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Effects of planting spacing on chemical, physical and energetic properties of biomass accumulation in a plantation of *Eucalyptus tereticornis* Sm

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TECHNOLOGY OF FOREST PRODUCTS

ABSTRACT

Background: The use of tree plantations for energy purposes has shown an increase in their use in tropical regions due to the species' rapid growth and low cost of energy generation. This has led to the development of optimization studies of crop conditions.However, the determination of the effect of spacing on physical, chemical and energy properties has not been precise for *Eucalyptus tereticornis*, which limits the development of plantations with optimal silvicultural conditions.

Results: The study analyzed the growth and chemical, physical and energetic properties in a four-year-old plantation. The results showed that mortality ranged from 29 to 69%, being the 1.0 x 2.0 m spacing the one that presented better yields with a significantly higher diameter and height (9.13 cm and 14.17 m, respectively) with a higher biomass accumulation (140.04 ton ha^{-1} without treetop) concentrated mainly in the stem. The other two spacings presented statistically lower and non-significant values. The physical properties were obtained densities of 0.57 to 0.66 g cm^{-3}, with a specific density of 0.58 and moisture content of 57.7%. The chemical properties only showed differences in carbon concentration (50.11 to 69.16%). The energetic properties showed a caloric power between 4780 to 6059 kcal kg^{-1}, with a variation in volatile content of 10.9% and 1.6% in ash.

Conclusion: The planting spacing generates a gradient in the production, mortality and property of the biomass, being the spacing of 1.0 x 2.0 m being optimum for establishing the study species for Costa Rica.

Keywords: Bioenergy, biomass, wood properties, Costa Rica

HIGHLIGHTS

Mortality in *Eucalyptus tereticornis* tends to increase as planting spacing is higher.
Planting spacing affects up to 35.5% of the productivity in *Eucalyptus tereticornis*.
The 1.0 x 1.0 m spacing showed the optimal properties for bioenergy production.
Planting spacing showed effects on physical and energetic properties.

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INTRODUCTION

In the last 20 years, there has been a constant increase in world energy demand (0.4 to 1.2% per year) due to population growth, economic dynamism in developing countries and modernization of industrial production systems (Pereira and Costa, 2017, Valverde et al., 2020). As a result, it is estimated that world energy consumption will increase by 4% between 2020 and 2030, making it necessary to exploit and optimize new energy sources (Arias et al., 2020). Nowadays, 78% of the world's energy comes from non-renewable sources (natural gas, coal and fossil fuels), while 22% comes from renewable sources such as hydro, solar, wind and biomass (Arias-Aguilar et al., 2018).

Biomass energy accounts for 10% of energy worldwide, being the renewable source with the highest implementation due to its ease of production, low market price, simple transformation technologies and low environmental impact (Pleguezuelo et al., 2015).

Cook (2021) and Zhang et al. (2021) estimate that the use of biomass will increase by 4 to 9% in the next decade due to the new generation of transformation technology. In addition, the implementation of gasifiers, high-efficiency boilers, composting and liquefaction processes will allow an increase in the efficiency of biomass use, the use of chips and pellets will allow the standardization of waste together with manufacturing processes that generate low moisture content in short periods, which will impact lower production costs and lower environmental impact (Hauk et al., 2014). Thus, the biomass generation process must be improved, which comes from two primary sources: i. agro-industrial waste and ii. high-density energy plantations (HDEP) (Valverde et al., 2020).

The latter option has had an important impulse in the last decade because these crops are focused on generating a greater amount of biomass in short harvest periods (three to five years in tropical regions) (Bilgili et al., 2017). Guerra et al. (2012) mention that HDEP must consider four key elements for its sustainable development: i. they must implement species that have the capacity to vegetative regrowth, ii. they must be fast-growing species, iii. species with a high caloric value in stem and branches and iv. they must allow a nutritional extraction mostly in leaves and allows nutritional recovery in the soil.

HDEP has been implemented in a limited way in the tropical region due to the high waste generation by agricultural and forestry industries (Valverde et al., 2020). However, current trends are focused on waste valorization and the generation of new by-products, which results in less available waste (Arias-Aguilar et al., 2018). This aspect has stimulated the development of energy plantations with planting densities of more than 5000 trees ha^{-1} (Bouillet et al., 2003). Moya et al. (2019) emphasize that energy plantations in the tropics should consider three elements: i. short harvesting periods of not more than four years, ii. morphometric development of the species allows biomass accumulation to be centered on the stem and branches, which will simplify harvesting, and iii. the capacity to develop the crop cyclically with resprouting management. Thus, the selection of species, site, planting density and management is fundamental for the productivity of the plantation.

The species that show the best development under the HDEP model include *Eucalyptus tereticornis* (Arias-Aguilar et al. 2018), which has been used in the highlands of Costa Rica under three planting densities: 1,000, 5,000, and 20,000 trees ha-1 (Navarro-Camacho et al., 2014). Using this as a reference, studies have determined the capacity to generate between 36.10 and 107.67 ton ha-1 of dry biomass (stem and branches) in four-year cycles, obtaining variations in biomass prodction as a function of planting density (Navarro-Camacho et al., 2014; Valverde and Arias, 2018; Arias et al., 2020).

Studies developed by Jiménez et al. (2018) have shown that planting density affects HDEP productivity due to the degree of competition in the plantation, which affects mortality. Moya et al. (2019) and Gaitán-Alvarez et al. (2020) found that biomass distribution depends on planting density; the biomass of branches and stem tends to decrease as the planting density increases. For their part, Tenorio et al. (2019) determined that increases in planting density generate increases in wood density, specific weight, caloric power and percentage of ash. Finally, Valverde and Arias (2018) mention that in the tropics, it is difficult to determine an optimal spacing for HDEP due to the plasticity of the species, so it is necessary to develop spacing tests.

Therefore, the objective was proposed to evaluate the biomass accumulation, physical, chemical and energetic properties of a plantation with three planting densities of *E. tereticornis*. in Costa Rica. The study hypothesized an increasing linear relationship between planting density and productivity, so the 1.0 x 0.5 m plantation will be optimal, showing biomass's best physical, chemical, and energetic properties for energy use, with mortality similar to the other two stocking densities.

MATERIAL AND METHODS

Conditions of the study area

HDEP of *Eucalyptus tereticornis* with an age of four years was evaluated; the plantation was located in Turrialba, Costa Rica(9°53′ 13.88″ N; 83°39′ 19.11″ W) (Figure 1). The site was characterized by an altitude of 600 m, with an average annual temperature of 21.8 °C and annual rainfall of 2600 mm arranged in seven rainy months (May to November) (IMN 2019); according to the Köppen-Geiger climate classification, it corresponds to a tropical rainforest climate (Beck et al., 2018). The plantation had a flat topography, with a gradient of less than 10°, with a clay loam soil, with little rocks, classified as an inceptisol soil. At the chemical level, it had a pH of 5.2, with nitrogen and potassium deficiencies, but a high presence of iron and aluminum. Therefore, a calcium amendment was applied to improve soil conditions (2 ton ha^{-1}), in addition to NPK fertilizer (nitrogen-phosphorus-

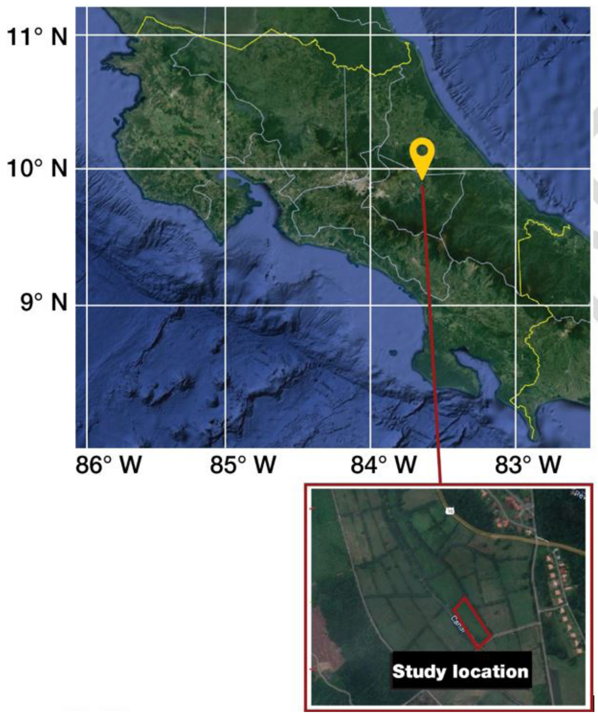

Figure 1. Location of the study site, Turrialba, Costa Rica.

potassium) with percentages 30-10-30 values given by a commercial product in Costa Rica (dose of 6 ton ha^{-1}), the improvement soil generated optimal nutritional conditions for the study species. Regarding magnesium and potassium, the site presented optimal conditions for the species.

The plantation considered three different planting spacing (considered as treatments): (i). 1.0 x 2.0 m (low density, 5000 trees ha^{-1}), (ii). 1.0 x 1.0 m (moderate density, 10000 trees ha^{-1}) and (iii) 1.0 x 0.5 m (high density, 20000 trees ha^{-1}) divided into three blocks. Every treatment was presented within each block (3 blocks x 3 treatments), where a monitoring plot was established within each repetition, consisting of 49 trees. Silvicultural management was minimum; the soil was subsoil and then calcium was applied to regulate the pH to 6.2, then fertilization was applied and sowing of trees that died in the first month after the plantation was established. This minimal management is due to cost reduction since the goal is biomass, which is standard for this plantation in Costa Rica (Arias-Aguilar et al. 2018).

Sampling of trees in the plantation and tree monitoring

All the trees were measured in each plot, evaluating the diameter of height to breast (DBH), total height (H), and mortality. Mortality was determined with equation 1, counting the number of living and dead trees. Subsequently, the average mortality of each spacing was determined from the mortality of the plots.Where: Mor is the percentage of mortality, DT is the number of dead trees in the plot and 49 is the initial number of trees per plot.

$$Mor\ (\%) = \frac{D_T}{49} \qquad (1)$$

Subsequently, 18 trees were harvested by spacing (6 trees x 3 blocks), selecting dominant, codominant, and suppressed trees. The methodology of Tenorio et al. (2019) for biomass quantification, which consisted of segmentation and separated weight in green condition of the stem, branches and leaves. Then the woody biomass (branches + stem) and total biomass (branches + stem + leaves) average per tree were determined. Also, the amount of woody and total biomass per hectare was determined with themortality percentages. Subsequently, a sample of 500 g of leaves and branches of each tree was collected; in addition to a segment of 10 cm in length from the lower, middle and upper part of stem. The samples were weighed in green condition and subsequently dried at 103 °C for 72 hours to estimate the dry weight (Tenorio et al., 2018).

Physical properties of biomass

Physical properties were determined only with the stem samples harvested from each treatment and the following were evaluated: moisture content (MC), basic density and specific gravity (SG). HR of the biomass was determined using the ASTM D 4442-20 (ASTM, 2021a) standard. For this purpose, a segment of the stem was cut from each individual, weighed in green condition and dried at 105°C for 72 hours. Then, equation 2 was applied to estimate MC. Where: MC is the percentage of moisture content, Gb is the green biomass in grams and Db is the dry biomass in grams.

$$MC\ (\%) = \left(\frac{G_b - D_b}{G_w}\right) \qquad (2)$$

In the case of basic density, the methodology of Moya et al. (2009) was implemented, where three samples per trunk were extracted from each treatment which were dried at 105°C for 72 hours, subsequently weighed and placed in a test tube with distilled water.

The volume displacement was determined by Equation 3. Finally, SG was determined with ASTM D 2395-17 (ASTM, 2021b). Where: Wd is basic density (g cm^{-3}), Ww is dry biomass weight in grams and Wv is biomass volume in cm^3.

$$W_d = \frac{W_w}{W_y} \qquad (3)$$

Energy properties of biomass

At the calorimetric level, the calorific power, ash content and volatile solids were analyzed. Three samples per individual were used (6 trees per spacing x 3 samples). The calorific power analysis was carried out according to ASTM D 5865-19 (ASTM, 2021c) methodology, using a calorimetric pump model 6725 Micro-Parr with a starting temperature of 20°C. Ash analysis was determined using the ASTM D 1102-84 (ASTM, 2021d) test and for volatile solids content, ASTM D 1762-84 (ASTM, 2021e) was used. For both tests, 2 mg of sample were used for each analysis.

Chemical properties of biomass

A composite sample of biomass obtained from a stem disk obtained at the height of DBH was used according to Moya et al. (2009). Each sample was dried to a MC of 12%. It was then ground and filtered with a 40-60 mesh strainer: the thicker material was used for lignin and cellulose analysis, while the finer biomass was used for elemental analysis. Cellulose content was determined using the methodology established by Seifert and Magalhães (2015), where three samples of 2 mg each were used per individual. Three samples of 2 mg were also used and analyzed for lignin according to the TAPPI T222 om-02 (TAPPI, 2002) standard. For the determination of nitrogen (N), carbon (C), hydrogen (H) and C/N ratio, an elemental analyzer model Vario Micro Cube (Eltra, Germany) was used, consisting of three samples of 0.5 g each per individual.

Statistical analysis

First, the Anderson-Darling test (normality test) and the Breush-Pagan test (homoscedasticity of variance test) were applied, followed by descriptive statistics and then the characterization of the different variables were analyzed. Next, to determine the differences between the spacings, a one-way analysis of variance (One-way ANOVA) was carried out to determine the variables that showed differences and then Tukey test was applied to determine the spacings that showed statistical differences. Finally, Principal Component Analysis (PCA) was performed with all the variables to determine the degree of similarity of the variables of the three spacings (Growth variables were considered, specifically DBH and height, in addition to physical, chemical and energetic properties). All analyses were performed in R version 4.1. with a significance of 0.05.

RESULTS

Plantation characteristics

The mortality varied from 29 to 69% showing a tendency that as the planting spacing was reduced, mortality increased, being the spacing of 1.0 x 2.0 m the one that showed the lowest mortality (29%), while 1.0 x 0.5 m showed the highest mortality (69%) (Table 1).

Regarding the dasometric variables, it was determined that both DBH and H were significantly greater in the 1.0 x 2.0 m spacing (9.13 cm in DBH and 14.17 m in H).

Compared to the other two smaller spacings and did not present statistical differences between them. They showed a DBH of 5.39 cm and H of 11.24 m.

Biomass production

The biomass production (Table 2) of stem, branches and leaves showed the same trend. As the spacing decreased. Obtaining that 1.0 x 2.0 m spacing presented the trees with the highest biomass accumulation (46.86 kg tree^{-1}) with the highest amount of foliar biomass (2.80 kg tree^{-1}) and branch biomass (3.61 kg tree^{-1}), while the 1.0 x 1.0 m and 1.0 x 0.5 m spacings showed statistically lower values (but not significant between both spacings). The total accumulated biomass is 49% lower, compared to an average of 59.3% for stem, 61.4% for branches and 71.7% for leaves. The differences obtained between spacings showed that the available biomass per hectare in the 1.0 x 2.0 m spacing was 162 ton ha^{-1} in total biomass and 140.05 ton ha^{-1} woody biomass, significantly higher than the 1.0 x 1.0 m and 1.0 x 0.5 m spacing that showed a lower average of100.1 ton ha^{-1} in total biomass and 88.57 ton ha-1 in woody biomass.

Physical and energetic properties of biomass

Differences were found in the basic density of the biomass (Figure 2a), the spacing of 1.0 x2.0 m showed the highest basic density (0.66 g cm^{-3}), while the other two spacings showed less non-significant values (average 0.57 g cm^{-3}). On the other hand, with SG (Figure 2b), no differences were found between the spacings with an average of 0.58 Finally, no differences were found in MC, with an average of 57.7% (Figure 2c).

In terms of energy with the caloric power (Figure 2d), the 1.0 x 2.0m spacing showed statistically higher value (6059 kcal kg^{-1}) compared to the 1.0 x 1.0 m and 1.0 x 0.5 spacings, which showed no differences between them and presented an average caloric power of 4780 kcal kg^{-1}. Similarly the ash content (Figure 2e) was significantly higher in the 1.0 x 2.0 m spacing (2.11%) than the other two spacings, which showed values lower than 1.6%. Finally with the volatile solids content (Figure 2f) it is the 1.0 x 0.5 m spacing that presented significantly higher values (89.9%) than the 1.0 x 1.0 m and 1.0 x 2.0 m spacings that did not show differences between them and their average value was 75.5%.

Chemical properties of biomass

Regarding the chemical properties of the biomass (Table 3), no differences were found in the lignin and cellulose contents among the three spacings, with an average of 21.2% lignin and 51.6% cellulose. Furthermore, hydrogen showed no differences between spacings with elemental composition, averaging 6.8%. By contrast, with N, C and C/N ratio differences were obtained among the spacings, being 1.0 x 2.0 m the one that showed statistically higher values of N and C concerning the 1.0 x 1.0 m and 1.0 x 0.5 m spacings that did not show differences between them; while C/N ratio was statistically lower in the 1.0 x 2.0 m spacing compared to the other two spacings which was in average 467.00.

Plant spacing similarity properties

The PCA (Figure 3), showed that the spacing of 2.0x1.0 m obtained a different behavior than the three two spacings due to the variations obtained by the physical, chemical and energetic properties. In contrast, the spacings of 1.0 x 1.0 m and 1.0 x 0.5 m showed the same grouping because the properties of the biomass did not show variations.

Table 1. Dendrometric parameters of *E. tereticornis* trees evaluated at three planting densities in Turrialba, Costa Rica.

Spacing (m)	Mortality rate (%)	Diameter (cm)	Total height (m)
2.0x1.0	29.0	9.13ª (1.71)	14.17ª (2.59)
1.0x1.0	51.0	5.78ᵇ (1.48)	11.63ᵇ (1.61)
0.5x1.0	69.0	5.01ᵇ (1.56)	10.85ᵇ (1.56)

Averages followed by the same lowercase letter in the column do not differ byTukey's test (p<0.05) and numbers in parentheses indicate the standard deviation.

DISCUSSION

Plantation characteristics

An increasing linear relationship was found between mortality and planting spacing (Table 1). This behavior is similar to Arias et al. (2020), Lintz et al. (2016) and Resquin et al. (2018) with different species of Eucalyptus. As spacing decreases, resource competition increases, generating more suppressed trees (Lonsdale, 1990). Bouvet (1997) mentions that mortality in HDEP depends on age, soil fertility and water availability. As the age of plantation increases, a hydric and nutritional gradient was generated, an aspect that affects the physiological stress of trees due to the availability of water and nutrients, individuals with less development (especially root), are those with the greatest vulnerability to dying (Dwyer et al., 2010).

It was ruled out that mortality was the product of nutritional or water deficiencies generated by the initial conditions of the study. Previously, an improvement was made in nutritional conditions and the water conditions in soil were homogeneous. The nutritional values of soil were improved and the study site had an average rainfall distribution pattern, so both aspects were disregarded. It was the product of the growth of trees that generated mortality, according to Alcorn et al. (2007) for *E. pilularis* and *E. cloeziana*, that increases in tree density produce a reduction in available nutrients per tree and an increase in rainfall interception canopy; this aspect generated an increase in water stress of plantation over time, which affected survival.

Planting spacing also affects plantation growth (Goulart et al., 2003). According to Pereira and Costa (2017), the differences in DBH obtained between spacings (Table 1) are due to the degree of competitiveness of the plantations. As the spacing is reduced, tree competition for resources (light, nutrients, water, among others) increases, causing the plant to focus on vertical growth as a response to stress and thus have a greater dominance on the site, so that diameter becomes a secondary growth, an aspect that was noted that the smaller spacing presented low diameters compared to the larger spacing (Resquin et al., 2018; Flores-Pinot et al., 2018). Furthermore, Piotto et al. (2003) mentioned that competition in H with more than 5000 trees ha-1 is relevant in the first three years of life because the more significant the H and development of Leaf Area Index.

Nevertheless, the study did not find an increase in H trend as spacing increased; this may be due to physiological stress generated by competition, an aspect similar to that determined by Chen et al. (2011) in two Eucalyptus species.

The growth differences generated by planting spacing generated significant changes in the accumulation and distribution of biomass (Table 2). The behavior obtained indicates that more than 80% of the biomass is concentrated in the stem, which is similar to that reported by Gominho et al. (2012), Hauk et al. (2014) and Silva et al. (2015) in

Table 2. Biomass production of different *E. tereticornis* trees at three planting densities in Turrialba, Costa Rica.

Biomass production	Spacing (m)		
	1.0x2.0	1.0x1.0	1.0x0.5
Stem (kg tree^{-1})	39.30ª (11.08)	18.12ᵇ (8.66)	14.87ᵇ (8.65)
Branches (kg tree^{-1})	3.61ª (3.26)	1.83ᵇ (1.27)	0.96ᵇ (0.94)
Leaves (kg tree^{-1})	2.80ª (1.16)	0.97ᵇ (0.58)	0.61ᵇ (0.48)
Woody biomass (kg tree^{-1})	39.45ª (9.95)	17.24ᵇ (7.78)	14.88ᵇ (6.69)
Tree biomass (kg tree^{-1})	45.86ª (13.39)	20.04ᵇ (9.68)	16.45ᵇ (9.52)
Total woody biomass plantation (ton ha^{-1})	140.05	84.47	92.26
Total biomass plantation (ton ha^{-1})	162.80	98.20	101.99

Averages followed by the same lowercase letter in the column do not differ by Tukey's test (p<0.05) and numbers in parentheses indicate the standard deviation.

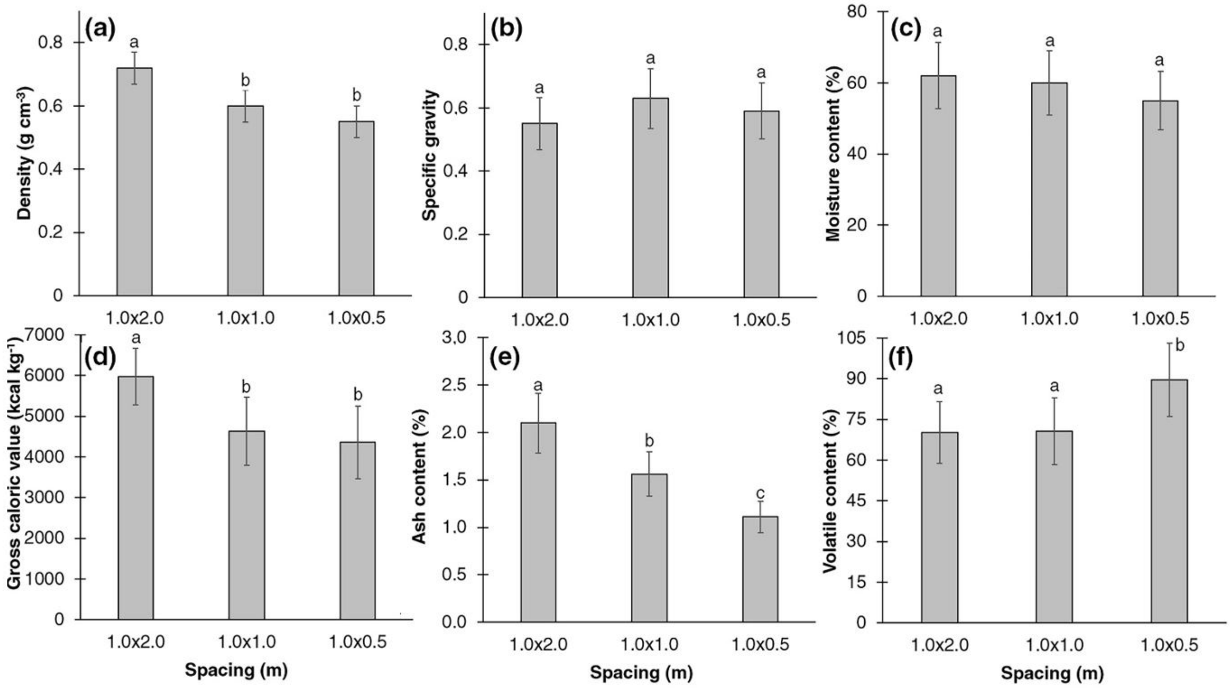

Figure 2. Physical and energetic characteristics and stem biomass of *E. tereticornis* trees established at three spacing in Turrialba, Costa Rica. Note: Averages followed by the same lowercase letter do not differ by Tukey's test ($p<0.05$) and whiskers indicate standard deviation.

their studies with Eucalyptus. This behavior is due to the competition of the plantation that prevents the development of comprehensive leaf coverage, which limits the plant in that the amount of branches and leaves is minimal and that they develop in the upper parts of the tree (Valverde and Arias, 2018). Furthermore, the accumulation of most of biomass in the stem simplifies the harvesting processes of tplantation since in tropics; there is a tendency that branches and leaves are left in place for a reincorporation of nutrients (Jiménez et al., 2018; Valverde et al., 2018), therefore, by having a more significant amount of biomass in stem, biomass harvesting will be more profitable (Flores-Pinot et al., 2018).

Biomass properties

Planting spacing did not generate variations in MC and SG because its variability is mainly associated with genetic characteristics (Rocha et al., 2016). In the case of basic density, previous research shows an increasing linear trend of density as a function of spacing (Goulart et al. 2003; Xue et al. 2011); However, this behavior was not obtained,reason according to Rachid (2008), maybe due to the effect of mortality in the plantation site. Also, Valverde et al. (2018) determined that plantations with greater spacing tend to have higher densities because the density of vessels per unit area is lower due to the diametrically larger size of the tree, which allows the hydraulic conductivity to increase.

Table 3. Chemical properties of biomass obtained from different parts of 4-year-old *E. tereticornis* trees at three planting densities for energy purposes in Costa Rica.

Chemical characteristic	Spacing (m)		
	1.0x2.0	1.0x1.0	1.0x0.5
Lignin (%)	27.88^{a} (7.56)	26.66^{a} (6.56)	27.11^{a} (5.69)
Cellulose (%)	51.23^{a} (5.99)	50.00a (6.89)	53.55^{a} (4.89)
N (%)	0.19^{a} (0.09)	0.12^{b} (0.05)	0.14 ^{b} (0.07)
C (%)	69.16^{a} (5.66)	52.11^{b} (6.00)	50.11^{b} (6.23)
H (%)	6.85^{a} (1.23)	6.55^{a} (1.50)	6.89^{a} (2.09)
C/N	440.28^{a} (58.55)	471.01^{b} (41.33)	462.11^{b} (36.66)

Averages followed by the same lowercase letter in the column do not differ by Tukey's test ($p<0.05$) and numbers in parentheses indicate the standard deviation.

With the energetic properties (Figure 2) it was determined that the larger spacing reported higher caloric powers because the biomass has a higher density, an aspect that influences it to have a greater amount of mass in the combustion process. This aspect influenced the ash content to be higher, similar to Bonomelli and Suárez (1999) and Rocha et al. (2016) with *Eucalyptus*, which was due to the biomass density volatile solids available in the wood. In the case of ashes, the limitation determined for the spacing of 1.0 x 2.0 m is because the higher the percentage of ashes, the greater the generation of residues after the combustion or gasification processes, which becomes a limitation in the process of biomass uses, but with the advantage that the caloric potential is greater (Tenorio et al., 2018).

Concerning chemical properties, the non-significant difference of lignin, cellulose and H concentrations is due to the few differences in environmental conditions that directly influence the generation of these compounds (Nielsen et al., 2009). On the other hand, the variations in the concentration of N and C were due to the effect of nutritional competence generated by spacing (Ericsson, 1994). N is a fundamental element for the growth of trees; it is fundamental for the processes of photosynthesis and respiration (Esquivel et al., 2013); Therefore, increasing the density of plantation, the availability of N per tree decreases, affecting the physiological processes of tree growth. In the case of C, it is a secondary effect of N; the decrease in a photosynthetic capacity directly affects fixation of C in organic molecules (especially in carbohydrates and proteins), significantly reducing the metabolism of trees (Guo et al., 2002).

Finally, *E. tereticornis* in HDEP showed a high potential for use under 1.0 x 2.0 m spacing with the best physical, chemical and caloric properties of three spacings under analysis, which allowed us to consider that it is an ideal spacing for the conditions of the study. It is important to consider financial and environmental aspects that were not considered in the study, but that can give importance to the final choice developed.

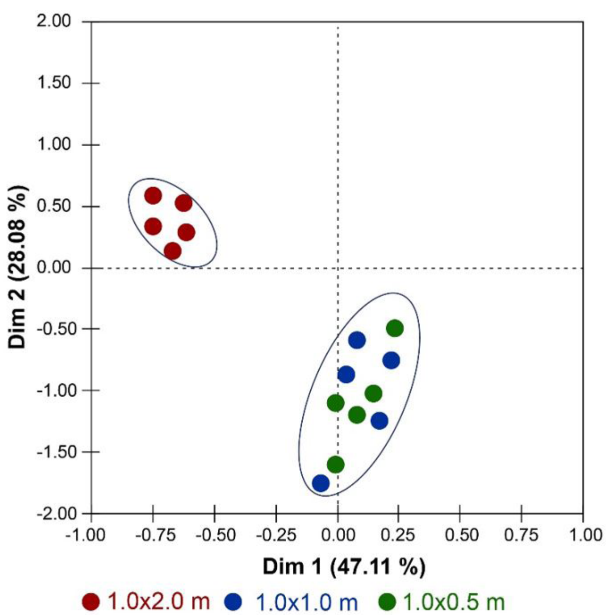

Figure 3. PCA to evaluate differences between three planting spacing of *E. tereticornis* in Turrialba, Costa Rica.

CONCLUSIONS

Planting spacing influences mortality, quantity and biomass distribution in *E. tereticornis*. The smaller spacing, mortality increases and the productivity of the plantation decreases. With this, it was determined that the spacing of 2.0 x 1.0 m showed the highest total amount of biomass (140.04 ton ha^{-1}), concerning the other two spacing that did not show differences (average 88.57 ton ha^{-1}) as the spacing decreases, the percentage of branches and leaves biomass and the stem increases.

Only the 2.0 x 1.0 m spacing showed differences in physical (basic density), chemical (C) and energetic (gross caloric power) properties; the other two spacing did not show differences between their properties.

AUTHORSHIP CONTRIBUTION

Project Idea: DA, JPM, LDJ
Funding: DA, RC, LDJ
Database: JCV
Processing: JCV, DA
Analysis: JCV
Writing: JCV, DA, RC, LDJ, JPM
Review: JCV, DA, RC, LDJ, JPM

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