

# Tree Modeling and Economic Evaluation of Agroforestry Systems in Southeastern Brazil

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**Abstract.** In this study, the authors aimed to apply a consistent, efficient and biologically correct model to estimate growth and yield of the tree component from eucalypt-based agroforestry systems and, through economic indicators, analyze and evaluate its products. The systems were composed by hybrid clones of *Eucalyptus* spp. in 10 x 4 m spacing, integrated with rice, soybean and pasture. The equation system developed by CLUTTER (1963) was used as the starting point for estimating growth and yield of Eucalyptus wood. The model application resulted in accurate estimates for both basal area and future volume, with adjusted coefficient of determination of 0.908 and 0.956, respectively. The economic criteria used in the analysis were the internal rate of return (IRR), the net present value (NPV), the equivalent annual value (EAV) and the benefit-cost ratio (B/C) with discount rates of 6, 8, 10 and 12 %. The agroforestry systems were economically viable considering all studied indicators and discount rates. Lastly, changes in the discount rate affect the systems profitability, so that the lower the rate, the higher the economic return.

**Key words:** agrosilvopastoral system, forest inventory, forest economy

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### **Modelagem de árvores e avaliação econômica de sistemas agroflorestais na região sudeste do Brasil**

**Sumário.** Neste estudo, os autores buscaram aplicar um modelo consistente, eficiente e biologicamente correto para estimar crescimento e produção do componente arbóreo de sistemas agroflorestais baseados em eucalipto e, através de indicadores econômicos, analisar e avaliar seus produtos. Os sistemas foram compostos por clones híbridos de *Eucalyptus* spp. em espaçamento de 10 x 4m, integrados com arroz, soja e pasto. O sistema de equações desenvolvido por Clutter (1963) foi usado como ponto de partida para estimar crescimento e produção de madeira de eucalipto. A aplicação do modelo resultou em estimativas precisas tanto para área basal quanto para volume, com coeficiente de determinação ajustado de 0.908 e 0.956 respectivamente. Os critérios econômicos utilizados nas análises foram a taxa interna de retorno (TIR), o valor presente líquido (VPL), o valor anual equivalente (VAE) e razão benefício-custo (B/C) com taxas de desconto de 6, 8, 10 e 12%. Os sistemas agroflorestais foram viáveis economicamente considerando todos os indicadores e taxas de desconto estudadas. Por fim, mudanças na taxa de desconto afetam a rentabilidade dos sistemas, sendo que, quanto menor a taxa, maior o retorno econômico.

**Palavras-chave:** sistema agrossilvipastoril, inventário florestal, economia florestal

### **Modélisation de arbres, et évaluation économique des systèmes agroforestiers dans le sud-est du Brésil**

**Résumé.** Dans cette étude, les auteurs ont cherché à utiliser un modèle cohérent, efficace et biologiquement correct pour estimer la croissance et la production du composant arboricole de systèmes agroforestiers ayant pour base l'eucalyptus, et, à travers des indicateurs économiques, analyser et évaluer ses produits. Les systèmes ont été formés par des clones hybrides d'*Eucalyptus* spp. avec des écarts de 10 x 4 m, complémentés avec du riz, du soja et du foin. Le système d'équations développé par Clutter (1963) a été utilisé comme point de départ pour estimer la croissance et la production de bois d'eucalyptus. L'application du modèle a abouti à des estimations précises tant pour l'aire de la base que pour le volume, avec un coefficient de détermination ajusté de 0.908 et 0.956, respectivement. Les critères économiques utilisés dans les analyses furent le taux interne de retour (TIR), la valeur liquide présente (VPL), la valeur annuelle équivalente (VAE) et le quotient bénéfice-coût (B/C), avec des taux de réduction de 6, 8, 10 et 12%. Les systèmes de l'agroforesterie ont été économiquement viables eu égard à tous les indicateurs et taux de réduction étudiés. Finalement, des changements dans le taux de réduction affectent la rentabilité des systèmes, étant donné que, plus le taux est bas, plus grand sera le retour économique.

**Mots clés:** système agrosilvipastoral, inventaire forestier, économie forestière

## Introduction

In recent years, due to worldwide concern about environment preservation and conservation, great attention has been given to the sustainable exploration of natural resources. Sustainable exploration can guarantee productive potential of such resources maintaining life expectancy of actual and future generations. Agroforestry systems (AFS) are considered an alternative use of natural resources that usually causes little or no environmental degradation, especially because it respects the basic principles of sustainable management of agroecosystems (MACEDO *et al.*, 2000).

Agrisilviculture provides income with agricultural species management during forest growth period and generates jobs in the countryside. Despite being a system that aims agricultural and forest products, there are environmental benefits resulting from the better occupation of the site: carbon sequestration, soil protection, regulation of water regime and increase on species diversity (VALE, 2004).

AFS helps to conserve and protect natural resources by, for example, mitigating non-point source pollution, controlling soil erosion and creating wildlife habitat. Agroforestry creates economic and environmental benefits. AFS may increase farm profitability because it generates new products add to the financial diversity and flexibility of the farming enterprise, and the total output per unit area of tree/crop/livestock combinations is greater than any single component alone (MOLUA, 2005).

In Brazil several experiences have shown the potential of the *Eucalyptus* genus to compose agroforestry systems (OLIVEIRA *et al.*, 2000; MACEDO *et al.*, 2006; MACEDO *et al.*, 2010). The first records about consortium between agricultural crops and eucalypt were made in the beginning of the century, being mentioned by ANDRADE & VECCHI (1918), ANDRADE (1928) and later, in the work of GURGEL FILHO (1962).

As said by MOLUA (2005), there is need to investigate the economic nature and profitability of agroforestry. Though there are multiple functions for agroforestry systems, the economic incentives derived could be catalytic in encouraging adoption.

DUBÈ *et al.* (2000) carried out an analysis of the economic aspects of a eucalypt-based agroforestry system established at the Brazilian savanna and showed that this system was economically more attractive than a monoculture. The region of study, allocated in the Northwest of the Minas Gerais state, has been target of researches related to agroforestry since the end of the 1990's. DUBÈ *et al.* (2002) applied a simulation model to evaluate technical and economic aspects of the

agroforestry system there established. At the same site, SOUZA (2005) used a model to predict the yield of eucalyptus clones. However, the model used by the author did not express increasing wood volumes proportionally to the increase in local production capacity (site index), resulting in lower volumes at more productive locations when compared with less productive places.

According to VAN der WERF *et al.* (2007), long term yield predictions are needed to assess long term economic profitability of AFS. Also, financing mechanisms are essential to promote and accelerate the adoption of these systems on a large scale. In this context, economic evaluations are important supporting tools to financing agents, technicians and producers involved in this type of investment (SANTOS & PAIVA, 2002; PATTANAYAK *et al.*, 2003; BENTES-GAMA *et al.*, 2005; MARTHA JUNIOR *et al.*, 2011).

The present study was also conducted with data of an agroforestry system located at the Northwest of Minas Gerais state, Brazil. The AFS included the cultivation rice, soybean, pasture and eucalypt.

The wood from commercial eucalypt plantations in Minas Gerais state has been used mostly for energy (in the form of charcoal) and sawn wood. The state stands as the largest producer and consumer of charcoal, as it has the largest steel making industry fueled by charcoal in the world. This fact contributes to the participation of the forest sector in 7% of the state's GDP (SANTOS *et al.*, 2012). Regarding the sawn wood, household consumption corroborates with the increase in the demand for eucalyptus wood, since the supply of native woods, mainly due to legal restrictions, tends to decrease (VALVERDE *et al.*, 2004).

The region has tradition in cattle and grain production. The soils of the sites have generally low natural fertility (SOUZA *et al.*, 2010). This scenario justifies the inclusion of rice in the first year, since this culture is less demanding on fertility. The soybean, introduced in the second year, benefits from the residual fertilizing of the rice and also improves fertility for the pasture aiming cattle fattening

In this scenario, the objectives of this study were: apply a consistent, efficient and biologically correct model to estimate growth and yield of the tree component from eucalypt-based agroforestry systems and, through economic indicators, analyze and evaluate its products.

## Material and methods

### *Site and agroforestry systems characterization*

The data for this research were obtained from agroforestry systems belonging to the unit Votorantim Siderurgia from Votorantim Enterprise Corporation, located in the municipality of Paracatu (17°13'00" S and 46°52'00" W), northwestern Minas Gerais state, Brazil (Figure 1). It's Brazil's largest AFS, covering about 1,500 ha. These systems are one of the most intensively managed in Brazil, providing to be an example of best practices for agrosilvopastoral systems (CUBBAGE *et al.*, 2012).



**Figure 1** - Location of the city where the studied agroforestry systems were situated.

The region's climate is Aw – humid tropical savanna, according to Köppen classification. Mean maximum annual temperature is 28 °C and mean minimum annual temperature is 17 °C. The mean annual precipitation is 1,350 mm, concentrated at the hottest semester. The driest month presents precipitations lower than 25 mm and the driest period is from April to October. The annual potential evaporation varies between 1,200 and 1,600 mm (INMET, 2013).

The average altitude is 550m and the relief varies from plain to slightly wavy. The soil is classified as dystrophic Red-Yellow latosol, clayey texture (16.25% of sand, 21.50% of silt and 62.25% of clay), with low fertility and high acidity.

The vegetation is composed by Brazilian savanna in several topologies, varying from fields to Brazilian savanna woodland and subperennial riparian forests, mainly in the extremities of rivers, developed on soils derived from basalt (GOLFARI, 1975).

The agroforestry systems adopted by the enterprise since 1993 were characterized by a stand of hybrid clones of *Eucalyptus* spp. integrated with rice (*Oriza sativa* L., Guarany cultivar), soybean [*Glycine max* (L.) Merr., Doko, Conquista and Vitória cultivars] and grass (*Urochloa brizantha*), in a defined time scale, aiming the production of wood for charcoal and lumber, agriculture products and beef.

The eucalyptus clones were planted in a 10 X 4 m spacing to allow agricultural cultivation between the rows in the first two years. The planting of rice was carried out in the first year, while soybean culture was added in the second year. The spacing in the rice and soybean plantations was 0.45 m between lines, using 80 and 24 seeds per linear meter respectively. To avoid competition, a minimum spacing of one meter was held between the lines of eucalypt and the lines of rice, soybean and grass.

The pasture formation began in the third year with the planting of *Urochloa brizantha* and as from the fourth year, steers were acquired for fattening, establishing sale of cattle every 2 years. Other details of these systems, mainly concerning about soil preparation, fertilization, silvicultural practices and production, can be found in the works of DUBÈ (1999) and TSUKAMOTO FILHO (2003).

The data for modeling was obtained from 17 permanent plots of 30 x 40 m (1,200 m<sup>2</sup>) containing three rows of 10 trees. They were implanted taking into account the criteria of continuous forest inventory by stratified random sampling, with an intensity of 1:10 (one plot for each 10 ha).

#### *Eucalyptus growth and yield modeling*

To include the timber production in the economic analysis, the forest component of the systems was modeled by fitting the Clutter model as seen in SALLES *et al.* (2012). The author successfully applied the non-reduced form of the model to estimate growth and yield of agroforestry systems at the same Brazilian region. The equation system on its non-reduced form is defined:

$$\ln B_2 = \ln B_1(I_1 I_2^{-1}) + \alpha_0(1 - I_1 I_2^{-1}) + \alpha_1(1 - I_1 I_2^{-1})S_1 + \varepsilon \quad (1)$$

$$\ln V_2 = \beta_0 + \beta_1 I_2^{-1} + \beta_2 S_1 + \beta_3 \ln B_2 + \beta_4 S_1 I_2^{-1} + \beta_5 S_1 \ln B_2 + \beta_6 \ln B_2 I_2^{-1} + \varepsilon \quad (2)$$

where  $I_1$  is the current age, in months;  $I_2$  is the future age, in months;  $B_1$  is the basal area at age  $I_1$ , in m<sup>2</sup>.ha<sup>-1</sup>;  $B_2$  is the basal area at age  $I_2$ , in m<sup>2</sup>.ha<sup>-1</sup>;  $S_1$  is the site index at age  $I_1$ ;  $V_2$  is the volume at age  $I_2$ , in m<sup>3</sup>.ha<sup>-1</sup>;  $\beta_i$  and  $\alpha_i$  are the model parameters; and  $\varepsilon$  is the random error, where  $\varepsilon \sim N(0, \sigma_2)$ .

The pairs of the variables  $I_1$  and  $I_2$  used on the fitting were: 20-35, 21-34, 21-42, 31-46, 32-47, 33-54, 34-41, 35-42, 43-58, 46-53, 47-54, 55-70, 58-65, 69-82, 70-77 and 82-89 months. The site index ( $S_1$ ), also called production capacity, was generated by the guide-curve method through the equations obtained by LOPES (2007), whose work was carried out in the same location as the present study. Based on the observed amplitude of the  $S$  variable, three classes of productivity were defined:  $S=32$  for good sites,  $S=22$  for average sites and  $S=12$  for poor sites.

The trends between  $\ln V_2$  and its predecessor variables were examined via scatter plots. It was seen that  $\ln V_2$  increases with increasing  $S_1$ ,  $\ln B_2$ ,  $S_1 \ln B_2$  and  $\ln B_2 I_2^{-1}$ , and decreases with increasing  $I_2^{-1}$  and  $S_1 I_2^{-1}$ . Therefore, it was expected negative signs for the coefficients  $\beta_1$  and  $\beta_4$  and positive for the others.

In addition to the usual  $t$  test, to assess the significance of the model parameters, it was verified the hypothesis of the absolute value of each parameter being greater than two times its respective standard error. If so, their estimate was considered reliable at 95% confidence level ( $p \leq 0.05$ ). This method is based on the  $t$ -statistic, which is given by the ratio between the estimated value of the parameter and its standard error.

The equation system was fitted by the two stages least squares (2SLS) method, using the software *EViews* 3.0 (LILIEN *et al.*, 1998). The 2SLS consists on two successive applications of the ordinary least squares (OLS) method. In the first stage, the parameters of the equation (1), formed by the endogenous variable as a function of the other exogenous variables in the system, are estimated. In the second stage, the estimated values of the endogenous variable obtained in the first step are used to estimate the structural equation (2) (GUJARATI, 2004).

#### *Economic analysis*

The methodology used for the economic evaluation of the agroforestry systems was based on the study developed by DUBÈ (1999). It was assumed that 60% of the wood produced would be used for charcoal production and 40% would be used in sawmills. Moreover, the selling prices were considered as being of standing timber, getting the operating, transportation, carbonization and sawmill costs on the buyer. The selling prices were equal to 35.09 US\$/m<sup>3</sup> for the charcoal production wood and 43.86 US\$/m<sup>3</sup> for the sawmill wood. The monetary values corresponding to July 2008 were compiled from information given by the company (Tables 1 and 2). The values in Brazilian Real were converted to American Dollar based on the average quote during 2008.

**Table 1** - Cost structure for the studied agroforestry systems.

| Item                             | Year          | Cost (US\$.ha <sup>-1</sup> ) |
|----------------------------------|---------------|-------------------------------|
| <i>Cultivation of Eucalypt</i>   |               |                               |
| Soil preparation / fertilization | 0             | 731.44                        |
| Tree planting                    | 0             | 88.20                         |
| Maintenance of trees             | 1             | 58.27                         |
| Maintenance of trees             | 2             | 90.73                         |
| Maintenance of trees             | 3             | 93.97                         |
| Maintenance of trees             | 4 to 11       | 19.33                         |
| <i>Cultivation of Rice</i>       |               |                               |
| Area and soil preparation        | 0             | 167.45                        |
| Seed planting and fertilization  | 0             | 258.61                        |
| Harvest                          | 1             | 98.83                         |
| <i>Cultivation of Soybean</i>    |               |                               |
| Area and soil preparation        | 1             | 228.01                        |
| Seed planting and fertilization  | 1             | 192.82                        |
| Harvest                          | 2             | 98.83                         |
| <i>Pasture establishment</i>     |               |                               |
| Area and soil preparation        | 2             | 87.98                         |
| Seed planting and fertilization  | 2             | 339.77                        |
| Infrastructure                   | 3             | 183.49                        |
| Maintenance of pasture           | 5 and 8       | 410.64                        |
| <i>Cattle raising</i>            |               |                               |
| Labor                            | 3 to 11       | 1.25                          |
| Depreciation                     | 3 to 11       | 3.63                          |
| Inputs                           | 3 to 11       | 36.99                         |
| Steers for fattening             | 3, 5, 7 and 9 | 263.16                        |



**Table 2** - Revenue structure for the studied agroforestry systems.

| Product           | Year           | Production (kg.ha <sup>-1</sup> ) | Sale price                    | Revenue (US\$.ha <sup>-1</sup> ) |
|-------------------|----------------|-----------------------------------|-------------------------------|----------------------------------|
| Rice              | 1              | 1,612.80                          | 0.60 (US\$.kg <sup>-1</sup> ) | 974.56                           |
| Soybean           | 2              | 1,500.00                          | 0.42 (US\$.kg <sup>-1</sup> ) | 628.65                           |
| Cattle            | 5, 7, 9 and 11 | 225.00                            | 3.20 (US\$.kg <sup>-1</sup> ) | 719.30                           |
| Wood for sawmill  | 11             | to be estimated                   | 43.86 (US\$.m <sup>-3</sup> ) | to be estimated                  |
| Wood for charcoal | 11             | to be estimated                   | 35.09 (US\$.m <sup>-3</sup> ) | to be estimated                  |

The economic criteria used for the analysis were the net present value, equivalent annual value, benefit-cost ratio and internal rate of return. The discount rates of 6, 8, 10 and 12% per year were established to perform a sensibility analysis involving the proposed indicators. These are the rates that comprise most studies involving agroforestry systems in the Brazilian forestry sector (DUBÈ *et al.*, 2000; OLIVEIRA *et al.*, 2000; BENTES-GAMA *et al.*, 2005; MÜLLER *et al.*, 2011). The expressions for calculating the economic criteria were:

$$NPV = \sum_{j=0}^n R_j(1+i)^j - \sum_{j=0}^n C_j(1+i)^j \quad (3)$$

$$EAV = [NPV(i)] / [1 - 1/(1+i)^n] \quad (4)$$

$$\sum_{j=0}^n R_j(1+IRR)^j - \sum_{j=0}^n C_j(1+IRR)^j = 0 \quad (5)$$

$$B/C = \sum_{j=0}^n R_j / \sum_{j=0}^n C_j \quad (6)$$

were NPV is the net present value; EAV is the equivalent annual value; IRR is the internal rate of return; B/C is the benefit-cost ratio; R is the total revenue in year j; C is the total cost in year j; i is the annual discount rate; and n is the project duration, in years.

## Results and discussion

### *Eucalypt growth and yield modeling*

The adjusted coefficient of determination () referring to the basal area equation ( $B_2$ ) was equal to 0.908, and the adjusted coefficient of determination referring to the volume equation ( $V_2$ ) was equal to 0.956.

The parameters estimates whose absolute values were higher than twice their standard errors and had signals as expected were considered significant at 95% probability. Also, all the estimates were significant by the t-statistic ( $p \leq 0.01$ ). The final equations were composed with those parameters (Table 3).

**Table 3** - Equations for estimating basal area and wood volume of the studied agroforestry systems, and the estimates of its parameters.

| Functional relation  | Coefficients*    |           | Standard error |
|--|------------------|-----------|----------------|
| $\ln B_2 = \ln B_1(I_1 I_2^{-1}) + \alpha_0(1 - I_1 I_2^{-1})$   | $\hat{\alpha}_1$ | 2.8475    | 0.0172         |
|  | $\hat{\beta}_0$  | 4.6798    | 0.0701         |
|  | $\hat{\beta}_1$  | -117.2166 | 4.1165         |
| $\ln V_2 = \beta_0 + \beta_1 I_2^{-1} + \beta_4 S_1 I_2^{-1} + \beta_5 S_1 \ln B_2 + \beta_6 \ln B_2 I_2^{-1}$ | $\hat{\beta}_4$  | -0.8531   | 0.1626         |
|  | $\hat{\beta}_5$  | 0.0078    | 0.0009         |
|  | $\hat{\beta}_6$  | 47.4437   | 1.7586         |

\*  $p \leq 0.01$  for all coefficients

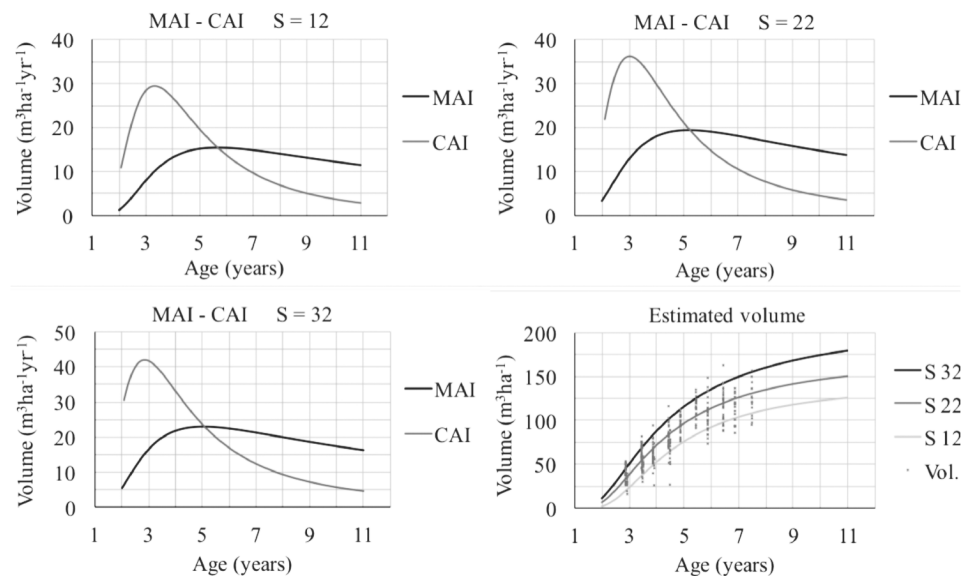
For the basal area equation, the  $\alpha_1$  parameter was not significant, removing the site variable from the final expression. Similar results were found by VALDEZ-LAZALDE & LYNCH (2000), DIAS *et al.* (2005), GEORGENS *et al.* (2007) and OLIVEIRA *et al.* (2009). Different values of  $B_1$  at 12 months were set, according to the observed data, to generate consistent  $B_2$  estimates for the different classes of site index.

The model is usually applied in the reduced form obtained by Clutter (1963), who fitted equations (1) and (2) to a sample of *Pinus taeda* trees. Nevertheless, SALLES *et al.* (2012) using the Clutter model to estimate growth and yield of agroforestry systems showed that the reduction of the model based on the

fitting made to a sample of the target population is a better alternative than using the pre reduced form. The results shown here support this idea, since the final equation system on Table 3 was different from all equation systems obtained by SALLES *et al.* (2012).

The volume curves (Figure 2) passed through the points that express the volume in the three observed productivity classes. This situation indicates that the model represented with accuracy the scenario observed in the field. Also, the residual distributions obtained from the estimations, had deviations lower than 20%. These values are related to good estimates for eucalyptus monoculture (CRUZ *et al.*, 2008; ARAÚJO JÚNIOR *et al.*, 2010; ZONETE *et al.*, 2010). When there is lack of accurate estimates for an agroforestry system, managers usually use literature and experiments data (BERTOMEU, 2006). This sometimes may generate untrustworthy feasibility analysis, as discussed by SALLES *et al.*, (2012).

It is important to note that the volume equation was applied in the form:  $V_2 = \exp(\beta_0 + \beta_1 I_2^{-1} + \beta_4 S_1 I_2^{-1} + \beta_5 S_1 \ln B_2 + \beta_6 \ln B_2 I_2^{-1})$ . Therefore, the volume curves presented the exponential tendency seen in Figure 2.



**Figure 2** - Mean annual increment in volume (MAI), current annual increment in volume (CAI), volume curves estimated for three site indexes (S), and observed volumes (Vol.).

Considering that the technical cutting age occurs when the forest's MAI (Figure

2) reaches its maximum and touches the curve of CAI, it is seen that the model was consistent when estimating this attribute, since lower technical cutting ages were obtained at sites of higher production capacity. For the site indexes 12, 22 and 32, the cutting ages were 68, 63 and 60 months respectively (Table 4). These values are in accordance with the results achieved by LOPES (2007), who fitted a diametric distribution model adapted from the one proposed by NOGUEIRA (2003), using data from the same region as the present study. According to the author, the cutting ages were compatible to the average rotation of conventional plantations (monocultures), suggesting that despite the large spacing, competition occurs at the plantation line.

**Table 4** - Estimates generated by the model of basal area ( $B_2$ ), in  $m^2.ha^{-1}$ ; wood volume ( $V_2$ ), in  $m^3.ha^{-1}$ ; and (MAI) mean monthly increment, in  $m^3.ha^{-1}.yr^{-1}$ ; for three classes of site index.

| Age<br>(yr) | S = 12 |        |        | S = 22 |        |        | S = 32 |        |        |
|-------------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
|             | $B_2$  | $V_2$  | MAI    | $B_2$  | $V_2$  | MAI    | $B_2$  | $V_2$  | MAI    |
| 2           | 2.06   | 2.39   | 1.193  | 3.79   | 6.53   | 3.266  | 5.37   | 11.01  | 5.507  |
| 3           | 4.19   | 23.59  | 7.865  | 6.28   | 38.07  | 12.688 | 7.92   | 49.85  | 16.616 |
| 4           | 5.97   | 52.30  | 13.075 | 8.09   | 71.60  | 17.900 | 9.62   | 87.49  | 21.873 |
| 5           | 7.38   | 75.39  | 15.078 | 9.41   | 96.57  | 19.315 | 10.81  | 115.30 | 23.061 |
| 6           | 8.50   | 91.82  | 15.304 | 10.41  | 114.03 | 19.006 | 11.69  | 135.09 | 22.515 |
| 7           | 9.40   | 103.32 | 14.761 | 11.19  | 126.33 | 18.048 | 12.35  | 149.39 | 21.341 |
| 8           | 10.14  | 111.48 | 13.935 | 11.81  | 135.21 | 16.901 | 12.88  | 159.99 | 19.998 |
| 9           | 10.76  | 117.40 | 13.045 | 12.32  | 141.79 | 15.754 | 13.31  | 168.06 | 18.674 |
| 10          | 11.28  | 121.79 | 12.179 | 12.74  | 146.80 | 14.680 | 13.65  | 174.37 | 17.437 |
| 11          | 11.72  | 125.12 | 11.374 | 13.09  | 150.69 | 13.699 | 13.95  | 179.40 | 16.309 |

#### *Economic analysis*

The cash flow covering the 11 years had positive accumulated balance only at the end of the last year (Table 5). This occurs because these AFS are a long term investment with a long time of capital conversion, mainly considering that the

highest revenue (which comes from the wood cut) occurs in the end of the 11<sup>th</sup> year. In agreement with this scenario, MÜLLER *et al.* (2011) studying an agrosilvopastoral system in Brazil, came to the conclusion that its viability depends mostly on its forest products.

**Table 5** - Cash flow for the 11 year rotation established for the studied agroforestry systems.

| Year | Cost     | Revenue                 | Balance   | Accumulated balance |
|------|----------|-------------------------|-----------|---------------------|
| 0    | 1,245.69 |                         | -1,245.69 | -1,245.69           |
| 1    | 577.93   | 974.56                  | 396.63    | -849.07             |
| 2    | 617.31   | 628.65                  | 11.35     | -837.72             |
| 3    | 582.49   |                         | -582.49   | -1,420.21           |
| 4    | 61.20    |                         | -61.20    | -1,481.41           |
| 5    | 735.00   | 719.30                  | -15.70    | -1,497.11           |
| 6    | 61.20    |                         | -61.20    | -1,558.30           |
| 7    | 324.36   | 719.30                  | 394.94    | -1,163.36           |
| 8    | 471.84   |                         | -471.84   | -1,635.20           |
| 9    | 324.36   | 719.30                  | 394.94    | -1,240.26           |
| 10   | 61.20    |                         | -61.20    | -1,301.46           |
| 11*  |          | 5,548.42 <sup>(1)</sup> | 5,487.23  | 4,185.77            |
|      |          | 6,535.45 <sup>(2)</sup> | 6,474.25  | 5,172.80            |
|      |          | 7,643.64 <sup>(3)</sup> | 7,582.44  | 6,280.98            |

\*Year presenting revenues from wood products where S=12<sup>(1)</sup>, 22<sup>(2)</sup> and 32<sup>(3)</sup>, added to the incomes from the sale of cattle.

The results of the economic analysis using the estimates from the Clutter model were consistent. With increasing productive capacity, the economic parameters (NPV, EAV and B/C) also increased (Table 6). From the balances in year 11, it can be seen that forestry is the portion that carries most revenue to the systems.

For the low, average, and high productive classes (site indexes 12, 33 and 32), the internal rates of return (IRR) were 14.35%, 16.14% and 17.88% respectively. Based on this indicator, the agroforestry systems adopted by the company were economically viable for all the discount rates used in the sensitivity analysis. They were also viable based on NPV, EAV and B/C to all discount rates in the simulations. In all cases, the NPV and the EAV were positive and the B/C was higher than 1.

MÜLLER *et al.* (2011), studying an agroforestry system in Brazil (also in the state of Minas Gerais) came to positive but more modest feasibility results when compared with the present study. In his work the economic analysis involved three different alternatives to the sale of wood. The values of NPV in US\$.ha<sup>-1</sup> were 576.12, 740.00 and 871.66, and the alternatives were feasible for discount rates lower than 10.0%, 11.0% and 11.7%.

**Table 6** - Net present value (NPV), in US\$.ha<sup>-1</sup>; equivalent annual value (EAV), in US\$.ha<sup>-1</sup>; and benefit-cost ratio (B/C) calculated for the studied agroforestry systems for four different discount rates.

| <i>i</i>        | <i>S</i> = 12 |        |      | <i>S</i> = 22 |        |      | <i>S</i> = 32 |        |      |
|-----------------|---------------|--------|------|---------------|--------|------|---------------|--------|------|
|                 | NPV           | EAV    | B/C  | NPV           | EAV    | B/C  | NPV           | EAV    | B/C  |
| <b>6% p.a.</b>  | 1,602.98      | 203.25 | 1.38 | 2,122.93      | 269.17 | 1.50 | 2,706.71      | 343.19 | 1.64 |
| <b>8% p.a.</b>  | 1,072.78      | 150.27 | 1.27 | 1,496.09      | 209.57 | 1.37 | 1,971.38      | 276.14 | 1.49 |
| <b>10% p.a.</b> | 650.22        | 100.11 | 1.17 | 996.17        | 153.37 | 1.26 | 1,384.58      | 213.17 | 1.36 |
| <b>12% p.a.</b> | 312.32        | 52.60  | 1.09 | 596.07        | 100.39 | 1.16 | 914.64        | 154.04 | 1.25 |

The results confirm agroforestry as a good investment. The values of NPV and B/C are similar to those obtained by RASUL & THAPA (2006) who found that the activity brings good social and economic benefits when compared with other traditional land use.

The impact of competition cannot be ignored in these systems. The effects of the soybean and rice over the eucalypt are minimized through the control zone of one meter maintained between the cultures and the trees (DUBÈ, 1999). Regarding the pasture, its competition with eucalypt is higher in the younger ages of the trees. As the pasture is sown when the eucalyptus is already two

years old, the impacts are minimal (TOLEDO *et al.*, 2000). There are also the effects of the eucalyptus shading over the pasture. The *Urochloa brizantha* is a forage species with moderate tolerance to shading and presents satisfactory nutritional value after its growth when planted between the rows of the 10 x 4 spacing (OLIVEIRA *et al.*, 2007).

The techniques here utilized, involving economic indicators, are better suited to answering specific questions rather than producing generalized assessments. They are especially important when using agroforestry as a development tool in the tropics or economic tool in temperate zones (MONTAMBAULT & ALAVALAPATI, 2005).

## Conclusions

This study gains importance by containing incipient information for decision making in the management of agroforestry systems in Brazil, once the adoption of AFS is happening in various regions as a result of financial support such as the “Low Carbon Agriculture Program” from the Brazilian government.

The results obtained in this study lead to the conclusion that the Clutter model used in the way showed by SALLES *et al.* (2012) produces consistent estimates of growth and yield to be applied in economic analysis. The systems adopted by the company are economically viable when considering the criteria: NPV, EAV, B/C and IRR.

Forestry is the main source of economic revenue in the systems. However, wood has shown strong price variation in Brazil. Thus, the cattle become important in the systems because it generates income and prevents that all the revenue occur at the end of the cash flow.

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