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Effect of plant density on growth and yield in Barraganete plantain (*Musa paradisiaca* (L.) AAB cv. Curare enano) for a single harvest cutting in Provincia de Los Ríos, Ecuador

Efecto de la densidad de siembra sobre el crecimiento y rendimiento en plátano (*Musa paradisiaca* (L.) AAB cv. Curare enano) Barraganete para un solo corte en la Provincia de Los Ríos, Ecuador

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Abstract

The optimum plant density in Barraganete plantain (*Musa paradisiaca* (L.) AAB cv. Curare enano) was determined in Los Angeles-Provincia de Los Ríos, Ecuador. Treatments (sowing distance: T1 = 3m x 4m, T2 = 3m x 3m, T3 = 3m x 2m, T4 = 3m x 1.5m and T5 = 3m x 1m), were evaluated in a randomized complete block design with five treatments and three replicates per treatment. The number of hands per cluster, hand weight, weeks to flowering, weeks to harvest, production for export and weed incidence in plantain crop, were evaluated. Variance analysis was performed and means were submitted to the Tukey test at 5% probability (p = 0.05). The optimum sowing distance was 2m between plants and 3m between rows. The best density was 1666 plants. ha^{-1} and obtained the best average hand weight (14.5 kg), the best average number of hands (4.9), the best average in weeks to harvest after flowering (12.1 Weeks) and the best production ($kg.ha^{-1}$) of export bunches (close to 22 $t.ha^{-1}$). Analysis with logistic models show the higher densities, which present advantages in their use, fact related to the increase of the annual plantain production. For this reason, values between 2150 and 2500 $plants.ha^{-1}$ are postulated as optimal densities. Weed decreases with increasing plant density to a minimum of 227.94 $g.m^{-2}$ in the highest plant density treatment.

Key words: Hands per cluster, production for export, weed control, weeks to flowering, weeks to harvest, weight of hands.

Resumen

Se determinó la densidad de siembra óptima en plátano Barraganete (*Musa paradisiaca* (L.) AAB cv. Curare enano) en el recinto Los Ángeles-Provincia de Los Ríos, Ecuador. Los tratamientos (distancia de siembra: T1= 3m x 4 m; T2= 3m x 3m; T3= 3m x 2m; T4= 3m x 1.5m y T5= 3m x 1m) se evaluaron en un diseño de bloques completos al azar, con cinco tratamientos y tres repeticiones por tratamiento. Se evaluó el número de manos por racimo, peso de manos, semanas a floración, semanas a cosecha, producción para la exportación e incidencia de malezas en el cultivo. Se realizó análisis de varianza y los promedios fueron sometidos a la prueba de Tukey al 5% de probabilidad (p=0.05). La distancia óptima de siembra fue de dos metros entre plantas y tres metros entre surcos. La mejor densidad fue de 1666 $plantas{\cdot}ha^{-1}$ y obtuvo el mejor promedio en peso de manos (14.5 kg), el mejor promedio en número de manos (4.9), el mejor promedio en semanas a la cosecha después de la floración (12.1 semanas) y la mejor producción ($kg.ha^{-1}$) de racimos de exportación (cercano a los 22 $t{\cdot}ha^{-1}$). Los análisis con modelos logísticos, muestran que las densidades superiores presentan ventajas en cuanto a su uso, hecho relacionado con el aumento de la producción anual. Por ello, se postulan como densidades óptimas valores comprendidos entre 2150 y 2500 $plantas{\cdot}ha^{-1}$. La maleza disminuye con el aumento de la densidad de plantas hasta un mínimo de 227.94 $g{\cdot}m^{-2}$ en el tratamiento de máxima densidad.

Palabras clave: Control de malezas, manos por racimo, peso de manos, producción para exportación, semanas a cosecha, semanas a floración.

Introduction

Plantain *(Musa paradisiaca* (L.) AAB) production, represents an important sector for the economy and food security of Ecuador (INIAP, 2015). The main varieties used are Dominico, which is mainly used for domestic consumption and Barragante, which is for export purposes. In 2014, a total of 159014 hectares of plantain, were reported, with a production of 634341 tons (Proecuador, 2015). For 2015, 203281 tons are exported, with 62% shipped to the United States. As main producing areas in 2013, highlights the provinces of Manabí (50376 ha), Santo Domingo (18981 ha), Esmeraldas (12034 ha), Guayas (10820 ha) and Los Ríos (10313 ha). According to foreign trade statistics from TRADEMAP, Ecuador ranks as the second plantain exporting country, supplying 17% of fruit imports worldwide (Proecuador, 2015).

Plant density, has a great influence on growth and development of every crop. Due to competition for sun light generated within the plant community (Cayón *et al.*, 2004). Management of plant density population is important to control the sun light amount received by the crop. Generally, higher yields per area unit as a result of efficient sun light use, are obtained during the early stages of crop growth. However, with high densities, agronomic performance of plantain crop can decrease by sun light competition, excessive water loss through transpiration and plant pest and disease (Cayón *et al.*, 2004).

Sarrwy *et al.* (2012), in a study with the Williams variety in Egypt, found the optimum plant density, which was derived from many factors, including the used cultivar, soil fertility, shoots selection, agronomic management, weed control, wind, topographic relief and economic reasons. For these authors, the competition between plants, is mainly related to the shadow effect and root system extent.

Plant density in plantain for a certain variety is determined by the distance between rows and the number of plants, and have a positive or negative effect in the stages development and crop production (Cayón *et al.*, 2004). In addition, several studies have shown the population density in plantain, can be increased to 3333 plants.ha^{-1} without affecting performance and product quality, improving profitability. This effect of reduction in shelf- life is not confirmed by Añez & Tavira (1999), who in a study with Dominico Harton CV in Venezuela, had higher yields with smaller growing distances (2 x 2m and 2 x 3m), without affecting the cluster weight over three generations.

Plant density in *Musa* genus is conditioned by its use, due to plantain and bananas are planted also as associated crops, when performed in mixed crops such as rubber (*Hevea brasiliensis* (Willd. ex A. Juss.) Müll. Arg.) (Rodrigo *et al.*, 2000) or coffee, (*Coffea arabica* L. and *Coffea canephora* Pierre ex A. Froehner) (Van Asten *et al.*, 2011; Zake *et al.*, 2015).

Production model of single cycle in plantain crop as an annual crop, includes the harvest in the first production cycle. In addition, stover has to be removed and a new plantation is established in the same area. Given these concerns, compared to traditional farms, this system modifies qualitative and quantitative growth and development parameters. This is offset by the high yields, which can be increased up to 100% (Belalcázar *et al.*, 2003). These same author points out other economic advantage to this operation, which take cover the added costs, i.e., the obligation of an annual planting.

Rosales *et al.* (2008), showed advantages of planting in a single cycle as follows: 1) Additional income, resulting from the large number of shoots, which can be used as high quality seeds. 2) Reducing the Black Sigatoka incidence and severity and soil pests as a result of the microclimate modification by high density (mainly relative humidity and temperature), soil movement after each harvest and the use of new seed per each new cycle. 3) Staggered planting, reduces risk of total destruction of plantations by several environmental factors (winds, storms, floods, etc.). In addition, provides facilities to handle parcels, soil tillage and weed control (Biswas & Kuwar, 2010).

In plantain crop, it have been reported an increased yield from 270 to 345% with densities between 3000 to 5000 plants.ha^{-1}, respectively, compared to conventional plantations with 1000 plants.ha^{-1} (Belalcazar *et al.*, 2003). High density plantations had lower incidence of yellow sigatoka (*Mycosphaerella musicola* R. Leach ex J. L. Mulder,) and black sigatoka (*Mycosphaerella fijiensis* Morelet). However, high densities increase the time to flowering and harvest. The increase in the number of plants per hectare has direct influence on growth factors and the total yield and a negative effect on production per plant and percentage of harvested plants. Athani *et al.* (2009), evaluated in his study densities up to 6250 plants.ha^{-1} but do not provide production data. Kesavan *et al.* (2002), conducted a study in Australia with the Cavendish variety, using densities between 1111 and 6667 plants.ha^{-1}, highlighting the protective effect of plants against heat stress and plant density effect on plantain size, lower stress and plant size, were reported at high densities, even with a longer crop cycle, where which plant densities were increased.

Barraganete plantain (*Musa paradisiaca* (L.) AAB cv. Curare enano) used in this research, is characterized by 2.5 m high, with a thicker than traditional and more wind resistant pseudostem. The cluster has five to seven hands, 30 to 50 fingers of curved shape, with a length of 10 to 12 inches. Given these concerns, the aim of this research was to determine the effect of plant density on growth and yield in Barraganete plantain (*Musa paradisiaca* (L.) AAB cv. Curare enano) for a single harvest cutting and seeking more income for plantain producers in Provincia de Los Ríos, Ecuador

Materials and methods

The experiment was conducted at Los Ángeles, Provincia Los Ríos, Hacienda Jatalón, Km 56 Santo Domingo-road to Quevedo, Ecuador. Performs a bimodal rainforest regime (bh -T), and it is located at 224 m. a. s. l. The average annual temperature is 24.6°C, annual rainfall of 2870 mm and relative humidity of 85%. The heliophany is 680 $h \cdot yr^{-1}$ sun and presents a sandy loam soil according to USDA classification.

Site preparation was carried out 20 days before planting. Previously, there was an oil palm cultivation established during past 20 years in the site. Weed control was carried out with a mowing machine. The planting date was held on April 13th, 2012. Subsequently, Barraganete plantain shoots, which were still attached to the mother plant (Son of a sword leaf), were selected, respectively. Quality selection parameters were assigned as follows: weight brunch, health plant and lower pest and disease attack. Planting material was previously treated with systemic fungicides (Carboxin 20 p/v + Tiram 20 w/v), shoots were planted in holes of 30 cm in diameter and 30 cm deep. Before planting, a fertilizer complex (boron, iron, manganese, zinc, nitrogen, phosphorus, potassium, sulfur, magnesium and microelements) at rate of 70 g per plant, was added.

During the growing season, weed control was performed using mowers and machete. Plantain leaf pruning was conducted regularly throughout the crop cycle. The new shoots were eliminated to enhance the principal shoot (mother plant) growth. Data were collected between 30th June 2012 and 30t^{h} June 2013. The evaluated variables (yield components) were as follows: number of hands per bunch, weight hands, weeks to flowering, weeks from flowering to harvesting, exporting quality production and weed incidence.

A randomized complete block design was performed with four replicates. Variance analysis showed statistical significance, Tukey test was applied at 5% probability to determine differences among treatments. Functional analysis for several nonlinear models were tested, choosing the logistics models due to better description of the production in relation to planting density. Treatments (planting distances) are described in Table 1.

Table 1. Treatments to determine the optimum plant density in Barraganete plantain (Musa paradisiaca (L.) AAB cv. Curare enano) in Provincia de Los Ríos, Ecuador.

Treatments	Plant distance (meters between plants and rows)	Plant density ($Plants \cdot ha^{-1}$)
T1	3 x 4	833
T2	3 x 3	111
T3	3 x 2	167
T4	3 x 1.5	222
T5	3 x 1	333

Twenty experimental units were used, within an area of 360 m^2 (15 x 24 m). 30 plants were used as an experimental unit in treatment 1, 40 in T2, 60 in T3, in T4 and 120 in T5 for five plants evaluated at least.

Weed incidence within each treatment was evaluated, taking fresh samples as follows: two, three, six and nine months after planting. Weed weight was determined per square meter ($kg.m^{-2}$). A variance analysis was performed, the main plots: evaluation dates and subplots: planting densities. In addition, the effect of treatments (densities) on weed incidence, were totalized. Statistical analyzes were performed with the R -project 2.12.2 software ®.

Results and discussion

Yield components

Table 2, shows the variance analysis, variation Coefficients (VC) and Tukey test results. Variance analysis shows the yield components and weed incidence performance with significant values (Table 2).

It is important to note that the number of hands per cluster with respect to Tukey test at 5% significance obtained four ranges as follows: T3 presented the highest number of hands per cluster (4.9 hands) and ranks first range A, which is shared with T1 with hands 4.7. In the last place of range D, T4 and T5 between 4.1 and 4.0 hands peer cluster on average, respectively. Among the highest and lowest value, there is a significant difference of 23.5 %.

Table 2. Effect of plant density on plantain (*Musa paradisiaca* (L.) AAB cv. Curare enano) yield components.

Treatment	Yield components					Weed incidence
	NHC[1]	WH (Kg)	TF (weeks)	TH (weeks)	EY (t)	(kg.m^{-2})
T1	4.65	14.4	34.7	12.2	10.1	245
T2	4.48	13.9	38.6	12.5	13.8	238
T3	4.94	14.5	41.0	12.1	21.8	233
T4	4.06	13.0	43.6	13.2	16.4	231
T5	4.00	12.1	45.8	13.5	19.0	227
HSD	16.2	14.9	43.7	12.8	10.8	3.80
VC %	4.44	3.85	3.20	2.63	16.9	6.42

1/ HNC: Hand number per cluster; WH: weight of hands; TF: Time to Flowering; TH: Time to harvest; EC: Exportable yield; HSD: Tukey test (0.05); VC: Variation coefficient.

This information is useful to compare treatments accordingly to means by Tukey on the weight of hands, three ranges were observed; A range header by T3 with an average of 14.53 kg, which it shares with T1 and T2. In last place, again T4 and T5 with averages of 12.99 and 12.14 kg respectively. It is seen as decreasing from 3333 to 1666 Plants.ha^{-1} (50 % reduction) by weight 2.13 kg hand increases. Between the highest and lowest value there is a difference of 17.9 %.

Tukey test at 5% for treatments with respect to the variable weeks from planting to flowering, lower density (T1) has an average of 34.73 weeks and ranks first range A significance and is not correlated to another treatment. T4 and T5 again, occupy last place with an average of 43 and 45.8 weeks, respectively. The increase of 2500 plants. ha^{-1} between T5 and T1, brought with it an increase of 11.02 weeks to flowering. Between the highest and lowest value, there is a significant difference of 31.7 %.

Given these concerns, T3, T1 and T2 with averages of 12.1, 12.2 and 12.5 weeks, respectively, are addressed to establish the evaluated variables as follows: weeks from flowering to harvest with Tukey test at 5% significance, three ranges were observed, respectively. In C range and ultimately, the T5 is set with 13.46 weeks from flowering to harvest. With both components, flowering and harvest data can be seen as T1 harvested to 12 weeks before T5, T3 and T5, five weeks before. Between the highest and lowest value, there is a difference of 11.0%. Alternatively, for production in kg.ha^{-1}, clusters per hand for export purpose in Tukey test 5%, three ranges of significance were detected as follows: In A range, are located treatments T3, T5 and T4, averaging 21.8, 18.9 and 16.4 t.ha^{-1}, respectively. T5 and T4 treatments are coupled with T2 in the range B. In addition, C range is correlated to T1 and T2 treatments, the latter, being the lowest performance with 10.1 t.ha^{-1}. Likely as a result of population increased from T1 to T3, an increased performance of 11.7 t.ha^{-1}. Between the highest and lowest value, there is a difference of 151.9 %, being the agricultural variable with greater variability.

Therefore, weed incidence with means treatment compared by Tukey test of significance of 5%, have allowed to establish two significance range as follows: A is headed by the T5 with 227.94 g.m^{-2} of weed incidence, which is correlated to T4, T3 and T2. Although, T1 being greater weed weight treatment with 245.06 g.m^{-2} and ranks in last position, B range. Processes that aim to generate a planting density increased with respect to weed incidence. Between the highest and lowest value, there is a significant difference of 7.51 %, being the evaluated variable with less variability.

This provides more accurate and reliable estimates of logistic models (Figure 1), where the plantain density is between 1400 and 2800 plants. ha^{-1}, being 2200 plants.ha^{-1}, the most reliable.

The optimum plantain density (accordingly to yield component) is between 2800 and 3000 plants.ha^{-1}, the optimum plantain density (for export quality) is around 2500 plants.ha^{-1}, which is correlated to T4 and T5 categories. These export categories keep the last positions according to Tukey test with the evaluated variables as follows: number of hands per bunch, hand weight, weeks and weeks flowering to harvest, which occupies a greater position export scale and weed control incidence. But the increase in annual production is the most decisive producer factor, which compensates other constraints such as the length of crop cycle correlated to plantain production throughout the study conditions. In this research, bunch production for export purpose increased in 62.4% from the lowest density to 2222 plants. ha^{-1} and 87.3 % for a plantain density of 3333 plants.ha^{-1}. Given these concerns, it is important to note that increased profitability is correlated from planting to harvesting, where production timing increased in terms of demand and price (Belalcázar *et al.*, 2003).

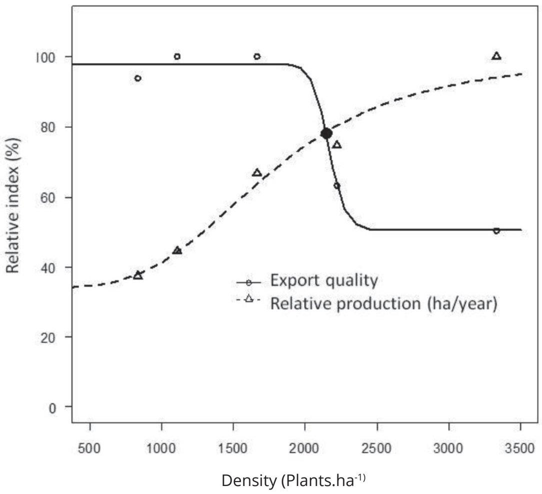

Figure 1. Effect of plant density on relative yield and inverse relative life cycle (Time from planting to harvest). In addition, can be noted that as plantain density increases, fruit quality, decrease. Figure 2, exposes the greater fingers of hands per cluster with the lower plantain density (2000–2800 plants.ha^{-1}) with export purpose (2150 plants.ha^{-1}), close to T4 export category.

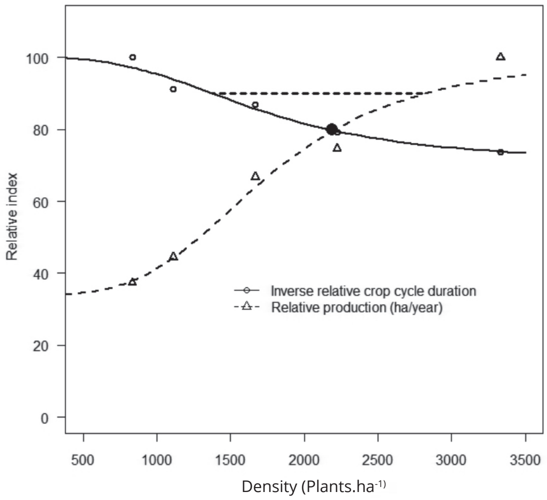

Figure 2. Influence of plant density on production and export quality plantain crop.

Nonetheless, a quadratic model showed as plantain density increases, export production increases to a plantain density value of 2500 plants.ha^{-1} (Figure 3).

Cayon *et al.* (2004), in an essay in Colombia, with Dominico Harton cultivar, found the number of hands is directly related to planting density. In addition, the plantain densities between 1500 and 2500 plants.ha^{-1}, have allowed to obtain hands with an increased number of fingers, weight and quality hands per cluster, with higher densities of 2750 plants.ha^{-1}, bunch weight was reduced to 22 %. These ranges match with respect to proposed in this research (2150-2500 plants.ha^{-1}). In the same research, the current performance, was calculated in based on harvest percentage and proportional directly to plantain density.

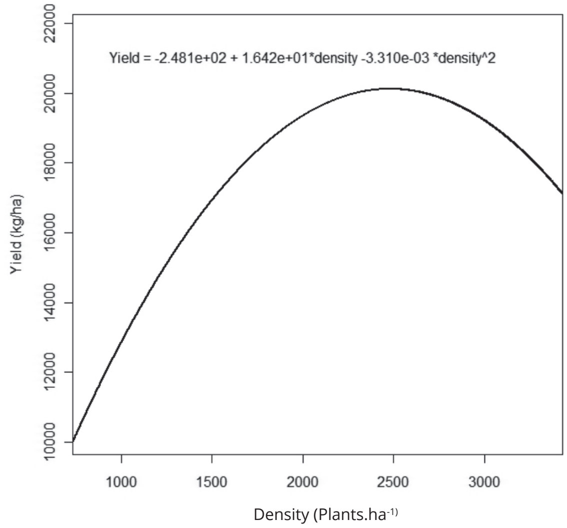

Figure 3. Effect of planting density in marketable plantain production for export.

In Venezuela with Dominico Harton cultivar, Delgado *et al.* (2008), evaluated the potential estimation and current plantain yields in t.ha^{-1}, shows there is a significant increase in weight of hands as density increases between 1100 and 2500 plants.ha^{-1}. Therefore, significant differences in higher density were identified as follows: planting density, bunch weight, finger weight, pseudostem diameter and number of leaves at flowering and harvest stage. In addition, performance in traditional plantain system was 8.5 t.ha^{-1} and 35 t.ha^{-1} at high density (2500 plants.ha^{-1}). However, a lower yield in this research is tempered by the exportable quality and not for total plantain yield.

Belalcázar *et al.* (2003), found an increase in production from 23.2 t.ha^{-1} with 1666 plants.ha^{-1} to 40.5 t.ha^{-1} with 3332 plants.ha^{-1} and 51.8 t.ha^{-1} with 4998 plants.ha^{-1}. Therefore, the duration of vegetative cycle gradually increases with population increase, the shortest cycle (15.5 months), records a plantain density of 1666 plants.ha^{-1} and the longest (20.0 months), with a population of 4998 plants.ha^{-1}.

Weed incidence

Weeds are harmful to plantain, as they compete for water, nutrients, space and some are host of pests and diseases (Marín & Romero, 1992; Orozco-Santos *et al.*, 2008). However, there is a little information about the specific weeds effect on incidence of black Sigatoka and its final impact on production. Reduction of incidence and severity of Sigatoka diseases (yellow and black) is the result of the modification of some environmental conditions within the cultural practices, mainly relative humidity and temperature, which affects the water presence in plantain leaf for fungus conidial germination with a smaller sun-light amount, which causes Cercospora toxicity, whose toxicity is increased in sun-light presence (Orozco-Santos *et al.*, 2008). In the present research, weed incidence increases with the increased plantain density to 7.51%.

Likely a result of plantain (cv. Mpologoma, AAA -EA) densities comparison (2500, 1600 and 1110 plants.ha^{-1}, respectively), Nankiga *et al.* (2005), in Uganda, found larger plantain clusters in plots with lower plantain densities, but the total production is higher in those plots with higher plantain densities, which coincides with the results of this research. However, they found no significant differences in the first crop cycle in terms of days from flowering to harvest stage.

Biswas & Kumar (2010), in a study with Cavendish in India raised densities between 4444 and 5555 plants.ha^{-1}, doubling the normal density from 2267 plants.ha^{-1}, but it required high technology system with respect to irrigation and fertilization program in plantain crop management. In addition, Wairegi *et al.* (2010), conducted an evaluation of agronomic traits in 159 banana plantations (*Musa* spp., AAA genome EA) in Uganda, attributing planting densities (average 1398 plants.ha^{-1}) with principal limitations (2.3 and 11.3 %, respectively).

Conclusion

The present research showed an increased planting density in plantain cultivation, between 2150 and 2500 plants.ha^{-1}, in a single crop cycle, improves the yield crop. In addition, an increase in annual production (between 62.4 % and 87.3 %, respectively) offset other crop limitations with respect to these plantain densities, such as the weight of hands or lengthening of plantain crop cycle.

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