Original Paper

Climatic variability and its impact on coconut production in Rocafuerte canton, Ecuador

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Abstract. *The climatic variability significantly impacts agricultural sustainability and food security. This study aimed to evaluate climate variability and its relationship with coconut production in the canton of Strong Rock. The production system was analyzed using an exploratory approach with stratified random sampling, dividing the canton into two strata:*

the upper area "El Cardón" and the lower area "El Pasaje". Seven production parameters were analyzed through surveys, and two meteorological stations were installed, one in each zone. Daily data on precipitation, temperature, humidity, and evapotranspiration were collected for six months (January – June 2024) and statistically analyzed using Pearson correlation. The data were compared with NASA's 12-year historical records starting in 2010. The most produced variety was manion, yielding 846.1 kg/m² in "El Cardón" and 297.8 kg/m² in "El Pasaje." Evapotranspiration and temperature had a high positive correlation with coconut production (0.78 in "El Cardón" and 0.82 in "El Pasaje"), while humidity and precipitation had a low negative correlation. The meteorological data closely matched NASA's historical values for June. The study shows that climatic variability affects coconut production parameters related to flowering and fruiting in the studied areas.

1. Introduction

Rainfall influences 80% of agricultural land and approximately 47% of the global economy depends on agriculture, highlighting the critical role of climatic conditions in food production and economic well-being (Ortiz & Ortega, 2018). Climate variability profoundly impacts global, regional, and local levels, causing extreme events that affect agriculture and food security (Kundzewicz et al., 2020; Franzke et al., 2020). In parts of Latin America, alternating drought and precipitation periods have significant social and economic implications (Aliaga, 2020). Ecuador's coastal region, particularly, experiences high climate variability due to Pacific Ocean temperature anomalies (León et al., 2021; Velasco et al., 2023).

In Manabí, Rocafuerte canton is divided into a dry, mega-thermal tropical upper zone (62% of the territory) suitable for winter crops with 500-1000 mm rainfall from January to April, and a tropical, semi-arid lower zone with less than 500 mm rainfall in the same period. The Poza Honda canals provide year-round irrigation to the lower zone, while the upper zone relies on winter rains, facing summer drought and high temperatures (Rocafuerte Territorial Development and Planning Plan [PDOT], 2016).

Climatic variables like temperature and precipitation significantly impact coconut growth, physiology, phenology, and ecological interactions, accelerating production changes (López et al., 2018). Water deficits can cause crop loss, reduced fertilization, premature fruit drop, and seedling death, while intense rains and extreme temperatures directly reduce production (Jayalath et al., 2020). Around 60% of coconut harvesting occurs under rainfed conditions in tropical climates, emphasizing the need for careful management to ensure long-term sustainability (Hebbar et al., 2022).

The PDOT of Rocafuerte (2016) highlights coconut as an economic pillar, with an area increasing from 354.01 ha to 434 ha in 2019-2023, underscoring agriculture's role in local development. Linking agriculture to the Sustainable Development Goals of the United Nations Development Program, particularly promoting responsible production, consumption, decent employment, and economic growth, is essential.

This study introduces a novel approach to investigating the relationship between climate variability and coconut production in Rocafuerte canton. By employing a multidisciplinary framework that incorporates climatic and productive factors, this investigation aims to evaluate climate variability and its relationship with coconut production in Rocafuerte canton. Our findings are expected to contribute to sustainable coconut production by minimizing losses, enhancing productivity, and aligning with Sustainable Development Goals. This research will provide a replicable model for future studies and inform the development of effective agroclimatic policies.

2. Methodology

2.1. Study area

This study investigated the coconut production system in the rural communities of El Cardón and El Pasaje, Rocafuerte canton, Ecuador. An exploratory approach was employed to analyze the relationship between climate variability and coconut production, aiming to identify patterns, trends, and areas for further research (Miranda et al., 2020).

2.2. Sampling and characterization of coconut production areas

To identify and characterize coconut production areas within Rocafuerte canton, a two-step approach was employed. First, a stratified random sampling technique was used. The canton was divided into two ecologically distinct zones: the upper zone, "El Cardón," and the lower zone, "El Pasaje." This ensured that farms from both areas were included in the study, providing a more representative picture of coconut production across the canton. Within each zone, simple random sampling was employed to select coconut farms. This method reduces bias by ensuring each farm has an equal chance of being chosen, avoiding situations where specific areas are overrepresented in the data.

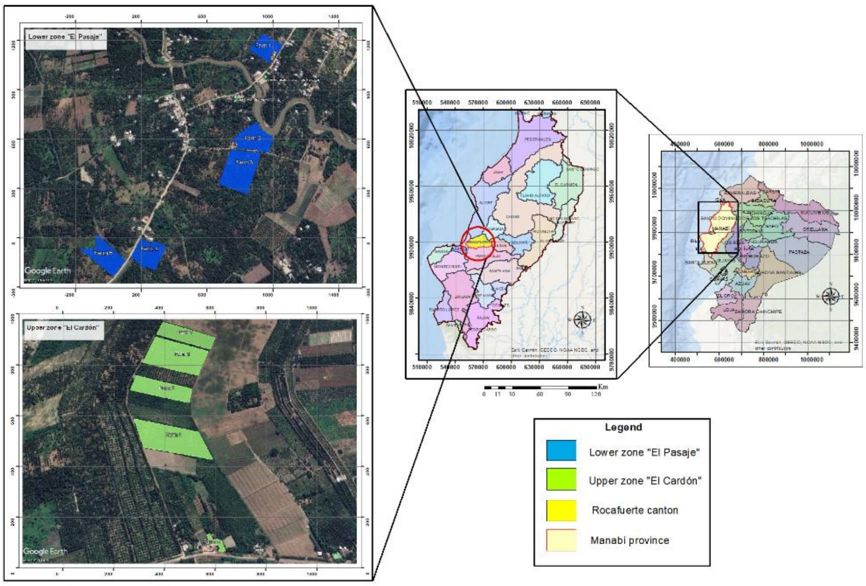


Figure 1. Location of the study area.

Second, representative farms were chosen based on key production characteristics. Reconnaissance visits guided by the Rocafuerte canton's PDOT (2016) helped identify these farms. Selection criteria included the number of coconut trees on the farm, the total area under cultivation, and the annual harvest. A standardized checklist adapted from Gámez & Negrete (2021) further facilitated the selection process.

Once the representative farms were identified, georeferencing was conducted. This process involved recording the geographical coordinates of each farm, allowing for the creation of a map that visually depicts the spatial distribution of the study areas (Gómez et al., 2022). Additionally, surveys were administered to the farm owners. These surveys, based on the work of Lechón & Chicaiza (2019), gathered data on the sociodemographic characteristics of the farmers and details on their coconut cultivation practices. This combined approach of geospatial data collection and surveys provided a comprehensive characterization of the coconut production system in Rocafuerte canton.

2.3. Determining coconut yield per unit area

An important aspect of this study was quantifying the total yield of coconuts from each farm. Researchers employed a method established by Alcántara et al. (2021) to calculate the yield per unit area. This approach expresses yield in kilograms per square meter (kg/m^2). To achieve this, the total coconut production (kg) harvested from each farm was multiplied by the farm's total area in square meters (m^2). In simpler terms, the total production refers to the total number of coconuts harvested, potentially multiplied by the average weight per coconut (if considered). The farm area represents the entire productive coconut-growing surface. By dividing the total production by the area, researchers obtained a standardized measure of yield that accounts for differences in farm size. This approach allows for a more accurate comparison of productivity across various farms.

$$Performance\ (kg * m^2) = Total\, production\ (kg)/area(m^2)\ [1]$$

Where:

- *Total production (kg):* number of coconuts harvested per farm
- *Area (m ^{2}):* surface area of the productive coconut farm

2.4. Setting up meteorological data collection

To understand the relationship between climate variability and coconut production, the study involved installing two meteorological stations. One station was placed in the upper zone ("El Cardón") and another in the lower zone ("El Pasaje") of the canton. These wireless stations boast a coverage radius of approximately 20 kilometers and connect to computers for data storage, as described by Barona et al. (2022). This setup facilitates continuous data collection through multiple sensors, allowing for real-time recording and display of current weather conditions. To ensure optimal functionality and reliable internet connectivity, the stations were strategically placed at homes with internet access within the designated areas.

Over a six-month period spanning January to June 2024, the stations diligently collected daily data on precipitation, temperature, humidity, and evapotranspiration. This valuable information was meticulously recorded in a Microsoft Excel spreadsheet for further analysis and processing, following the methods outlined by Martínez et al. (2021). This data plays a crucial role in exploring the potential influence of climate variability on coconut production in the region.

To understand the relationships between the collected meteorological variables, a statistical analysis was conducted using Pearson correlation coefficients. This method, as described by Escobar et al. (2018), measures the linear association between two continuous variables. By applying Pearson correlation to the data from each station's database, the study aimed to gain a deeper understanding of the interplay between these climatic elements.

2.5. Comparison with historical NASA data

To investigate potential long-term trends and assess the representativeness of the collected data, the average values for each meteorological variable (precipitation, temperature, humidity, and evapotranspiration) were calculated for the six-month monitoring period (January-June 2024). These averages were then compared with historical data from NASA covering the same period for the past twelve years (2010-2024). This approach, following the methods outlined by Bernal et al. (2020), allowed for a direct comparison between the current study's findings and historical climate patterns in the region. By analyzing these similarities and differences, researchers aimed to gain a broader understanding of potential climate variability and its impact on coconut production.

3. Results and discussion

3.1. Coconut producer survey results

Interviews with coconut producers revealed that 70% reported stable crop yields over the years. Detailed findings from the production diagnosis are presented in Table 1.

The coconut producer survey provided valuable insights into the experience and practices of these individuals. A significant portion (70%) of those surveyed have been cultivating and selling coconuts for over ten years, aligning with the findings of Alcívar et al. (2021). This suggests a long-standing tradition of coconut farming passed down through generations in Rocafuerte canton.

In terms of the coconut variety, the Manilon reigns supreme, constituting 70% of the cultivated trees. This dominance is consistent with observations by Basurto et al. (2022) regarding coconut plantations in Portoviejo. However, as noted by Álava et al. (2022), the Manilon variety requires careful handling during harvest due to its susceptibility to chontaduro, a type of weevil damage.

Table 1. Summary of the productive diagnosis of coconut

Variable	Options	Percentage
Production time	More than 10 years	70%
Most used variety	Manilon	70%
Cultivated area	Between 1 ha and 2 ha	70%
Number of plants/ha	From 100 to 200 plants	40%
Number of coconuts/plant	From 1000 to 2000 coconuts	60%
Harvest time	3 to 6 times	100%
Irrigation system	Aspersion	50%
	Pumping	50%

Moving on to yield and harvest practices, a majority (60%) of producers report harvesting between 1,000 and 2,000 coconuts per harvest, with a frequency of 3 to 6 harvests annually. This aligns with findings by Khaidir et al. (2022) who reported similar harvest frequencies in Indonesia, highlighting the global practice of multiple harvests per year. Similarly, Burbano et al. (2020) reported coconut yields ranging from 1500 to 2500 coconuts per harvest, aligning with the findings of this study.

The survey also revealed details about land and palm ownership. Producer land ownership is concentrated between 1 and 2 hectares for 70% of those surveyed. In terms of palm ownership, 40% reported having between 100 and 200 coconut palms on their land. According to Woittiez et al. (2018), an optimal planting density of 120-125 palms per hectare can significantly influence both productivity and management practices.

Irrigation practices also emerged as a key finding. The survey indicates a balanced distribution of methods, with 50% of producers using sprinkler systems and the other 50% relying on pumping systems. As described by Patel & Prajapati (2020), sprinkler irrigation offers advantages like reduced water waste and improved water management compared to traditional methods.

Finally, the survey investigated the water source for coconut cultivation. Half of the producers utilize refineries as their primary water source. This finding, along with the PDOT (2019-2023) of Rocafuerte canton, suggests a reliance on various water sources, including rivers, irrigation canals, and the La Esperanza aqueduct (which supplies water stored in albarradas or reservoirs in the upper zone).

3.2. Analysis of coconut production

To calculate crop yield, we averaged the weight of 15 coconuts from each farm in both zones. This average weight was then used to determine the total production (kg) for each area.

In the lower zone, the total crop yield was 297.8 kg/m², while in the upper zone, it was 846.1 kg/m², indicating significantly higher yields in the upper zone. According to Samarasinghe et al. (2018), areas with favorable climatic conditions, such as adequate rainfall distribution and moderate temperatures, tend to have higher yields.

Hernandez et al. (2024) note that yield is a dependent variable influenced by factors such as soil quality, climate, and cultivar type. Furthermore, Khaki and Wang (2019) emphasize that crop yield is also affected by management practices and technological advancements.

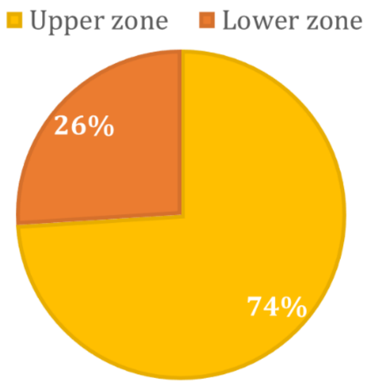
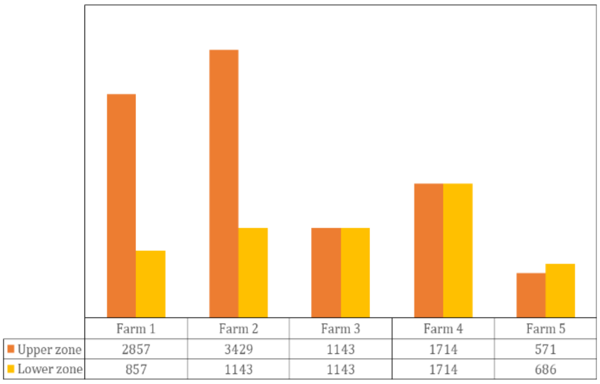


Figure 2. Crop production.

3.3. Coconut production variations between zones

It was determined that the upper zone has higher coconut production compared to the lower zone, based on the monthly number of coconuts harvested by each producer on each farm in the studied areas. Specifically, the upper zone reports a total of 9,714 coconuts harvested, while the lower zone reaches 5,543 coconuts.

Studies such as Woittiez et al. (2018) have highlighted those environmental conditions, including climate and soil quality, play a crucial role in the productivity of coconut palms. The higher production in the upper zone may be attributed to more favorable climatic conditions or soils better suited for cultivation, which could partly explain its higher yield compared to the lower zone.



	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5
🟧 Upper zone	2857	3429	1143	1714	571
🟨 Lower zone	857	1143	1143	1714	686

Figure 3. Coconut crop production

3.4. Pearson correlation

To assess the linear relationships between the collected meteorological variables (precipitation, temperature, humidity, and evapotranspiration), a Pearson correlation analysis was conducted. The resulting correlation coefficients were interpreted based on the standard interpretation scale established by Montaño (2016). This scale provides guidelines for interpreting the strength and direction (positive or negative) of the relationships between the variables.

Table 2. Pearson correlation

Variable 1	Variable 2	Pearson	
		Value	Meaning
Upper zone temperature	Upper zone humidity	-0.05	Very low negative correlation
Lower zone temperature	Lower zone humidity	-0.02	Very low negative correlation
Upper zone evapotranspiration	Upper zone temperature	0.78	High positive correlation
Lower zone evapotranspiration	Lower zone temperature	0.82	High positive correlation
Upper zone humidity	Upper zone precipitation	0.23	Low positive correlation
Lower zone humidity	Lower zone precipitation	0.98	Very high positive correlation
Upper zone temperature	Upper zone precipitation	0.34	Low positive correlation
Lower zone temperature	Lower zone precipitation	0.12	Very low positive correlation
Upper zone evapotranspiration	Upper zone humidity	-0.36	Low negative correlation
Lower zone evapotranspiration	Lower zone humidity	-0.32	Low negative correlation
Evapotranspiration upper zone	Lower zone precipitation	-0.25	Low negative correlation
Evapotranspiration lower zone	Upper zone precipitation	-0.31	Low negative correlation

Temperature and humidity exhibited a strong negative correlation in both the high and low zones, consistent with Escobar et al. (2017) who reported a correlation coefficient of -0.9. This inverse relationship between temperature and humidity is detrimental to coconut flowering and fruit development as noted by Sudhalakshmi et al. (2023) and Albuquerque et al. (2020), ultimately reducing productivity.

Conversely, evapotranspiration and temperature displayed a high positive correlation in both study areas, deviating from the findings of Azevedo et al. (2019). This suggests that prolonged drought conditions, particularly in arid regions, can exacerbate water loss through evapotranspiration, leading to premature coconut drop as reported by Samarasinghe et al. (2018) and Jayalath et al. (2020). As highlighted by Maheswarappa & Krishnakumar et al. (2018), increased evapotranspiration rates amplify the water requirements of coconut palms.

Humidity and precipitation exhibited a low positive correlation in the high zone, contrasting with a strong positive correlation in the low zone. These findings diverge from Ruiz et al. (2023); Rahaman et al. (2019), who reported moderate positive correlations between these variables. Barreto et al. (2024) attributed such discrepancies to factors like water availability and soil properties (Abhinav et al., 2018; Pathmeswaran et al., 2018).

Similarly, temperature and precipitation showed weak positive correlations in both zones, aligning with Rahaman et al. (2019); Bahena et al. (2017). Wasko et al. (2019) and Das et al. (2020) emphasized the negative impact of inconsistent rainfall patterns on coconut flowering. Notably, coconut palms can experience water stress or excess independent of temperature fluctuations (Fernandes et al., 2024; Ruiz et al., 2023).

Evapotranspiration and humidity displayed a weak negative correlation in both zones, similar to the negative Pearson correlation (-0.29) reported by Yongping et al. (2019) between evapotranspiration and precipitation. High humidity levels in coastal coconut plantations can potentially buffer the adverse effects of climate change, reducing yield losses as suggested by Hebbar et al. (2020). However, while coconuts exhibit resilience to short-term drought (Godage, 2022), prolonged dry periods intensified by climate change can have lasting negative impacts on fruit production (Hebbar et al., 2022). Garcon et al. (2019) explained that the inverse relationship between evapotranspiration and humidity is primarily driven by seasonal variations, with higher evapotranspiration rates during dry periods and lower rates during the rainy season.

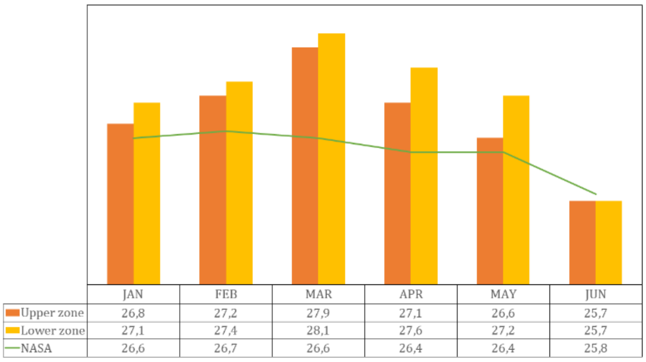
3. 4. Contrast with historical NASA data from the last 12 years

In figure 4, the average temperature in the lower zone reaches a maximum of 28.1°C in March, slightly higher than the upper zone's maximum of 27.9°C. Both zones experience a notable decrease in June, with temperatures dropping to 25.7°C. Historically, NASA data over the past 10 years shows that from January to May, temperatures remain constant between 26.4°C and 26.7°C, with a small decrease to 25°C in June, similar to the study zones. These results align with Hebbar et al. (2020), who describe optimal temperatures for coconut cultivation as ranging between 27°C and 32°C.

The study period coincided with the transition of the tropical Pacific from El Niño conditions to neutral, as reported by the Instituto Oceanográfico y Antártico de la Armada (ERFEN, 2024). This shift resulted in a gradual temperature decrease of 0.4°C between May 26 and June 26 within the study areas.

Figure 5 shows that the average humidity in the upper zone slightly exceeds that of the lower zone, peaking at 87.5% in January. In March and June, the lower zone's humidity decreases significantly to 81.8%, while the upper zone also shows a decrease in June, recording 81.9%. Historical data from the past 12 years indicate that the lowest humidity levels are in January and June, with values of

79.6% and 78.5%, respectively, and a high of 83.1% in March. A study by Alvarado et al. (2018) determined that the optimal humidity level for coconut cultivation ranges between 65% and 80%, which supports favorable yields. The study zones generally exceed this optimal range, suggesting a potential impact on coconut productivity due to higher-than-ideal humidity levels.



	JAN	FEB	MAR	APR	MAY	JUN
🟧 Upper zone	26,8	27,2	27,9	27,1	26,6	25,7
🟨 Lower zone	27,1	27,4	28,1	27,6	27,2	25,7
— NASA	26,6	26,7	26,6	26,4	26,4	25,8

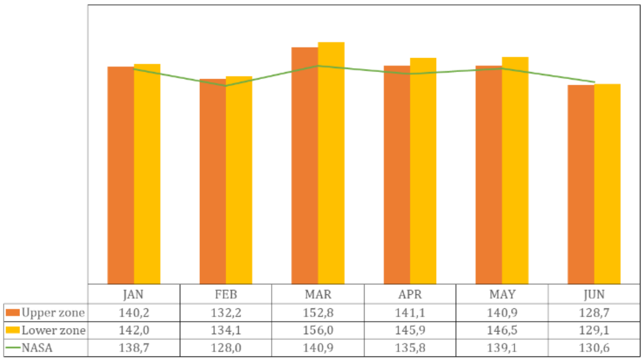
Figure 4. Current and historical temperature data.

Soil moisture, a critical factor in coconut production as highlighted by Nilmini (2018), is influenced by climate, hydrology, and drainage. Coconut palms exhibit optimal growth with balanced water availability, though they can endure brief periods of water stress. However, both insufficient and excessive moisture can adversely impact yield (Zhang et al., 2022).

	JAN	FEB	MAR	APR	MAY	JUN
🟩 Upper zone	87,5	86,6	81,9	83,4	84,2	82,9
🟦 Lower zone	86,6	86,3	81,8	81,8	82,1	82,2
— NASA	79,6	82,4	83,1	82,4	80,4	78,5

Figure 5. Current and historical humidity data.

Figure 6 shows that the upper and lower zones exhibit a similar trend in evapotranspiration values. In the lower zone, values range from 129.1 mm/month to 156 mm/month, while in the upper zone, they vary between 128.7 mm/month and 152.8 mm/month. Both zones reach their highest peaks in March, with 152.8 mm/month in the upper zone and 156 mm/month in the lower zone.



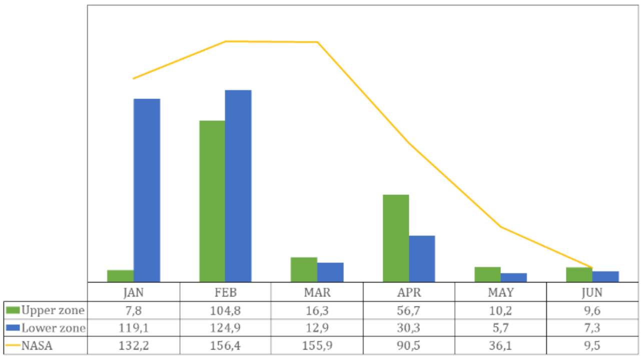
	JAN	FEB	MAR	APR	MAY	JUN
🟧 Upper zone	140,2	132,2	152,8	141,1	140,9	128,7
🟨 Lower zone	142,0	134,1	156,0	145,9	146,5	129,1
— NASA	138,7	128,0	140,9	135,8	139,1	130,6

Figure 6. Current and historical evapotranspiration data

Over the past 12 years, average monthly precipitation in the study areas ranged from a low of 128 mm in February to a high of 140.9 mm in March. These values align with the evapotranspiration estimates of Azevedo et al. (2011), which ranged from 126 to 174 mm/month. Garcon et al. (2019) emphasized that evapotranspiration is influenced by factors such as plant age, climate, and soil conditions.

High temperatures, strong winds, and inadequate soil moisture can significantly elevate evapotranspiration rates, inducing water stress in coconut palms (Bappa et al., 2020; Teixeira et al., 2019). This stress can reduce coconut yields to as low as 35-70 coconuts per palm annually. Conversely, optimal evapotranspiration, characterized by a balanced water supply and atmospheric demand, can lead to higher yields of 80-120 coconuts per palm per year (Carr, 2011).

Figure 7 illustrates that the upper zone exhibits relatively low precipitation patterns during the rainy season, with 7.8 mm/month in January and 16.3 mm/month in March. In comparison, the lower zone experiences its lowest precipitation in March with 12.9 mm/month. Moving into the early dry season, the upper zone shows slightly higher values than the lower zone with 10.2 mm/month in May and 9.6 mm/month in June.



	JAN	FEB	MAR	APR	MAY	JUN
🟩 Upper zone	7,8	104,8	16,3	56,7	10,2	9,6
🟦 Lower zone	119,1	124,9	12,9	30,3	5,7	7,3
— NASA	132,2	156,4	155,9	90,5	36,1	9,5

Figure 7. Current and historical precipitation data

In contrast, NASA data from the past 12 years indicates significantly higher precipitation values during the rainy season, with 132.2 mm/month in January, 156.4 mm/month in February, and 155.9 mm/month in March, gradually decreasing to 9.5 mm/month in June. The agreement among these data sources is most apparent in June, where values align closely.

The physiographic characteristics of the study areas promote orographic rainfall, contributing to precipitation in both low and high altitudes (PDOT, 2016; Alvarado et al., 2018). Optimal coconut cultivation requires monthly rainfall exceeding 130 mm (Corona et al., 2022), a threshold met in the present study. While well-drained, sandy soils and a limited dry season (no more than four months) favor coconut growth (Fernandes et al., 2024), climate change-induced rainfall reductions can negatively impact flowering and yield (Aidoo et al., 2021).

Rainfall and soil moisture are critical factors influencing coconut growth and yield, particularly in regions with pronounced wet and dry seasons. Excessive or intense rainfall during the crucial flowering and early fruit development stages can lead to reduced productivity (Rajapakse et al., 2010). Conversely, prolonged drought during nut filling can diminish coconut size and copra content (Rao, 2016). Implementing effective water management practices, such as supplemental irrigation during dry spells, is essential to optimize coconut production and mitigate the negative impacts of variable rainfall patterns.

4. Conclusions

In the upper zone "El Cardón" and lower zone "El Pasaje" of Rocafuerte canton, the predominant coconut variety is Manilón, constituting 74% and 26% of coconut production per unit area, respectively. Evapotranspiration and temperature showed a strong positive correlation with coconut production (0.78 in the upper zone and 0.82 in the lower zone), highlighting their significant influence on crop yield. Conversely, humidity and precipitation exhibited a low negative correlation across both zones. Comparing data from local meteorological stations with NASA records revealed consistent values, particularly evident in June over a 12-year period. This consistency underscores the reliability of local meteorological data for understanding climatic influences on coconut production in the region.

This study's findings are subject to limitations due to its six-month timeframe and reliance on data from only two meteorological stations, potentially limiting the representation of annual climatic variability. To enhance future research, extending the study period to multiple years and expanding the meteorological network is recommended. Additionally, investigating the influence of specific agricultural practices, management strategies, and technological advancements on coconut production under varying climatic conditions would provide valuable insights for mitigating climate change impacts.

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