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RENOVATION AND REHABILITATION PRACTICES OF UNPRODUCTIVE CACAO PLANTATIONS: STRATEGIES TO MAINTAIN PRODUCTION IN COLOMBIA

PRÁCTICAS DE RENOVACIÓN Y REHABILITACIÓN DE PLANTACIONES IMPRODUCTIVAS DE CACAO: ESTRATEGIAS PARA MANTENER LA PRODUCCIÓN EN COLOMBIA

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SUMMARY

The advanced age of cacao plantations (more than 20 years) is one of the main factors that decrease yield. Rehabilitation of these plantations is one of the management practices that is increasingly debated but rarely adopted. Three practices were defined to assess the effect of the renewal and rehabilitation of cacao plantations on fruit yield and quality, including E1: lateral grafting in adult trees, E2: grafting in basal sucker, E3: structural rehabilitation and E4: control treatment without pruning. These practices were implemented at two locations in the Colombian Caribbean region (Zona Bananera, department of Magdalena and Valledupar, department of Cesar). Practices of strong structural pruning and lateral grafting in adult trees, and approach grafting in a basal sucker with renewal of plant material were implemented under a completely randomized design in clones CCN51, EET8 and TSH565 at Zona Bananera, and clones CCN51, EET8 and FLE2 at Valledupar. The control treatment was maintained without intervention using clone CCN51 trees at Zona Bananera and hybrid trees at Valledupar. After three years of performance evaluations, significant differences ($P \leq 0.05$) were found between the implemented strategies, with significantly higher yields in trees intervened with structural pruning. The morphological characteristics of the fruit showed significant differences between the evaluated clones (CCN51, EET8, FLE2 and TSH565) in both locations. Results showed a positive effect of the implementation of a package of rehabilitation/renovation strategies on crop yield, and the lateral graft showed a positive effect on earliness of trees, compared to the basal sucker graft. Clone CCN51 showed higher yields compared to TSH565 and EET8 clones in Zona Bananera and clones TSH565 and FLE2 in Valledupar.

Index words: *Theobroma cacao*, basal shoots, lateral grafting, pruning, sucker.

RESUMEN

La edad avanzada de las plantaciones de cacao (más de 20 años) es uno de los principales factores que disminuyen el rendimiento. La rehabilitación de estas plantaciones es una de las prácticas de manejo que se debate cada vez más, pero rara vez se adopta. Para evaluar el efecto de la renovación y rehabilitación de las plantaciones de cacao sobre el rendimiento y la calidad del fruto se definieron tres prácticas, incluyendo E1: injerto lateral en árboles adultos, E2: injerto en chupón basal, E3: rehabilitación estructural y E4: tratamiento control sin poda. Estas prácticas se implementaron en dos localidades en la región del Caribe colombiano (Zona Bananera, departamento del Magdalena y Valledupar, departamento del Cesar). En un diseño completamente al azar se evaluaron las prácticas de poda estructural fuerte e injerto lateral en árboles adultos e injerto por aproximación en un chupón basal con renovación de material vegetal de los clones CCN51, EE8 y TSH565 en la Zona Bananera, y los clones CCN51, EET8 y FLE2 en Valledupar. El tratamiento de control se mantuvo sin intervención, utilizando árboles del clon CCN51 para la Zona Bananera, y árboles híbridos en Valledupar. Después de tres años de evaluaciones de desempeño se encontraron diferencias significativas ($P \leq 0.05$) entre las estrategias implementadas, con rendimientos significativamente más altos en los árboles intervenidos con la poda estructural. Las características morfológicas de la fruta presentaron diferencias significativas entre los clones evaluados (CCN51, EET8, FLE2 y TSH565) en las dos localidades. Los resultados mostraron un efecto positivo de la implementación de un paquete de estrategias de rehabilitación/renovación en el rendimiento de los cultivos, y el injerto lateral mostró un efecto positivo en la precocidad de los árboles comparado con el injerto en chupón basal. El clon CCN51 presentó mayores rendimientos comparado con TSH565 y EET8 en Zona Bananera y los clones TSH565 y FLE2 en Valledupar.

Palabras clave: *Theobroma cacao*, brote basal, chupón, injerto lateral, poda.

INTRODUCTION

Cacao (*Theobroma cacao* L.) production assumed a commercial dimension in the early 19th century in Ghana (Peprah, 2019), and since then, together with Ivory Coast, they have been at the forefront of world production (Coulibaly, 2019). In 2018, world production was 5.25 million tons, where Ivory Coast was the largest producer with an estimated 1.96 million tons (37 %), followed by Ghana (947,632 t) and Cameroon (307,867 t).

In Colombia, for the same year, 145,471 ha with cacao trees were reported, with a dry bean production of 52,743 t (FAO, 2020). In the last three decades, a decrease in yield has been observed, going from 0.46 t ha^{-1} in 1990 to 0.36 t ha^{-1} in 2018 (FAO, 2020). There is a variety of agronomic factors that influence yield; the basic lesson learned is that

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the desired effect of efforts to expand the area will not be very noticeable if productive capacity is not addressed simultaneously (Abbot *et al*., 2017). Ramírez *et al*. (2009) indicated that among the main reasons for cacao to reduce its productivity is the advanced age of the plantations (> 20 years), the age at which the cacao tree decreases its production. The lack of proper crop management, especially the lack of pruning, both in cacao trees and shade trees, makes their management and harvest difficult, and increases the incidence of pests and diseases; this, in turn, increases production costs and reduces crop profitability.

In Colombia, most of the cocoa farms (94%) are managed by small producers, where the extensions of land dedicated to cacao cultivation are less than 5 ha (equivalent to 60 % of the area dedicated to cacao cultivation), together with peasant economy production systems and in some cases, subsistence (Castellanos *et al*., 2007).

Likewise, more than 60 % of the cacao trees are plantations older than 30 years that are characterized by being unproductive, established from hybrid genetic materials obtained by crosses between Trinitarian and Amazonian clones, and in good proportion, offspring of hybrids. Only a low percentage is established with genetic materials from universal clones; thus, 32 % of the cocoa-producing areas are planted with common and universal materials (clones), and 58 % with hybrids (MADR, 2005).

According to Ramírez *et al*. (2009), a drastic intervention is required to recover the productive capacity and profitability of a cacao plantation. For this, two intervention strategies are proposed: renovation and rehabilitation. Renovation consists of the gradual or rapid replacement of the existing genetic material, generally hybrids, by cacao clones with higher productive potential and better quality. On the other hand, Wood and Lass (2001) defined rehabilitation as the restoration of yields to their maximum level in a cacao plantation.

Wood and Lass (2001) consider that the mere fact of implementing good management in unproductive cocoa farms to recover crop yield is a form of rehabilitation. Among the cultural methods that can be considered as rehabilitation strategies, the adjustment of shade, application of fertilizers, weed control, sanitary management, improvement of drainage and management of the tree architecture through pruning stand out (Petithuguenin, 1995).

In Colombia, according to Ministerio de Agricultura y Desarrollo Rural (MADR-CNC, 2008) in its ten-year cacao plan 2012-2021, it was expected to have 130,000 modernized ha and a production of 156,000 t by year 2020. This approach, proposed from the institutional point of view, recognizes the cocoa-derived market potential, and in general, the production chain, as well as the production of derivatives (Cely, 2017). This reveals the need to reactivate the productive system based on rehabilitation strategies that will allow to reactivate and promote productivity. Accordingly, the aim of this study was to evaluate renovation/rehabilitation strategies as an alternative to increasing the yields of unproductive cacao plantations in the Colombian dry Caribbean.

MATERIALS AND METHODS

Study site

This study was carried out the Colombian dry Caribbean region in two locations: the district of El Palmar, municipality of Valledupar, department of Cesar, located at the coordinates 10º 28′ 43.5″ N and 73º 25′ 9.6″ W, at an altitude of 500 masl, and the municipality of Zona Bananera, department of Magdalena, at the Research Center C. I. Caribia of Corporación Colombiana de Investigación Agropecuaria (Agrosavia), located at the coordinates 10º 45 50.6″ N and 74º 08 48.8″ W, at 20 masl. Both plantations had low yields (< 400 kg ha^{-1}) and a high incidence of pests and diseases (> 70 %). The climatic conditions of the studied locations in the first quarter of the year depend on a dry period, with low rainfall and evapotranspiration (ET) exceeding precipitation (P). This is why an irrigation system is required in these periods to guarantee water and nutrients for plants (Palmar, P = 152.5 mm, ET = 351.53 mm; Caribia, P = 150.20 mm, ET = 351.53 mm). From April to November, rainfall increases, significantly exceeding ET (Palmar, P = 1783.20 mm, ET = 956.90 mm; Caribia, P = 1882.18 mm, ET = 947.31 mm). In addition, temperatures follow a linear trend pattern, where abrupt changes between temperatures are not reflected during all months of the year (average temperature, Palmar = 26.45 ºC; Caribia = 27.15 ºC).

Farm diagnosis

After the selection of plots, a tree-by-tree diagnosis was made to assess the phytosanitary status and define the type of intervention to be used according to the case. Two strategies were implemented. 1) renovation strategy: in this case two treatments evaluated were E1: lateral graft in adult tree implemented in older trees (> 20 years), unproductive (< 400 g dry cocoa/tree/year) and with deterioration in their productive branches; however, their trunk should have good phytosanitary conditions and a diameter of less than 15 cm. E2: grafting in basal sucker implemented in unproductive trees, with a high incidence of pests and diseases in the trunk. These trees were pruned at ground level, after which the cut area was healed and covered with organic fertilizer to stimulate the emission of new suckers from the ground base; finally, the best developed one was selected and based on this one, a new crown was grafted with an approach graft. In both strategies (E1 and E2), the practice of grafting allowed to renew the unproductive genetic material with new materials. For this purpose, the same cacao genetic materials were evaluated in E1 and E2: clones CCN51, EE8 and TSH565 in Zona Bananera, and clones CCN51, EET8 and FLE2 in Valledupar.

The second strategy implemented was the cacao trees rehabilitation. E3: structural rehabilitation by strong pruning; this practice consisted of cutting branches, leaving between two and three main branches on each tree, and reducing the height of the trees by up to 3 m; moreover, diseased branches and suckers were removed; and E4: control treatment, this treatment consisted in selecting trees that remained under the traditional management of the producer, to which no intervention was made in terms of canopy pruning. In Zona Bananera the clone CCN51 was used for the rehabilitation strategy, and in Valledupar, a creole hybrid material from seed (IMC67) was used. In all the treatments a plant density of 1,111 trees ha^{-1} was adjusted, with a distance of 3 × 3 m between cacao trees.

Experimental design

Two independent experiments were established under a completely randomized design with three replications and an experimental unit composed of five trees was used. The firs experiment consisted of evaluating the renovation strategy, with two treatments (E1: lateral graft in adult tree, and E2: grafting in basal sucker). The second experiment aimed to evaluate the rehabilitation strategy (E3: structural rehabilitation, and E4: control, without rehabilitation).

Evaluated traits

The variables evaluated were pod weight, number of grains per pod, fresh and dry cocoa beans, two yield components - pod index (PI) and grain index (GI), and cocoa dry bean yield (kg per tree). Grain and pod index are the most important variables for commercialization and determine the performance of a cocoa phenotype (Jiménez *et al*., 2018; Vera *et al*., 2014), these two yield components were determined as follows: PI as the average number of pods needed to obtain 1 kg of dry bean cocoa, and the GI as the average weight of grain in g, taken from a sample of 100 dry cocoa beans.

Additionally, in the renovation experiment, the growth of the cocoa pod was characterized for each of the clones evaluated from measurements on the length and width of the pod, in the localities of Zona Bananera and Valledupar.

Statistical analysis

The data from the morpho-agronomic characterization were analyzed using the SAS statistical program version Enterprise Guide 5.1 (SAS Institute, 2007). A descriptive analysis (mean, standard deviation, standard error, coefficient of variation, and minimum and maximum values) was performed to establish the variability of the quantitative characteristics at the treatment level; an analysis of variance and Tukey mean multiple comparison test ($P \leq 0.05$) were used to carry out the multiple mean comparisons for variables pod weight, number of grains per pod, grain weight in slime and dry, pod index, grain index and grain yield.

RESULTS AND DISCUSSION

Renovation strategy

After three years of implementing the renovation strategies (lateral grafting and grafting on a basal sucker) at the locations of Zona Bananera and Valledupar, there were significant differences between treatments for production of dry cocoa, being higher in trees intervened with lateral graft, with productions of 0.81 kg/tree (second year) and 0.72 kg/tree (third year) in the C.I. Caribia; and 0.24 kg/tree (second year) and 0.50 kg/tree (third year) in Valledupar (Table 1). In contrast, the trees intervened through the practice of basal sucker grafting only produced dry cocoa bean at the third year after implanting the grafting on the trees, which indicates a late response with an effect on the dry cocoa yield.

The lateral graft treatment had a positive effect on earliness, compared to the basal sucker graft, regardless of not exceeding the yield of the control treatment. It is expected that from the third year, production will increase due to the fact that the plants recover the photosynthetically active leaf surface, which allows increasing the capture of light energy, and improving its photosynthetic activity, to distribute assimilates to the organs such as flowers and fruits. Monteith (1972) mentioned that the estimation of the productivity of a crop is based on the fraction of radiation absorbed by the photosynthetically active elements of plants and its efficiency to convert it into biomass.

Regarding the treatment of graft in a basal sucker, after three years of its implementation, the established crowns have not started the production cycle, which represents a slow development compared to the lateral graft that showed higher production, being consistent with what López (2019) described. By the third year of the intervention in both locations, when comparing the productivity (kg of dry cocoa/tree/year) between the different materials, significant differences were found, being the productivity of clone CCN51 higher compared to that of clones TSH565 and EET8 in the locality of Zona Bananera, and clones TSH565 and FLE2 in Valledupar (Table 2).

Regarding the yield components in Zona Bananera, significant differences were found in pod length, with the largest pod size found in clones TSH565, and the lowest GI in clone TSH565 (Table 3). According to Fedecacao (2015), a number of grains per pod larger than 46 is considered superior, from 36 to 45 intermediate, and less than 35 is inferior; therefore, clones CCN51 and TSH565 were classified as intermediate, while clone EET8 was classified as an inferior material. Likewise, a pod index (PI) less than or equal to 17 is considered very good, 18 to 20 is good and larger than 21 is not adequate. In this sense, clone CCN51 outperform clones TSH65 and EET8, being considered very good; meanwhile, the ETT8 clone is classified as good, and TSH565 is adequate.

In Valledupar (El Palmar district), significant differences were found for the variables weight, length and diameter of the fruit, the pod size of clone FLE2 being larger than that of the EET8 and CCN51 clones and the hybrid. Additionally, there was a difference in the weight in slime per pod (Table 3). The three clones showed a number of pod grains from 36 to 45, being classified into the intermediate class, according to Fedecacao (2015). The FLE2 and CCN51 clones presented pod indexes equal to or less than 17, *i.e.*, considered to be very good, while the EET8 clone was in the range of 18 to 20, *i.e.*, in a good range. The material of the producer was classified in the unsuitable range for having a PI higher than 21 (Table 3); however, the productivity showed in the structural pruning treatment was high (3.34 kg dry cocoa/tree/year) because the number of pods harvested per tree was high (> 50 pods/tree/year).

Regarding the yield components of clones CCN51 and EET8, Perea *et al.* (2013) reported MI values of 15 and 13, and IG of 1.6 and 1.58 respectively, values that show a better response than those found in the Zona Bananera and Valledupar for CCN51, with MI of 17.95 and 16.38, and GI of 1.53 and 1.58 respectively; and for EET8 in the same locations with MI of 20.34 and 19.41, and IG of 1.56 and 1.45 respectively (Tables 3 and 4). For the specific case of clone TSH565, the mentioned authors also found a better response for these indicators, with MI of 19 and GI of 1.2, while in Zona Bananera MI value of 21.23 and a GI of 1 were reported (Table 3).

As mentioned, when finding that the results of the present investigation were not as low as those documented by Perea *et al*. (2013), it can be deduced that the yield responses could be related to the wide climatic differences of the study areas; for example, in the Colombian Caribbean (Zona Bananera and Valledupar) the conditions are not favorable for cultivation, mainly due to prolonged dry seasons (first months of the year), since according to Zuidema *et al.* (2005), cocoa yields depend to a great extent on the water inputs during the two driest months of the year. Another relevant aspect is the genotype × environment interaction, highlighting the importance of optimizing the use of genetic resources and proposing basic collections for the design of breeding programs (Osorio-Guarín *et al.*, 2017).

Within the cocoa market, in addition to bulk cocoa, a new category known as specialty cocoa has been established, which has experienced the highest percentage of growth compared to other cocoa segments (Santander *et al*., 2019). This category includes fine or flavored cocoas and those that are characterized by differentiating factors such as origin, certifications and uniqueness (Ríos *et al*., 2017). Given the above, it is important to carry out the renovations of the old plantations of the country with outstanding genetic materials that allow to generate a fine cocoa line differentiated by its quality.

Figure 1 shows the growth of cocoa pods from clones in renovation in Zona Bananera (clones CCN51, EET8 and TSH565). Clone CCN51 was the one that required the longest time to complete its maturation cycle and to reach an optimal stage for harvest (162 days), while clones EET8 and TSH565 required an average of 138 and 141 days, respectively.

On the other hand, according to information from Valledupar, clone CCN51 was also the one that needed the longest time to reach an optimal harvest stage (140 days); however, the time was less than 22 days compared to the time recorded in Zona Bananera. Conversely, the FLE2 and ETT8 clones needed an average of 127 days to reach an optimal stage for harvest (Figure 2).

Pinzón *et al*. (2014) mentioned that productive behavior is highly related to agroclimatic conditions, cultural practices implemented in cultivation, and sexual compatibility between clones. Cacao trees grow best in tropical areas, being cultivated from the sea level to more than 2,000 meters above sea level; however, according to García *et al*. (2009; Com. Pers.)[1], the optimal altitude range for cacao cultivation is between 400 and 1200 meters. For this reason, climatic factors influence the production of a

[1]**García J., M. Romero y L. Ortiz (2009)** Caracterización y zonificación de áreas potenciales para el cultivo del cacao en Colombia. Convenio CORPOICA - MINAGRICULTURA No 034/2003, FEDECACAO. Bogotá, Colombia. 5 p.

Table 1. Production of dry bean (kg/tree) of cocoa trees intervened with different renovation practices in Zona Bananera (C. I. Caribia) and Valledupar (El Palmar district), Colombia.

Treatment	Year 1 (kg/tree)		Year 2 (kg/tree)		Year 3 (kg/tree)	
	Caribia	Palmar	Caribia	Palmar	Caribia	Palmar
Lateral graft	0.0	0.0	0.81 a	0.24 a	0.72 a	0.50 b
Basal sucker graft	0.0	0.0	0.0 b	0.0 b	0.06 b	0.03 b

Lower case letters in the same column indicate a non-significant statistical difference (Tukey, P ≤ 0.05).

Table 2. Production of dry cocoa (kg/tree) in cacao trees intervened with different practices such as lateral grafting and grafting on the basal sucker in Zona Bananera (C. I. Caribia) and Valledupar (El Palmar district) in Colombia during year 3.

Treatment	Basal sucker	Lateral graft
	Caribia	
CCN51	0.0	1.21 c
TSH565	0.0	0.64 b
EET8	0.0	0.17 a
	El Palmar	
CCN51	0.0	0.90 b
TSH565	0.0	0.42 a
FLE2	0.0	0.64 a

Lower case letters in the same column within each location indicate a non-significant statistical difference (Tukey, P ≤ 0.05).

Table 3. Morphological characteristics and yield components of the cacao clones evaluated in Zona Bananera (C. I. Caribia) and Valledupar (El Palmar district), Colombia.

Clone	Fruit weight (g)	Fruit length (cm)	Fruit diameter (cm)	Grains per pod	Slime weight per pod (g)	GI (g)	PI
				Caribia			
TSH565	881.9 a	23.60 a	9.44 a	39.60 a	171.68 a	1.22 b	21.23 a
CCN51	621.6 a	19.82 b	9.16 a	39.00 a	178.56 a	1.53 a	17.95 a
EET8	604.0 a	20.90 ab	9.26 a	32.20 a	139.06 a	1.56 a	20.34 a
				El Palmar			
FLE2	1.188.6 a	27.30 a	9.90 a	45 a	240.0 a	1.50 a	14.78 a
CCN51	874.0 ab	23.40 b	9.72 ab	42 a	214.1 ab	1.58 a	16.38 a
EET8	616.8 b	19.32 c	8.36 b	36 a	169.0 b	1.45 a	19.41 a

Lower case letters in the same column within each location indicate a non-significant statistical difference (Tukey, P ≤ 0.05). GI: average cocoa bean weight in a sample of 100 g, PI: number of pods necessary to obtain 1 kg of dry cocoa grains.

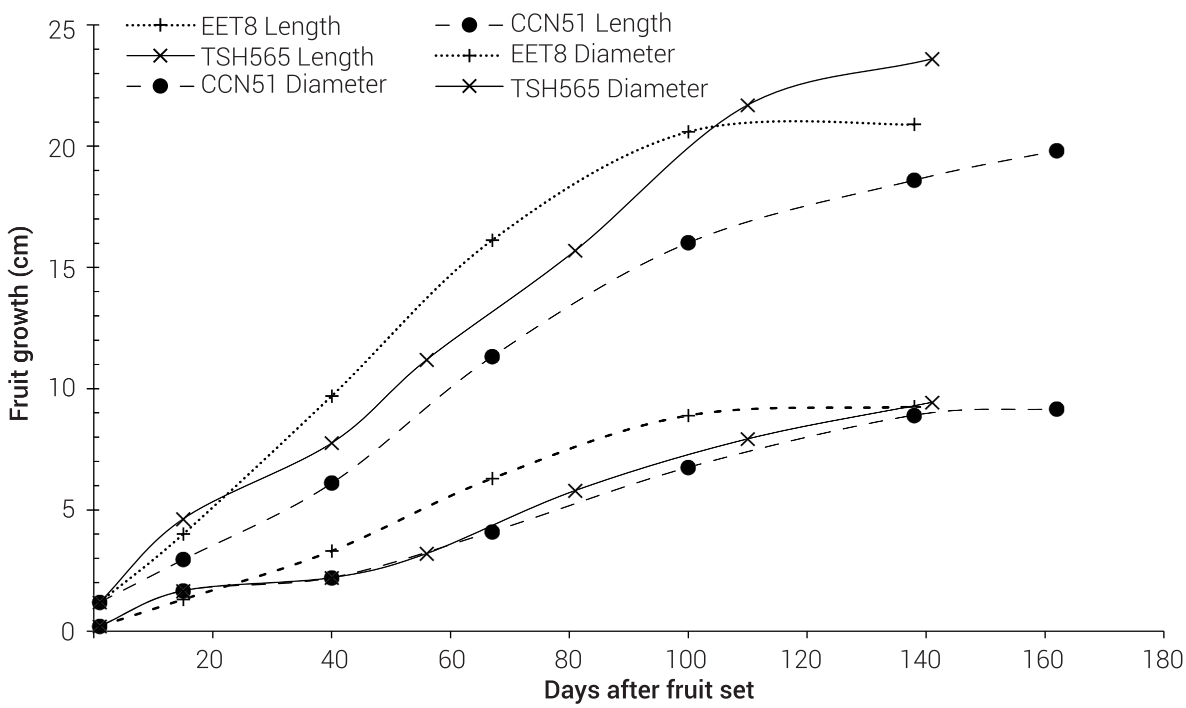

Figure 1. Fruit growth from the cucumber-shaped stage (< 10 cm) until harvest under the edaphoclimatic conditions of Zona Bananera (C. I. Caribia), Magdalena department, Colombia.

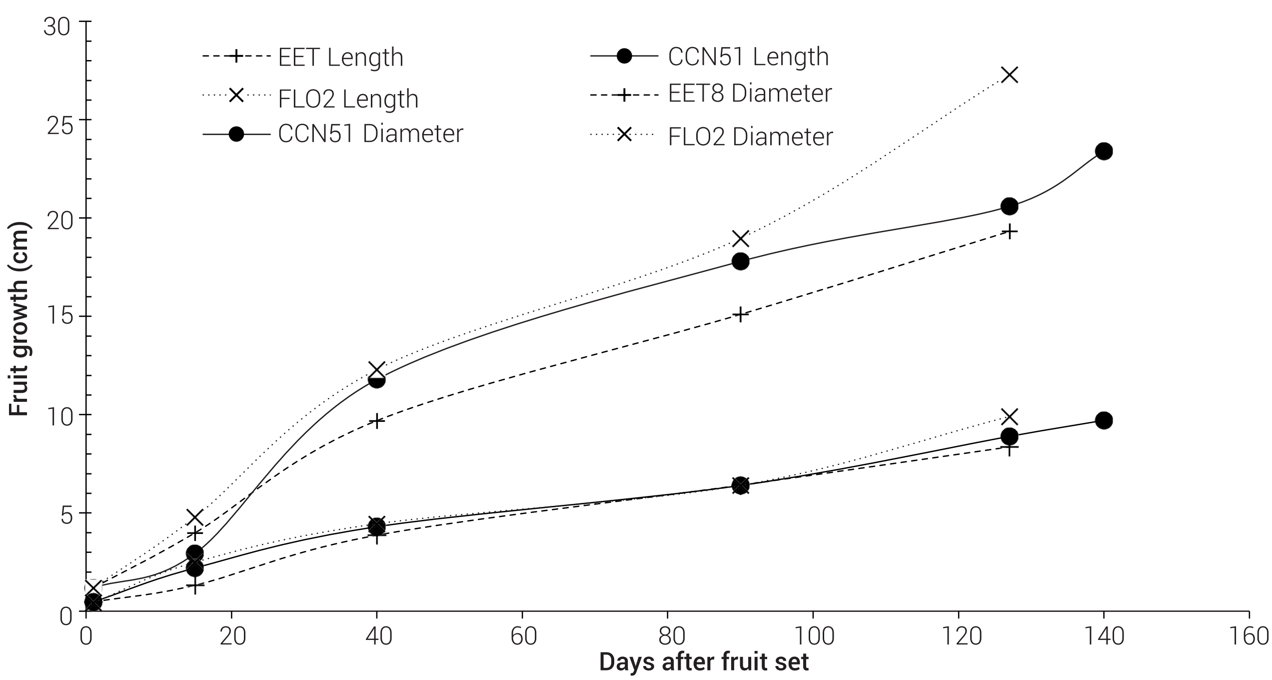

Figure 2. Fruit growth from the cucumber-shaped stage (< 10 cm) to harvest under edaphoclimatic conditions of Valledupar, El Palmar district, Cesar department, Colombia.

plantation.

According to Paredes (2003), the optimal rainfall for cacao is between 1600 and 2500 mm distributed throughout the year, and temperature should be between the following values: minimum 23 °C, maximum 32 °C, and optimal 25 °C. Comparing with the climatic conditions of Zona Bananera, a contrast is observed, in which the altitude is significantly lower (30 masl), the maximum temperature in some months can reach 38 °C, and the minimum temperature is 19 °C; however, under these conditions, cacao trees have shown good yields and behavior, which potentiates and widens the adaptation range.

Rehabilitation strategy

For the implementation of the rehabilitation strategies (structural pruning) in the locations of Zona Bananera and Valledupar, there were significant differences in the production of dry cocoa between treatments, being higher in trees intervened with structural pruning, with productions of 1.78 kg/tree (first year), 1.86 kg/tree (second year) and 1.86 kg/tree (third year) in the C. I. Caribia; and 1.49 kg/tree (first year), 1.63 kg/tree (second year) and 3.34 kg/tree (third year) in Valledupar (Table 4).

Results in both localities show a positive effect in the short term when performing structural pruning. Trees subjected to this practice showed higher production compared to trees of the control treatment without any intervention.

Trees of the control treatment were managed agronomically according to the criteria of producers, and their production in year three after the implementation of the treatments was 0.75 kg of dry cocoa/tree/year for C. I. Caribia and 1.44 kg of dry cocoa/tree/year for El Palmar district, contrary to what happened in trees intervened with structural pruning in the two localities, where productions in the third year increased compared to the control by 131 % (3.34 kg of dry cocoa/tree/year) in Valledupar, and 148 % (1.86 kg of dry cocoa/tree/year) in Zona Bananera. These data show the benefits of rehabilitation strategies, which allow the producer to recover an unproductive plantation and increase production compared to the cultivation without intervening.

Leiva-Rojas *et al*. (2019) mentioned that intensifying pruning decreases the capacity of trees to maintain fruits due to the alteration in the physiological balance, mainly in the source/sink relationship. Villacis *et al*. (2019) stated that unpruned cacao trees that reach a height greater than 10 m must be pruned after harvest to control diseases, improve grain quality and increase yields. The foregoing favored the structural rehabilitation treatment of the present investigation, since the physiological conditions of the canopy were improved.

Pruning regulates the vegetative capacity to generate terminal buds and increase flowering and fruit production (Bedker *et al*., 2004). It is important to carry out pruning taking into account the weather forecasts, in order to reduce risks due to droughts and heat waves, as occurs in the study area, where rainfall is reduced in the months of January and February, which is unfavorable for cacao.

According to Quiroz and Amores (2010), within the renovation strategies, strong prunings to the cacao treetops should be carried out eliminating 70 % of the volume to obtain a low height renewed crown (5-8 m) and stem cuts at different heights, including a) 0.3 m for trees older than 40 years, b) 1.0 m for trees between 25 and 35 years old, and c) 2.0 m in trees younger than 25 years. Assiri *et al*. (2012) demonstrated that the rehabilitation of cacao tree plantations between 20 and 30 years old increases production from 20 to 221 %, with an average rate of return that reaches 377 % compared to the control treatment; moreover, mineral fertilization contributes to an additional production percentage from 35 to 65 % from the second year in rehabilitated cacao plantations. This is in agreement with the results of Wessel and Quist-Wessel (2015), who demonstrated that rehabilitation of cacao plantations is feasible and profitable with good maintenance and integrated control of pests and diseases, increasing yield up to 40 %, from around 500 to 700 kg

Table 4. Production of dry cocoa of cocoa trees intervened with different rehabilitation practices in Zona Bananera (C.I. Caribia) and Valledupar (El Palmar district), Colombia.

Treatment	Year 1 (kg/tree)		Year 2 (kg/tree)		Year 3 (kg/tree)	
	Caribia	Palmar	Caribia	Palmar	Caribia	Palmar
Structural pruning	1.78 a	1.49 a	1.86 a	1.63 a	1.86 a	3.34 a
Control without pruning	0.52 b	0.0 b	0.82 b	0.76 b	0.75 b	1.44 b

Lower case letters in the same column indicate a non-significant statistical difference (Tukey, P ≤ 0.05).

ha^{-1} in four years of study on cacao trees of 25-30 years; additionally, the use of fertilizers increased yield to 1000 kg ha^{-1} from the third year of application onwards.

In studies conducted in West and Central Africa, Asare *et al*. (2018) found that rehabilitated cacao trees older than 15 years had a survival rate of 79 %. It is important to mention that the government of Ghana grants financial benefits to farms that decide to rehabilitate their cocoa plantations through the following criteria: the cacao plantation cannot be in a site with a slope greater than 3 %, it must not be in flooded land, near a forest or a natural reserve, the cacao plantation must be more than 25 years old and have productions of less than 200 kg ha^{-1} (O'Sullivan *et al*., 2018).

Riedel *et al*. (2019) found that the unproductive period of cacao trees is reduced to 2 years when performing a renovation pruning, compared to the method of replanting trees that extends the unproductiveness period from 3 to 5 years, suggesting that the yields of the pruned systems allow small farmers to wait for a short unproductive phase moving from monoculture to a sustainable cocoa production system.

CONCLUSIONS

The structural pruning increased the cocoa bean yield productions in Valledupar and Zona Bananera, Colombia compared to the control treatment. The lateral graft treatment showed a positive effect on earliness, compared to the basal sucker graft. CCN51 clone showed higher yields compared to the TSH565 and EET8 clones in the locality of Zona Bananera and TSH565 and FLE2 clones in Valledupar. In materials with unsatisfactory behavior it is suggested to implement crown renovations through lateral grafting and renewing the crown with more productive and better-behaving materials.

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BIBLIOGRAPHY

Abbott P. C., T. J. Benjamin, G. R. Burniske, M. M. Croft, M. C. Fenton, C. R. Kelly, ... y M. D. Wilcox (2017) Un Análisis de la Cadena Productiva de Cacao en Colombia. Universidad de Purdue y Centro Internacional de Agricultura Tropical. Cali, Colombia. 220 p.

Asare R., V. Afari-Sefa and S. Muilerman (2018) Access to improved hybrid seeds in Ghana: implications for establishment and rehabilitation of cocoa farms. *Experimental Agriculture* 54:273-285, https://doi.org/10.1017/S0014479716000247

Assiri A. A., E. A. Kakou, F. A. Assi, K. S. Ekra, K. F. Dji., J. I. Couloud A. R. Yapo (2012) Rentabilité économique des techniques de réhabilitation et de replantation des vieux vergers de cacaoyers (*Theobroma cacao* L.) en Côte d'Ivoire. *Journal of Animal and Plant Sciences* 14:1939-1951.

Bedker P. J., J. G. O'Brien and M. M. Mielke (2004) How to Prune Trees. Forest Service, United States Department of Agriculture. Washington, D. C., USA. 30 p.

Castellanos D. O. F, L. M. Torres P., S. L. Fonseca R., V. M. Montañés y A. Sánchez (2007) Agenda Prospectiva de Investigación y Desarrollo Tecnológico para la Cadena Productiva de Cacao-Chocolate en Colombia. MADR-UNAL-Cadena Productiva Cacao-Chocolate. Bogotá, Colombia. 174 p.

Cely T. L. A. (2017) Oferta productiva del cacao colombiano en el posconflicto. Estrategias para el aprovechamiento de oportunidades comerciales en el marco del acuerdo comercial Colombia-Unión Europea. *Equidad y Desarrollo* 28:167-195, https://doi.org/10.19052/ed.4211

Coulibaly S. K. and C. Erbao (2019) An empirical analysis of the determinants of cocoa production in Cote d'Ivoire. *Journal of Economic Structures* 8:5, https://doi.org/10.1186/s40008-019-0135-5

FAO, Food and Agriculture Organization Statistical database (2020) Food and agriculture data. Food and Agriculture Organization of the United Nations. Rome. http://www.faostat.fao.org/ (March 2020).

Fedecacao (2015) Guía Técnica para el Cultivo del Cacao. Sexta edición. Federación Nacional de Cacaoteros. Bogotá, Colombia. 244 p.

Jiménez J. C., I. G. Tuz J., J. N. Quevedo G. y R. M. García B. (2018) Presecado: su efecto sobre la calidad sensorial del licor de cacao (*Theobroma cacao* L.). *Revista Científica Agroecosistemas* 6:63-73.

Leiva-Rojas E. I., E. E. Gutiérrez-Brito, C. J. Pardo-Macea and R. Ramírez-Pisco (2019) Comportamiento vegetativo y reproductivo del cacao (T*heobroma cacao* L.) por efecto de la poda. *Revista Fitotecnia Mexicana* 42:137-146, https://doi.org/10.35196/rfm.2019.2.137-146

López J. L. P. (2019) Propagación de plantas de cacao mediante injertos. *Kuxulkab* 25:33-40, https://doi.org/10.19136/kuxulkab.a25n51.2923

MADR, Ministerio de Agricultura y Desarrollo Rural (2005) La Cadena del Cacao en Colombia. Una Mirada Global de su Estructura y Dinámica 1991-2005. Ministerio de Agricultura y Desarrollo Rural. Bogotá, Colombia. 49 p.

MADR-CNC, Ministerio de Agricultura y Desarrollo Rural-Consejo Nacional Cacaotero (2008) Plan Nacional de Desarrollo Cacaotero 2012-2021. Ministerio de Agricultura y Desarrollo Rural y Consejo Nacional Cacaotero. Bogotá, Colombia. 30 p.

Monteith J. L. (1972) Solar radiation and productivity in tropical ecosystems. *Journal of Applied Ecology* 9:744-766, https://doi.org/10.2307/2401901

O'Sullivan R., M. Roth, Y. A. Antwi, P. Ramirez and M. Sommerville (2018) Land and tree tenure innovations for financing smallholder cocoa rehabilitation in Ghana. 2018 World Bank Conference on Land and Poverty, March 19-23, 2018. The World Bank. Washington D. C., USA. pp:1-27. https://www.land-links.org/wp-content/uploads/2018/04/Session-08-06-OSullivan-585_paper.pdf (November, 2021).

Osorio-Guarín J. A., J. Berdugo-Cely, R. A. Coronado, Y. P. Zapata, C. Quintero, G. Gallego-Sánchez and R. Yockteng (2017) Colombia a source of cacao genetic diversity as revealed by the population structure analysis of germplasm bank of *Theobroma cacao* L. *Frontiers in Plant Science* 8:1994, https://doi.org/10.3389/fpls.2017.01994

Paredes A. M. (2003) Manual de Cultivo de Cacao. Programa para el Desarrollo de la Amazonía-Proamazonia. Ministerio de Agricultura. Lima, Perú. 83 p.

Peprah K. (2019) Cocoa plant, people and profit in Ghana. *In*: *Theobroma Cacao*. Deploying Science for Sustainability of Global Cocoa Economy. P. Aikpokpodion (ed.). IntechOpen. London, UK. pp:1-

15, https://doi.org/10.5772/intechopen.81991
Perea V. A., N. Martínez G., F. Aranzazu H. y T. Cadena C. (2013) Características de Calidad del Cacao de Colombia: Catálogo de 26 cultivares. Federación Nacional de Cacaoteros-Universidad Industrial de Santander. Bucaramanga, Colombia. 107 p.
Petithuguenin P. (1995) Regeneration: successful techniques but low adoption levels. *In*: Cocoa Cycles: The Economics of Cocoa Supply. F. Ruf and P. S. Siswoputranto (eds.). Woodhead Publishing Limited. Cambridge, UK. pp:89-106.
Pinzón U. J. O. y J. Rojas A. (2014) Guía Técnica para el Cultivo del Cacao. Quinta edición. Federación Nacional de Cacaoteros. Fondo Nacional del Cacao. Bogotá, D.C., Colombia. 194 p.
Quiroz V. J. y F. Amores P. (2010) Rehabilitación de cacaotales tradicionales. Boletín Técnico No. 150. Programa Nacional de Cacao. Estación Experimental Boliche, INIAP. Guayaquil, Ecuador. 15 p.
Ramírez G. S. I., O. López B., S. Espinosa Z. y J. M. Villarreal F. (2009) Guía Práctica para la Renovación de Plantaciones Improductivas de Cacao. Universidad Autónoma de Chiapas. Fundación Produce Chiapas. Tuxtla Gutiérrez, Chiapas. 38 p.
Riedel J., N. Kägi, L. Armengot and M. Schneider (2019) Effects of rehabilitation pruning and agroforestry on cacao tree development and yield in an older full-sun plantation. *Experimental Agriculture* 55:849-865, https://doi.org/10.1017/S0014479718000431
Ríos F., A. Ruiz, J. Lecaro y C. Rehpani (2017) Estrategias País Para la Oferta de Cacaos Especiales. Políticas e Iniciativas Privadas Exitosas en el Perú, Ecuador, Colombia y República Dominicana. Fundación Swisscontac. Bogotá, Colombia. 140 p.
Santander M. M., J. Rodríguez C., F. E. Vaillant and S. Escobar P. (2019) An overview of the physical and biochemical transformation of cocoa seeds to beans and to chocolate: flavor formation. *Critical Reviews in Food Science and Nutrition* 60:1593-1613, https://doi.org/10.1080/10408398.2019.1581726
SAS Institute (2007) Basic Statistics Using SAS Enterprise Guide: A Primer. SAS Institute, Inc. Cary, North Carolina, USA. 224 p.
Vera C. J., C. Vallejo T., D. Párraga M., W. Morales R., J. Macías V. y R. Ramos R. (2014) Atributos físicos-químicos y sensoriales de las almendras de quince clones de cacao nacional (*Theobroma cacao* L.) en el Ecuador. *Ciencia Sociales y Económicas* 7:21-34.
Villacis A., J. Alwang and V. Barrera (2019) Does the use of specialty varieties and post-harvest practices benefit farmers? Cocoa value chains in Ecuador. 2020 Annual Meeting Southern Agricultural Economics Association, February 1-4, 2020. Louisville, Kentucky, USA. 45 p. https://doi.org/10.22004/ag.econ.302303
Wessel M. and P. M. F. Quist-Wessel (2015) Cocoa production in West Africa, a review and analysis of recent developments. *NJAS - Wageningen Journal of Life Sciences* 74-75:1-7, https://doi.org/10.1016/j.njas.2015.09.001
Wood G. A. R. and R. A. Lass (2001) Cocoa. Fourth edition. Wiley-Blackwell. Hoboken, New Jersey, USA. 647 p.
Zuidema P. A., P. A. Leffelaar, W. Gerritsma, L. Mommer and N. P. R. Anten (2005) A physiological production model for cocoa (*Theobroma cacao*): model presentation, validation and application. *Agricultural Systems* 84:195-225, https://doi.org/10.1016/j.agsy.2004.06.015