araguaia, PA. In order to assess the growth and carbon stock of the forest species, annual measurements were taken up to 60 months of age in 10 plots measuring 524 m², the first of which was at six months old. The volume of 74.52 m³ ha^{-1} was observed with an estimated carbon stock of 15.98 Mg of C ha^{-1} and 58.58 Mg of CO_2 eq ha^{-1} being sequestered from the atmosphere, thus providing a potential to neutralize methane emission of 6.23 AU ha^{-1} $year^{-1}$.
Key words: Sustainable production; Integrated production systems; Carbon stock

INTRODUCTION

The integrated crop-livestock-forest system (ICLF) consists of the joint management of crops, cattle breeding and forest cultivation based on the integration, succession or rotation of its components. The system tends to oppose the current monoculture models, thus providing the diversification of activities (VILELA et al., 2011; BALBINO et al., 2011). It can also increase the environmental and economic benefits in the properties that adopt it (BALBINO et al., 2011) in order to reconcile productivity with sustainability.

ICLF enables the achievement of satisfactory productivity and compensates for greenhouse gas emissions from livestock activities (OLIVEIRA et al., 2017), providing a positive carbon balance thanks to the reduction of CO_2 emissions into the atmosphere as compared to traditional systems, as well as the consequent mitigation of global climate change (MÜLLER et al., 2009). Trees in this system provide a valuable environmental service because they sequester carbon and provide thermal comfort to animals, in addition to wood and non-wood products, generating greater income opportunities for producers. This study aimed to assess eucalyptus growth and estimate its carbon sequestration in a crop-livestock-forest integration system located in the region of São Domingos do Araguaia, PA.

MATERIAL AND METHODS

The study was conducted at *Fazenda Cristalina*, in the municipality of São Domingos do Araguaia, PA, from 2013 to 2018. The area is located at latitude 5°36'63" S, longitude 48°29'26" W and an altitude of 120 meters. According to Köppen (1936), the climate is tropical semi-humid (Aw/As), with average monthly temperatures between 22.9 and 32.0 °C and an annual average of 26.0 °C. The soil has been classified as Moderate A Espesarenic Red-Yellow Dystrophic Latosol with medium texture on flatlands (RAMOS et al., 2016).

In September 2013, 1.5 t ha^{-1} of dolomitic limestone was applied to the study area by broadcasting. In December of the same year, the ICLF system was implemented using eucalyptus (*Eucalyptus*

urocam cv VM 01) in a simple arrangement, with 25-m spacing between rows and 3-m spacing between plants, resulting in 133 trees ha^{-1}. In the planting pit, 400g/plant of thermophosphate (Yoorin) and 50g $plant^{-1}$ of NPK 10-28-20 were used. For cover fertilization, 200g $plant^{-1}$ of the NPK 10-28-20 formulation was used, divided into two applications, as well as 50g $plant^{-1}$ of FTE BR12 (micronutrients). In the first two years, maize intercropped with brachiaria was cultivated for ground cover and biomass production. In the second cycle, maize was again cultivated and the definitive pasture was introduced by sowing *Panicum maximum* cv Mombaça. Basic maize fertilization consisted of 200 kg ha^{-1} of NPK 10-30-10 formulation, and 200 kg ha^{-1} of NPK 20-00-20 formulation was used in the cover. The maize/grass/eucalyptus intercrop was adopted only in the first two years, after which only Mombaça grass was kept between the eucalyptus lines for animal grazing.

In order to assess the growth and carbon stock of the eucalyptus trees, measurements were taken at 6 months after planting and every year after implantation. Data collection from the eucalyptus was carried out in 25 x 21-m plots, totaling 524 m^2 in each plot, in which height (H) was measured from the vertex, and the diameter at breast height (DBH) by a tape measure. The volumes per plant and per hectare (m^3 ha^{-1}) were calculated using the adjusted equation of the model by Schumacher and Hall (1933), according to Campanha et al. (2017).

According to Oliveira et al. (2018), in order to estimate the carbon stock (C) in the eucalyptus trunk, an average carbon content of 49% and an average wood density of 0.35 Mg m^{-3} were considered, estimating 0.17 Mg of C m^{-3}. According to IPCC (2006), it can be considered that 1 t of C is equivalent to 3.6667 t of CO_2 eq, thus estimating a fixation of 0.62 Mg of CO_2 eq per m^3 of wood. The trunk biomass was estimated by multiplying the volume by the respective density of the adopted wood, multiplied by the carbon content.

RESULTS AND DISCUSSIONS

The trees implanted according to the ICLF system in the studied region showed good development, with a mean height of 4.6 and 6.8 m at 6 and 12 months, and a mean DBH of 3.73 and 8.01 cm, respectively (Table 1), with an estimated mean volume per hectare of 0.31 m^3 ha^{-1} at 6 months and of 2.10 m^3 ha^{-1} at 12 months with a capacity of 133 trees ha^{-1}. At 24 months, eucalyptus showed a gain of 66.17% and 107.36% in height and mean DBH, respectively. At 60 months, the mean height was 18.7 m, and mean DBH was 28.70 cm, with a mean volume of 74.52 m^3 ha^{-1}. These results are lower than those reported by Campanha et al. (2017), who found eucalyptus (*Eucalyptus grandis* (Hill) ex Maiden x *Eucalyptus urophylla* S.T Blake strains GG100), with a mean height of 32 m, a mean DBH of 17.9 cm and a volume of 82.8 m^3/ha at 60 months in an ICLF system intercropped with agricultural crops (333 trees ha^{-1}, 15 x 2 m) in Sete Lagoas, MG. In Macedo et al. (2006), the results were similar to those found in the first years.

Table 1. Mean height, DBH and volume of eucalyptus by month and by hectare in an integrated crop-livestock-forest system (ICLF). São Domingos do Araguaia, PA.

Age in months	Mean Height (m)	Mean DBH (cm)	Mean Volume (m^3 ha^{-1})
6	4.6	3.73	0.31
12	6.8	8.01	2.10
24	11.3	16.61	15.05
36	16.5	22.19	39.25
48	18.5	25.90	60.04
60	18.7	28.70	74.52

Eucalyptus in the ICLF system showed a linear behavior over the months in relation to carbon sequestration from the atmosphere. At 12, 24, 36 and 48 months, eucalyptus was responsible for sequestering 0.45; 3.23; 8.41; 12.57 Mg of C ha^{-1}, respectively, reaching 60 months with a carbon stock of 15.98 Mg of C ha^{-1} (Table 2).

It is estimated that 11.83 Mg ha^{-1} of CO_2 eq are sequestered at 24 months, and 58.58 Mg $ha^{-1}$of CO_2 eq at 60 months of age. According to IPCC (2006) an AU (Animal Unit) that is equal to 450 kg (live weight) on average emits 1.88 Mg ha^{-1} of CO_2 eq $year^{-1}$. Thus, after 60 months of age, the ICLF system with 133 trees ha^{-1} and a 15 x 2-m arrangement has the potential to neutralize the methane emission of 6.23 AU ha $year^{-1}$, that is, a total of 31 adult bovines per hectare (31 AU) in five years. Such results are similar to those found by Campanha et al. (2017), which, in an ICLF system with 333 trees ha^{-1} in the 15 x 2-m arrangement, defined such neutralization in 5.81 AU ha^{-1} $year^{-1}$, with a total of 29 adult bovines per hectare (29 AU) in five years.

Table 2. Estimated carbon and CO_2 eq stock per hectare in the trunk of eucalyptus trees and the potentially neutralized stocking rate for an Integrated Crop-Livestock-Forest System with 133 eucalyptus trees per hectare. São Domingos do Araguaia, PA.

Age in months	Carbon stock (Mg of C ha^{-1})	CO_2 eq stock (Mg ha^{-1} of CO_2 eq)	Neutralized stocking rate (AU ha^{-1} $year^{-1}$)
6	0.07	0.24	0.26
12	0.45	1.65	0.88
24	3.23	11.83	3.15
36	8.41	30.85	5.47
48	12.87	47.19	6.28
60	15.98	58.58	6.23

Thus, it is observed that the trees in the ICLF system have great capacity to mitigate GHG emissions from animal production, since according to Alves et al. (2015), the average stocking rate of Brazilian pastures comes close to 1.0 AU ha^{-1} $year^{-1}$.

CONCLUSIONS

Eucalyptus in the ICLF system and under the observed conditions showed a volume of 74.52 m^3 ha^{-1} at 60 months of age with an estimated carbon stock of 15.98 Mg C ha^{-1} and 58.58 Mg ha^{-1} of sequestered CO_2 eq from the atmosphere, thus providing a potential to neutralize methane emission of 6.23 AU ha^{-1} $year^{-1}$.

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