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# Influence of spatial arrangements on silvicultural characteristics of three *Eucalyptus* clones at integrated crop-livestock-forest system

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**This research evaluated the influence of different spatial arrangements on the growth of three *Eucalyptus* clones as well as the characteristics that influence the quality of the timber. The experiment was carried out at Embrapa - Beef Cattle station, Campo Grande city, Mato Grosso do Sul State, Brazil. The design was in randomized blocks in a factorial scheme (3 × 3) with plots subdivided by time and four repetitions. Three clones of *Eucalyptus* were used (Urocam VM1, Grancam 1277 and Urograndis I144), and there were three spatial arrangements (single, double and triple row). At 20 and 32 months after planting, the variables, total plant height, diameter at breast height (DBH), volume of timber per tree, volume of timber per hectare, straightness and forking, and cylindricity were evaluated. The spatial arrangements influenced the behavior of the genetic material, and the greatest tree heights were observed in the triple row arrangements. The single row arrangement provided greater gains in DBH. The Grancam clone stood out from the others in the characteristics of straightness and forking, independent of the spatial arrangement and time of evaluation. It was concluded that the volume of timber per tree and the volume of timber per hectare were associated with the planting density, low density results in lower volume.**

**Key words:** Agroforestry-pasture systems, spacing, timber quality.

## INTRODUCTION

The search to increase the sustainability of agricultural production systems has stimulated interest in integrated production models, cultivating various species in the same area. To adopt integrated crop-livestock-forest

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systems (ICLF), the different components of the system need to be installed optimally to maximize the yield of each component. The tree can be considered as the component that applies the greatest influence on the others, since it has a high capacity to compete for water, light and nutrients. Thus, it is fundamental to use the correct tree species and the right spacing arrangement in the area to be cultivated.

Previous research results justify greater usage of species from the *Eucalyptus* genus in ICLF systems, because of their high adaptability to various soil and climate conditions, vigorous growth, efficiency in the use of water and mineral resources, tolerance of low-fertility soils, and low to moderate rates of infestation by pests, diseases and weeds. They also produce quality timber for multiple uses, including the furniture industry (Del Quiqui et al., 2001; Silva et al., 2015). Oliveira et al. (2009) emphasized that the production of *Eucalyptus* timber for sawmills, rather than for pulp, demands a longer cutting cycle, specific silvicultural treatment and wide spacing, which alters the silvicultural management patterns that are used currently for most forest communities in Brazil, since the mainly product is pulp and paper.

The correct spacing and density of the tree component in the ICLS are of paramount importance, as they may be in single or double rows, or in in groups of more than two rows, with different spacing between plants, rows and stands. However, the number of trees per area and the spacing between them will be defined as a function of the objective of the system, considering the production of timber, width of the agricultural machinery of the property, establishment of crops with a short cycle, livestock intervention, and facilities for the pruning and harvest of timber (Balbino et al., 2011). Thus, the association of trees, pasture and agricultural crops should be in the appropriate dimensions to obtain the greatest yield of meat, grain and forest products (Montoya et al., 2000).

Studies on the responses of *Eucalyptus* trees in ICLFS are limited, given that most studies with the genus concentrate on spacing in pure forest communities, using 2 to 3 m between plants and between planting rows. Indeed, according to Oliveira et al. (2009) the spatial arrangement of trees and the maintenance of the same useful area per plant have an influence on growth characteristics and, consequently, on yield.

Thus, the objective of this research was evaluate the influence of different spatial arrangements for *Eucalyptus* trees planted in integrated crop-livestock-forest system on the growth and initial yield of three clones at Mato Grosso do Sul state, Brazil.

## MATERIALS AND METHODS

### Description of the experimental area

The integrated crop-livestock-forest systems were installed in January 2012 at the Embrapa Beef Cattle Research Center in Campo Grande, Mato Grosso do Sul State, the soil class of the area is a distroferric red latosol (LVdf), as described by Santos et al. (2013). The area is located between the geographical coordinates: 20°27’04” S and 54º42’57” W. The climatic pattern in the region is described, in accordance with Köppen (1948), as transition zone between Cfa and Aw wet tropical. The mean annual rainfall is 1560 mm, with a wet summer and a dry winter.

### Establishing the experimental area

Soil acidity in the experimental area was corrected with a surface application of lime (3.5 t ha$^{-1}$), incorporated by means of a harrow with 18 discs and a width of 81 cm. Dolomitic limestone was used with calcium carbonate equivalent (CCE) of 75% (25% of calcium oxide and 11% of magnesium oxide). Due to the complexity of the integrated crop-livestock-forest system, a decision was taken to correct soil acidity to meet the needs of the most demanding crop, making the soil saturation volume (V%) reach 60 to fulfill the nutritional requirements of the soybean crop. Soybean (*Glycine max* cv. BRS 285) was seeded in November 2011 in a conventional tillage system, and rows were marked out in advance for the later preparation of trenches in which *Eucalyptus* would be planted with the different spatial arrangements described subsequently.

The planting of *Eucalyptus* clones was carried out after soybean was established. Preparation and planting took place in January 2012, with the planting trenches prepared using below-ground fertilizer, applying 200 g of the formula NPK 06-30-06 with 0.5% of zinc and 0.5% of boron per meter of trench. Cover fertilization of the *Eucalyptus* plants was carried out in two plots (3 and 9 months after planting), applying formula NPK 20-00-20 with 0.5% of boron and 0.5% of zinc, at a rate of 120 g plant$^{-1}$ in each dressing, as recommended by Gonçalves (1995).

For the planting, the tube surrounding each seedling was used to open a hole with the same dimensions as the root system of the seedling. The *Eucalyptus* seedlings measured on average 30 cm in height and were irrigated on the day of planting with 2 L of water per seedling. The spacing between the stands of *Eucalyptus* was 14 m, the gap was the space occupied by soybean crop (*Glycine max* cv. BRS 285) at the first year. After the harvested soybean, millet was sown as soil mulch for later planting in no-till system.

In November 2012, the spaces between the *Eucalyptus* stands were again used for the cultivation of soybean in the summer, under no-till planting. After the soybean had been harvested, the forage grass, *Brachiaria brizantha* cv. Marandu, was sown in March 2013. Animals were put out to pasture, after the forage grass had been established, in June 2013. The first grazing in the area took place when the *Eucalyptus* trees showed diameter at breast height (DBH) bigger than 6 cm, which allowed for lower branches to be removed to obtain better quality timber and so that the animals could then move into the area.

### Experimental design and treatments

A randomized block design was used, in a factorial scheme (3 × 3), with plots subdivided in time and with four repetitions. Three *Eucalyptus* clones were used: Urocam VM1 (*Eucalyptus urophyla* × *E. camaldulensis*), Grancam 1277 (*E. grandis* × *E. camaldulensis*) and Urograndis I144 (*E. urophyla* × *E. grandis*) and three spatial arrangements (single, double and triple row). Each experimental plot had 10 plants in the single row arrangement, 20 in the double rows and 30 in the triple rows.

In the single row arrangement, the spacing was 14 m between stands and 2 m between trees in the row (14 m × 2 m), totaling 357 trees ha$^{-1}$. In the double row arrangements, spacing of 14 m between stands of trees were used, 3 m between rows within the

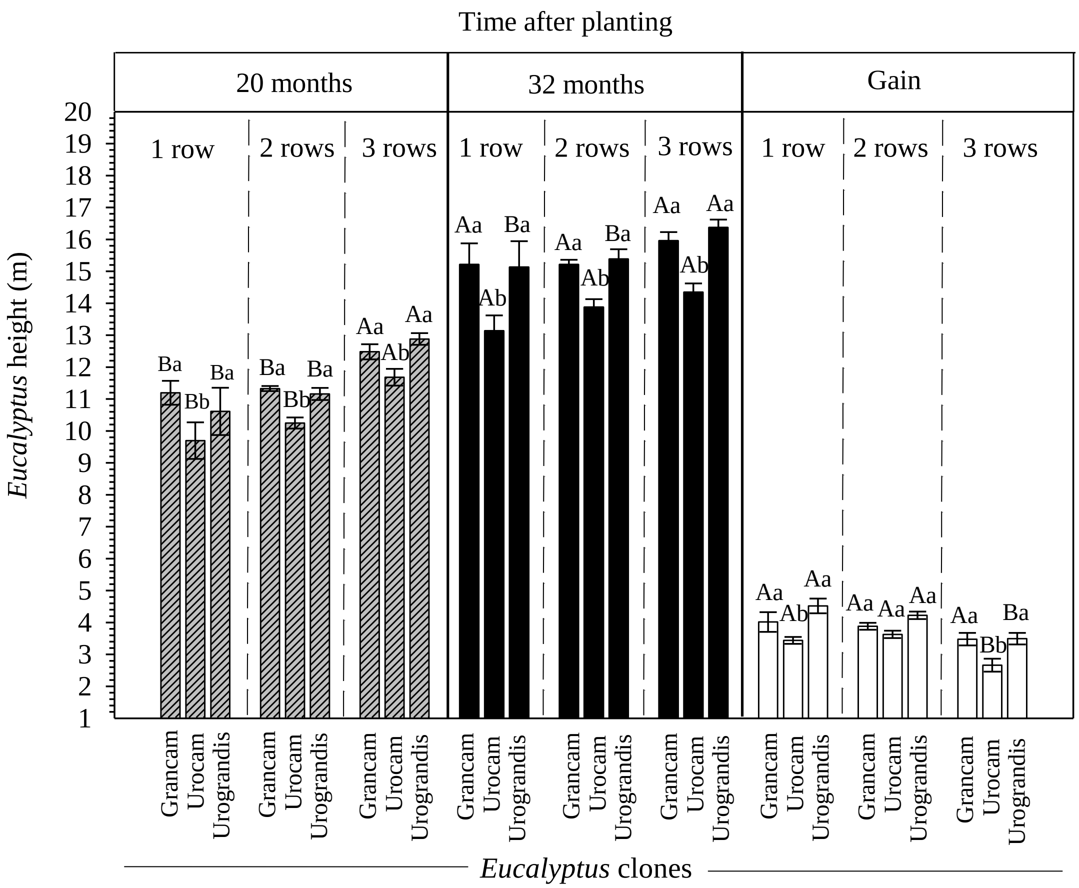


**Figure 1.** *Eucalyptus* height clones in three spatial arrangements assessed 20 and 32 months after planting and gain, between the measurement time. Different lowercase letters indicate significant difference (p≤0.05) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference (p≤0.05) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

stand and 2 m between trees in the row (3 m × 2 m) + 14 m, totaling 588 trees ha$^{-1}$. The triple rows were planted with a space of 14 m between stands, 3 m between rows within the stand and 2 m between trees in the row [(3 m + 3 m) × 2 m] + 14 m, totaling 750 plants ha$^{-1}$. The areas occupied by the tree component were 14.3, 29.4 and 40.0% in the single, double and triple row arrangements, respectively, in a total area of 3 ha.

#### Variables analyzed

Evaluations of total plant height, DBH, and grades for straightness and forking, and cylindricity, according to the scale proposed by Malinovski et al. (2006), were performed at 20 and 32 months after planting the trees. From the height and DBH data, the volume of timber per plant was calculated (using the form factor equal to 0.45) as was the volume of timber per hectare.

#### Statistical analysis

The data were submitted to analysis of variance and, when there were significant differences between means up to 5% significance, the means were compared by Scott Knott test with 5% probability, using SISVAR software (Ferreira, 2008).

## RESULTS AND DISCUSSION

### Height and DBH

There was a significant interaction between the spatial arrangement treatments and the *Eucalyptus* clones in both the tree heights and the height gains from 20 to 32 months after planting. Clone Urocam was inferior in tree height in all three spatial arrangements at both evaluation times (Figure 1).

All clones had greater height at 20 months after planting in the triple row arrangement compared with the single and double row arrangements (Figure 1). However, at 32 months after planting, only clone Urograndis had significantly greater height in triple rows than the other arrangements. The height gain between

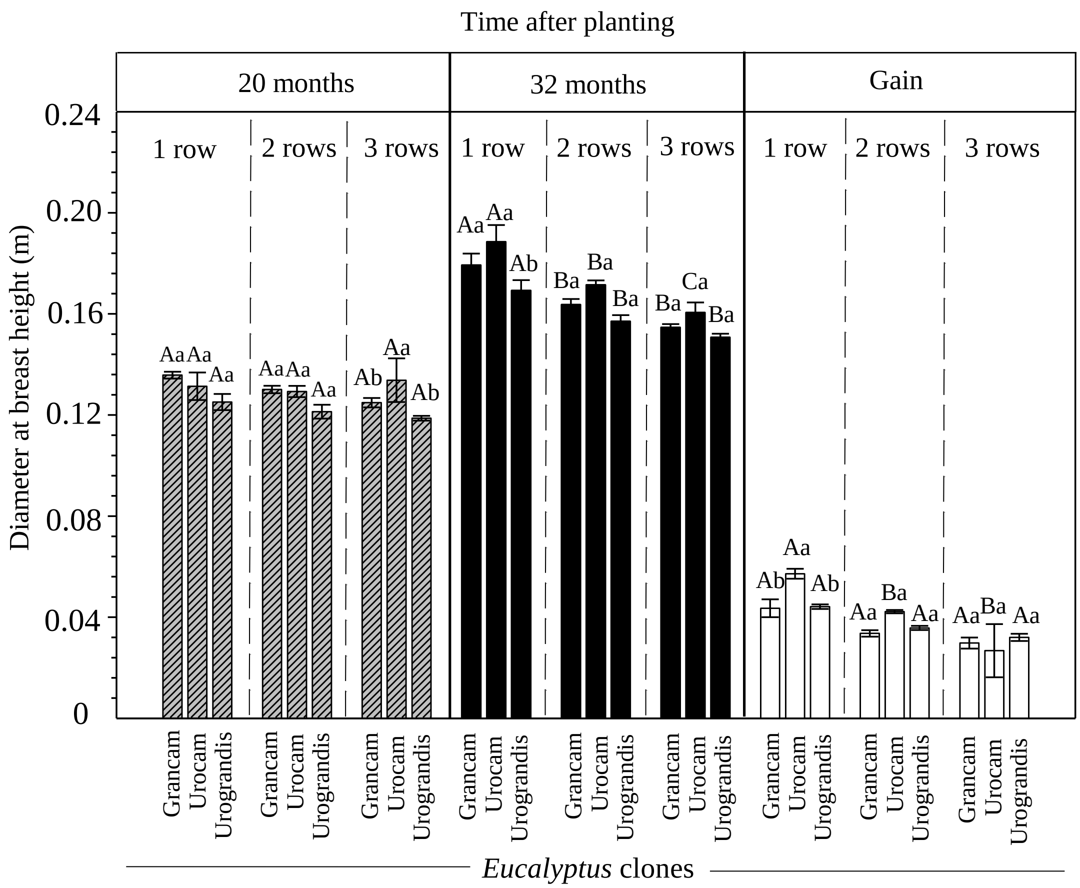


**Figure 2.** Diameters at breast height (m) of Eucalyptus clones in three spatial arrangements measured at 20 and 32 months after planting, and gain between the measurement time. Different lowercase letters indicate significant difference (p≤0.05) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference (p≤0.05) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

20 and 32 months of clones of Urocam and Urograndis was less in triple rows than in single rows and double rows, possibly due to greater competition for water, light and nutrients. The increase in tree height is linked to their genetic constitution, their tolerance of competition and their efficiency in using environmental resources (Binkley, 2004; Macedo et al., 2006; Magalhães et al., 2007; Boyden et al., 2008), explaining the influence of tree spatial arrangement on their increase in height. Although there are greater heights of plants in denser arrangements, these arrangements often show a reduction in mean height indices over time due to the greater concentration among trees in the competition for environmental resources (Bernardo, 1995; Kruschewsky et al., 2007). Silva (2005) highlighted that variations in the gains in *Eucalyptus* plant height are more accentuated after the third year. After this age, there are significant responses to the spacing used and, according to Garcia (2010), the increase in the useful area per plant provides smaller gains in height and greater gains in stem diameter. However, in the present work, the differences in the height of the clones as a function of the spatial arrangement were more marked up to 20 months after planting; after 32 months there was a reduction in the range of the values.

Clone Urocam possessed greater DBH than the other clones at 20 months after planting in triple rows (Figure 2). DBH did not differ significantly between clones in the other spatial arrangements. Clone Urograndis had lower DBH than the other clones after 32 months in the single row arrangement. DBH gains from 20 to 32 months did not differ significantly between clones within a spatial arrangement, except that clone Urocam had greater gain than the other clones in the single row arrangement.

The different spatial arrangements did not affect DBH of any of the clones at 20 months after planting. However, at 32 months after planting, highest DBH was found in the single row arrangement for all three of the clones (Figure 2). The greatest DBH gain from 20 to 32 months was in clone Urocam planted in the single row

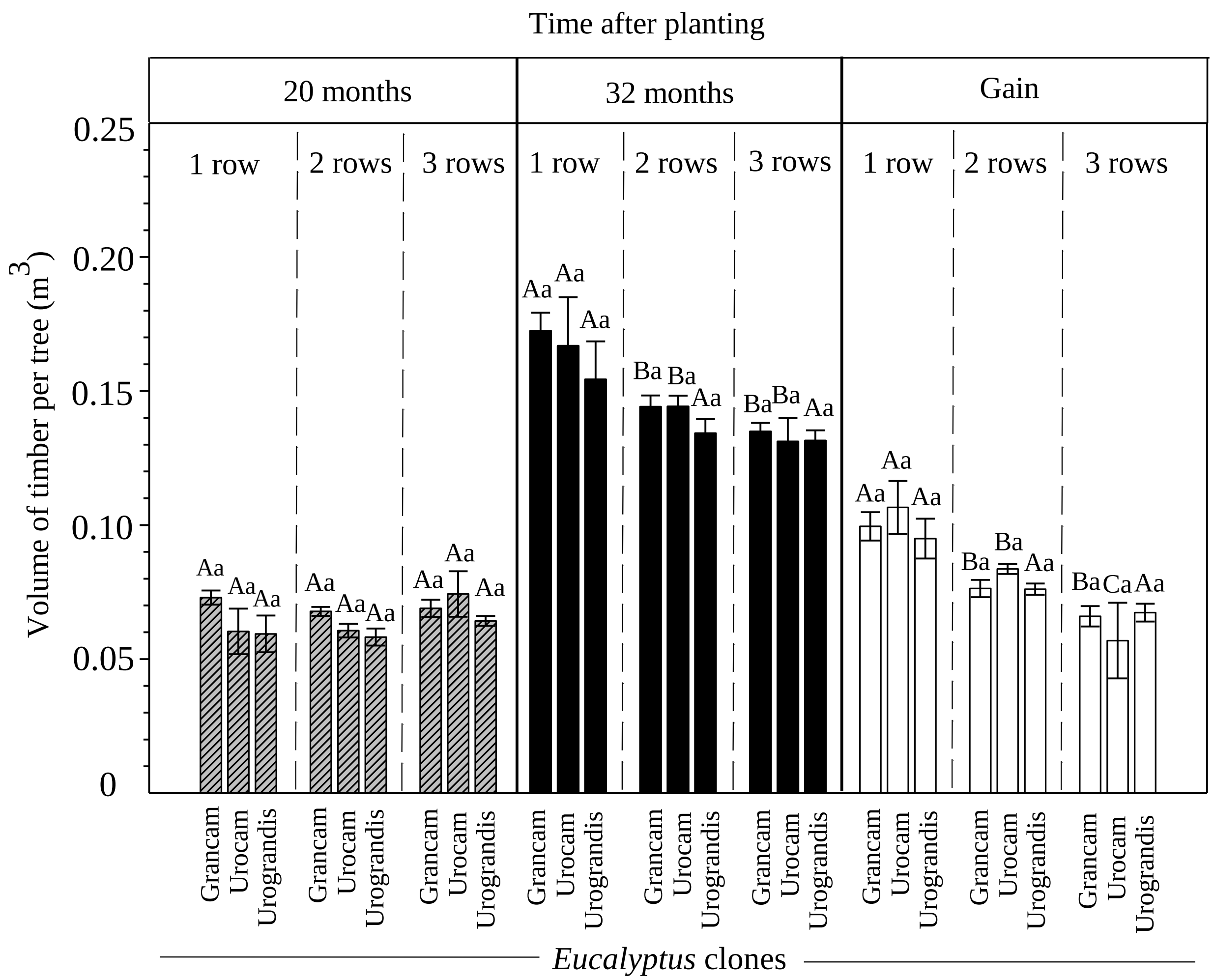


**Figure 3.** Volume of timber per tree ($m^3$) of *Eucalyptus* clones in three spatial arrangements assessed at 20 and 32 months after planting, and gains between the measurement time. Different lowercase letters indicate significant difference ($p \leq 0.05$) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference ($p \leq 0.05$) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

arrangement at 32 months age.

The DBH results were therefore linked to the spatial arrangement, noting that the single row arrangement, which provides the greatest useable area per plant, provided the highest DBH values. Often, the greater the area available for plant growth, the greater will be the stem diameter (Berger et al., 2002; Sanquetta et al., 2003; Lima, 2010). The increase in the useable area per plant results in greater availability of environmental resources such as water, light and nutrients.

## Volume of timber per tree and volume per hectare

Timber volume per tree did not differ significantly ($p>0.05$) among clones (Figure 3). However, at 32 months after planting, clones Grancam and Urocam had higher volume per tree in a single row arrangement than in the other spatial arrangements. The gain in timber volume per tree from 20 to 32 months after planting reflected the volume data at 32 months, with the greatest gains for clones Grancam and Urocam obtained in the single row arrangement. Spatial arrangements that provide a larger useable area per plant often increase the basic density of timber (Berger et al., 2002), which is desirable in trees from integrated crop-livestock-forest systems because the timber produced in these systems is used preferably for sawn logs from sawmills.

The triple row arrangement provided the lowest tree volume for two of the clones, probably due to greater competition among plants for water, light and nutrients (Martins et al., 2009; Reiner et al., 2011). However, the reduction in planting space can increase timber production by area (Reiner et al., 2011).

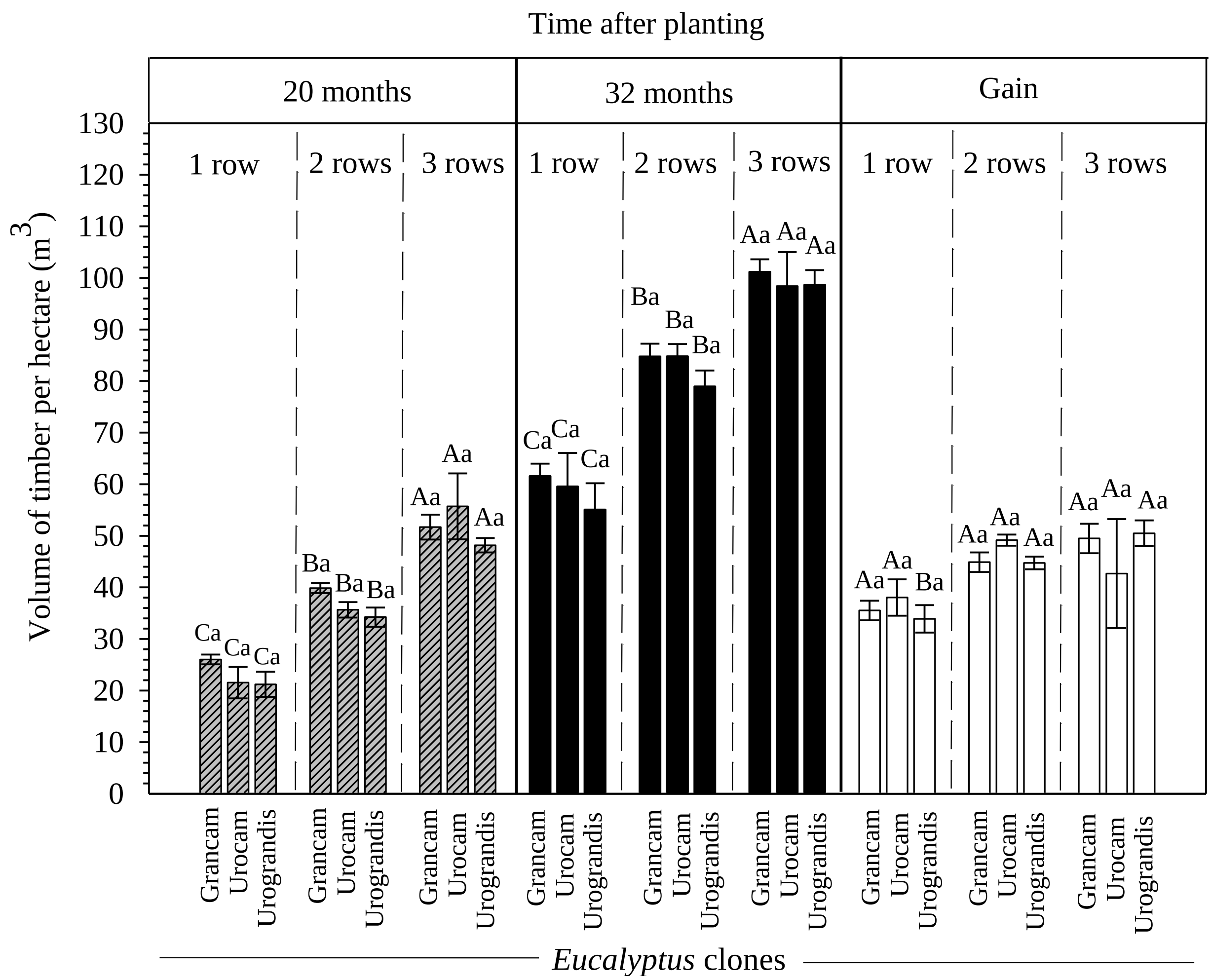


**Figure 4.** Volume of timber per hectare ($m^3$) of *Eucalyptus* clones in three spatial arrangements assessed 20 and 32 months after planting, and gains between the times of evaluation. Different lowercase letters indicate significant difference (p≤0.05) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference (p≤0.05) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

Timber volume per hectare at both 20 and 32 months after planting, as well as the gain between these times, did not differ significantly among the three clones (Figure 4). However, the triple row arrangement provided greater timber yield per hectare at both evaluation times in all clones, corroborating previous results (Leles et al., 2001; Gonçalves and Mello, 2004; Muller et al., 2005).

Although the DBH of trees in the single row arrangements was significantly greater than that of plants in triple rows, this was not enough to compensate for the decrease in the number of trees per hectare, as found previously by Schneider et al. (2000), Muller et al. (2005), Leite et al. (2006), Garcia (2010), Santos (2011) and Paulino (2012). This demonstrates that there is a strong relationship between the number of plants per area and the base area of the trees. However, the difference in volume of timber per hectare between less- and more-densely planted spatial arrangements tends to fall as the tree community ages. This is because of greater competition for water, light and nutrients among the individual trees in denser plantings, which reduces their growth rate. More-densely planted communities reach site capacity before wider-spaced plantings, generating a plateau in the dimensions of the timber products (Oliveira et al., 2009). Initial differences in yield dwindle as the more widely spaced plants consume the available natural resources, sometimes resulting in the same yield per hectare across all the arrangements (Berger et al., 2002).

Straightness and forking are two of the main parameters that determine timber quality for an individual tree (Mattos et al., 2003). Clone Grancam possessed superior trunk quality at both time points and in all three spatial arrangements, except that it had similar quality to clone Urograndis in the triple row arrangement at 20

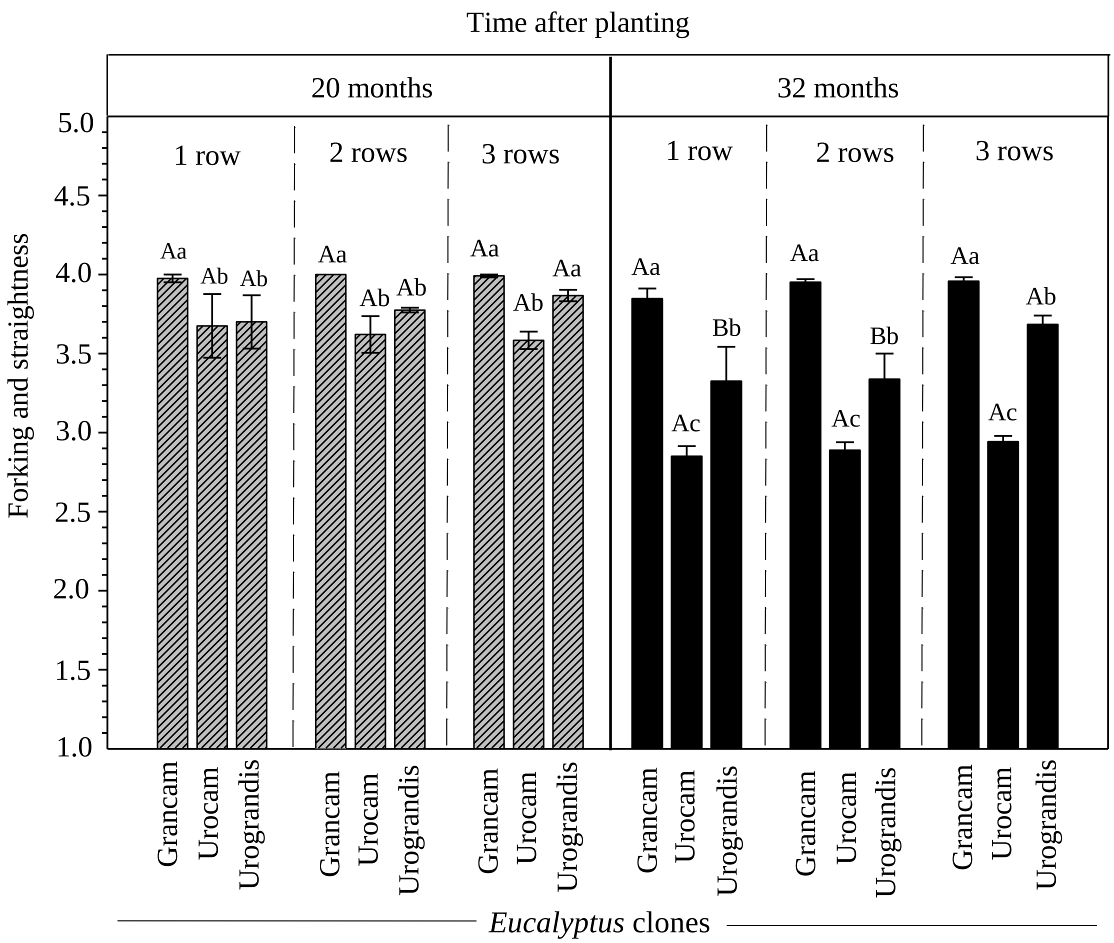


**Figure 5.** Forking and straightness of *Eucalyptus* clones in three spatial arrangements measured at 20 and 32 months after planting. Different lowercase letters indicate significant difference ($p \leq 0.05$) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference ($p \leq 0.05$) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

months after planting (Figure 5).

Spatial arrangements did not affect straightness and forking at 20 months but, at 32 months after planting, clone Urograndis had higher trunk grade in the triple row arrangement than the other arrangements (Figure 5). This may possibly have been influenced by the higher grades of trees in the central row of the stands, with trees in the outer rows forcing the central trees to grow straighter in shadier conditions.

Cylindricity of the trunk did not differ significantly at either evaluation time, either between clones or between spatial arrangements (Figure 6). However, the cylindricity of a tree trunk can be influenced by age, with older plants often having a more cylindrical trunk (Scolforo and Figueiredo, 1993). Less-dense spatial arrangements sometimes make it possible for trunks to develop with less cylindricity according to Grosser (1980), cited by Scanavaca and Garcia (2003). Nevertheless, in this work, no influence of the spatial arrangement on *Eucalyptus* trunk cylindricity was detected up to 32 months after planting.

## Conclusions

Clones Grancam and Urograndis had greater tree height than Urocam when planted in single, double or triple row arrangements. Clone Grancam had the highest final grade of trunk straightness and forking, followed by clone Urograndis, in all three arrangements. Growth of the *Eucalyptus* clones was also influenced by the spatial arrangements. The triple row arrangement provided greater tree height only for clone Urograndis. However, the single row arrangement provided greater DBH for all three clones. The volume of timber per tree and the volume of timber per hectare were most closely

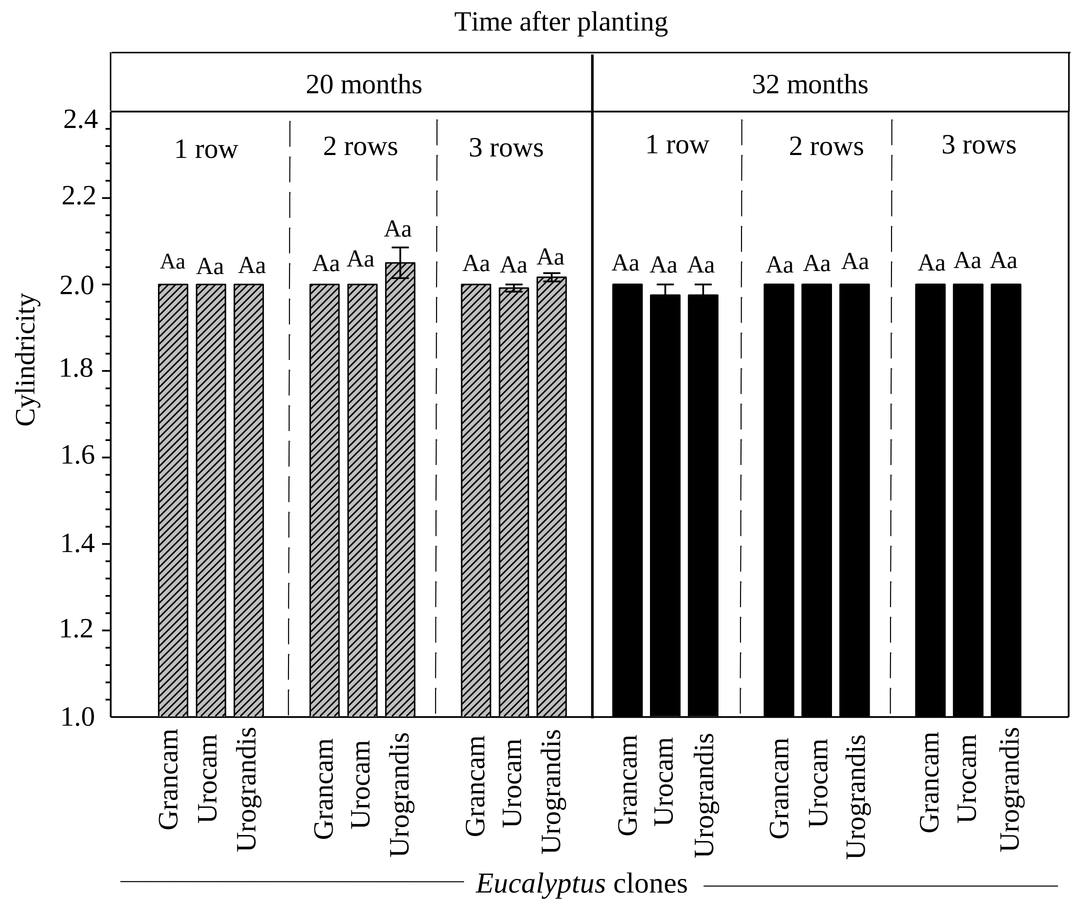


**Figure 6.** Cylindricity of *Eucalyptus* clones in three spatial arrangements assessed 20 and 32 months after planting. Different lowercase letters indicate significant difference (p≤0.05) among different clones within the same spatial arrangement, while different uppercase letters indicate significant difference (p≤0.05) among different arrangements, by ANOVA and Scott-Knott test of means. The error bars are standard errors.

associated with reduced planting density and increased planting density, respectively.

## Conflict of Interests

The authors have not declared any conflict of interests.

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