Article

Effect of population densities on rubber growth and yield in Veracruz

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Abstract

In Mexico, the average annual yield of rubber (*Hevea brasiliensis* [Willd. ex A. Juss] Muell. Arg.) is less than 1.2 t ha^{-1}, by optimizing population density is sought to increase yield and productivity. The work was carried out in the central region of the state of Veracruz. The planting arrangements 4x2, 6x3 (control), 8x4 and 10x5 m, with densities of 1 250, 556, 312 and 200 trees ha^{-1}, respectively, were evaluated. The experimental design was randomized blocks with four repetitions and 40 trees of clone IAN-754 per experimental unit. The main variables evaluated were stem circumference, rubber yield and biomass yield. At the seventh year, it was obtained that the higher the density, the lower the percentage of trees suitable for extracting latex (stem circumference >45 cm). The circumference of the stem at the end of the period ranged between 67 and 120 cm, at a higher density there was less growth and greater number of trees suppressed. At a higher density, lower yield in grams per tree per tapping of rubber, but higher yield in kg per hectare per year, with an oscillation between 960 and 2 040 kg, were obtained. The total biomass per tree ranged from 223 to 924 kg and the total biomass per hectare between 158 and 240 t ha^{-1}. In addition, with higher population densities, the rubber yield was higher and with 556 trees, a better balance was achieved.

Keywords: biomass, latex, planting arrangements, productivity.

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Introduction

The world demand for rubber is 28.33 million tonnes per year, 62% of the raw material is used in the automotive industry and 38% in other industrial uses (gloves, glues, balloons, etc). Forty-eight percent of the rubber consumed in the world is natural and 52% synthetic. The rubber tree (*Hevea brasiliensis* Müell. Arg.) is the main source of natural rubber in the world, world production during 2019 was 13.82 million tonnes, of which 91% was produced in Asian countries, 6% in African countries and 3% in American countries [Association of Natural Rubber Producing Countries (ANRPC), 2020].

Traditionally, natural rubber occupies an important position in the economy of tropical regions, not only as an important product for export, but also as a generator of employment and source of income for millions of farmers, most with low incomes and small production units (Senevirathna *et al*., 2010). The industry's demand for natural rubber in Mexico is approximately 120 000 t year^{-1}, an area of approximately 30 000 hectares is cultivated, of which 70% are in production, with an average yield of 1 200 kg ha^{-1} year^{-1}, so that national production is around 25 200 t per year, which supply 20% of the demand and more than 100 000 t are imported annually, with a value of 160 million dollars, with the consequent flight of foreign currency (SIAP, 2019).

There is a high agroecological potential in more than 350 000 ha of the south-southeast region, with which the country would achieve its self-sufficiency and could become an exporter (Ramírez-Jaramillo *et al*., 2018). There is an important contribution from the sector of small producers, although they are affected by low productivity, largely due to the size of the farm unit, poorly productive clones, low technology adoption, lack of capital and price instability. Therefore, it is sought to develop components that contribute to the increase of land productivity and an approach of optimization of population density (Qi *et al*., 2016).

Planting density depends mainly on soil properties and availability of water, light and nutrients (Obouayeba *et al*., 2005; Verheye, 2010). In the agronomic optimum, plants capture and use elements for growth efficiently, providing the highest yield per unit area (Rodrigo, 2007; Ballo *et al*., 2019). The planting arrangement is important to determine its optimal density; for convenience in management, the planting is in rows and the distance between trees within the rows is shorter (Rodrigo *et al*., 2004).

Rubber trees usually begin to compete with each other in the fourth year of planting, when the crowns of individual trees intermingle forming a closed crown (Obouayeba *et al*., 2005). High population densities have the advantage of higher dry matter production per unit area during the first years of growth (Silva, 2007; Dey and Datta, 2013), trees take longer to reach the parameters for commercial latex extraction, the absolute number of trees in tapping increases and the percentage of trees in tapping is lower (Ng *et al*., 1993; Rodrigo, 2007; Silva, 2007).

High densities induce strong competition between trees that can cause their reduction in biomass production and yield (Radtke *et al*., 2003; Obouayeba *et al*., 2005; Dey and Datta, 2013). The optimal density should consider the best balance between yield per tree and labor performance, so that maximum productivity is achieved (Obouayeba *et al*., 2005; Pathiratna and Perera, 2006; Rodrigo, 2007). High planting densities give high yields per hectare, but low yields per tree and low efficiency of tappers at the beginning of plantation exploitation (Ng *et al*. 1993; Verheye, 2010).

In Mexico, the recommendation for planting arrangements is 6 m between rows and 3 m between plants, with a density of 556 plants ha^{-1}, regardless of the clone (Picón *et al*., 1997). Planting densities and arrangements influence some secondary characteristics; according to Rodrigo (2007), higher densities resist strong winds more effectively, which favors a greater number of trees in tapping during the productive life (Roy *et al*., 2005; Rodrigo, 2007; Dey and Datta, 2013; Qi *et al*., 2016).

In terms of total volume of wood per hectare, it is higher in high planting densities, but the volume of the trunk is smaller, presents greater height of branching, less branching and smaller diameter of crown (Ng *et al*., 1993; Dey and Datta, 2013; Sulaiman, 2015). To obtain adequate planting densities, under different agroclimatic and management conditions, adaptive research trials must be carried out and social factors must be taken into account. Therefore, the objective of the work was to evaluate the influence of the planting arrangement and densities with the clone IAN-754 on the growth, yield and productivity of rubber plantations in the central region of Veracruz.

Materials and methods

Location

The work was developed in the El Palmar Experimental Field, of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), for its acronym in Spanish), in the municipality of Tezonapa, Veracruz, Mexico, located at 18° 30' 56" north latitude and 96° 45' 32" west longitude. The region has an average annual rainfall of 2 800 mm and an average annual temperature of 26 °C. The greatest rainfall occurs from July to October. The predominant soils are deep Fluvisols, with clayey texture and moderately acidic pH (Monroy *et al*., 2006).

Vegetative material, experimental design and treatments

The experiment was established in September 1982 with vegetative material of the clone IAN-754, which is fast-growing, high-yielding, tolerant to foliar diseases and has slow metabolic activity (Picón *et al*., 1997). Four planting arrangements were evaluated: 4x2, 6x3 (control), 8x4 and 10x5 m, with population densities of 1 250 (D1250), 556 (D556), 312 (D312) and 200 (D200) trees per hectare, respectively, under a randomized block experimental design with four replications and 40 trees per experimental unit (EU).

Variables evaluated

Stem circumference (SC). It was measured semiannually, at the height of 1.3 m of the graft-rootstock union in June and December, considering three periods: pre-productive (1st to 7th year), young productive (8th to 15th year) and mature productive (16th to 22nd year). With this information, the annual increase in stem circumference was estimated for each stage.

Number and percentage of trees in tapping. With data on the stem circumference obtained seven years after planting, the percentage of trees in tapping (NTT%) was obtained and with these data, the number of trees in tapping per hectare (NTTH) was estimated. The trees were considered suitable for the tapping when they reached a SC> 45 cm at the height of 1.3 m. Likewise, the NTTH was obtained at 7, 10, 14, 16 and 21 years of plantation.

Yield. The tapping or bleeding of the trees began seven years after planting (September 1989), the opening of the panels was made at 1.2 m from the graft-rootstock union. The tapping system was downward half-spiral with tappings every other day (S2 d2 6d/7), without stimulation. Production was evaluated over a period of 16 years (1989-2003), during which two virgin panels, B01 and B02 (4 and 5 years, respectively), and two regenerated panels, BI1 and BI2 (5 and 3 years, respectively), were consumed. The trees were tapped between 6:00 and 9:00 h and the latex coagulated between 10:00 and 11:00 h, by adding 5% acetic acid. After mixing well, the clot was left in the cup for 24 h.

The next day, the clots were inserted into a wire and hung from the tree in the open and remained until the end of each month. At the end of the month, the clots were collected, and production was recorded (g tree^{-1}). To determine the dry weight of each repetition, rubber samples were taken for each density, they were placed in a drying oven at 65 °C for 24 h and the dry rubber was weighed.

The dry clots obtained during the tapping were recorded monthly by tree throughout the year, they were added to obtain grams tree^{-1} (GT), for each density, the total sum of the production per tree was divided by the total number of tappings, to obtain the production in grams per tree per tapping (GTT). The yield in kg ha^{-1} (KH), for the planting densities, was determined from the yield in GTT, using the relationship: KH= (GTT x NT X NTTH)/1 000. Where: GTT= average grams per tree per tapping; NT=Number of tappings performed in the year; and NTTH= number of trees in tapping per hectare.

Biomass yield. Data on SC at 22 years after planting were used, transforming them to diameter (D). Plant height (H) was estimated based on the diameter, using the equation obtained by Monroy *et al*. (2006): $H=\exp(-0.7200) + (1.6420 * \log D) + (-0.16375 * \log D^2)$. Branch biomass (BB), stem biomass (STB) and total biomass (TTB) were obtained by the equations obtained by Brahma *et al*. (2017): $BB= \exp(-2.76 + 2.03 (\ln D)) * 1.2$; $STB= (\exp(-4.57 + 1.05 (\ln D^2H))) \times 1.03$ and $TTB= (\exp(-2.84 + 0.9 (\ln D^2 H))) \times 1.02$, respectively.

Data processing and statistical analysis

The information obtained in the field was captured in the Microsoft Excel program and subsequently analyzed using the statistical package SAS version 9.0 (SAS Institute, 2009). Analyses of variance (Anova), Tukey’s multiple comparison tests (α= 0.05) and regression analyses were performed.

Results and discussion

Stem circumference (SC)

During the first 3.2 years, there were no differences ($p > 0.05$) between densities for SC; during this stage light is not a limiting factor at high densities, as reported by Obouayeba *et al*. (2005); Verheye (2010) and the competition of that factor begins when the crowns of the trees close. Seven years after planting, the Anovas showed highly significant differences ($p < 0.0001$) between densities, mean tests showed that the lowest densities, D200 and D312, favored greater growth in SC, with 59.95 and 56.17 cm, respectively ($p < 0.0001$), while the highest densities, D1250 and D556, had lower growth in SC, with 43.58 and 51.83 cm, respectively ($p < 0.0001$) (Table 1).

Table 1. Stem circumference (SC) at 3.2 and 7 years, annual increase in stem circumference (ISC) up to 7 years and percentage of trees with SC> 45 cm at seventh year.

Planting density	SC		ISC	Trees per hectare[3] (%) with SC > 45	[4]R
	3.2 years	7 years	1st to 7th year		
D1200	21.11 a	43.58 d	6.38 d	42.5 (531) b	4
D556	21.41 a	51.83 c	7.44 c	77.5 (431) a	3
D312	22.48 a	56.17 b	7.88 b	83.13 (259) a	2
D200	22.48 a	59.95 a	8.57 a	85 (170) a	1
Mean	21.87	52.69	7.57	72.03	
MS(ERR)	1.96	75.64	0.0429	42.4	
DF(ERR)	9	599	9	9	
CV	6.4	16.5	2.739174	9.04	
PR> F	0.4187	<0.0001	<0.0001	<0.0001	

Means with the same letter in the columns do not present significant differences. The numbers in parentheses indicate the number of surviving trees per hectare by planting density; [3]= data in %, transformed by Arsin (SQRT(X)); [4]= ranking of treatment means.

The lowest densities, D200 and D312, showed an increase in average annual stem circumference of 8.57 and 7.88 cm, respectively ($p < 0.0001$), while the highest densities (D1250 and D556) presented 7.44 and 6.38 cm per year, respectively ($p < 0.0001$). This shows that higher densities induce trees with a lower annual increase in SC, which is in accordance with what was reported by Dey and Datta (2013), regarding that the increase in planting density induces a reduction in stem circumference, presenting the same trend over the years (Table 1).

For the number of trees suitable for tapping at the seventh year (SC> 45), there were significant differences between densities ($p < 0.0001$). The highest density (D1250) had 42.48% of suitable trees, which corresponds to 531 trees per hectare (Table 1). The densities D556, D312 and D200 showed 77.51 (431 trees), 83.14 (259 trees) and 85% (170 trees) of suitable trees, respectively, without significant differences between them ($p > 0.05$). According to the above, the high planting densities favor that the plantations take more years to start their exploitation, contributing to the prolonged pre-productive period, which coincides with what was reported by Ng *et al*. (1993); Rodrigo (2007); Silva (2007), who indicate that, at high densities, trees take longer to reach exploitable size, the absolute number of trees in tapping is high, but the percentage of trees in tapping is lower (Table 1).

Regarding the growth in SC, after seven years of planting, the Anova showed highly significant differences between densities ($p< 0.0001$), the mean tests indicate that, throughout the evaluation period, there were differences in growth in SC, the highest planting densities always presented the lowest growths (Table 2). In the end, the lowest population densities, D200 and D312, showed higher SC, with 120 and 98.93 cm in circumference, respectively; while the lowest growths were presented by the highest densities (D1250 and D556), with 66.85 and 88.40 cm, respectively.

Table 2. Stem circumference at 10, 14, 16 and 21 years of planting, increase in average annual circumference (ISC) from 8th to 15th year and ISC from 16th to 21st year in four planting densities.

Planting density	Stem circumference (SC)				Average ISC		^{2}R
	10 years	14 years	16 years	21 years	8th to 15th year	16th to 21st year	
D1250	52.4 d	61.43 d	62.4 d	66.85 d	2.08 d	1.43 c	4
D556	64.47 c	74.57 c	77.77 c	88.4 c	3.13 c	1.96 b	3
D312	71.17 b	83.84 b	87.81 b	98.93 b	3.98 b	2.08 b	2
D200	80.03 a	98.13 a	105.49 a	120.15 a	5.67 a	2.73 a	1
Mean	66.6	79.44	83.17	92.58	3.72	2.05	
MS(ERR)	115.21	162.03	207.47	304.58	0.1157	0.0627	
DF(ERR)	594	573	578	588	9	9	
CV	16.11	16.02	17.31	18.85	9.16	12.22	
PR> F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	

Means with the same letter in the columns do not present statistical differences; ^{2}= ranking of means.

The results obtained are consistent with what was reported by Silva (2007); Rodrigo (2007); Dey and Datta (2013), where they indicate that during the first years of growth, the high population densities favor a greater production of dry matter per unit of area and consequently greater growth in circumference of the stem of the trees. From the 8th to 15th year, densities D200 and D312 showed the largest average annual increases in SC, with 5.67 and 3.98 cm, respectively ($p< 0.0001$), compared to densities D1250 and D556, which had averages of 2.08 and 3.13 cm ($p< 0.0001$), respectively (Table 2).

From the 16th to the 21st year, the largest increases in SC were obtained in the lowest densities (D200 and D312), with 2.74 and 2.08 cm per year, respectively ($p< 0.0001$); while the highest densities, D1250 and D500, had the smallest average increases with 1.43 and 1.96 cm, respectively ($p< 0.0001$) (Table 2). According to Dey and Datta (2013), SC increases with the age of the trees and the difference in SC between densities is maintained over the years, these results coincide with those obtained in this work.

Number of trees in tapping per hectare

For the average number of trees in tapping at 7, 10, 14, 16 and 21 years after planting, the analysis of variance showed significant differences ($p< 0.0001$) between densities throughout the evaluation period (Table 3). The density D1250 had the highest average number of trees in tapping, although the percentages with respect to the initial density varied between 38% (475 trees) in the seventh year and 84% (1 072 trees) at the 22nd year.

Table 3. Number of trees in tapping per hectare at 7, 10, 14, 16 and 21 years of planting in four planting arrangements of rubber (*Hevea brasiliensis*) in the central region of Veracruz.

Planting arrangement	Number of trees in tapping (NTTH)				
	7 years[1]	10 years	14 years	16 years	21 years
4x2 m	4475 (38%)[2] a	1 047 (84%) a	1 054 (84%) a	1 031 (82%) a	1 072 (84%) a
6x3 m	3372 (67%) ab	525 (94%) b	542 (97%) b	537 (97%) b	539 (97%) b
8x4 m	2234 (75%) bc	287 (92%) c	282 (90%) c	284 (91%) c	282 (90%) c
10x5 m	1154 (77%) c	188 (94%) c	174 (87%) d	174 (87%) d	166 (83%) d
Mean	308.17	511.31	512.58	506.6	514.68
MS(ERR)	8607	4045	3540	3732	4466
DF(ERR)	9	9	9	9	9
CV	30.1	12.44	11.61	12.06	12.98
PR> F	0.0039	<0.0001	<0.0001	<0.0001	<0.0001

[1]= means with the same letter in the columns do not present significant differences; [2]= the values in parentheses are the percentage of trees suitable for tapping (NTT%).

The density D556 began its exploitation with 67% of suitable trees (372 trees), but it reached 94% (525 trees) 10 years after planting and increased to 97% (542 trees) in the last years of evaluation. The lowest density (D200) began its exploitation with 77% of suitable trees (154 trees), it increased to 94% (188 trees) at 10 years, but it decreased to 83% (166 trees) in subsequent years. This is consistent with what was reported by Ng *et al*. (1993); Rodrigo (2007); Silva (2007), who indicate that, at the seventh year, the highest densities have the lowest percentage of trees suitable for tapping, although the absolute number of trees in tapping is higher (Table 3).

Yield

The yield of dry rubber in grams per tree per tapping (GT) evaluated for 16 years showed significant differences ($p< 0.0001$) between densities (Figure 1). The high planting densities induced strong competition between trees, which favored low yield per tree and low efficiency of labor (tappers), especially at the beginning of the exploitation of the plantations, results that coincide with what was reported by Ng *et al*. (1993); Verheye (2010). The lowest densities (D200 and D312) showed higher average yield, with 67.21 and 51.61 g per tree per tapping; respectively, which corresponds to an annual average of 6.72 and 5.16 kg per tree, respectively. The densities D1250 and D556 had lower yields of 23.63 and 35.82 g, respectively, equivalent to an annual average of 2.36 and 3.58 kg per tree, respectively. According to Dey and Datta (2013), the yield per tree per tapping is negatively influenced by the increase in population density, which coincides with the results obtained, Figure 1 shows the yields and equations of adjustment of the densities.

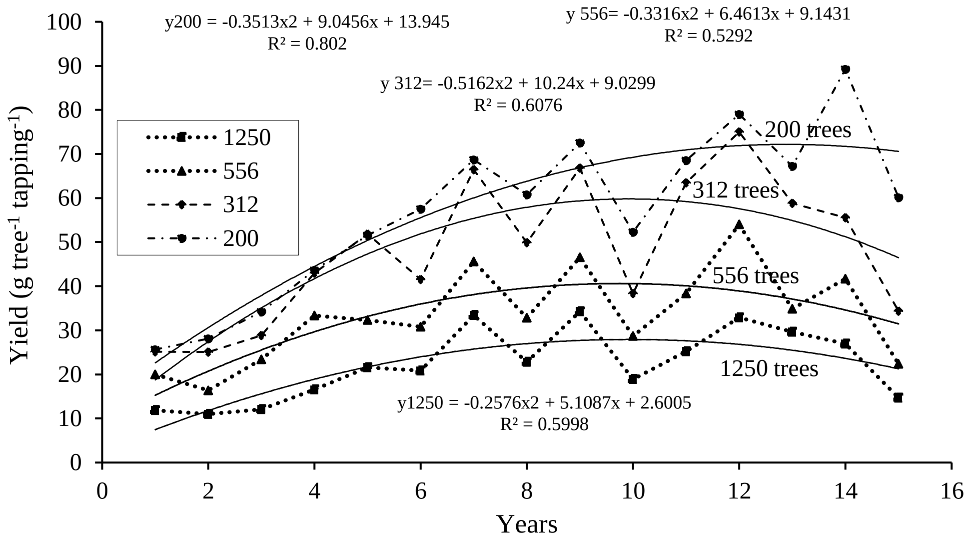

Figure 1. Yield in grams per tree per tapping for four population densities in rubber (*Hevea brasiliensis*) in the central region of the state of Veracruz.

The rubber yield in kilograms per hectare per year (KHY) during the 16-year period showed significant differences (p< 0.0001) between densities (Figure 2). The densities D1250, D556, D312 and D200, had average yields of 2 040, 1 940, 1 016 and 960 kg ha^{-1} year^{-1}, respectively (p< 0.0001).

The accumulated yield of dry rubber per hectare (KH) during the period showed highly significant differences (p< 0.0001) between densities. The higher the density, the greater the number of trees in tapping and the higher the yield of dry rubber per unit area, which coincides with what was reported by Qi *et al*. (2016). The densities D1250 and D556 had accumulated yield of the entire period of 30.62 and 27.17 t of dry rubber, respectively, with significant differences between them (p< 0.0001), while densities D200 and D312 produced yields of 14.4 and 15.24 t of dry rubber, respectively (p< 0.0001). According to the results, the annual yield per hectare and the accumulated yield per hectare were higher at higher density, which is in accordance with what was reported by Dey and Datta (2013). Figure 2 shows the yields and equations of adjustment of the densities.

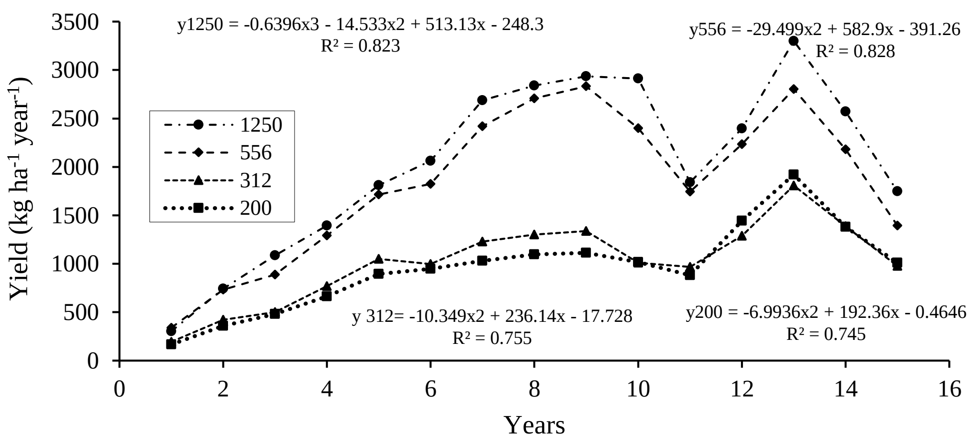

Figure 2. Yield in kg ha^{-1} year^{-1} (KHY) of four population densities in rubber in Tezonapa, Veracruz.

Biomass yield

For stem diameter (SD) and plant height (PH) at 21 years, the analysis of variance showed significant differences (*p*> 0.0001) between densities. At lower density (D200), the trees presented higher ST and PH, therefore, greater individual volume of biomass, although the total volume per hectare was lower compared to the highest densities (Table 5).

Table 5. Volume of biomass per tree and per hectare of four rubber planting arrangements.

Population density	Average diameter (cm)[1]	Average height (m)	Biomass per tree (kg)			Biomass per hectare (t ha^{-1})		
			Branches	Stem	Total	Branches	Stem	Total
1078	21.28 d	20.25 d	40.59 d	182 d	223 d	43.8 a	197 a	240 a
542	28.14 c	23.85 c	69.16 c	361 c	430 c	37.47 b	197 a	233 a
283	31.48 b	25.45 b	85.85 b	476 b	562 b	24.64 c	137 b	161 b
171	38.25 a	28.48 a	126.8 a	797 a	924 a	21.68 c	136 b	158 b
Mean	29.47	24.36	78.96	442.29	521	32.4	167	200
MS(ERR)	30.86	7.41	835.3	46206	59355	228	9358	12483
DF(ERR)	588	588	588	588	588	588	588	588
CV	18.85	11.18	36.61	48.61	46.7	46.7	57.7	55.8
PR> F	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[1]= means with the same letter for the variables in the columns do not present significant differences.

The results are consistent with what was reported by Sulaiman (2015); Dey and Datta (2013), who indicate that, in high planting densities, the total volume of biomass per hectare is higher, although the volume of the trunk is smaller, the branching height is greater and less branching and crown diameter are observed. The total biomass volume per tree ranged from 924 (D200) to 22 3 kg $tree^{-1}$ (D1250); while the volume of biomass per hectare varied between 158 (D200) and 240 t ha^{-1} (D1250). The density D556 showed the best balance, with 542 trees per ha, 430 kg of biomass per tree and 233 t of biomass per hectare, which coincides with what was indicated by Silva (2007); Dey and Datta (2013), regarding that high densities have the advantage of greater dry matter production per unit area during the first years of growth, although strong competition between trees causes the reduction in yield and biomass production in later years.

Conclusions

The results will guide producers in the use of the best planting densities and arrangements using the clone IAN-754 and other materials with similar behavior. At the end of the experiment, it is concluded that, at a lower population density, there will be greater growth in stem circumference (120 cm), yield in grams per tree per tapping (67.21 grams per tree per tapping) and biomass yield per tree (923 kg), while at a higher population density, higher yield in kg ha^{-1} (2 040 kg) and total biomass yield per hectare (240 t) will be obtained.

The best balance between the variables related to growth, rubber yield per hectare and biomass yield per hectare was obtained with 556 trees per ha. However, for producers with limited resources and small production units, where their main resource is labor, planting arrangements with densities ranging from 500 to 650 trees per ha may be recommended to obtain the highest productivity from rubber plantations in the central region of Veracruz.

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