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Translated from the original in spanish **Original article**

Quantification of biomass in cocoa systems (Theobroma cacao L.) in the Duarte province, Dominican Republic

Cuantificación de biomasa en sistemas cacaoteros (Theobroma cacao L.) de la provincia Duarte, República Dominicana

Quantificação de biomassa em sistemas de cacau (Theobroma cacao L.) da província Duarte, República Dominicana

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ABSTRACT

Theobroma cacao (cocoa) in the Dominican Republic is one of the main export items, registering a sustained growth in the last five years. There are more than 36,000 producers in the country, indirectly benefiting more than 300 thousand people. The country has great potential for cocoa production, but due to the lack of fertilization of the plantations combined with the lack of information on the contribution of nutrients from the mineralization of biomass in the production systems, low yields are presented. The study was carried out in the Duarte province in the period from July 2016 to June 2017, with the objective of quantifying the biomass production in four agroforestry systems: cocoa in monoculture (C), cocoa plus *Erythrina* spp (C+ Am), cocoa plus *Persea americana* (C+Ag), and cocoa plus citrus (C+Ci). A multifactorial experimental design 4x15x12 was used: with four agroforestry systems, in fifteen locations and twelve sampling dates, where each farm was considered as a replicate. Four pipe and sack mesh traps were installed per farm, with an area of 1 m^2. The average biomass by location and date was analyzed by analysis of variance and Duncan test (P = 0.05%). The highest average biomass production was obtained in C + Am with 49.3 T ha^{-1} $year^{-1}$ (41.08 % of the total). It was followed by system C with 27.02 T ha^{-1} $year^{-1}$, C + Ag with 22.2 T ha^{-1} $year^{-1}$ and C + Ci with 17.2 T ha^{-1} $year^{-1}$. The annual net production was 120 T ha^{-1} $year^{-1}$, of which 115.2 T ha^{-1} $year^{-1}$ was attributable to the species under study, and 4.2 T ha^{-1} $year^{-1}$ to other species. The values demonstrate a high biomass production in agroforestry systems associated with cocoa.

Keywords: system agroforestry, carbon, shade, organic matter, waste, mulch.

RESUMEN

Theobroma cacao (cacao) en República Dominicana es uno de los principales rubros de exportación, registrando un crecimiento sostenido en los últimos cinco años. Son más de 36.000 productores en el país, beneficiando indirectamente a más de 300 mil personas. El país tiene un gran potencial para la producción de cacao, pero debido a la falta de fertilización de las plantaciones combinado con la falta de información sobre el aporte de nutrientes provenientes de la mineralización de biomasa en los sistemas de producción, se presentan bajos rendimientos. El estudio se desarrolló en la provincia Duarte en el período de julio 2016 a junio 2017, con el objetivo de cuantificar la producción de biomasa en cuatros sistemas agroforestales: cacao en monocultivo (C), cacao más *Erythrina spp*.(C+ Am), cacao más *Persea americana* (C+Ag), y cacaos más cítricos (C+Ci). Se usó un diseño experimental en arreglo multifactorial 4x15x12: con cuatro sistemas agroforestales, en quince localidades y doce fechas de muestreo, donde se consideró a cada finca como una repetición. Se instalaron cuatro trampas de tubo y maya de saco por finca, con un área de 1 m^2. La biomasa promedio por ubicación y fecha se analizó mediante análisis de varianza y prueba de Duncan (P=0,05 %). La mayor producción promedio de biomasa se obtuvo en C+Am con 49,3 T ha^{-1}año^{-1} (41,08 % del total). Le siguió el sistema C con 27,02 T ha^{-1} año^{-1}, C+Ag con 22,2 T ha-1año^{-1} y C+Ci con 17,2 T ha^{-1}año^{-1}. La producción neta anual fue de 120 T ha^{-1}año^{-1}, siendo 115,2 T ha^{-1}año^{-1} atribuible a la especie en estudio, y 4,2 T ha-1año^{-1} a otras especies. Los valores demuestran una alta producción de biomasa en los sistemas agroforestales asociados al cacao.

Palabras clave: sistema agroforestal, carbono, sombra, materia orgánica, residuos, mantillo.

RESUMO

Theobroma cacao (cacau) na República Dominicana é um dos principais itens de exportação, registrando crescimento sustentado nos últimos cinco anos. São mais de 36 mil produtores no país, beneficiando indiretamente mais de 300 mil pessoas. O país tem grande potencial para a produção de cacau, mas devido à falta de fertilização das plantações aliada à falta de

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informações sobre a contribuição dos nutrientes provenientes da mineralização da biomassa nos sistemas de produção, ocorrem baixos rendimentos. O estudo foi desenvolvido na província Duarte no período de julho de 2016 a junho de 2017, com o objetivo de quantificar a produção de biomassa em quatro sistemas agroflorestais: cacau em monocultura (C), cacau mais Erythrina spp. (C+ Am), cacau mais Persea Americana (C+Ag) e mais cacau cítrico (C+Ci). Foi utilizado um delineamento experimental em arranjo multifatorial 4x15x12: com quatro sistemas agroflorestais, em quinze localidades e doze datas de amostragem, onde cada fazenda foi considerada uma repetição. Foram instaladas quatro armadilhas tipo tubo e rede por fazenda, com área de 1 m^2. A biomassa média por local e data foi analisada por meio de análise de variância e teste de Duncan (P = 0,05 %). A maior produção média de biomassa foi obtida em C+Am com 49,3 T ha-1ano^{-1} (41,08 % do total). Seguiu-se o sistema C com 27,02 T ha^{-1}ano^{-1}, C+Ag com 22,2 T ha^{-1} ano^{-1} e C+Ci com 17,2 T ha^{-1} ano^{-1}. A produção líquida anual foi de 120 T ha-1ano^{-1}, sendo 115,2 T ha-1ano^{-1} atribuíveis às espécies em estudo e 4,2 T ha-1ano^{-1} às demais espécies. Os valores demonstram uma elevada produção de biomassa nos sistemas agroflorestais associados ao cacau.

Palavras-chave: sistema agroflorestal, carbono, sombra, matéria orgânica, resíduos, cobertura morta.

INTRODUCTION

In the Dominican Republic, there are about 150,000 hectares of cocoa planted, with about 36,000 direct producers and 36,236 registered farms (IICA, 2023), with an average yield level between 390 kg ha^{-1} and 436 kg ha^{-1} of dry cocoa (IICA, 2017, 2023). CODESPA (2024) indicates that annual yields can fluctuate between 500 to 600 kg ha^{-1} of dry cocoa, with even 5% of producers above that, which is still low when compared to other countries with clonal plantations in Ecuador and Trinidad and Tobago with 1000 and 1,500 kg ha^{-1}, respectively (CODESPA, 2024).

Among the main cocoa producing regions of the country are the agricultural regions of the Northeast, which has 61% of the production; East (13%), Central (10%), North (9%) and North-Central (7%). Cocoa plantations cover 13 % of the Dominican forest cover, generating environmental services such as water generators, carbon dioxide consumers and habitats for fauna (Ministry of Agriculture, 2014).

Cocoa production is sensitive to environmental conditions: the cocoa tree in the production phase demands large quantities of nutrients, which, if not supplied in time, will be expressed in reduced relative yields (Rodríguez-Velázquez *et al* ., 2022). However, the required quantities of these nutrients are not found in the soils, which is why their application is mandatory (Rodas *et al*., 2022). In the country, P, K and Mg are the nutrients that limit the productivity of the grain (González-González, 2020). Dominican cocoa plantations are production systems with low use of inputs (pesticides and fertilizers), where around 95% of producers do not fertilize their plantations and the remaining 5% who do so, do not do so continuously or systematically, nor based on technical recommendations, after soil analysis (Batista, 2009).

Thus, an alternative for fertilization is the incorporation of organic matter (OM) as a contribution to the soil and the corresponding mineralization and immobilization, key processes in the nitrogen (N) cycle and other nutrients in the soil-plant system (Villar-Santamaria, 2023). These processes are highly complex, since organic matter is a very heterogeneous mixture, consisting mainly of plant remains, and associated with the activity of microorganisms and environmental variations such as temperature, humidity, pH and the energy state of the soil (Villar-Santamaria, 2023). A large amount of plant waste is generated in cocoa monocultures; however, its slow decomposition does not allow a timely delivery of nutrients to the plants, much less in unfertilized cocoa plantations (Mora-Ramos and Cabrera-Rubiano, 2020).

One contribution of OM is the leaf litter of other associated species that compensates the nutritional requirements of the different cocoa production systems (cocoa and fruit trees, for example), which is estimated at 40% (Mora-Ramos and Cabrera-Rubiano, 2020). In countries such as Colombia, Costa Rica, Trinidad and Tobago, Venezuela and Ecuador, cocoa plantations have been studied from this perspective, with the aim of having a database that allows quantifying the flow of organic waste in plantations and their contributions to nutrient recycling. In Colombia, Mora-Ramos and Cabrera-Rubiano (2020) reported up to approximately 20 T/ha/year of leaf litter production in cocoa systems associated with *Acacia mangium* and *Anadenanthera peregrina*. Thus, in cocoa-producing localities around the world, information is available related to the contributions of biomass, organic matter and nutrients.

In the Dominican Republic, it is necessary to obtain this information so that producers can implement a fertilization program for their plantations based on knowledge of the contributions of OM and nutrients that enter the system, soil-climate conditions and nutritional requirements of the crop. Therefore, this study quantified the contribution of biomass, mainly leaf litter, of cocoa production systems (crop + associated plants) in the country to generate technical information for its proper management.

MATERIALS AND METHODS

Study area

The study was carried out in the Duarte province, between 19°182 N and 70°152 W, starting in July 2016 and ending in June 2017, with the distribution of the plots in the municipalities and municipal districts as indicated in Table 1.

Table 1. - *List of farms, locations, producers and study areas*

No.	Municipality	Community	Producer	Hectares
1	Hostos (DM)	The Gina	Harry Disgust	101
2	Pimentel	Campeche Up	Jesus Remigio	70
3	San Francisco	Long Bush	USA. Mata Larga (IDIAF)	63
4	The Rock (DM)	The Table	Victor Garcia	38
5	The Rock (DM)	Pontoon	Oriol Negrin	31

6	The Rock (DM)	The Rock	Jorge Luis Ramos	16
7	San Francisco	The Fence	Dr. Pedro Compre	16
8	Castle	Magua	Faustino Hernandez	13
9	Castle	The Mahogany	Isaac Ureña Hernandez	8
10	San Francisco	The Jewel	Awilda Reyes	5
11	Pimentel	San Felipe Up	Peter Hernandez	3
12	Pimentel	San Felipe Down	Hector Hernandez	2
13	Castle	The Cafes	Ramon Emilio Rubio	1
14	The Rock (DM)	I thought	Juan Gomez Castillo	1
15	Villa Riva	The Indian	Rafael Rojas	1
Total	15	15	15	369

The average annual temperature along the route traced (Figure 1) reached 26.2° C, an average annual relative humidity of 80 %, with an average annual rainfall of 1,687 mm, and wind speeds between 8-11 km hour^{-1} for the study period (AccuWeather, 2017).

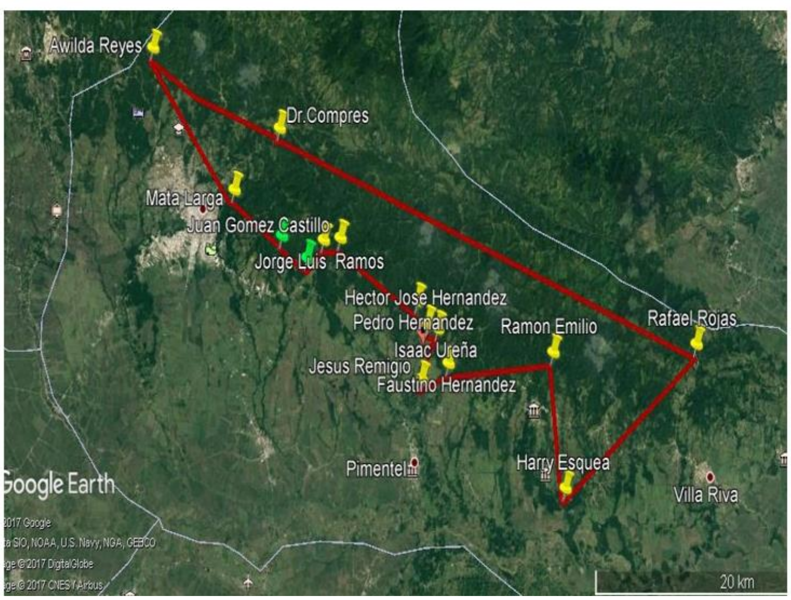

Figure 1. *- Location of the fifteen farms where the research was carried out, identified by the name of the owner. Prepared by the authors*

Experimental design

A survey was carried out on the biomass from *Theobroma cacao*, *Persea americana*, citrus fruits (sweet orange - *Citrus sinensis* -, sour orange - *C. aurantium* -, lemon - *C. limon* L-, grapefruit - *C. paradisi* -) and *Erythrina spp*., from the fifteen farms already mentioned on the dates already cited (Figure 2A), using a 4x15x12 multifactorial arrangement (system x locations x dates), where each farm became a replicate. The systems were: 1. cocoa in monoculture (C), 2. cocoa plus *Erythrina spp*. (C+ Am), 3. cocoa plus Persea americana (C+Ag), and 4. cocoa plus citrus (C+Ci) . Each system had 15 replicates for a total of 60 per trap. Following the methodology of Jaimez and Franco (2000), four traps were placed in each plot. They consisted of a 1 m^2 pipe frame with legs at the corners, with a diameter of 20 cm, and a height from the frame of 30 cm, for a total height of 50 cm, covered by a sack mesh to facilitate the drainage of rainwater and prevent anaerobic decomposition of the biomass (Figure 2C). Every month, the plant material was collected in each trap, separated, weighed wet and dry, and packed (Figure 2B). The weight was expressed in metric tons per hectare.

The traps were placed 1 to 3 m away from the tree trunks. The source species of the collected plant biomass were identified at the Mata Larga Experimental Station, IDIAF.

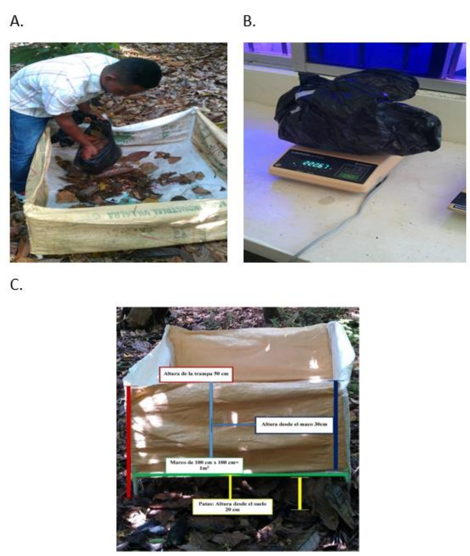

Figure 2. *- A. Lifting of biomass from Theobroma cacao, Persea americana, citrus (sweet orange C. sinensis -, sour orange C. aurantium -, lemon C. limon L-, grapefruit C. paradisi-) and poppy*

(Erythrina spp.). B. Weighing of both wet and dry biomass. C. 1 m² quadrangular trap for collecting plant biomass from the study trees.

Variables

The response variable was the dry aboveground biomass collected by each trap at each location by date. It was represented almost exclusively by leaf litter from the agroforestry systems evaluated. The data are expressed in units of mass per m^2.

Experiment management

T. cacao plantations L. were pruned, weed control was carried out manually twice a year. No fertilizers or insecticides were applied. Fruit harvesting took place ten to fifteen days during the harvest periods. Those plants where traps were placed were not pruned to avoid alteration of the fallen biomass. Fruit trees such as a *Persea americana* were not subject to agronomic management, but *Erythrina spp* was not use.

Data analysis

Levene's test was performed for homogeneity. The data were transformed to square root ranges, since the variables did not comply with normality and homogeneity of variance (0.01 %). The transformed data were subjected to analysis of variance with a Duncan Multiple Range comparison at 0.05% using *Infostat statistical program* (Di Rienzo *et al.,* 2016).

RESULTS AND DISCUSSION

Biomass contribution by shade system

Erythrina spp. as a shade tree had a contribution of 4,134.6 Kg ha^{-1} of biomass, exceeding by 82% the second biomass production system studied: cocoa alone. The citrus shade produced the lowest amount of biomass with 1,426.4 Kg ha^{-1}, 62% lower than the cocoa alone system (Table 2).

Table 2. *-Average monthly contribution of biomass according to the species associated with cocoa (Kg ha-1)*

Species	Average biomass produced	PRM
Citrus fruits (sweet orange – *C. sinensis* -, sour orange – *C. aurantium* -, lemon – *C. limon* L-, grapefruit – *C. paradisi* -)	1,426.4	a
***Persea americana*)**	1,804.2	b
Theobroma cacao	2,271.1	c
Erythrina spp.	4,134.6	d

PRM= Duncan multiple range test at 0.05%.

Biomass production from cocoa agroforestry systems

Cocoa cultivation contributed 27 T $ha^{-1}year^{-1}$ of biomass, *Erythrina spp.* cultivation 49.3 T ha^{-1} $year^{-1}$, *P. americana* cultivation 22.2 T ha^{-1} $year^{-1}$ of biomass, and citrus cultivation 17 T ha^{-1} $year^{-1}$. The biomass coming from different unidentified plants was 4.2 T ha^{-1} $year^{-1}$. The total biomass in the cocoa production systems during the year was 120 T ha^{-1}. Thus, poppy contributed 41.15 % of the biomass produced, cocoa 22.5 %, *P. americana* 18.51 %, and citrus 14.18 %. The remaining 3.57 % corresponds to unidentified plants.

These are very high values of biomass production collected in pitfall traps, mainly leaf litter, when compared with studies in cocoa agroforestry systems in the Latin American tropics (Table 3). In fact, the reported C+Am value is the highest recorded for an agroforestry system of this type, reaffirming that this association is the most highly productive of leaf litter in cocoa systems, and one of the most popular for its multiple ecosystem benefits along with laurel.

Table 3. *- Production of biomass collected in pitfall traps, mainly leaf litter, in cocoa agroforestry systems in the Latin American tropics*

System	Biomass (T $ha^{-1}year^{-1}$)	Country	Fountain
Cocoa + *Erythrina* spp.	35	Costa Rica	Fassbender *et al.* (1990)
Cocoa + *C. alliodora*	28	Costa Rica	Fassbender *et al.* (1990)
Cocoa	20.3	Colombia	Mora-Ramos and Cabrera-Rubiano (2020)
Cacao + *Anadenanthera peregrina*	16.2	Colombia	Mora-Ramos and Cabrera-Rubiano (2020)
Cocoa + *Acacia mangium*	15	Colombia	Mora-Ramos and Cabrera-Rubiano (2020)
Cocoa + *Inga* sp.	12.3	Ecuador	Barragan (2008)
Cacao + *Schizolobium parahybum*	11.6	Ecuador	Barragan (2008)
Cocoa + *Pouteria sapota*	10.9	Venezuela	Jaimez and Franco (2000)
Cocoa + legumes	9.4	Mexico	Guadalupe *et al.* (2009)
Cocoa + *P. americana*	8.9	Venezuela	Jaimez and Franco (2000)
Unspecified agroforestry cocoa	8.4	Costa Rica	Alpizar *et al.* (1985)
Cocoa + fruit trees	8.1	Mexico	Guadalupe *et al.* (2009)
Cocoa + *P. americana* + *Annona muricata*	7.3	Venezuela	Jaimez and Franco (2000)
Unspecified agroforestry cocoa	6.7	Bolivia	Rivero and Merida (2009)
Cocoa + *Erythrina spp.*	6.5	Costa Rica	Alpizar *et al.* (1985)
Cocoa + *Cordia spp.*	5.8	Costa Rica	Alpizar *et al.* (1985)
Cocoa + *Myrica spp.*	5	Ecuador	Barragan (2008)

Cocoa + *Dalbergia glomerata*	4.8	Honduras	Infocacao (2015)
Cocoa	4.4	Bolivia	Rivero and Merida (2009)
Cocoa + *Dipterix panamensis*	4.4	Honduras	Infocacao (2015)
Cocoa + *Guarea grandifolia*	4.3	Honduras	Infocacao (2015)
Cocoa + *Terminalia superba*	4	Honduras	Infocacao (2015)
Cocoa + *Cojoba arborea*	2.8	Honduras	Infocacao (2015)
Cocoa	1.5	Colombia	Leiva-Rojas (2012)
Average	16		

Theobroma cacao in all cases. Source: Prepared by the authors.

These findings agree with the studies by Leiva-Rojas (2012), Mora-Ramos, and Cabrera-Rubiano (2020), where agroforestry systems double the leaf litter production of cocoa monoculture. If we take into account the high nutritional requirements of cocoa and self-sufficiency of up to 40%, as a contribution of the OM of the system itself. In addition to the ecosystem service of provision of forest species, this becomes even more relevant in the productive balance of the system. However, the sole provision of OM is insufficient to cover the nutrient demands of the plant, especially in minor elements that are poor or non-existent in the plant tissues of the leaf litter, so the nutrition of an agroforestry crop should not be entrusted solely to this source.

Regarding the Dominican Republic, it is confirmed that the country's low production, which averages half to a third of the yield of countries such as Ecuador (CODESPA, 2024), contrasts with its comparative advantages such as the high contribution of OM found in this study. The above implies stating that the poor management of cocoa plantations, mainly in the timely supply of essential nutrients such as P, K and Mg, these limit the yields in dry cocoa, being the bottleneck that prevents the expression of the genetic potential of the cultivars.

For the above reasons, the poor fertilization culture of cocoa production systems on the island (which includes Haiti), which is only around 5% of registered farms (Batista, 2009), must begin with the expansion of the practice of fertilization associated with a greater flow of waste in cocoa plantations and the country, with special emphasis on the contribution of essential nutritional elements for cocoa.

CONCLUSIONS

Cocoa production systems in association with perennial forest species, in this case, cocoa agroforestry systems produce approximately twice as much OM, mainly as leaf litter, than monoculture systems.

In the association of cocoa plus *Erythrina spp*., it is confirmed that the most productive agroforestry system of residues and MO is the combination of *T. cacao* and *Erythrina spp.* with a production of approximately 50 T ha^{-1} $year^{-1}$.

Poor nutrient management in cocoa plantations with key elements such as P, K and Mg limit dry cocoa yields. This prevents the expression of the potential of cocoa cultivars in the Dominican Republic, and not the levels of available OM.

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The authors declare not to have any interest conflicts.

***Contribution of the authors*:**

The authors have participated in the writing of the work and analysis of the documents.