Productivity of bananas (Musa AAA) grown in Urabá, Carepa, department Antioquia

Productividad de plátanos (Musa AAA) cultivados en Urabá, Carepa, departamento Antioquia

Produtividade da banana (Musa AAA) cultivada em Urabá, Carepa, departamento de Antioquia

Ana Francisca González-Pedraza[1]
Raúl Andrés Romero Calderón[2]
Marisol Maestre Delgado[3]

Received: June 15th, 2024
Accepted: August 20th, 2024
Available: September 16th, 2024

How to cite this article:
A. F. González-Pedraza, R. A. Romero Calderón, y M. Maestre Delgado, "Productivity of bananas (Musa AAA) grown in Urabá, Carepa, Department Antioquia," *Revista Ingeniería Solidaria,* vol. 20, no. 3, 2024.
doi: https://doi.org/10.16925/2357-6014.2024.03.04

Research article. https://doi.org/10.16925/2357-6014.2024.03.04

1 Full time professor, Agronomy Engineering Programme, Faculty of Agricultural Sciences. University of Pamplona, Colombia.
Email: ana.gonzalez2@unipamplona.edu.co
ORCID: https://orcid.org/0000-0002-4392-3724
CvLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0000127857

2 Agricultural engineer. Banco Contactar, Colombia.
Email: agrop.andres@gmail.com
ORCID: https://orcid.org/0009-0007-2826-8075
CvLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0000113488

3 Full time professor, Faculty of Economics and Business. University of Pamplona, Colombia.
Email: marisol.maestre@unipamplona.edu.co
ORCID: https://orcid.org/0000-0002-0548-2710
CvLAC: https://scienti.minciencias.gov.co/cvlac/visualizador/generarCurriculoCv.do?cod_rh=0001566413

Abstract

Introduction: Bananas are in high demand worldwide and play a vital role in the economies of several tropical countries. Colombia ranks as the ninth-largest banana producer globally, with Carepa, located in the Urabá region of Antioquia, serving as the nation's leading producer and exporter. The region's diverse soil types and agricultural practices significantly impact the quality and yield of banana crops. This project was conducted in 2021 with the support of the University of Pamplona.

Objective: To determine the relationship between banana productivity and the level of soil compaction by evaluating plant vigor parameters and physical soil characteristics on three farms in Urabá.

Methodology: On three farms, productivity parameters were measured for plants with high vigor (HV) and low vigor (LV): circumference of the pseudostem of the mother plant (CPP), height of the young sword sucker (HSS), number of hands per bunch (NHB), number of fingers per hand (NFH), length of the middle finger (LMF), and diameter of the middle finger (DMF). Soil bulk density (SBD), texture, and other physical properties were also assessed.

Results: CPP, HSS, and NHB were statistically higher ($p < 0.05$) in HV plants compared to LV plants. For NFH and LMF, no significant differences were observed between HV and LV plants at the Velero and Fragata farms ($p > 0.05$), while at the Piragua farm, HV plants exhibited significantly greater NFH and LMF.

Conclusion: Soil compaction has a direct effect on banana productivity. Adverse effects were noted at the Fragata farm, which exhibited lower yields and bunch weight compared to the other farms.

Originality: This study uniquely correlates soil compaction with banana productivity within an agricultural context in Colombia.

Limitations: The study was limited to three farms, so it is recommended to extend the analysis to additional locations for more generalized results.

Keywords: Soil compaction, bulk density, plant vigor, yield.

Resumen

Introducción: el banano tiene una alta demanda mundial y juega un papel crucial en la economía de varios países tropicales, Colombia ocupa el noveno lugar en la producción mundial. Carepa en Urabá, Antioquia, es el principal productor y exportador del país. La variabilidad en los tipos de suelo y las prácticas agrícolas en esta región influyen en la calidad y el rendimiento de los cultivos.

Objetivo: determinar la relación entre la productividad del banano y el nivel de compactación del suelo mediante la evaluación de parámetros de vigor de planta y características físicas del suelo en tres fincas de Urabá.

Metodología: en tres fincas se midieron parámetros de productividad para plantas con alto vigor (HV) y bajo vigor (LV): circunferencia del pseudotallo de la planta madre (CPP). altura del chupón espada joven (HSS), número de manos por racimo (NHB), número de dedos por mano (NFH), longitud (LMF) y diámetro del dedo medio (DMF). Densidad aparente del suelo (SBD), densidad aparente del suelo (SBD) y textura.

Resultados: CPP, HSS y NHB fueron estadísticamente superiores ($p < 0,05$) en las plantas HV en comparación con las plantas LV. NFH y LMF, se observaron similitudes entre plantas HV y LV en las fincas Velero y Fragata ($p > 0.05$), mientras que en la finca Piragua, las plantas HV exhibieron significativamente mayor NFH y LMF. La DMF fue significativamente mayor en las plantas HV de Piragua ($p < 0,05$), sin que se registraran diferencias significativas en Velero y Fragata.

Conclusiones: la compactación del suelo afecta la productividad del plátano, observándose efectos adversos en la finca Fragata, la cual presentó menores valores de rendimiento y peso del racimo.

Originalidad: este estudio relaciona directamente la compactación del suelo con la productividad del banano dentro de un contexto agrícola en Colombia.

Limitaciones: el estudio se limitó a tres fincas; se recomienda extender el análisis a otras localidades para obtener resultados más generalizables.

Palabras clave: compactación del suelo, densidad aparente, vigor de la planta, rendimiento.

Resumo

Introdução: A banana tem alta demanda global e desempenha um papel crucial nas economias de diversos países tropicais. A Colômbia ocupa a nona posição na produção global. Carepa, em Urabá, Antioquia, é a principal produtora e exportadora do país. A variabilidade nos tipos de solo e nas práticas agrícolas nessa região influencia a qualidade e a produtividade das culturas.

Objetivo: Determinar a relação entre a produtividade da banana e os níveis de compactação do solo, avaliando os parâmetros de vigor das plantas e as características físicas do solo em três fazendas em Urabá.

Metodologia: Os parâmetros de produtividade para plantas de alto vigor (HV) e baixo vigor (LV) foram medidos em três fazendas: circunferência do pseudocaule (PSC), altura do broto de espada jovem (YSH), número de braços por cacho (NHB), número de dedos por braço (NFH), comprimento (LMF) e diâmetro do dedo médio (MDD). Densidade do solo (SBD), densidade do solo (SBD) e textura.

Resultados: CPP, HSS e NHB foram estatisticamente maiores ($p < 0{,}05$) nas plantas HV em comparação às plantas LV. Semelhanças em NFH e LMF foram observadas entre as plantas HV e LV nas fazendas Velero e Fragata ($p > 0{,}05$), enquanto na fazenda Piragua, as plantas HV exibiram NFH e LMF significativamente maiores. DMF foi significativamente maior nas plantas HV em Piragua ($p < 0{,}05$), sem diferenças significativas observadas nas fazendas Velero e Fragata.

Conclusões: A compactação do solo afeta a produtividade da banana-da-terra, com efeitos adversos observados na fazenda Fragata, que apresentou menores valores de produtividade e peso do cacho. Originalidade: Este estudo relaciona diretamente a compactação do solo com a produtividade da banana em um contexto agrícola na Colômbia.

Limitações: O estudo limitou-se a três fazendas; recomenda-se que a análise seja estendida a outras localidades para obter resultados mais generalizáveis.

Palavras-chave: compactação do solo, densidade do solo, vigor da planta, produtividade.

1. INTRODUCTION

The banana (Musa spp.) is one of the most demanded fruits worldwide, with a presence in all tropical regions. It ranks as the fourth-largest food in terms of gross value production, following rice, wheat, and corn, and is considered a staple food for millions of people. Moreover, its cultivation is vital for the economic development of many developing countries, contributing to food security while generating income and employment in rural areas [1][2].

Colombia is a major player in the global banana market, ranking ninth in production and contributing 3% of the world's output, according to the Ministry of Agriculture and Rural Development [3]. The banana agro-industry has become a cornerstone of Colombia's agricultural export sector, generating substantial revenues and establishing the country as a net exporter. Over recent decades, this sector has been pivotal to the social and economic development of key production regions [4].

In 2018, the departments of Antioquia, Magdalena, and La Guajira accounted for 85% of the country's total banana production, reaching 1,769,646 tons [5]. The main producing regions, including Urabá, Magdalena, Cesar, and Norte de Santander, benefit from tropical climatic conditions that are ideal for banana cultivation. These regions not only lead in production but also in the high quality of their bananas, which enables them to compete effectively in international markets [3].

However, banana cultivation in Colombia faces significant challenges, such as threats from diseases and pests, including Panama Disease and Black Sigatoka, which can devastate plantations and reduce productivity. Additionally, extreme weather events like floods and droughts pose substantial risks. The lack of access to modern agricultural technologies and sustainable farming practices further exacerbates these challenges for farmers [6][7].

These issues underscore the urgent need for increased investment in agricultural research, farmer education, and disease prevention strategies to ensure the sustainability and continued growth of Colombia's banana sector [7].

1.1 Literature review

Banana cultivation takes place in a variety of soils and agricultural systems, which results in significant differences in their characteristics and quality. Production is closely linked to soil properties, with parameters such as the number of hands per bunch, pseudostem circumference, and height of the young sword sucker being highly correlated with plantation productivity and vigor [8], [9], [10], [11]. Rodríguez and Rodríguez [12] reported pseudostem circumferences greater than 76.36 cm, while González-Pedraza et al. [13] observed circumferences of 86.18 cm in high-productivity plants and 64.4 cm in low-productivity plants. The height of the young sword sucker varied from 209 cm in high-productivity plants to 164 cm in low-productivity plants, and the number of hands per bunch ranged from 12 in high-productivity plants to 8 in low-productivity plants.

The relationship between vigor, productivity, and soil properties—particularly bulk density—is a crucial aspect of tropical agriculture. Soil bulk density, reflecting the soil's compactness and porosity, significantly influences the growth, development, and yield of bananas. Understanding this relationship is essential to improving agricultural practices and optimizing banana production in tropical regions [14], [15], [16].

In a study conducted by Olivares [17], the main soil variables related to banana productivity in Venezuela were identified, and an empirical correlation model was developed to predict banana productivity based on soil characteristics. Using multiple linear regression models, the study estimated a model that included soil variables such as magnesium (Mg), penetration resistance, total microbial respiration, bulk density, and omnivorous free nematodes. The model explained productivity (PI) with an R^2 of 0.55, a mean absolute error (MAE) of 0.8, and a root mean square error (RMSE) of 1.0. This model provides a practical methodology that could be applied to other banana-growing areas in Venezuela and Latin America, offering a potential tool for sustainable land management.

The relationship between microbial activity and soil physicochemical properties in banana plantations is also critical due to the impact these variables have on agricultural productivity. Olivares et al. [18] evaluated six agricultural fields in two of the main banana production areas in Venezuela. They distinguished between high and low productivity levels for the "Great Nain" banana variety and identified ten variables: free nematodes (FLN), bacteriophages, predators, omnivores, phytonematodes, saturated hydraulic conductivity, total organic carbon, nitrate (NO_3-), microbial respiration, and fungi. Partial Least Squares Discrimination Analysis (PLS-DA) was applied to identify soil properties that distinguished between productivity levels. The Debiased and Poor Partial Correlation (DSPC) algorithm was used to correlate the most important variables. The network revealed positive correlations between FLN predators, microbial respiration, and NO_3-.

In Uganda, banana yields in upland areas (5-30 t ha^{-1} $year^{-1}$) are significantly lower than the potential yields (70 t ha^{-1} $year^{-1}$), which is attributed to pest and disease pressures, soil fertility decline, and inadequate management practices. Although soil depletion is recognized as a major cause of low yields, there is limited evidence to support this relationship. Most studies suggest that banana soils are relatively fertile and often contain sufficient nutrients, although deficiencies in potassium (K), nitrogen (N), and magnesium (Mg) are detected in fertilization tests and leaf samples [19].

In this study, growth and development parameters were measured, including the circumference of the mother plant's pseudostem (cm), the number of hands per bunch, the number of fingers per hand, finger length (cm), finger diameter (cm), height of the young sword sucker, plant density per hectare, and productivity at harvest (including bunch weight and harvest loss). The study was conducted at various farms of the company Banaexport S.A.S. in the Urabá region, Carepa, Antioquia, with the objective of quantifying banana productivity in soils with contrasting textures and examining its relationship with apparent soil density.

2. MATERIALS Y METHODS

Study area:

The study area was located in Carepa, Antioquia, at an altitude of 36 meters above sea level, with annual precipitation ranging from 2300 to 3000 mm. The area has an annual average temperature of 28°C and a relative humidity that reaches a maximum of 87%, with an average of 83% [20]. According to González et al. [21], the soils of Urabá have a cation exchange capacity ranging from medium to high, high base saturation, low organic carbon content, and belong to the Entisol and Inceptisol orders.

Type of Research: A field study was conducted using a systematic, targeted random design, as proposed by Otzen and Manterola [22]. The population of this study consisted of three production units. The sample included the number of plants and soil samples selected from each subplot.

Selection of Sampling Sites: The selection of sampling sites was based on factors such as farm productivity, planted cultivars, planting density, production per hectare, and returns, ensuring that all sites shared the same agronomic management practices. Three farms were selected, covering a total area of 498.93 ha. On each farm, two subplots were chosen, with plants classified as having either low vigor (BV) or high vigor (AV), following the criteria established by Rodríguez and Rodríguez [12]. According to their criteria, plants with a pseudostem circumference greater than 76.36 cm and an average of seven hands per bunch can be considered high productivity, along with the characteristics of the young sword sucker. Each subplot covered an area of 1000 m² (50 m long x 20 m wide).

Crop productivity variables

Plant Selection: Twenty plants were marked in each 1000 m² plot, approximately three weeks before harvest.

Plant Parameters:

Circumference of the Pseudostem of the Mother Plant (CPP): The circumference of the pseudostem of each mother plant was measured at a height of one meter above the soil surface.

Number of Hands per Bunch (NHB): The number of hands in each bunch was counted.

Number of Fingers per Hand (NFH): The number of fingers was determined on the second hand of each bunch.

Length of the Middle Finger of Each Hand (LMF): Measured from the base of the pedicel to the apex of the finger using a tape measure.

Diameter of the Middle Finger (DMF): Measured with a vernier caliper at the midpoint of the three central fingers of the second hand of the bunch.

Height of the Young Sword Sucker (HSS): The height of the young sword sucker was measured from ground level to the insertion of the pseudopectiol of the last fully expanded candela leaf.

Plant Density per Hectare (PD): Plant density ranged from 1550 to 1600 plants per hectare. For each subplot, the total number of plants present was multiplied by 10 to extrapolate to one hectare.

Harvest: Bunches were harvested at commercial maturity (11-12 weeks), following the quality protocols established for marketing. Four bunches from the plants in each subplot were selected for this purpose.

Bunch Weight (BW): The gross weight of 20 bunches per treatment was determined using the SIOMA application, a precision agriculture ecosystem based on the Internet of Things (IoT) and sensors for the collection of productive data.

Soil Sampling: Two transects were plotted in each subplot, along which five simple soil samples were taken at a depth of 0-4 cm to determine bulk density.

Soil Bulk Density (SBD): Soil bulk density was determined using the cylinder method according to Blake and Hartge [23].

Soil Texture: Particle size distribution was determined using the Bouyoucos method [24].

Statistical analysis

A one-way analysis of variance (ANOVA) was applied, assuming normality, homogeneity of variance, and independence of samples. When the ANOVA was significant ($p < 0.05$), a Tukey multiple comparison test was performed with a 95% confidence level. To relate variables, a simple linear regression analysis was used, with the parameters associated with plant vigor as the dependent variables and the measured soil characteristics as the independent variables.

3. RESULTS

Productivity parameters

Table 1 shows the average values of the productivity parameters evaluated in banana cultivation for each of the farms analyzed. In all the farms, HV plants exhibited significantly higher values for CPP, HSS, NHB, and certain parameters related to fruit development (NFH and DMF) compared to LV plants, indicating that high vigor positively influences these growth metrics. Specifically, the Velero and Piragua farms show a clear distinction between HV and LV plants, with HV plants outperforming LV plants in all parameters measured, except for NFH in Velero and LMF in Fragata.

Table 1. Plant vigor parameters in each farm

Farm	Plant vigor	Productivity Parameters					
		CPP (cm)	HSS (cm)	NHB	NFH	LMF (inch)	DMF (inch)
Velero	LV	65.3±6.9a	212.8±35.9a	7.6±0.5a	16.8±2,2a	9.2± 0,8a	12.4±1.4a
	HV	89.7±4.5b	322.05±33.0b	8.5±0.6b	16.0±1.5a	9,7±0.7a	14.7±1.5b
Fragata	LV	58.9±5.2a	194.8±21.5a	5.3±0.4a	16.4±2.7a	9.3±0.5a	12.25±1.0a
	HV	70±4.4b	227.3±28.8b	6.4±0.7b	17.5±3.1a	9.3±0.5a	12.05±0.9a
Piragua	LV	56.9±5.5a	193.2±26.18a	7.4±0.7a	16.8±2.3a	9.2±0,3a	12.5±0.8a
	HV	74.4±4.6b	241.3±33.8b	9.0±0.8b	18.5±2.6b	9.5±0.4b	13.5±0.9b

Average values in each column, followed by the standard deviation and separate letters, indicate statistical differences ($p < 0.05$) between low vigor (LV) and high vigor (HV) lots for each variable. CPP: circumference of the pseudostem of the mother plant; HSS: height of the young sword sucker; NHB: number of hands per bunch; NFH: number of fingers per hand; LMF: length of the middle finger of each hand; DMF: diameter of the middle finger. Source: Own work.

In banana farms, Contreras [25] identifies different types of plant vigor based on several key indicators of their development and productivity, such as the height of the young sword sucker and the circumference of the pseudostem of the mother plant. These parameters allow for the evaluation of plant vigor and potential yield. For example, fast-growing plants are those with a parturition interval of 28-32 weeks, a young sword sucker height greater than 3.25 m, and a pseudostem circumference greater than 80 cm, indicating more vigorous and productive plants. Normal plants have intermediate production cycles, with an interval of 33-37 weeks, a young sword sucker height between 2.50-3.25 m, and a pseudostem circumference between 70-80 cm, reflecting a balance between productivity and vigor. Slow-growing plants have longer cycles, with intervals of more than 38 weeks, lower productivity and vigor, a young sword sucker height less than 2.50 m, and a pseudostem circumference of less than 70 cm, suggesting less robust and efficient plants.

When comparing the data obtained in this study, only on the Velero farm did plants in the high vigor lots have an average pseudostem circumference greater than 80 cm. In contrast, the Fragata and Piragua farms presented a type B vigor as established by the author. On the other hand, the low vigor lots in all three farms were classified as type C (Sailboat) and type D (Fragata and Piragua), with pseudostem circumferences of 60-69 cm and less than 59 cm, respectively.

Relationship of productivity parameters to soil variables

Table 2 presents the analysis of bunch weight in relation to plant vigor, plant density per hectare, and the textural class of the soil on the three farms examined: Velero, Fragata, and Piragua. The results indicate that, on all farms, high-vigor lots showed a significantly higher bunch weight compared to low-vigor lots ($p<0.05$).

On Velero farm, bunches from high-vigor plants weighed an average of 28.91 kg, while those from low-vigor plants weighed 26.50 kg, indicating a notable difference in productivity. On Fragata farm, high-vigor lots had an average bunch weight of 26.34 kg, compared to 19.78 kg in low-vigor lots, making this farm the one with the greatest variation between the two groups. The heaviest bunches were recorded on Piragua farm, where high-vigor plants produced bunches weighing 29.67 kg, while low-vigor plants yielded bunches of only 20.18 kg.

Regarding plant density per hectare, high-vigor lots also tended to have a higher plant density compared to low-vigor lots, suggesting that in addition to differences in plant vigor, plant density may also play a role in affecting productivity (Table 2).

e-ISSN 2357-6014 / Vol. 20, no. 3 / september-december 2024 / Bogotá D.C., Colombia
Universidad Cooperativa de Colombia

Table 2. Bunch weight for low and high vigor lots for each farm

Farms	Plant vigor	Parameter	
		Bunch weight (kg)	Plant density (ha)
Velero	LV	26.50a	1690
	HV	28.91b	1760
Fragata	LV	19.78a	1630
	HV	26.34b	1670
Piragua	LV	20.18a	1520
	HV	29.67b	1560

Average values in each column, followed by standard deviation and separate letters, indicate statistical differences ($p<0.05$) between low (LV) and high vigor (HV) lots for the bunch weight variable. Source: Own work.

Table 3 reveals that no statistically significant differences were found in soil bulk density (SBD) between high and low vigor lots on the Velero and Fragata farms. Notably, the soil bulk density on Velero farm was within the range typically associated with loam-textured soils (1.35 to 1.50 g/cm³). This suggests that the soils on Velero farm are optimal for banana cultivation, as these conditions promote the free penetration of plant roots into the soil, ensuring adequate porosity, aeration, and water infiltration—all of which positively affect banana production.

Farm	Plants vigor	Soil parameter	
		SBD (g/cm³)	Class textural
Velero	LV	1.36±0.03a	Clay loam
	HV	1.32±0.06a	Silty clay loam
Fragata	LV	1.44±0.10a	Clay
	HV	1.43±0.12a	Clay
Piragua	LV	1.40±0.12a	Clay
	HV	1.37±0.06b	Clay

Average values in each column, with standard deviation followed by separate letters, indicate statistical differences ($p<0.05$) between low (LV) and high vigor (HV) lots for each soil bulk density and soil texture. SBD: Soil bulk density. Source: Own work.

"At the Velero farm, the soil bulk density in low-vigor lots was 1.36 g/cm³, slightly higher than in high-vigor lots, which had 1.32 g/cm³; however, this difference is not statistically significant ($p>0.05$). At the Fragata farm, the soils of both lots had very similar soil bulk densities (1.44 g/cm³ for low-vigor lots and 1.43 g/cm³ for high-vigor lots), with no significant differences ($p>0.05$). Bulk density reflects porosity, aeration, and infiltration capacity, which influence the circulation of water and air in the soil, as well as plant establishment processes (e.g., germination and rooting) and soil management [26]. Regarding texture, the soils were classified into the textural classes of clay loam, silty clay loam, and clay.

4. DISCUSSION AND CONCLUSIONS

HV plants consistently exhibited greater CPP across all farms, indicating stronger growth in more vigorous plants. A similar trend was observed, with HV plants having significantly taller suckers, which may suggest better health and growth conditions. While HV plants showed higher NHB in Velero and Piragua, no significant difference was found in Fragata, suggesting variability in farming practices or soil conditions. NFH showed no significant differences in Velero and Fragata, indicating that this metric might be less influenced by plant vigor in these contexts. Both HV and LV plants in Fragata had similar LMF, whereas in Piragua, HV plants exhibited greater LMF. The significant difference in DMF between HV and LV plants in Piragua further supports the idea that vigorous plants tend to produce larger fruit.

The consistent patterns of improved parameters in HV plants suggest that management practices aimed at enhancing plant vigor could lead to higher yields and better fruit quality. The variability in results between farms highlights the importance of localized agricultural practices and soil conditions, which should be considered when developing strategies for banana production. Overall, the data clearly indicates a clear advantage in productivity parameters for HV plants, reinforcing the need for interventions that promote plant vigor in banana cultivation to optimize yield and quality.

The comparative analysis of yield results among the three farms highlights significant differences in bunch weight. On the Velero farm, HV plants averaged 28.91 kg compared to 26.50 kg for LV plants, suggesting effective management practices for HV plants. Similarly, on the Fragata farm, the increase from LV (19.78 kg) to HV (26.34 kg) suggests that enhancing plant vigor could lead to substantial yield improvements. On the Piragua farm, the pronounced difference in bunch weight—HV plants yielding 29.67 kg compared to 20.18 kg for LV plants—reinforces the benefits of maintaining high vigor across all sites.

The plant density varied slightly across farms for both LV and HV lots, ranging from 1520 to 1760 plants per hectare. While higher plant densities are generally associated with increased competition for resources, the data suggests that HV plants can still produce heavier bunches even with varying densities.

The consistent increase in bunch weight for HV plants across all farms highlights the importance of promoting plant vigor through appropriate agricultural practices.

Strategies to improve soil health, reduce compaction, and enhance nutrient availability could lead to higher plant vigor and, consequently, greater bunch weights. These results also suggest that even with slightly different planting densities, maintaining high vigor is crucial for maximizing production.

Clay soils had a higher bulk density, probably due to their ability to retain water and compact more easily. However, the clay-free or silty clay-free soils (such as those in the Velero plot in the high-vigor lots) likely present better aeration and drainage, which could explain why plants in these lots show greater vigor, even without significant differences in bulk density. In the Fragata and Piragua farms, where the soils are predominantly clay, compaction appears to be a limiting factor, although the high-vigor lots in Piragua have managed to maintain a lower bulk density, which could be attributed to more effective soil management practices.

The data clearly demonstrate that high-vigor plants produce significantly heavier bunches across all farms, emphasizing the need for agricultural practices that support plant health and vigor to optimize banana production and improve economic returns for farmers.

In conclusion, proper management of factors that influence vigor, such as planting density and soil quality, is essential to improving productivity on farms. High-vigor lots tend to generate higher yields, as demonstrated by this study. While farms showed slight variations in soil texture, which could affect water and nutrient retention, strategies should be adopted to optimize plant growth and agricultural productivity. In the Fragata and Piragua farms, the soils are predominantly clay, indicating a similar behavior in terms of texture between high and low vigor lots. However, the presence of the same textural class does not guarantee optimum performance. This suggests that other factors, such as agronomic management and cultural practices, are key determinants of plant vigor and productivity [9], [27].

The variability in plant vigor on farms with the same textural class highlights the significant impact of agronomic management on productivity. The implementation of good soil management, drainage, and fertilization practices is essential to maximize yield in plots with less favorable textural characteristics [28], [29], [30], [31], [32].

This study underscores the need for an integrated approach that considers both soil characteristics and agronomic management practices to improve plant vigor and, consequently, production. Continuous monitoring of soil health and adjusting cultural practices to farm-specific conditions is recommended to ensure sustainable and productive development over time.

5. REFERENCES

[1] Departamento Administrativo Nacional de Estadística (DANE), *Censo Nacional Agropecuario: Novena entrega de resultados 2014*, pp. 1–50, 2015. [Online]. Available: https://www.dane.gov.co/files/CensoAgropecuario/entrega-definitiva/Boletin-9-cultivos/9-Boletin.pdf

[2] FAO, *La economía mundial del banano 1985–2002*, 2004, pp. 65. [Online]. Available: https://www.fao.org/3/y5102s/y5102s00.htm#Contents

[3] Ministerio de Agricultura y Desarrollo Rural, *Cadena de banano*, Dirección de Cadenas Agrícolas y Forestales, pp. 1–27, 2020. [Online]. Available: https://sioc.minagricultura.gov.co/Banano/Documentos/2020-12-31%20Cifras%20Sectoriales.pdf

[4] FINAGRO, *Ficha de inteligencia banano tipo exportación*, Fondo para el Financiamiento del Sector Agropecuario, pp. 1–14, 2018. [Online]. Available: https://www.finagro.com.co/sites/default/files/node/basic-page/files/ficha_banano_version_ii.pdf

[5] Departamento Administrativo Nacional de Estadística (DANE), *Censo Nacional Agropecuario: Novena entrega de resultados 2014*, pp. 1–27, 2015. [Online]. Available: https://www.dane.gov.co/files/CensoAgropecuario/entrega-definitiva/Boletin-9-cultivos/9-Boletin.pdf

[6] BASF, *Plagas y enfermedades del banano*, BASF Agricultura, pp. 1–10, 2024. [Online]. Available: https://agriculture.basf.com/co/es/contenidos-de-agricultura/plagas-enfermedades-banano

[7] Organización Internacional del Trabajo (OIT), *COVID-19 y el mundo del trabajo en América Latina y el Caribe: Impactos y respuestas en los primeros meses de la pandemia*, pp. 1–66, 2020. [Online]. Available: https://www.ilo.org/sites/default/files/wcmsp5/groups/public/@americas/@ro-lima/documents/publication/wcms_764319.pdf

[8] F. Rosales, L. Pocasangre, J. Trejos, E. Serrano, and W. Peña, *Guía de diagnóstico de la calidad y salud de suelos bananeros*, pp. 1–80, 2021. [Online]. Available: https://www.bioversityinternational.org/fileadmin/_migrated/uploads/tx_news/Guia_de_diagnostico_de_la_calidad_y_salud_de_suelos_bananeros_1375.pdf

[9] J. C. Escalante and E. Fuenmayor, "Estandarización de los criterios físicos de calidad del fruto del plátano hartón (Musa AAB) en función de su comercialización," *Ciencia y Tecnología Agropecuaria*, vol. 5, no. 1, pp. 21–26, 2020. [Online]. Available: https://ojs.unipamplona.edu.co/index.php/rcyta/article/view/790/1134

[10] A. Martínez and D. Cayón, "Dinámica del crecimiento y desarrollo del banano (Musa AAA Simmonds cvs. Gran Enano y Valery)," *Revista Facultad Nacional de Agronomía – Medellín*, vol. 64, pp. 6055–6064, 2011. [Online]. Available: https://www.redalyc.org/pdf/1799/179922664003.pdf

[11] E. Delgado et al., "Determinación de un índice de calidad y salud de suelos para plantaciones bananeras en Venezuela," *Interciencia*, vol. 35, no. 12, pp. 927–933, 2010. [Online]. Available: https://www.interciencia.net/wp-content/uploads/2018/01/927-c-DELGADO-7.pdf

[12] V. Rodríguez and O. Rodríguez, "Biometría de la cepa de plátano (Musa AAB subgrupo plátano cv. Hartón) en plantas con rendimientos superiores a 18 kilogramos por racimo, en Venezuela," *Revista de la Facultad de Agronomía (LUZ)*, vol. 15, pp. 439–445, 1998.

[13] A. González-Pedraza et al., "Relación entre el vigor de plantas de banano y la actividad microbiana en suelos de un sector de la Ceiba, estado Trujillo," in *Memorias del XIX Congreso Venezolano de la Ciencia del Suelo*, Calabozo, Venezuela, 21–25 nov. 2011, pp. 1–6.

[14] B. Olivares et al., "Relationship between soil properties and banana productivity in the two main cultivation areas in Venezuela," *Journal of Soil Science and Plant Nutrition*, vol. 20, pp. 2512–2524, 2020. https://doi.org/10.1007/s42729-020-00317-8

[15] A. Vargas, W. Watler, R. Morales, and R. Vignola, *Prácticas efectivas para la reducción de impactos por eventos climáticos en el cultivo de banano en Costa Rica*, Ministerio de Agricultura y Ganadería, Costa Rica, 2017. [Online]. Available: http://www.mag.go.cr/bibliotecavirtual/reduccion-impacto-por-eventos-climaticos/Informe-final-Banano.pdf

[16] J. Villareal, L. Pla-Sentis, L. Agudo, J. Villalaz, F. Rosales, y L. Pocasangre, "Índice de calidad del suelo en áreas cultivadas con banano en Panamá," *Agronomía Mesoamericana*, vol. 24, no. 2, pp. 301–315, 2013.

[17] B. O. Olivares Campos, "Identification of the Main Soil Variables Correlated with Banana Productivity," in *Banana Production in Venezuela*, The Latin American Studies Book Series, Springer, Cham, pp. 119–140, 2023. 10.1007/978-3-031-34475-6_5

[18] B. O. Olivares, J. C. Rey, G. Perichi, and D. Lobo, "Relationship of Microbial Activity with Soil Properties in Banana Plantations in Venezuela," *Sustainability*, vol. 14, no. 20, p. 13531, 2022. 10.3390/su142013531

[19] P. Van Asten, C. Gold, J. Wendt, D. De Waele, S. Okech, H. Ssali, and W. Tushmereirwe, "The contribution of soil quality to banana yield problems and its relation with other banana yield

loss factors," in *Proceedings of the Workshop on Farmer-Participatory Testing of IPM Options for Sustainable Banana Production in Eastern Africa*, Montpellier, International Plant Genetic Resources Institute, pp. 100–115, 2004.

[20] Instituto de Hidrología, Meteorología y Estudios Ambientales (IDEAM), *Condiciones hidrometeorológicas actuales No. 0548: 01 de julio de 2024, 06:00*, pp. 1–74, 2024. [Online]. Available: https://ideam.gov.co/sites/default/files/prensa/boletines/condiciones_hidrometeorologicas_actuales_ndeg_0548_01_de_julio_de_2024_0600.pdf

[21] R. González, E. Álvares, and D. Castañeda, "Evaluación de la calidad química del suelo en agroecosistemas cacaoteros de la subregión del Nordeste y Urabá Antioqueño," *Revista Colombiana de Investigaciones Agroindustriales*, vol. 5, no. 1, pp. 41–52, 2018. 10.23850/24220582.730

[22] T. Otzen y C. Manterola, "Técnicas de Muestreo sobre una Población a Estudio," *International Journal of Morphology*, vol. 35, no. 1, pp. 227–232, 2017. [Online]. Available: https://dx.doi.org/10.4067/S0717-95022017000100037

[23] G. R. Blake and K. H. Hartge, "Particle density," in *Methods of Soil Analysis, Part I. Physical and Mineralogical Methods: Agronomy Monograph No. 9*, 2nd ed., pp. 377–382, 1986.

[24] G. L. Bouyoucos, "Recalibration of hydrometer method for making mechanical analysis of soil," *Agronomy Journal*, vol. 43, no. 9, pp. 434–438, 1951.

[25] M. A. Contreras, *Bananos Manual de Agricultura*, Apartadó, Urabá, Colombia, 2006.

[26] J. Sánchez y J. Mira, "Principios para la nutrición del cultivo de banano," *AUGURA*, pp. 29–33, 2013.

[27] A. Vargas, W. Watler, R. Morales, y R. Vignola, "Prácticas efectivas para la reducción de impactos por eventos climáticos en el cultivo de banano en Costa Rica," Ministerio de Agricultura y Ganadería, Costa Rica, pp. 1–56, 2017. [Online]. Available: http://www.mag.go.cr/biblioteca-virtual/reduccion-impacto-por-eventos-climaticos/Informe-final-Banano.pdf

[28] T. A. Sial, M. N. Khan, Z. Lan, F. Kumbhar, Z. Ying, J. Zhang, D. Sun, and X. Li, "Contrasting effects of banana peels waste and its biochar on greenhouse gas emissions and soil biochemical properties," *Process Safety and Environmental Protection*, vol. 122, pp. 366–377, Feb. 2019. 10.1016/j.psep.2018.10.030

[29] J. Sun *et al.*, "Rhizosphere soil properties and banana Fusarium wilt suppression influenced by combined chemical and organic fertilizations," *Agriculture Ecosystems and Environment*, vol. 254, pp. 60–68, 2018.

[30] J. Tobón y K. Villada, "Determinación del desarrollo del cultivo de banano variedad Cavendish bajo dos tratamientos de aireación de suelo y aporte de materia orgánica en la finca Bonito Amanecer del municipio de Chigorodó," Universidad Nacional Abierta y a Distancia, pp. 1–64, 2016. [Online]. Available: https://repository.unad.edu.co/bitstream/handle/10596/6458/1040355478.pdf?sequence=4&isAllowed=y

[31] L. Castellanos González y J. Serrano Ortiz, "Pérdidas económicas por babosas en fresa (fragaria × ananassa, duch) bajo las condiciones de Pamplona, Norte de Santander," *FACE*, vol. 20, no. 1, pp. 49–60, Jun. 2020. https://doi.org/10.24054/face.v20i1.465

[32] P. C. Ladino Marín, "Aproximación conceptual a las variables del marketing agropecuario. Caso, productos agrícolas destacados en Colombia," *FACE*, vol. 21, no. 3, pp. 81–90, Sep. 2021. https://doi.org/10.24054/face.v21i3.1137