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Effect of fertilization on cacao (*Theobroma cacao* L) seedlings in the southwest of Colombia.

Efecto de la fertilización en plántulas de cacao (*Theobroma cacao* L.) en el sur oeste de Colombia

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ABSTRACT

Inadequate understanding of the meaning of cocoa seedlings fertilization during the nursery stage is a significant problem in the performance and profitability of cacao crops, as it negatively affects cacao yield. Therefore, it is crucial to make adequate fertilization plans and, on the other hand to replenish the nutrients extracted and preserve soil health. This study was conducted to evaluate the effect of different doses of N, P, K, Ca and Mg fertilizers on the growth and development of cocoa (*Theobroma cacao* L.,) seedlings (FEAR-5), under nursery conditions. A completely randomized design was used, with five treatments and three replications. Treatments were defined according to fertilization recommendations for cocoa seedlings (2 to 6 months old) (i.e., N 2.4g; P 0.6g; K 2.4g; Ca 2.3g; and Mg 1.1g) with this we came up with five treatments based on soil analysis: Treatments: T1= recommended fertilization, T2= based on a soil analysis and the addition of 7 g Ca and 3.2 g Mg; T3= 50% of recommended fertilization; T4= 150% of recommended fertilization; and T5= no fertilizer application. Our results indicate that the plants subjected to T2 showed better performance in the variables plant height, stem diameter, leaf area, number of leaves, leaf area, fresh and dry weight of the stem, fresh and dry weight and total fresh and dry weight of the seedlings. In economic terms, T4 had the highest costs. The highest profitability was recorded by T5, despite the low performance in the physiological variables.

Keywords: soil health**,** cocoa profitability; soil nutrients; nursery, pacific coast.

RESUMEN

La falta de conocimientos sobre la importancia y métodos de aplicación de la fertilización del suelo es un problema determinante en el desarrollo del cultivo del cacao, debido a que afecta negativamente al rendimiento de este. Por lo tanto, es crucial realizar planes de fertilización adecuados y por otra parte reponer los nutrientes extraídos y conservar la salud del suelo. Este estudio se realizó con el objetivo de evaluar el efecto de diferentes dosis de fertilizantes N, P, K, Ca y Mg sobre el crecimiento y desarrollo de plántulas de cacao (Theobroma cacao L.,) (FEAR-5), bajo condiciones de vivero. Se utilizó un diseño irrestricto al azar, con cinco tratamientos y tres repeticiones que se definieron teniendo en cuenta las recomendaciones de fertilización (i.e., N 2.4g; P 0.6g; K 2.4g; Ca 2.3g; y Mg 1.1g) para plántulas de cacao de 2 a 6 meses de edad para otras regiones colombianas: Tratamientos: T1= fertilización recomendada, T2= basado en un análisis de suelo del sustrato, se consideró el contenido nutricional del sustrato y la adición de Ca (7g) y Mg (3,2g) , T3= 50% de la fertilización recomendada, T4= 150% de fertilización recomendada; y T5= sin aplicación de fertilizantes. Nuestros resultados indican que las plantas sometidas al T2 presentaron mejor desempeño en las variables altura de la planta, diámetro del tallo, área foliar, número de hojas, área foliar, peso fresco y seco del tallo, peso fresco y seco total de la planta. En lo económico, T4 presentó los costos más altos. La mayor utilidad la registró T5, a pesar del bajo desempeño en las variables fisiológicas.

Palabras clave: salud del suelo, rentabilidad del cacao; nutrientes del suelo; vivero, costa pacífica.

INTRODUCTION

Cacao is cultivated in 70 Countires mostly situated in tropical regions and sustains the livelihoods of about 5 million small-scale farmers (Rafflegeau *et al*. 2015). Colombian cacao has been qualified as fine and aroma, which is very important, given that only 5% of the total cocoa produced and marketed on the planet is classified in this ranking. There are around 65,000 cocoa families supported by this crop (Fedecacao, 2020).

In Nariño departamento, Tumaco has 93% of the cacao crops in approximately 17,809 hectares (Agronet, 2024). In Tumaco cacao beans are recognized specially by its aroma with fruity and floral tones and chocolate flavor (Casa Luker, 2011). Unfortunately, most of the cocoa crops is cultivated with very low technology. For instance, seedlings come from empirical selection without any care in their initial stages.

The average yearly output in Tumaco has been almost constant, ranging from 210 to 500 kg ha^{-1} (Agronet 2024). Potential yield estimations exceed 2000 kg ha^{-1} according to Fedecacaco (2020). Considerable yield gaps are believed to arise from cultivation in climatically unfavorable regions (Asante *et al*., 2021), old plantations (Wessel & Quist-Wessel, 2015), inadequate farm management techniques (Aneani & Ofori-Frimpong, 2013) coupled with high pests and disease pressure and insufficient fertilizers application (Abdulai et al., 2020; Wessel & Quist-Wessel, 2015). Likewise, mechanisms underlying yield responses to increased nutrient availability are still largely unknown (Goudsmit *et al*. 2023).

An essential determinant of plant quality is the early nutrition (Hartmann *et al*., 1997). However, In Colombia scientific literature is scarce on cocoa nutrition during the nursery. As similar to other countries, the extension services continue to suggest exclusive formulas that fail to consider differences in soil composition, environmental conditions, safety factors, or the nutrient balance required according to the context (Snoeck *et al*., 2016). For this reason, an adequate cocoa nutrition is crucial for crop growth to achieve the wanted yields.

The main disadvantage in cacao crop performance is sometimes the lack of understanding about edaphic and foliar fertilization of early plants (seedlings), which determines yield and profitability. To ensure sufficient and well-proportioned nutrient levels for support of cacao growth and production, researchers and cocoa growers must take note of the specific requirements of cacao, the existing soil composition, and the methods for making these soil nutrients accessible to the cacao trees (Snoeck *et al.* 2016).

Every plant species has unique nutritional requirements and individual mechanisms for absorbing nutrients from the soil. The physiological development of plants relies on the presence of 16 key elements that constitute their structural composition (Snoeck *et al*. 2016).

Furthermore, a significant number of small-scale farmers remain doubtful about the necessity and impact of fertilizer on the productivity of cocoa beans (Kenfack Essougong *et al.,* 2020). The observed outcome might be attributed to the considerable variability in the impact of fertilizer application, which can range from a twofold increase in crop production to no impact at all (Dossa et al., 2018). This variability is further compounded by the absence of definitive fertilizer guidelines supported by reliable scientific evidence (Kenfack Essougong *et al*., 2020).

The aim of this study was to assess the impact of various doses fertilizers on the growth and development of cocoa seedlings (FEAR-5) in a nursery in the municipality of Tumaco. The study also included a cost analysis of to enhance understanding of the needs of these dosage on seedlings from their early stages.

MATERIAL AND METHODS

Location

The study was carried out at the Asprocat center, in the municipality of Tumaco, Vereda Inguapi del Carmen Kilometer 22, via Tumaco-Pasto, Colombia, at 1°40›24” north latitude and 78°45’25” West longitude, at 18.82 m.a.s.l. There, the climate is as follows: precipitation 3,050 mm, temperature 25.5 °C, and relative humidity of 88% (IGAC, 2014). The site study belongs to the life zone of humid tropical rain forest (Holdridge, 1982).

Experimental material

Cocoa seedlings were propagated by seeds from a self-compatible clone FEAR-5. Mature pods were harvested, the central beans were taken, the beans was cleaned with wood sawdust and left to dry in the shade. Then they were sown in a germinator. After 10 days the better seedlings were planted in a special bag. Before placing the seeds in the germinator, we applied fungicide and insecticide to the soil to prevent de seedlings from pests and diseases.

Treatments

The treatments were defined according to Crespo del Campo & Crespo (1997) and the soil analysis.

T1 = Application of N (2.4g), P (0.6g); K (2.4g), Ca (2.3g), Mg (1.1g), (Crespo del Campo & Crespo, 1997), without discounting the minerals in the soil.
T2 = This calculation was made based on the recommended dose and the soil analysis, for this treatment only 7 g de Ca and 3.2 g of Mg were applied.
T3 = 50% of the recommended dose without discounting the content of nutrients in the soil. Dose: N (1.2g), P (0.3g), K (1.2g), Ca (1.15g), Mg (0.55g).
T4 = Application of 150% of the recommended dose without discounting the content of nutrients in the soil. Dose: N (3.6g), P (0.9g); K (3.6g), Ca (3.4g), Mg (1.65g).
T5 = Control.

Experimental design

The study was carried out using a completely random design (CRD), consisting of five treatments and three repetitions. The experimental area amounted to 24 square meters. The treatments were arranged at random.

Variables

Plant height (PH). With a graduated ruler, every 15 days, seedlings were measured from the base of the stem to the apex during three-months.

Total leaf area (TLA). The evaluation was carried out at 30, 60, and 90 days; three plants were selected, and the leaves were measured from the middle third using the graph paper method.

Individual leaf area (ILA). At the end of the investigation, one plant was taken at random and the area of each leaf was measured using the graph paper method.

Diameter at transition zone (DTZ). Using a caliper or Vernier, the diameter of the plants was measured at the base of the stem (Transition zone).

Number of leaves (NL). The leaves of each plant were counted every 15 days,

Total fresh weight (TFW). Seedling by each treatment were harvested after 90 days and weighed on an analytical balance.

Stem fresh weight (SFW). Seedlings were cut at the transition zone. Then seedling stems by each treatment were weighed on an analytical scale.

Root-fresh weight (RFW). The roots were carefully cleaned to remove all traces of soil and washed under running water, then dried at room temperature and weighed on an analytical scale.

Root length (RL). These roots then were measured.

Stem dry weight. Stems were dried at 70°C to a constant weight and weighed on an analytical scale.

Root dry weight (RDW). Seedling roots were dried in an oven at the same temperature as the stem and then weighed on an analytical scale.

Total dry weight (TDW). Dry stems and roots were weighed on an analytical scale.

Statistical analysis

An analysis of variance for a completely randomized design was performed to identify treatment differences. Tukey's HSD (honestly significant difference) test, was performed to compare treatment differences. Data processing and analysis was performed using the statistical software Infostat, V 9.0., with 95% of probability.

RESULTS AND DISCUSSION

In the analysis of variance, there were contrasting statistical differences among treatments. Treatment T2 showed statistical differences (P>0.05) in in plant height, total and individual leaf area, diameter at transition zone, total fresh and dry weight, root fresh and dry weight, and total dry weight. Variables plant height, amount of leaves, root length, and root dry had not statistical differences (Table 1).

Table 1. Treatments means in the different variables.

Variables	Code	Treatments					
		T1	T2	T3	T4	T5	S.D
Plant height (cm) ns	PH	45.07	61.53	48.77	48.4	45.4	6,04
Total leaf area (cm2) *	TLA	39.03	82.93	44.53	44	55.3	15.80
Individual leaf area (cm2) *	LAH	5.73	7.53	6.77	6.5	6.17	0,60
Diameter at transition zone (mm)*	SD	6.57	8.47	7.6	8.33	7.17	0.71
Number of leaves ns	NL	10.67	14	10.33	10.67	10	1,45
Total fresh weight (g) *	TFW	12.67	18.87	9.43	12.59	14.2	3,08
Stem fresh weight (g) *	SFW	10.53	14.13	8.63	10.92	8.3	2,33
Root fresh weight (g)*	RFW	2.13	4.73	2.8	1.63	7.83	2,26
Root length (cm) ns	RL	29.9	30.73	30.27	19.93	33.4	4,62
Stem dry weight (g) *	SDW	2.13	7.5	3.3	5.47	3.53	2,11
Root dry weight (g) ns	RDW	0.97	1.33	1	1.07	2.13	0,29
Total dry weight (g) *	TDW	3.3	8.83	4.3	2.13	5.2	2,55

*: significant differences; (P < 0.05), ns: no significant differences; (P>0.05).

S.D: standard deviation

Stem diameter (mm). In the analysis of variance, there were significant statistical differences (P<0.05) among treatments; the highest value was found in treatment 2 with 8.47 mm, the lowest values were recorded in treatments 1, 5 and 3. The T1 treatment, with the application of the recommended dose, presented the lowest average value with 6.57mm compared to T2 where the minerals in the soil was discounted, with an average of 8.47mm. According to Martinez *et al*. (2015), it is important to highlight the diameter of the stem of cocoa plants because the greater the diameter, the better the performance of the seedlings on the field.

Leaf area (cm2). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 2 with 82.93 cm2, the lowest values were found in treatments 1, 3 and 4. Treatment T1 had the lowest mean with 39.03 cm2. Nutrients associated with metabolism are found in greatest concentration in the early stages of leaf or other organ formation. A decrease of concentration trigger low seedlings performance, due to concentration dilution effects from increases in cell wall material during leaf expansion and from nutrient reabsorption during senescence. (Epstein & Bloom, 2004).

Leaf area (cm^2). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 2 with 7.53 cm^2, the lowest in treatments 1, 5 and 4. From these T1 presented the lowest value with 5.73 cm^2. According to Barceló *et al*. (2001), the greater growth of the leaf area of the plants is due to the higher content of nutrients, such as mineral ions; Seedling relative growth rate (RGR) obtained under optimal growing conditions might be considered a valuable bioassay of a species' potential capacity to exploit its advantageous development prospects, namely its growth strategy (Wright & Westoby, 2001).

The leaf area of a tree defines its capacity to intercept incident solar radiation, a primary source of energy used by plants for the manufacture of tissues and food compounds (Almeida & Valle, 2007, Tang *et al.*, 2014). Leaf area is synonymous with photosynthetic potential and influences growth, development, biological and agronomic yield potential, solar radiation interception, efficient water use and mineral nutrition (Rodríguez *et al.*, 2016); in addition, it is related to agronomic, biological, environmental and physiological processes.

Stem fresh weight (g). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 2 with 14.13 g, the lowest in treatments 3, 5 and 1. Among these T3, 50% of the recommended dose, had the lowest with 8.63g, Plants absorb a number of nutrients from the soil in specific proportions, and it is important that they are kept in balance to facilitate their absorption. Furthermore, Amores *et al*. (2014) state that prior to the development of a fertilization program, it is necessary to have a diagnosis of the level of natural fertility of the soil and of the substrates, if it is at the nursery level, through soil and foliar analysis.

Root fresh weight (g). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 5 with 7.83 g, the lowest in treatments 4, 1 and 3. Treatment T4, 150% of the recommended dose, had the lowest with 1.63 g. This makes it possible to highlight the importance of adding organic matter as a conditioner of soil characteristics and a source of nutrients for plants, as well as an activating substrate for soil-dwelling microorganisms (Félix *et al*., 2010; García *et al*., 2011). For this reason, treatment T5 registered higher values in the root fresh weight variable.

Total fresh weight (g). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 2 with 18.87 g, while the lowest values were found in treatments 3, 4 and 1. These treatment T3 had the lowest value with 9.43 g. This is possibly the nutrients applied to the plants of T2, thus favoring their strengthening, which therefore allowed them to have better growth of the seedlings.

Stem dry weight (g). The analysis of variance showed significant statistical differences (P<0.05) between treatments; the highest value was found in treatment 2 with 7.5 g and the lowest in treatments 1, 3 and 5. From these, T1 had the lowest mean with 2.13 g. Root and stem malformations originating from container production of *Pinus nigra* plants cause mechanical instability and plant mortality when seedlings are transplanted (Zahreddine *et al.,* 2004).

Variables with non-significant statistical differences

The statistical analysis of variance revealed no statistically significant differences (P>0.05) in the variables of PH, NL, RL, and RDW. Explanations of these findings are provided below.

Plant height, Gómez (1999) mentions that cocoa seedlings normally remain in the nursery for five to six months. In many cases, they do not reach the necessary vigor for planting (40 cm height), mainly due to inadequate management of irrigation, fertilization, and substrates, and even after six months in the nursery, they do not reach the ideal height for transplanting. In our case, in only four months of research, the seedlings showed a high vigor to be taken to sowing; the lowest height was 45.07 cm, and the highest was 61.53 cm, thanks to the fertilization.

Planting seedlings that are not vigorous results in slow growth in the field, long production time and susceptibility to disease attack. For these reasons, cocoa growers should choose seedlings with good physiological performance. (Reyes & González, 2003).

Regarding the number of leaves per plant, (NeSmith & Duval, 1998) state that, with the decrease in root volume, less leaf area per plant is yielded. The reduction in leaf area occurs due to the reduction in the size and number of leaves per plant.

Concerning root length and root dry weight, Peterson et al. (1991) assert that confining roots in a container that limits their growth intensifies competition for vital resources. As root biomass increases and rooting space decreases, there is a corresponding competition for oxygen and a decrease in accessible pore space. The total dry weight, reported earlier, may be attributed to the application of only the necessary fertilizers to the plants at T2, as per the soil requirements.

A significant challenge faced was the insufficient research on the application of chemical and organic fertilizers to cocoa during the nursery stage. Therefore, we suggest conducting research using various fertilization methods and different cocoa hybrids or varieties to determine the best dosage for the crop. Some of the findings obtained are already over a decade old, and we need current information to facilitate a more comprehensive comparison.

Financial analysis

In the financial analysis, the treatments showed differential performance. Treatment T4 was the most expensive, while treatment T5 had the lowest cost. In the profit analysis (Table 2), with a selling price of $3000 Colombian pesos per plant, it can be seen that each treatment had a profit of more than $1000 per plant, being the highest profit for treatment T5, which was the control, due to the fact that this treatment did not apply the doses of fertilizers, which resulted in low cost; of the fertilized treatments, the highest profit was presented by treatment T3, followed by treatment T2.

Table 2. Financial analysis of the treatments.

COSTS	TREATMENTS				
	T1	T2	T3	T4	T5
Unit seed value	$ 100	$ 100	$ 100	$ 100	$ 100
Unit value bag	$ 35	$ 35	$ 35	$ 35	$ 35
Substrate value	$ 133	$ 133	$ 133	$ 133	$ 133
Fertilizers	$ 123	$ 71	$ 64	$ 186	$ 0
Irrigation	$ 833	$ 833	$ 833	$ 833	$ 833
Labour	$ 667	$ 667	$ 667	$ 667	$ 0
Total	$ 1.891	$ 1.839	$ 1.832	$ 1.954	$ 1.101
Revenue	$ 3.000	$ 3.000	$ 3.000	$ 3.000	$ 3.000
Utility	$ 1.109	$ 1.161	$ 1.168	$ 1.046	$ 1.899

Treatment T2 had exceptional performance in almost all the assessed aspects. Although it placed third in terms of profitability among all the treatments, it achieved the second position among the fertilized therapies in our analysis. The results suggest that the application of fertilizers at the nursery stage of cocoa plantation is beneficial as it allows for the generation of seedlings with outstanding development at a low cost.

Treatment T1, the dosage advised by Crespo & Crespo (1997), had the third highest value. Among the assessed variables, this treatment displayed the poorest performance, indicating that the soils in each region are diverse and inconsistent with universal formulas for cocoa fertilization.

In their study, Quiroz & Amores (2000) assert that the fertilization of cocoa does not yield any economic advantages. They highlight that the application of fertilizers to the crop in a profitable manner is more intricate compared to most tropical crops. They further comment that the challenges mostly stem from the genetic diversity of the plant material. The aforementioned comments align with the conclusions of this study, since the conclusive determination of the beneficial impact of fertilizer application remains uncertain.

Proper fertilization of cacao crops is crucial for the physiological growth and optimal development of the crop, ensuring the attainment of predicted production levels based on the planted age and variety. The composition of essential nutrients in the soil or topsoil for plants can vary because the soil is a dynamic organism influenced by changing climatic conditions, weathering of source materials, and the organisms that coexist with it (Compañía Nacional de Chocolates, 2021).

It should be emphasized that the plants generated are rootstock, which will subsequently be grafted with scions from high-yielding cacao clones. It is at this crop phase that the impact of fertilization on plant vigor and responsiveness to grafting is properly determined.

CONCLUSIONS

The different doses of fertilizers applied to the soil presented significant statistical differences; Treatment T2 showed the best performance in the variables: stem diameter, leaf area, stem fresh and dry weigh, and total fresh weight, demonstrating to be the best treatment evaluated and determining an optimal growth and development for the cocoa seedlings. Treatment T5 (control) displayed the highest root fresh weight.

In the economic analysis, treatment T4 had the highest costs, while the lowest was treatment T5. The highest profitability was obtained with treatment T5, despite the low performance in its physiological variables.

The findings apply to places or soils that share similar characteristics, such as cocoa plantations located in comparable soil and climatic circumstances. Nevertheless, it is crucial to take into account the soil analysis to administer the appropriate amount of fertilizer without causing excess strain on the seedlings.

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BIBLIOGRAPHIC REFERENCES

Abdulai, I.; Hoffmann, M.P.; Jassogne, L.; Asare, R.; Graefe, S.; Tao, H.H.; Muilerman, S.; Vaast, P.; Van Asten, P.; Läderach, P.; Rötter, R. P. (2020). Variations in yield gaps of smallholder cocoa systems and the main determining factors along a climate gradient in Ghana. *Agricultural Systems*. 181: 102812. https://doi.org/10.1016/j.agsy.2020.102812

Agronet (2024). Reporte: Área, Producción, Rendimiento y Participación Municipal en el Departamento por Cultivo. https://www.agronet.gov.co/estadistica/Paginas/home.aspx?cod=4

Almeida, A. A. F.; Valle, R. R. (2007). Ecophysiology of the cacao tree. *Brazilian Journal of Plant Physiology*. 19:425-448.

Amores, F.; Saquicela, D.; Sarabia, W.; Tarqui, O.; Sotomayor, I.; Vasco, A. (2014). *Buenas prácticas para la renovación de huertas improductivas de cacao tradicional. Manual técnico No. 97.* Quevedo-Los Rios-Ecuador: INIAP. 171 p.

Aneani, F.; Ofori-Frimpong, K. (2013). An analysis of yield gap and some factors of cocoa (*Theobroma cacao*) yields in Ghana. *Sustainable Agriculture Research.* 2(4): 117-127. http://dx.doi.org/10.5539/sar.v2n4p117

Asante, P.A.; Danaë M.A.; Rozendaal, E. R.; Zuidema, P.A.; Quaye, A.K.; Asare, R.; Läderach, P.; Niels P.R. A. (2021). Unravelling drivers of high variability of on-farm cocoa yields across environmental gradients in Ghana. *Agricultural Systems*. 193: 103214. https://doi.org/10.1016/j.agsy.2021.103214.

Barceló, J.; Nicolás, G.; Sabater, B.; Sánchez, R. (2001). *Fisiología vegetal*. Madrid: Editorial Pirámide. 298 p.

Casa Luker. (2011). Nuevo enfoque del cacao cultura colombiana. http://www.appcacao.org/descargas/seminario2011/Cacao%20Colombiano.pdf

Compañía Nacional de Chocolates. (2021). Modelo productivo para el cultivo de cacao (*Theobroma cacao* L.) nutrición y fertilización. https://chocolates.com.co/wp-content/uploads/2021/08/PDF-WEB-FOLLETO-NUTRICION-Y-FERTILIZACION.pdf

Crespo del Campo, E.; Crespo, A. (1997). Cultivo y Beneficio del cacao CCN51. Quito: Editorial El Conejo. 136 p.

Dossa, E.L.; Arthur, A.A.; Dogbe, W.; Mando, A.; Snoeck. (2018). Improving fertilizer recommendations for cocoa in Ghana Based on inherent soil fertility characteristics. In: Bationo, A.; Ngaradoum, D.; Youl, S.; Lompo, F.; Fening, J. (eds) *Improving the Profitability, Sustainability and Efficiency of Nutrients Through Site Specific Fertilizer Recommendations in West Africa Agro-Ecosystems*. pp. 287-299 Springer, Cham.399p https://doi.org/10.1007/978-3-319-58789-9_16

Holdridge, L. (1982). *Ecology based on life zones*. San José, Costa Rica: IICA. 216 p.

Epstein, E.; A.J. Bloom. (2004). *Mineral nutrition of plants: principles and perspectives*. 2. Ed. Sunderland: Sinauer Associates.

Fedecacao. (2020). Presentación El Sector Cacaotero en Colombia en Reunión de acercamiento Fedecacao - Incentivo al Seguro Agropecuario ISA 2020. https://www.finagro.com.co/sites/default/files/ficha_de_inteligencia_-_cacao.pdf

Félix, J.; Serrato, A.; Armenta, G.; Rodríguez, R.; Martínez, H. (2010). Propiedades microbiológicas de compostas maduras producidas a partir de diferente materia orgánica. *Ra Ximhai*. 6(1): 105-113.

García, F.; Jaramillo, S.; Carrillo. A. (2011). Efectos del abono orgánico mineral sobre la población microbiana de un haplustalf vértico. *Cultura Científica*. 9: 81-89.

Gómez, Y. (1999). Producción de plántulas de cacao. Regional Nordeste SEA (comunicación personal). http://www.cedaf.org.do/digital/cacao.pdf#page=26

Goudsmit, E.; Danaë M.A.; Rozendaal, A. T.; Slingerland. (2023). Effects of fertilizer application on cacao pod development, pod nutrient content and yield. *Scientia Horticulturae.* 313: 111869. https://doi.org/10.1016/j.scienta.2023.111869.

Hartmann, H.; Kester, D.; Davies, F.; Geneve, R. (1997). *Plant propagation: principles and practices*. 6th ed. Englewood Cliffs, NJ: Prentice-Hall. 770p.

Instituto Geográfico Agustín Codazzi - IGAC. (2014). Tumaco, uno de los municipios nariñenses en los que renacerá la paz. bit.ly/3KT5kCc

Kenfack Essougong, U.P.; Slingerland, M.; Mathé, S.; Wouter, V.; Precillia, I.; Ngome, T.; Boudes, P.; Ken E.; Giller, L.S W.; Cees L. (2020). Farmers' Perceptions as a Driver of Agricultural Practices: Understanding Soil Fertility Management Practices in Cocoa Agroforestry Systems in Cameroon. *Human Ecology*. 48:709–720. https://doi.org/10.1007/s10745-020-00190-0

Martinez, M. R.; Mendieta, L. M.; Castellón, O. M. (2015). Prendimiento de dos tipos de injertos en cacao en distintas fases lunares, Siuna, 2014. *Ciencia e Interculturalidad*. 17(2): 92-105.

NeSmith, D.; Duval. J. (1998). The effect of container size. *HortTechnology*. 8(4):1-4.

Peterson, T.; Reinscl, M.; Krizek, D. (1991). Tomato (Lycopersicon esculentum Mill. cv 'Better Bush') plant response to root restriction. Root respiration and ethylene generation. *Journal of experimental botany*. 42: 1241-1249.

Quiroz, J.; Amores, F. (2000). Rehabilitación de plantaciones de cacao en Ecuador. *Manejo Integrado de Plagas*. 63: 73-80.

Rafflegeau, S.; Losch, B.; Daviron, B.; Bastide, P.; Charmetant, P.; Lescot, T.; Prades, A.; Sainte-Beuve, J. (2015). Contributing to Production and to International Markets. In: Sourisseau J-M (ed). *Family Farming and the Worlds to Come*. pp. 129-144. Netherlands: Springer. 361p. 10.1007/978-94-017-9358-2_8

Reyes, E. R.; González, A. (2003). Evaluación de sustratos para la producción de plántulas de cacao (*Theobroma cacao* L) en vivero. https://agris.fao.org/search/ru/records/6472460408fd68d546007efc

Rodríguez, P. R. A.; Lopes, S. J.; Swarowsky, A.; Rosales, C.; Nogueira, C. U.; Maffei, M. (2016). Non-destructive models to estimate leaf area on bell pepper crop. *Ciência Rural*. 46: 1938-1944. https://doi.org/10.1590/0103-8478cr20151324

Snoeck, D.; Koko, L.; Joffre, J.; Bastide, P.; Jagoret, P. (2016). Cacao nutrition and fertilization. *Sustainable Agriculture Reviews.* 19: 155-202.

Tang, H.; Dubayah, R.; Brolly, M.; Ganguly, S.; Zhang, G. (2014). Large-scale retrieval of leaf area index and vertical foliage profile from the spaceborne waveform lidar (GLAS/ICESat). Remote Sensing of Environment. 154: 8-18. https://doi.org/10.1016/j.rse.2014.08.007.

Wessel, M.; Quist-Wessel, P.M. Foluke. (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

Wright, I.; Westoby, M. (2001). Understanding seedling growth relationships through specific leaf area and leaf nitrogen concentration: generalisations across growth forms and growth irradiance. *Oecologia*. 127: 21–29. https://doi.org/10.1007/s004420000554

Zahreddine, H.; Struve, D.; Quigley, M. (2004). Growing Pinus nigra seedlings in spinout™-treated containers reduces root malformation and increases growth after transplanting. *Journal of Environmental Horticulture*. 22(4):176182. 10.24266/0738-2898-22.4.176