Reception: **October 23, 2023** | Acceptance: **May 12, 2024** | Publication: **October 1, 2024**

Initial Renovation of Traditional Cocoa Plantation through Decoupling Pruning

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To quote this article:
López Báez, O., Isabel Ramírez, S., Hernández Escobar, C., Espinosa Zaragoza, S., & Romero Tirado, R. Renovación Inicial de Plantación Tradicional de Cacao Mediante Poda de Descopado. *Espacio I+D, Innovación más Desarrollo, 13*(38). https://doi.org/10.31644/IMASD.38.2024.a02

— Abstract—

The cocoa produced in Mexico has great cultural, environmental, and social relevance, and is cataloged by the IICO as fine-aroma cocoa, which is produced mainly by small producers in agroforestry systems in the states of Tabasco and Chiapas, however it has plantations with trees that are over 20 years old, which is one of the factors that impact the low productivity and profitability of the crop, so the objective was to validate the agronomic and economic feasibility, in the renovation of a traditional and unproductive plantation of cocoa with two forms of execution of pruning, one manual and the other mechanized. The research was carried out in a 45-year-old plantation, located in Comalcalco, Tabasco, it was carried out in two stages, in the first the two forms of execution were tested: traditional pruning with a machete and the use of a chainsaw, each on one hectare, comparing. The efficiency and cost of each one and the best result were evaluated in a second stage on 6 hectares, in the first stage the number of days of labor and the cost of the tools and supplies required were counted, and in the two stages The number of shoots formed at the base and in the upper part of the trunk, the number of bearings in flowering, fruiting and the incidence of fruits diseased by moniliasis were evaluated monthly, for which analysis of variance was performed. The results indicate that pruning with a chainsaw is more efficient and lower cost. In pruned trees, a greater number of shoots, greater flowering, and fruiting are observed; also a considerable reduction in the incidence of moniliasis.

Keywords:

Theobroma cacao L.; rehabilitation of plantations; agronomic practices.

Cocoa is considered one of the main tropical plantation crops in southeastern Mexico. According to the SIAP report (SIAP-SADER, 2020), there is a cultivated area of 59,655 ha; the states with the largest area are Tabasco and Chiapas; and of lesser relevance, Oaxaca and Guerrero. The average national production is 26,076 tons of dry beans, which is insufficient to supply domestic demand, forcing the industry to import cocoa beans from other countries. It is estimated that 70% of the cocoa consumed in Mexico is imported, either as dry beans or in the form of processed products.

In many of the cocoa-producing countries, yield per productive unit is considered low and is declining, among the causes are limited technological management, damage caused by diseases and pests, and the aging of plantations (Quiroz & Amores, 2002; Assiri et al., 2009; Adebiyi & Okunlola, 2013; Taiwo et al., 2015; Assiri et al., 2016; Santos et al., 2016; Niether et al., 2018).

A relevant aspect of the renovation is the size of the farm. In countries where producers have large plantations, the renovation does not present a major problem. However, in many countries in Mexico, producers have small production units with cocoa, since most of them only cultivate 1 to 2 hectares per family. In Mexico, cocoa is traditionally grown in permanent accompaniment of trees in a diverse agroforestry system, so that the population of cocoa trees ranges between 500 and 600 per ha, which are planted at distances of between 4 and 5 m between plants, and tops reach heights that on average range between 6 and 8 meters. 80% of existing cocoa plantations are over 40 years old, so their productive potential is limited, in addition to the losses caused by diseases, especially moniliasis (*Moniliophthora roreri*) and black spot (*Phytophthora spp*.) that cause serious crop losses, and the poor technical management of the plantation. One hectare of cocoa produces between 100 and 300 kg/year of dry cocoa, so to recover the production and profitability of this crop, the renewal of the current plantations is imminent (Ramírez 2008; Avendaño et al., 2011; Díaz-José et al., 2013; Espinosa-García et al., 2015).

In an old cocoa plantation, the renovation implies the elimination or gradual change of the old cocoa trees and their replacement with improved material with greater productive potential, while incorporating practices such as the replanting of cocoa plants, pruning, sanitary management, plant nutrition, and regulating or improving shade (Ramírez et al., 2009).

For the renewal and recovery of the production of decaying or unproductive cocoa plantations, various technological strategies have been developed, among which the pruning of the crown and reduction of height, the total renewal of the crown, the reception of the trunk, the regeneration of the tree using a basal pacifier with or without grafting, practices that must be done partially to preserve the best branches and stimulate basal shoots to be grafted with outstanding materials (Enríquez 1985; Bourgoing et al., 2009; Ramírez et al., 2009; Arvelo et al., 2017; Govindaraj & Jancirani, 2017; Gutiérrez-Brito, Leiva-Rojas & Ramírez-Pisco, 2019).

A technological alternative for recovering the productive capacity of old and unproductive plantations has been developed by the AUDES CACAO-CHOCOLATE of the Autonomous University of Chiapas (UNACH). The basis of this renewal strategy is the pruning of old trees, which allows them to reduce their height and prepares the plantation for the integration of disease management practices, especially moniliasis, fertilization, shade regulation, replanting, and grafting on basal shoots (Ramírez et al., 2009).

Taking the background described, this research aimed to validate on a commercial scale the agronomic response of a traditional cocoa plantation to the application of tree decoupling pruning as part of the renovation, as well as the estimation of the costs of this intervention.

MATERIALS AND METHODS

Test facility and plant material

In collaboration with the company Cocoa Farms Mexico SAPI de C.V. and a cooperating producer, a research module was established in July 2019 taking a 6.5-hectare traditional plantation, formed by a typical cocoa-shadow agroforestry system, located in the Emiliano Zapata community of Comalcalco, Tabasco. The plantation is 45 years old and receives a little technical traditional management (no pruning, no phytosanitary management, no fertilization). Cocoa trees come from a genetic mixture of the Trinitario type, they are planted in a frame 4x4 m between plants.

In Stage 1, the decoupling pruning was carried out between July and August 2019, the criterion applied was to cut the trunks or canopies at a height of 3 m from the ground, which is equivalent to reducing approximately 70% to 80% of the leaf area. A test was developed in which two forms of execution were compared: a) manual pruning with a machete and manual pruner was carried out on one hectare, and b) pruning with a chainsaw was carried out on an area of one hectare.

From the results obtained in this first stage, Stage 2, was carried out, in which decoupling pruning was applied to the surface with the best form of execution until the 6 ha were completed.

Witness treatment

As a control treatment, an area of 0.5 ha was left; the cocoa trees were not pruned and received the producer's traditional management.

Quantified variables

In the initial test, the number of days of labor and the cost of the tools and supplies required were counted.

To quantify the response of the trees to pruning, monthly, from the pruning carried out, the number of shoots formed at the base and the top of the trunk, the number of bearings in flowering, the fruiting, and the incidence of fruits sickened by moniliasis were recorded, for which a sample of 100 pruned trees and 100 from the control lot was taken. The data generated were processed using the analysis of variance.

Agronomic management of the experimental site

Weed control: weed control was carried out every three months by manual cutting with a machete complemented by the help of a gasoline engine weeder; the first weeding was carried out in July.

Disease management: at the time of pruning, all fruits affected by moniliasis and black spot diseases were manually removed. Subsequent sanitary management consisted of monthly sprays of 10% calcium polysulfide, based on the results reported by Ramírez et al., (2011).

Fertilization: to nourish the cocoa plants, foliar sprays are made monthly of liquid fertilizer in a concentration of 2% V/V, prepared by the technique proposed by López et al., (2015) that contains the elements: nitrogen, phosphorus, potassium, calcium, magnesium, manganese, iron, sodium, boron, zinc, and copper.

Climatic data: during the period from July 2019 to March 2020, which includes the information presented, the monthly records of total precipitation and average, maximum, and minimum temperature, generated at the National Meteorological Service (https://smn.conagua.gob.mx/es/) were taken for the CARTB station located in the municipality of Cárdenas, Tabasco (Longitude -93.41 W; Latitude 17.80 N) which is located approximately 15 km from the experimental lot.

RESULTS AND DISCUSSION

The data on the climatic conditions that were presented during the period from July 2019 to March 2020, such as rainfall and average, maximum, and minimum temperatures, are presented in Table 1, which shows that the driest months were August 2019 and March 2020; those that recorded the highest rainfall were October and September 2019. As for the average temperature, it ranged from 24.2 to 29.9 °C, the minimum from 19.8 to 24.7 °C, and the maximum from 27.8 to 35.7 °C, which are considered suitable for cocoa growth.

Table 1

Monthly precipitation and average, maximum, and minimum temperature during the period from July 2019 to March 2020

Months	Total precipitation (mm)	Average temperature (°C)	Minimum temperature (°C)	Maximum temperature (°C)
July 2019	104.0	29.3	24.4	34.2
August	50.5	29.9	24.7	35.7
September	211.1	27.3	23.9	32.7
October	367.2	27.3	23.4	31.2
November	332.5	25.0	21.2	28.8
December	125	24.0	21.1	27.8
January 2020	92.5	24.2	19.8	28.2
February	134	24.8	20.5	29.1
March	0	27.4	21.4	33.4

Note. Data recorded at the CARTB Station, of the National Meteorological Service, Cárdenas, Tabasco, Mexico. Longitude -93.41 W; Latitude 17.80 N.

The estimated costs for one hectare of the decoupling pruning application are presented in Table 2, considering the two techniques, the traditional execution with a machete and the technified one with a chainsaw. The results obtained show that the execution of this practice in a traditional way is more expensive and requires more time than when it is executed with the help of a chainsaw. The data show that the labor required in the first case was 1.9 times higher than that required when it is done with a chainsaw. The cost of the remaining tools used in both techniques is similar.

The cost of the traditional pruning technique was 6,466.00 MXN, which is higher than the estimated cost with the use of a chainsaw. In addition, the time in which this driving practice is executed is reduced, since the chainsaw allows a more efficient handling of the workforce, thus reducing working hours.

It should be noted that, in technified pruning, even when the cost of fuel and engine additive is added, and an annual depreciation cost of the equipment, the total calculation per hectare results in 4,448.70 MXN, which is 2,017.3 MXN cheaper than that of the traditional technique.

As for the acquisition cost of the chainsaw equipment, this is variable since it depends on the brand and capacity, the producer can access inexpensive price equipment. In the market, there is equipment whose price ranges from 3,000 MXN to 12,000 MXN, depending on the brand and capacity. For the analysis, a chainsaw with an estimated cost of 4,300 MXN and a useful life of 6 years was considered. In this way, an annual amortization cost of 728.9 MXN was estimated.

Table 2

Cost per hectare of applying decoupling pruning in a traditional cocoa plantation

Concept	Traditional pruning		Technified pruning	
	Amount	Cost	Amount	Cost
Labor (wage)	38	5700	20	3000
Machetes	4	280	4	280
High branch pruner	1	390	0	0
Sharpening files	8	96	4	48
Gas (l)	0	0	15	277.5
Engine additive (llitro)	0	0	0.5	45
Annual chainsaw depreciation cost	0	0	1	728.9
Cost (Mexican pesos)		$6,466.00		$∫4,448.70

Note. 1 US Dollar = 18.07 Mexican pesos

One of the immediate effects of the application of pruning is that when shading is reduced, there is a greater entry of light and better ventilation of the plantation, whose effects are remarkable since the induction of vegetative buds that give rise to shoots is stimulated, both at the base of the trunk and at the top. The results obtained presented in Table 3 show that the number of induced shoots per plant, both in the aerial part and at the base of the trunks, is higher in the pruned trees compared to the control treatment. The average number of aerial shoots was 7.5 in pruned trees and 5.0 in the control trees. In induced shoots at the base of the trunk, an average of 1.56 was quantified in pruned trees and 0.20 in the control.

Table 3

Average number of induced shoots per plant at the top and base of the trunk

Months	Induced renewals at the base of the trunk				Upper trunk renewals			
	Pruned	Control	F-value	Probability > F	Pruned	Control	F-value	Probability > F
Sep 2019	1.74	0.59	37.88	0	13.8	1.28	170.46	0
Oct	1.99	0.44	43.31	0	13.44	24.75	103.21	0
Nov	2.8	0.41	43.30	0	20.7	9.2	64.98	0
Dic	1.3	0	25.3	0	0	0.01	1	0.310
Jan 2020	1.4	0	1	0.319	0	0	0	0
Feb	0.8	0	0	0	1.9	0.01	38.75	0
Mar	0.91	0	31.50	0	2.4	0	22.41	0
Average	1.56	0.20			7.5	5.0		

Figure 1 shows the reaction of trees to pruning, the induction of shoots, both at the base of the trunk and at the top is widespread in pruned trees.

It should be noted that the shoots quantified in the control plants, from September to November, correspond to climatic effects that cause reactions in the phenology of cocoa, an effect that was also observed in surrounding plantations.

Regarding the effects on flowering, Table 4 shows that in September, October, and November, there is a flowering period that manifests itself both in pruned trees and in those of the control treatment, in which the pruning was applied, an average of 6.4 bearings with flowers and 3.8 in the control was quantified, and an extension of the flowering period until December and January was also observed.

Table 4

Average number of bearings in flowering per pruned and control plant

Months	Pruned	Control	F-value	Probability > F
Sep 2019	15.86	7.6	73.787	0
Oct	10.15	13.62	29.964	0
Nov	15	5.5	119.913	0
Dec	2.9	0	22.779	0
Jan 2020	0.96	0	3.964	0.048
Feb	0.05	0	1	0.319
Mar	0	0	0	0
Average	6.4	3.8		

Due to the structure of the traditional agroforestry system in which cocoa is grown under the permanent shade of trees, often with excessive shade to which is added the self-shading effect generated by cocoa trees, which increases with age and the poor management of the tree crown and height, it is undoubtedly that the system influences the phenological behavior of the crop (Blaser et al., 2018). In these conditions of excessive shade, the emission of leaf shoots and flowering is less intense and less frequent than those observed in plantations with less shade, a criterion that is consistent with the reports of various investigations (Ampofo & Bonaparte, 1981; Enríquez, 1985; Ken-Ichi, da Silva & Alvim, 1997; Bouley, Somarriba & Olivier, 2000; Vanhovea, Vanhoudtb & Van Dammea, 2016) which indicate that in very shaded plantations the leaf regrowth and flowering are of less intensity and frequency than in cocoa trees with less or little shade; if the age of the plantation is added to this effect, the expected yields of cocoa per hectare are not high.

According to Niether et al. (2018), cocoa agroforestry systems, in addition to providing shade, create a suitable microclimate for cocoa development. According to these authors, it is necessary to consider the time and intensity to balance light and water availability in case of pruning, since this generates seasonal changes in temperature and humidity with effects on cocoa phenology and production.

Figure 1. Induction of vegetative tissue (shoots) as a reaction of cocoa trees to de-copping pruning

Regarding the effect of pruning on fruiting, Tables 5 and 6 show the average number of chilillos per tree, referred to as young fruits less than two months old, and the production of cobs or developed fruits per tree, during the period from September 2019 to March 2020. In general, pruned trees showed higher fruiting compared to the control.

It is important to note that even though decoupling pruning considerably reduces the productive area of the trees, the productive capacity of these trees exceeded the response of the control treatment. In pruned trees, an average of 8.51 chilillos and 2.74 healthy cobs per plant were quantified, while in the control, the values reached were 4.2 chilillos and 0.83 cobs per tree, respectively.

An additional important effect is the reduction in the incidence of diseased fruits due to moniliasis as an effect of pruning. The average number of infected chilillos by moniliasis in pruned trees was 0.32, while in the control, an average of 2.7 infected chilillos was quantified, which is equivalent to a reduction of the disease by 88.14 %. In the case of developed fruit, a similar tendency was observed; in the control, an average of 2.16 diseased fruit per tree was quantified, while in the pruned trees only 0.02 was quantified, equivalent to a 99.02% reduction of the disease. One of the effects of pruning is to favor better aeration and greater air circulation in the plantation, which reduces humidity or prevents its accumulation, thus counteracting the microclimate that favors conditions for M. roreri to grow (Ramirez, 2008, Ochoa-Fonseca, et al., 2017).

Table 5

Mean number of healthy and diseased chilillos (fruit less than 2 months old) per tree in pruned and control treatments

Months	Healthy chilillos				Infected chilillos			
	Pruned	Control	F-value	Probability > F	Pruned	Control	F-value	Probability > F
Sep 2019	1.74	2.79	35.9	0	1.31	3.17	26.9	0
Oct	1.99	7.69	80.5	0	0.3	4.7	191.1	0
Nov	7.90	8.64	0.51	0.474	0.22	8.9	280.4	0
Dec	12.17	4.45	26.7	0	0.19	0.94	4.96	0.027
Jan 2020	18.90	2.94	77.2	0	0.07	0.43	5.24	0.023
Feb	11.30	2.17	60.3	0	0.12	0.34	3.01	0.084
Mar	5.57	0.6	84.9	0	0.02	0.13	3.39	0.067
Average	8.51	4.2			0.32	2.7		

Table 6

Average number of healthy and infected cobs per tree in pruned and control treatments

Months	Healthy cobs				Infected cobs			
	Pruned	Control	F-value	Probability > F	Pruned	Control	F-value	Probability > F
Sep 2019	0.05	0.14	1.966	0.162	0.04	1.04	29.66	0
Oct	0.4	0.6	2.223	0.138	0.06	1.23	26.71	0
Nov	1.35	0.71	4.937	0.027	0	6.09	190.6	0
Dec	1.17	1.38	0.365	0.546	0.07	3.47	56.95	0
Jan 2020	1.81	1.08	3.433	0.065	0	0.61	16.03	0
Feb	7.8	1.3	63.419	0	0	2.01	31.97	0
Mar	6.6	0.61	83.065	0	0	0.67	13.17	0
Average	2.74	0.83			0.02	2.16		

Figure 2 shows the effects of pruning in pruned trees on the induction of flowering and fruiting.

Figure 2. Effects of topping pruning on flowering and fruiting induction in treated trees

Given the importance of cocoa and the value of the cocoa-chocolate chain, the production and profitability of the crop are of great importance, especially for small producers. Previous experiences related to plantation management (Enriquez, 1985; Quiroz & Amores, 2002) indicate that the productive life of a plantation from an economic point of view is between 20 and 25 years. At this stage, the trees are generally very tall, many of them have died or are decayed or infected, and there is excessive shading (Assiri et al., 2009; Niether et al., 2018). In addition, diseases such as black rot (*Phytophthora* spp.) and Moniliasis (*Moniliophthora* roreri) have accumulated their effects as evidenced by the damage in various parts of the tree and the damage caused to crops (Ramirez, 2008). In general, yields are low, so to restore production it is necessary to renew the plantation.

However, in addition to the technical implications, renovation presents economic, social, and cultural repercussions (Bourgoing et al., 2009; Assiri et al., 2009; Assiri et al., 2016; Santos et al., 2016; Ogunlade et al., 2017). There is a general perception of grower opposition to changing traditional management systems and renewing the old plantation. In addition, the financial aspect occupies an important place, since it is common that the producer does not have the resources to finance the costs of plantation renovation. In addition, future income will depend on the size of the farm, the recovery of the plantation and the yields to be achieved after the intervention.

Two strategies can be used to renovate an old cocoa plantation: the first consists of cutting the old trees and planting a new plantation, which makes it possible to change the tree population, the planting design, and the genetics of the cultivated material. Generally, this is observed in countries where cocoa is grown on large extensions; renovation consists of the felling of the old plantation, followed by replanting with improved material.

For producers who have small extensions of crops, as is the case of Mexico and most Latin American producing countries, the strategy is to take advantage of the existing plantation and through management change or rejuvenate the aerial structure of the trees. In this sense, to rejuvenate old trees, pruning becomes a crucial practice through which the aerial structure is changed, the height of the trees is reduced and above all the productive tissue is renewed, which leads the plant to a greater photosynthetic activity and, therefore, a better production (De Almeida & Valle, 2007; DaMatta, 2007). From the social point of view, the technique is adaptable to the conditions of each producer, and a plan can be established to partially renew, for example, a determined number of plant rows, in a staggered manner, according to the producer's available resources.

Pruning as a management practice for adult cocoa trees has effects on plant phenology as well as on some yield components. Previous research has shown that, for optimal production, it is necessary to apply proper tree management to maintain an appropriate canopy and height (Enriquez, 1985; Quiroz & Amores, 2002; Ramirez et al., 2009; Arvelo, 2017; Govindaraj & Jancirani, 2017; Gutierrez-Brito, Leiva-Rojas & Ramirez-Pisco, 2019).

On the other hand, pruning opens the possibility of incorporating other technological components such as sanitary management and fertilization (Quiroz & Amores, 2002; Ramírez et al., 2011; López et al., 2015). To increase the population of cocoa trees, Enriquez (1985), Adegbola (1988), and Moreira (1994) suggest sowing plants after pruning to increase the density by modifying the planting pattern or arrangement. Also, the shoots or "suckers" that are induced at the base of pruned trunks by pruning can be used to obtain new plants, which may or may not be grafted with improved material (Enriquez, 1985; Napitulu & Pamin, 1994; Moreira, 1995; Ramirez et al., 2009; Quiroz & Amores, 2002; Adebiyi & Okunlola, 2013; Arvelo et al., 2017).

Regardless of the renovation strategy chosen by the producer, pruning old trees will be an essential activity, and its application will depend to a large extent on the size of the farm, the condition of the trees, and the available resources. The results presented show that regardless of the quantity, intensity, and proportion of trees to be pruned, the incorporation of technology such as the use of chainsaws results in more efficient work in time and lower cost.

CONCLUSIONS

The pruning of old cocoa trees with a chainsaw was more efficient in terms of yield, time, and lower cost than traditional pruning using a machete as a cutting tool.

Pruning induces in a short time the formation of vegetative and reproductive tissue in the plants, which is manifested in the emission of new shoots in the upper part and at the base of the trunks, and there is a greater flowering and fruiting per tree. Pruning also induces a considerable reduction in the incidence of moniliasis-infected fruit.

The technique of decoupling pruning by incorporating the use of a chainsaw presents an adaptable alternative for small producers due to the reduction in costs, less labor, and greater time efficiency.

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ACKNOWLEDGMENTS

To Cocoa Farms México and the cocoa producers of the Emiliano Zapata community of Comalcalco, Tabasco, for the support and facilities provided.