Performance of Cocoa Fruit (Theobroma cacao L.)

by Syamad Ramayana

Submission date: 31-Mar-2024 09:55PM (UTC-0400)
Submission ID: 2336386204
File name: UJAR9-10436583-3.pdf (730.72K)
Word count: 8813
Character count: 47276

Universal Journal of Agricultural Research 12(2): 299-309, 2024 http://www.hrpub.org
DOI: 10.13189/ujar.2024.120209

Performance of Cocoa Fruit *(Theobroma cacao* L.*)* at Different Slope Positions in a Wet Tropical Climate

A. Syamad Ramayana*, Taufan Purwokusumaning Daru, Hamsyin, Alidi

Faculty of Agriculture, Mulawarman University, Indonesia

Received January 18, 2024; Revised March 4, 2024; Accepted March 20, 2024

Cite This Paper in the Following Citation Styles

(a)*: [1] A. Syamad Ramayana, Taufan Purwokusumaning Daru, Hamsyin, Alidi, "Performance of Cocoa Fruit (Theobroma cacao L.) at Different Slope Positions in a Wet Tropical Climate," Universal Journal of Agricultural Research, Vol. 12, No. 2, pp. 299 - 309, 2024. DOI: 10.13189/ujar.2024.120209.*

(b)*: A. Syamad Ramayana, Taufan Purwokusumaning Daru, Hamsyin, Alidi (2024). Performance of Cocoa Fruit (Theobroma cacao L.) at Different Slope Positions in a Wet Tropical Climate. Universal Journal of Agricultural Research, 12(2), 299 - 309. DOI: 10.13189/ujar.2024.120209.*

Abstract This research aims to determine the soil chemical properties (N, P, K, pH, organic C) at different slope positions, assess the performance of cocoa fruit (*Theobroma cacao* L.) at different slope positions, and understand the relationship between climate components and the performance of cocoa fruit (*Theobroma cacao* L.) in a wet tropical land. The study was conducted for three months (October to December 2017) in Karangan Hilir Village, Karangan District, East Kutai Regency. The research employed a Randomized Complete Block Design (RCBD) with slope position (P) as the treatment, consisting of three slope positions: P1 (lower slope), P2 (middle slope), and P3 (upper slope). Each treatment was replicated five times. Observed variables included flower count, fruit count, fruit length, fruit diameter, wet fruit weight, seed count, and wet seed weight. Data were analyzed using Analysis of Variance (ANOVA), and mean separation was performed using the Least Significant Difference (LSD) test at the 5% significance level. The results indicated significant differences in slope positions for observed parameters such as flower count and seed count, while fruit count, wet fruit weight, and wet seed weight showed non-significant differences. Correlation analysis revealed a positive correlation (0.343) between cocoa fruit performance and climatic factors, although it was not statistically significant with a p-value of 0.211, greater than 0.050.

Keywords Performance, Cocoa Fruit, Slope Position, Climate, Land, Wet Tropics

1. Introduction

The significant increase in population in developing countries, including Indonesia, has led to a growing demand for food and agricultural land. Concurrently, the progress in development has resulted in competition for land use, prompting farmers to utilize sloping dry lands for agriculture without adequate soil conservation measures. This situation renders the land vulnerable to erosion and degradation, ultimately turning it into critical land.

The development of the agriculture, plantation, and forestry sectors aims to improve the welfare of the community by increasing income while adhering to three principles: ecological sustainability, economic productivity and profitability, and social acceptability. Food, energy, environmental, and biodiversity crises collectively pose major challenges in the management of natural resources in Indonesia. An alternative strategy to enhance crop production potential, meet market demands, and simultaneously engage in conservation is the utilization of sub-optimal land, which holds considerable potential for the cultivation of crops such as cocoa and other commodities.

Cocoa plants (*Theobroma cacao* L.) are one of the significant agricultural productions that play a crucial role in realizing agricultural development programs, particularly in providing employment opportunities, improving the welfare of farmers, and increasing the country's foreign exchange [1].

Cocoa cultivation in Indonesia is largely carried out in smallholder plantations in villages scattered across almost the entire country. Common issues faced include limited cultivated land, damage caused by pests and diseases, insufficient attention to nutrient needs, and seed quality [2]. Therefore, the involvement of various stakeholders is crucial to help address these challenges.

The use of land that neglects soil conservation will impact the decline in land productivity, subsequently leading to land degradation. Land use systems can be modified according to models, especially in the selection of economically valuable perennial crops, which can enhance land productivity and reduce soil erosion rates [3].

According to previous research [4], the increasingly steep slope conditions result in the influence of gravity and the movement of detached organic materials down the slope, affecting soil fertility levels. Therefore, cultivation practices need to be considered to ensure optimal cocoa fruit performance, particularly addressing environmental factors such as slope steepness that influence plant growth and development.

The increase in slope and rainfall intensity directly impacts runoff rate. Steeper slopes and higher rainfall intensity result in faster water flow and increased runoff. This can lead to a significant increase in runoff rate, ranging from 20% to 90% [5]. Steep and long slopes are more prone to soil erosion as they provide less resistance to water flow and allow for greater distance for erosion. Soil texture, specifically the proportion of sand, silt, and clay particles, also plays a crucial role in soil erosion. Soils with more sand particles allow for easier water infiltration and less erosion, while soils with more clay particles make infiltration harder and increase erosion likelihood.

Various activities related to plant growth, whether in agriculture, plantation, or forestry, greatly require basic climate data. According to Hatfield et al [6], climate greatly affects plant growth and production, as supported by plant ecology research. This connection is seen through three main aspects: agronomy, physiology, and agroclimatology. Having knowledge about how different plant types, climatic elements, and soil properties work together is crucial for ensuring the successful growth of a specific crop.

Previous studies [7] state that the development of commodities in a region based on climate type, regional form, and soil, is expected to enhance agricultural efficiency and stimulate the local economy. Another potential factor in plantation development is the agroecosystem conditions, including geographical conditions, sunlight exposure, rainfall intensity, and soil diversity, which are highly supportive and have potential for the development of plantation commodities [8]. Plantation commodities can be harvested several times before experiencing a decline in yield and becoming economically unproductive. There are also other plantation crop products that are cultivated on a small and less intensive scale but are collected and processed as plantation products [9], [10].

The outcome of a specific plant species is greatly influenced by the interaction of genetic factors and environmental factors. These environmental factors include soil type, topography, crop management, climate patterns, and technology [11], [13]. Different soil elements impact plant growth significantly, including composition, arrangement, and depth. Soil pH usually has an indirect impact on plant growth as it affects the solubility of ions and the activity of microorganisms [14]. The main limiting factors for both rainfed crops and perennial crops are topography, effective soil depth, surface rocks, and soil erosion [15].

According to a previous study [16], various factors can lead to low productivity or a decline in crop yields. These factors include a decrease in soil fertility, rapid changes in the agro-climate, and improper soil management that does not adhere to soil conservation rules. Consequently, the soil quality deteriorates due to extensive erosion and nutrient loss caused by the washing process that infiltrates the ground.

In addition to soil factors, climate is another crucial determinant of plant growth [17], [18]. Soil conditions are significantly influenced by rainfall, temperature, and humidity. This influence can be advantageous, but at times it can also be detrimental. Unlike soil factors that have been extensively studied and understood, weather and climate are among the most challenging variables to control in food [7]. Information regarding the compatibility between annual plants, climate, and soil becomes a crucial element in enhancing the success of planting programs. The compatibility between climate, soil components, and the planted crop type significantly determines the success of planting activities.

The study seeks to uncover the soil chemical properties (N, P, K, pH, organic C) at different slope positions, evaluate the growth of cocoa fruit *(Theobroma cacao* L.*)* at different slope positions, and determine the correlation between climate factors and the growth of cocoa fruit *(Theobroma cacao* L.*)* in a humid tropical environment.

2. Materials and Methods

2.1. Time and Place of Research

The study took place between June and December 2017, with the research site being Karangan Hilir Village in Karangan District, East Kutai Regency, East Kalimantan Province, Indonesia.

2.2. Research Tools and Materials

The tools used include a machete, calipers, scale, raffia rope, scissors, wheelbarrow, camera, clinometer, writing tools, and laboratory equipment for analyzing soil chemical properties. Meanwhile, the materials used are 13-year-old Sulawesi 1 cocoa plants, sacks, label paper, plastic bags, soil samples, and chemicals for soil chemical property analysis.

2.3. Research Design

This research is a single factor, namely slope position (P) which is designed following a Randomized Complete Block Design (RCBD) consisting of three positions slope: p1 = Lower Slope, p2 = Middle Slope, and p3 = Upper Slope. Each position was replicated five times.

2.4. Research Procedure

2.4.1. Determining Slope Steepness and Slope Positions

The slope steepness was determined using a clinometer (%) tool, and areas with a slope steepness of 10-25% (Moderately Steep) were selected. The slope positions were determined based on a land size of 225 m X 75 m, then divided into three slope positions (Lower, Middle, and Upper), with each area measuring 75 m X 75 m.

2.4.2. Determining Age and Sampled Plants

Cocoa plants (*Theobroma cacao* L.) were identified as 13 years old, Sulawesi I variety, with the criteria of tree height being 2 meters and branch length being 2 meters. There were 9 rows of trees for each slope position with 5 replications.

2.4.3. Soil Sampling

Eight points were sampled at each slope position with a depth of 20 cm, totaling 8 kg, mixed evenly, and 1 kg was taken as a composite soil sample. Subsequently, the soil samples were analyzed for N, P, K, Organic C, and pH at the Chemistry and Soil Fertility Laboratory, Faculty of Agriculture, Mulawarman University.

2.4.4. Secondary Data

Secondary data on climate components from 2013-2017, including air temperature, air humidity, rainfall, and sunlight, were obtained from the Meteorology, Climatology, and Geophysics Station at APT Pranoto Samarinda Airport.

2.5. Observation Variables

2.5.1. Number of Flowers per Tree (Pistils)

The total number of cocoa flowers was determined by counting the flowers on each tree. We sampled 45 trees from each slope position to calculate the average number of flowers. The flower count was done in single observation.

2.5.2. Number of Fruits per Tree (Fruit)

The total count of cocoa fruits was determined by tallying the number of fruits on each tree, with 45 trees sampled from every slope position. The calculation of the fruit count was carried out in a single observation.

2.5.3. Fruit Length (cm)

The average fruit length was calculated by measuring the distance from the bottom to the top of the fruit using a ruler, with a total of 45 trees sampled from each elevation level. The fruit length calculation was performed in a single observation.

2.5.4. Fruit Diameter (cm)

The average fruit diameter was determined by measuring the circumference of the fruit with calipers at the widest part of the fruit, with 45 sampled trees. The fruit diameter calculation was conducted in a single observation.

2.5.5. Wet Fruit Weight (g)

The average wet weight of fruits was obtained by weighing harvested fruits with yellow skin using a scale, with 45 sampled trees from each slope position. The wet fruit weight calculation was performed in a single observation.

2.5.6. Number of Seed per Fruit (Seeds)

The number of seeds in each cocoa fruit was calculated by counting the harvested seeds from 45 trees at different slope positions. The seed count calculation was conducted in a single observation.

2.5.7. Wet Weight of Seeds per Fruit (g)

The average wet weight of cocoa seeds per fruit was determined by weighing the harvested seeds from 45 sampled trees at each slope position. The calculation of the wet weight of seeds was performed in a single observation.

2.8. Data Analysis

The obtained primary data were subjected to variance analysis for analysis. In the event that the effect is found to be significant, a comparison between the means of the two treatments is carried out using the Least Significant Difference (LSD) test at a significance level of 5%.

Secondary data in the form of data on climatic factors related to cocoa fruit performance were tested by correlation test using SPSS. Furthermore, the data were interpreted with the correlation coefficient as shown in Table 1.

Table 1. coefficient correlation

Coefficient interval	Level of relationship
0.00 to 0.19	Very weak
0.20 to 0.39	Weak
0.40 to 0.59	Moderate
0.60 to 0.79	Strong
0.80 to 1.00	Very strong

3. Results and Discussion

3.1. Availability of Nutrients N, P, K, Organic C, and Soil pH in each Slope

Table 2 presents the analysis results for N, P, K, organic C, and pH availability at different slope positions.

Table 2. Availability of N, P, K, Organic C and pH at Lower Slope, Middle Slope, and Upper Slope Positions

Slope Position	Soil Chemical Parameters	Soil Chemical Values	Unit Status	Soil Chemical Status
P1 (Lower Part)	N Total	0,20	%	Low
	P	10,64	ppm	Low
	K	104,61	ppm	Very High
	pH	5,43	-	Acidic
	Organic C	2,12		Moderate
P2 (Middle Part)	N Total	0,15	%	Low
	P	3,95	ppm	Very Low
	K	67,38	ppm	Very High
	pH	5,38	-	Acidic
	Organic C	1,74		Low
P3 (Upper Part)	N Total	0,11	%	Low
	P	1,72	ppm	Very Low
	K	35,46	ppm	Moderate
	pH	5,23	-	Acidic
	Organic C	1,61		Low

Source: Data processed, source Soil Chemistry and Fertility Laboratory, Faculty of Agriculture, Mulawarman University (2017)

Soil chemical analysis reveals that the lower slope outperforms the middle and upper slopes. This is due to leaching, surface runoff, and soil erosion, which transport soluble nutrients along with soil particles and organic matter. As stated by previous research [19], [20], nutrient loss due to leaching results in the movement of nutrients downward to the root zone and the lower slope position. Meanwhile, organic matter significantly influences soil fertility [21], indeed organic matter is crucial for successful plant cultivation [22]. Organic matter has the ability to improve the soil's chemical, physical, and biological fertility.

The process of decomposing organic matter on land without tillage and maximum tillage will release organic acids, causing the soil to become slightly acidic compared to minimum tillage techniques [23].

Nitrogen (N) Content

The nitrogen (N) chemical status of the three slope positions is classified as low. However, there is a tendency for the highest N content to be found in the lower slope position at 0.20%, followed by the middle slope position at 0.15%, and the lowest in the upper slope position at 0.11%. This condition is closely related to the high content of organic carbon (C-organic) in the lower slope position. Meanwhile, the soil N content is directly proportional to its organic matter content [24].

Nitrogen is an essential nutrient used in large quantities by all forms of life. It is grouped into organic nitrogen and inorganic nitrogen, but the majority of nitrogen in the soil is in organic form [20]. The reduction or loss of nitrogen from the soil occurs not only through leaching by rainwater (in the form of NO_3^-) but also due to utilization by plants and microorganisms [25].

Phosphorus (P) Content

The lower slope position has a phosphorus (P) content of 10.64 ppm (low), which is higher than the middle slope position with 3.95 ppm (very low) and the upper slope position with 1.72 ppm (very low). The high available P content in the lower slope is suspected to be due to the transport of soil nutrients from the upper and middle slope positions, along with water during rainfall.

Meanwhile, the low phosphorus (P) content in the upper and middle slope positions is suspected to be due to the presence of a relatively high clay fraction. Braskerud [26] states that factors influencing P retention in the soil include clay content. The retention capacity of phosphate increases with the increasing clay fraction in the soil. Kaolinite clay minerals tend to adsorb more P compared to montmorillonite clay minerals [27]. This is because kaolinite clay minerals have a larger number of open OH groups in the Al layer, which can be exchanged with P.

Potassium (K) Content

The soil potassium (K) content in the lower slope position, middle slope position, and upper slope position is respectively 104.61 ppm (very high), 67.38 ppm (very high), and 35.46 ppm (moderate). The lower slope position has a higher K content compared to the middle and upper slope positions. This is suspected to be due to water flowing from the upper and middle slopes during rainfall, leading to the accumulation of water carrying nutrients on the lower slope. The loss of K from the soil occurs through leaching towards groundwater, surface runoff, and soil erosion that carries soluble K along with soil particles and organic matter [28].

Olson and Papworth [29] state that K loss through leaching occurs due to continuous high-dose K application surpassing the plant's uptake and the soil's K retention capacity, resulting in the movement of K downward to the root zone [20].

Organic C Content

The organic carbon content of the soil in the lower slope position is 2.12% (moderate), which is higher compared to the middle slope position at 1.74% (low) and the upper slope position at 1.21% (low). The elevated organic carbon content in the lower slope position is suspected because it serves as a deposition site for materials resulting from the erosion process from the middle and upper slope positions, including soil particles, nutrient elements, and organic matter. According to Banjarnahor et al [19], erosion caused by water leads to the transport of soil particles, plant nutrients, and organic matter.

High organic carbon indicates a high level of soil organic matter. Organic matter plays a crucial role in soil fertility [21]. Soil organic matter consists of complex organic compounds that are in the process of decomposition, including humus from humification and inorganic compounds from mineralization.

Organic matter is a significant factor in determining the success of plant cultivation [22]. This is because organic matter can enhance the chemical, physical, and biological fertility of the soil.

Soil pH

The soil pH values in all three slope positions are classified as acidic. The lower slope position tends to provide a higher pH value (5.43) compared to the middle slope position (5.38) and the upper slope position (5.23). The extreme pH decreases microbial activity in the soil which in turn leads to decreased organic carbon decomposition, and nitrification [30]. The higher pH value in the lower slope position is suspected to be related to the high content of organic carbon in the lower slope.

High organic carbon values indicate a high level of soil organic matter. Soil organic matter contains organic acids that can bind H+ ions, causing soil acidity, and consequently lowering the soil pH. Previous studies [31], [32] mentioned that organic acids can bind H+ ions through carboxyl groups with negative charges.

Bayer et al [33] conducted a study on soil pH fluctuation and found that it is primarily influenced by the presence of H+ and OH- ions. They observed that an increase in H+ ions leads to a decrease in pH, making the soil more acidic. Conversely, an increase in OH- ions results in a rise in pH, making the soil more alkaline. Cookson et al [24] built upon this understanding by explaining the implications of soil pH on plant growth, particularly during the flowering stage. They noted that even under slightly acidic soil conditions, nutrients in the soil can still be effectively processed and taken up by plants. This means that plants are still able to absorb essential nutrients from the soil, despite the slight acidity.

3.2. Cocoa Fruit *(Theobroma cacao* L.*)* Performance at Difference Slope position (Lower Part, Middle Part, and Upper Part)

Table 3 illustrates the yield of cocoa pods *(Theobroma cacao* L.*)* across various slope positions.

Table 3. Cocoa Fruit *(Theobroma cacao* L.*)* Performance at Difference Slope position (Lower Part, Middle Part, and Upper Part)

Slope Position	Average number of flowers (pistils)	Average Fruit Length (cm)	Average Fruit Diameter (cm)	Average Number of Fruits (fruit)	Average Fruit Wet Weight (g)	Average Number of Fruit Seeds (seeds)	Average Fruit Seed Wet Weight (g)
P1 (Lower part)	68,17 a	14,52	7,73	15	420,07	35,07 a	245,93 a
P2 (Middle part)	41,43 b	13,58	7,53	15	358,22	33,10 a	241,13 a
P3 (Upper part)	29,49 c	12,79	7,28	16	248,64	26,16 b	321,31 b
Description	Mean numbers followed by the same lowercase letter in the same column indicate the results are not significantly different in the 5% LSD test.	Not significantly different	Not significantly different	Not significantly different	Not significantly different	Mean numbers followed by the same lowercase letters in the same column indicate the results are not significantly different in the 5% LSD test.	Mean numbers followed by the same lowercase letters in the same column indicate the results are not significantly different in the 5% LSD test.
LSD 5%	10.75					2.34	41,3
CV	8	5	6	9	11	6	7

The position of the lower slope has a higher nutrient content so as to provide better performance of Cocoa *(Theobroma cacao* L.*)* fruit in terms of the number of flowers formed, fruit length, fruit diameter, number of fruits, fruit wet weight, number of seeds and wet weight of seeds. Plants can grow optimally if their nutrient needs are met. Nutrients N, P and K are nutrients that are needed by plants to grow and produce [34].

The availability of nutrients N, P and K which are macro nutrients is very important in supporting plant growth and development [35]. Nitrogen plays a role as a constituent of proteins, amino acids, nucleic acids, vitamins, and enzymes, chlorophyll factors in leaves, as the basic ingredients of DNA, RNA and all plant biological functions. Phosphorus has multiple functions in plants, including promoting cell division, forming albumin, aiding in flower and fruit formation, speeding up maturation, enhancing stem strength, supporting root development, facilitating carbohydrate metabolism, and boosting overall plant quality. Potassium acts as an activator of various enzymes in metabolic processes and spurs carbohydrate translocation from leaves to plant organs [36], root development, starch formation, and physiological processes.

Average of Number of Flowers (Pistils)

The analysis of variance results indicates a significant difference in the number of flowers across the three slope positions. The number of flowers is much higher on the lower slope position than on the middle and upper slope positions. During the generative phase, the blooming process is affected by the presence of phosphorus and potassium, whereas nitrogen is predominantly needed in the vegetative phase. The increased presence of phosphorus in the lower slope area boosts the growth of additional flowers in comparison to the middle and upper slopes. According to Chrysargyris et al [37], suggest that the growth and blooming of plants are strongly influenced by the presence of nutrients, particularly phosphorus (P). This essential element plays a crucial role in triggering the generative phase of plants, leading to the formation of flower primordia that eventually transform into flowers. phosphorus (P) plays a role in flower formation, and P deficiency can suppress the number of flowers and delay flowering initiation due to changing phytochrome balance [38].

The soil acidity level (pH) is also suspected to affect the flower formation process. The lower, middle, and upper slope positions fall into the acidic category but are still within the tolerance limits for plants to undergo the flower formation process. As stated by Jadeja and Hirpara [39], with acidic soil pH conditions, nutrients available in the soil can still be processed effectively by the soil and absorbed by plants during the flowering process.

Average of Fruit Length (cm), Fruit Diameter (cm), and Fruit Number (Fruit)

The analysis of variance results shows that the length of the fruit is not significantly different. This is suspected to be because the slope position does not affect the number of fruits since potassium is very high but not significant enough to directly cause a large quantity of cocoa fruits. The growth process of the number of fruits is certainly influenced by environmental, physiological, and genetic factors of the plant. According to Hapsari et al [40], the number of fruits is often observed as a measure of plant growth and as a parameter used to measure the influence of the environment or applied treatments.

The lower slope position tends to produce longer fruits, wider fruit diameter, and a greater number of fruits. This is likely due to the higher phosphorus and potassium content in that area compared to the middle and upper slope positions. As a result, longer fruits, wider fruit diameter, and a greater number of fruits are encouraged to form.

According to Gregory et al [41], a plant will not yield maximum results if the required nutrients are not available, and the availability of nutrients is one of the factors that can affect the yield of a plant. Tando [35] adds that N, P, and K nutrients are very important macronutrients for plant growth and development. Furthermore, Raihan [42] adds that phosphorus and potassium can increase the size of harvested fruits, seeds, and tubers.

N, P, and K nutrients in corn plants will be translocated during the formation of cobs and seed filling, thus increasing the cob diameter [43]. The role of phosphorus nutrients in flower formation affects the formation and size of cobs because the cob is the development of the female flower [44]. According to Isnaeni [45], corn plants lacking N and P nutrients result in imperfect cob development. The size of the cob circumference, influences the yield because the larger the circumference, the higher the weight of the plant's fruits.

Average of Fruit Wet Weight (g)

The analysis of variance results indicates that there is no significant difference in wet weight. Nevertheless, it appears that fruits from the lower slope tend to be heavier than those from the middle and upper slopes. This could be because the lower slope position has more nutrients like N, P, and K, which contribute to the heavier fruit weight. Additionally, the weight of the fruit is also influenced by the process of transferring photosynthate products to the fruit.

Rahni [46] highlights that when a plant's root system can absorb more nutrients from the soil, it helps the fruit grow bigger and heavier. This happens because more photosynthate is transported into the fruit. Another literature [47] suggests that weight is a way to gauge the progress and advancement of plants. This is because weight represents the buildup of organic substances that plants have effectively created. It serves as an indicator of a plant's overall health and can determine whether its growth and development are thriving or struggling. Additionally, weight is closely tied to the availability of nutrients, making it an important factor to consider.

The available N, P, and K elements in the soil play a role in stimulating the flowering process, and if the flowers undergo successful pollination, the fruit's growth will be maximized. The generative process is influenced by the number of leaves formed because the photosynthesis process that produces carbohydrates takes place in the leaves. Subsequently, the carbohydrates ($C_6H_{12}O_6$) produced will be stored as food reserves. According to Sarminah et al [48], the photosynthates produced in leaves and other photosynthetic cells must be translocated to other organs or tissues to be utilized for growth or stored as food reserves.

Parveen et al [49] add that the primary role of potassium in plants is as an activator for various enzymes involved in metabolic processes and promotes the translocation of carbohydrates from leaves to plant organs. Meanwhile, phosphorus plays a role in the growth and yield of plants [27]. Nitrogen, as mentioned by previous studies [3], [50], is essential for vegetative growth, carbohydrate formation, protein, fat, and other organic compounds.

Soil acidity (pH) also affects crop yield because of its relationship with nutrient availability. Anita-Sari & Wahyu [51] state that soil pH plays a crucial role in maintaining the balance of nutrients and soil fertility. The optimal condition for plants is when soil pH is neutral because nearly all nutrients are available for plants, thereby supporting optimal production.

Average of Number of Seeds Per Fruit (Seeds) and Wet Weight of Seeds Per Fruit (g)

The results show a clear difference in seed count per fruit, with the bottom slope having the highest number compared to the middle and upper slopes. This is likely due to the bottom slope's higher levels of nutrients like N, P, and K.

The availability of N, P, and K nutrients influences the formation of fruit and seeds, as stated by Raihan [42] indicating that N, P, and K have an impact on the size and quantity of fruits and seeds produced, Hapsari et al [40] add that fruit length indicates seed density and is closely related to the number of seeds per fruit, with a tendency for larger fruits to produce more seeds. Sharar et al [52] state that the number and weight of seeds increase with the availability of specific nutrients.

The length and circumference of the cobs affect the yield, as a larger circumference corresponds to a higher fruit weight. Hapsari et al [40] state that longer fruits tend to yield higher results because they indicate a higher number of seeds. The availability of nutrients is closely related to the seed-filling process [40]. Nutrient uptake accumulated in the leaves will be transformed into protein and play a role in the seed formation process. The accumulation of metabolized materials during seed formation will increase, resulting in seeds with maximum size and weight. The metabolic process runs optimally when the nutrient requirements are met.

Soil acidity (pH) also influences the number of seeds produced. The availability of N, P, and K nutrients in the soil can be decomposed and absorbed by plants effectively due to the support of higher soil pH. The bottom slope position tends to have higher soil pH because organic materials and water flow to the slope below it [20]. With these soil pH values, the availability of macro-nutrients is possible to be easily absorbed, even if their availability is low.

Ruseani et al [53] state that nitrogen is required in small amounts for the formation of cocoa fruit seeds compared to macro-nutrients. The largest amount of nitrogen is needed during the generative phase because nitrogen plays a crucial role in the growth and development of plants [54].

Phosphorus is involved in many important processes in plants. It helps with photosynthesis, which is how plants make food using sunlight. It also plays a role in respiration, which is how plants release energy from food. Phosphorus is important for transferring and storing energy in plants. It is also needed for cell division and enlargement, which helps plants grow. Phosphorus improves the quality of fruits, vegetables, grains, and seeds. It is involved in the formation of genetic traits and helps roots develop and seeds germinate faster. Phosphorus also helps plants use water more efficiently and makes them more resistant to diseases [49, 50].

3.3. Climatic Conditions and Cocoa Fruit Performance *(Theobroma cacao* L.*)* at the Lower Slope, Middle Slope, and Upper Slope Positions

Table 4 displays the impact of climatic conditions on the performance of cocoa fruit at different slope.

Table 4. Relationship between Climatic Conditions and Cacao *(Theobroma cacao* L.*)* Fruit Performance at Lower Slope, Middle Slope, and Upper Slope Positions

Year (average)	Temperature (°C)	Humidity (%)	Rainfall (mm)	Illumination (%)
2013	27.40	80.00	237.80	54
2014	27.70	80.00	210.20	51
2015	27.80	80.00	174.80	51
2016	27.70	78.98	156.22	46,33
2017	27.80	81.30	213.90	39,26

Table 5. Results of statistical analysis of correlation of cocoa pod performance with climate in 2013, 2014, 2015, 2016, 2017

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.343[a]	.117	.050	104.78102	.033	1.730	107.4779	54.4657	.211

Model summary[a]

a. Predictors: (Constant), Rain_Fall, Temperature, Relative Humidity, Radiation

b. Dependent Variable: performance of cocoa fruits

As in correlation test results in Table 5, we can observe a positive correlation (0.343) between cacao fruit performance and climatic factors (as shown in Table 1 criteria), even though it is not statistically significant with a sig value of 0.211 higher than 0.050.

The positive correlation test results between cocoa fruit performance and climate factors truly indicate the existence of an interaction between climate, soil, and plants that are very important and mutually influential. Information on the suitability of climate and soil factors for perennial plants is crucial to know. The general requirements of climate and soil factors for perennial plants usually involve a range of annual rainfall from 500 to 3000 mm, monthly air temperatures of 15-34°C, monthly relative humidity of 70-90%, and pH of 4.0-8.5 [19].

The characteristics and types of climate can determine the types and production of plants that can grow well in a region, so climatology studies in agriculture are very necessary [11], [12]. Several climate elements that affect plant growth are rainfall, temperature, humidity, sunlight, and evapotranspiration [55].

Cocoa (*Theobroma cacao* L.) grows optimally in tropical forest regions [56], especially at latitudes 10°N to 10°S, altitudes of 0-600 meters above sea level, annual rainfall of 1500-2500 mm, minimum temperatures of 18-21°C and maximum temperatures of 30-32°C, with the desired average annual temperature of 25-27°C, air humidity of 80%, sunlight between 50-70%, slope below 45 degrees, soil texture of sandy clay, clay sandy, and sandy clay, and pH of 6.0-7.5.

East Kalimantan has a wet tropical climate, with daily sunlight ranging from 40-80% (sky always cloudy), daily air temperatures between 26-27°C (range between 20-32°C), daily air humidity about 80%, and annual rainfall ranging from 2,000-4,000 mm [57]. Considering these climate conditions, cocoa plants *(Theobroma cacao* L.*)* are suitable for cultivation in East Kalimantan because they have growing requirements that are in line with the climatic characteristics of the region.

This is done so that even though soil conditions experience changes due to climatic influences, the changes will be as minimal as possible and will not cause significant losses to human life and the environment [20]. Generally, the growth of plants is influenced by soil temperature and humidity. Kramer [58] suggests that the temperature of the soil can be affected by the quantity of solar radiation that is absorbed by the surface of the soil. During the day, the soil temperature varies greatly from the temperature at night. When the sun heats up the soil surface, the air nearby also becomes hot. However, as night falls, the soil temperature drops significantly [59].

Kramer [58] found that soil temperature affects water absorption by plants. Higher soil temperatures lead to faster water uptake by plant roots due to increased metabolic activities and faster evaporation. Warm soils also have lower viscosity and surface tension, making water flow more easily through the soil pores. A sudden decrease in soil temperature can lead to plant wilting because the roots absorb less water when the temperature is low. The depth of the soil determines the variations in soil temperature. Soil moisture levels are constantly changing due to evaporation from the surface of the soil, transpiration, and percolation. Soil moisture is crucial for the government to gather data on various aspects like potential surface flow and flood control, soil erosion failure and slope, water resource management, geotechnics, and water quality [60].

Soil moisture is crucial for plant growth and is influenced by factors such as rainfall, soil composition, and evapotranspiration [19]. Rainfall replenishes soil water content, with higher rainfall leading to higher soil moisture levels. Different soil types have varying water-holding capacities, affecting their ability to retain moisture. Evapotranspiration, the combined process of evaporation and transpiration, impacts soil moisture levels, with higher rates leading to increased water loss from the soil. Soil moisture is essential for plant growth as it determines the availability of water for plants.

4. Conclusions

In conclusion, the availability of nutrients in the lower, middle and upper slope positions shows levels of nitrogen (low), phosphorus (very low to low), potassium (medium to very high), organic carbon (low to medium), and pH (acidic). The performance of cocoa fruits (*Theobroma cacao* L.) at different slope positions showed significant differences in the number of flowers, number of seed and wet weight of seed per fruit. Meanwhile, fruit length, fruit diameter, number and wet weight of fruit were not significantly different. The lower slope position provides the best cocoa fruit (*Theobroma cacao* L.) performance.

The climate and soil conditions in East Kalimantan were identified as suitable for cocoa cultivation, characterized by an average temperature of 26-27°C, annual rainfall of <2000-4000 mm, relative humidity of 80%, and sunshine duration of 40-80%.

Novelty Statement

There has been no data on Cacao *(Theobroma cacao* L.*)* Fruit Performance at Different Slope Levels in Wet Tropical Land (East Kutai District).

Conflict of Interest

The authors have no conflict of interest.

REFERENCES

[1] I. Waris and A. Anshary, "Implementation Of the National Movement Program To Increase The Production And Quality Of Cocoa Plants In Sigi District," *Int. J. Soc. Sci. Educ. Commun. Econ. (SINOMICS JOURNAL)*, vol. 1, no. 6, pp. 881–892, 2023, doi: 10.54443/sj.v1i6.100.

[2] D. de Boer, G. Limpens, A. Rifin, and N. Kusnadi, "Inclusive productive value chains, an overview of Indonesia's cocoa industry," *J. Agribus. Dev. Emerg. Econ.*, vol. 9, no. 5, pp. 439–456, 2019, doi: 10.1108/JADEE-09-2018-0131.

[3] Nurdin, P. Maspeke, Z. Ilahude, and F. Zakaria, "Pertumbuhan dan Hasil Jagung yang Dipupuk N, P, dan K pada Tanah Vertisol Isimu Utara Kabupaten Gorontalo," *J. Trop. SOILS*, vol. 14, no. 1, pp. 49–56, 2009, doi: 10.5400/jts.2009.v14i1.49-56.

[4] D. B. Gadana, P. D. Sharma, and D. T. Selfeko, "Effect of Soil Management Practices and Slope on Soil Fertility of Cultivated Lands in Mawula Watershed, Loma District, Southern Ethiopia," *Adv. Agric.*, vol. 2020, pp. 1–13, 2020, doi: 10.1155/2020/8866230.

[5] Karyati, S. Sarminah, Karmini, Rujehan, V. F. E. Lestari, and W. S. Panorama, "Silvicultural, hydro-orological and economic aspects of a combination of vegetative (Falcataria moluccana-vigna cylindrica) and terrace systems in soils of different slopes," *Biodiversitas*, vol. 20, no. 8, pp. 2308–2315, 2019, doi: 10.13057/biodiv/d200828.

[6] J. L. Hatfield *et al.*, "Climate impacts on agriculture: Implications for crop production," *Agron. J.*, vol. 103, no. 2, pp. 351–370, 2011, doi: 10.2134/agronj2010.0303.

[7] M. Bagbohouna, D. S. Ragatoa, S. O. Simon, and I. K. Edjame, "Rainfall and temperature predictions: Implications for rice production in the lower river region of the Gambia," *Univers. J. Agric. Res.*, vol. 8, no. 4, pp. 97–123, 2020, doi: 10.13189/ujar.2020.080403.

[8] D. S. Jayanti, S. Goenadi, and P. Hadi, "Evaluasi Kesesuaian Lahan dan Optimasi Penggunaan Lahan untuk Pengembangan Tanaman Kakao *(Theobroma cacao L.)* (Studi Kasus di Kecamatan Batee dan Kecamatan Padang Tiji Kabupaten Pidie Propinsi Aceh)," *Agritech J. Fak. Teknol. Pertan. UGM*, vol. 33, no. 2, pp. 208–218, 2013, doi: 10.22146/agritech.9808.

[9] B. W. Minifie, "Chocolate, Cocoa and Confectionery: Science and Technology," *Choc. Cocoa Confect. Sci. Technol.*, p. 904, 1989, doi: 10.1007/978-94-011-7924-9.

[10] S. Chakraborty and A. C. Newton, "Climate change, plant diseases and food security: An overview," *Plant Pathology*, vol. 60, no. 1. pp. 2–14, 2011, doi: 10.1111/j.1365-3059.2010.02411.x.

[11] Y. Hazriyal, A. Anhar, and A. Karim, "Evaluasi Karakteristik Lahan Dan Produksi Kakao di Kecamatan Peudawa dan Peunaron Kabupaten Aceh Timur," *J. Manaj. Sumberd. Lahan*, vol. 4, no. 1, pp. 579–590, 2015, doi: https://jurnal.usk.ac.id/MSDL/article/view/7162/5873.

[12] S. Ramayana, S. D. Idris, R. Rusdiansyah, D. N. Faizin, and H. Syahfari, "Pertumbuhan Dan Hasil Tanaman Jagung (Zea mays L.) Dengan Pengayaan Mikoriza Dan Pupuk Majemuk Pada Lahan Pasca Tambang Batubara," *Agrika*, vol. 16, no. 1, pp. 55–68, 2022, doi: 10.31328/ja.v16i1.3710.

[13] G. A. Reineccius, D. A. Andersen, T. E. Kavanagh, and P. G. Keeney, "Identification and Quantification of the Free Sugars in Cocoa Beans," *J. Agric. Food Chem.*, vol. 20, no. 2, pp. 199–202, 1972, doi: 10.1021/jf60180a033.

[14] D. Adamczyk-Szabela and W. M. Wolf, "The Impact of Soil pH on Heavy Metals Uptake and Photosynthesis Efficiency in Melissa officinalis, Taraxacum officinalis, Ocimum basilicum," *Molecules*, vol. 27, no. 15, pp. 4671–4682, 2022, doi: 10.3390/molecules27154671.

[15] J. Sudibyo and A. S. Kosasih, "Analisa Kesesuaian Lahan Hutan Rakyat Di Desa Tambak Ukir, Kecamatan Kendit Kabupaten Situbondo," *J. Penelit. Hutan Tanam.*, vol. 8, no. 2, pp. 125–133, 2011, doi: 10.20886/jpht.2011.8.2.125-133.

[16] A. F. Maroeto, W. Santoso, and R. P. Siswanto, "Assessment of Land Suitability Evaluation for Plantation Crops Using AHP-GIS Integration in the Wonosalam Forest Area, East Java," *Univers. J. Agric. Res.*, vol. 10, no. 5, pp. 569–586, 2022, doi: 10.13189/ujar.2022.100512.

[17] N. K. Fageria, V. C. Baligar, and C. A. Jones, "Growth and mineral nutrition of field crops, third edition," *Growth Miner. Nutr. F. Crop. Third Ed.*, p. 590, 2010, doi: 10.1201/b10160.

[18] C. Loehle, "Criteria for assessing climate change impacts on ecosystems," *Ecol. Evol.*, vol. 1, no. 1, pp. 63–72, 2011, doi: 10.1002/ece3.7.

[19] N. Banjarnahor, K. S. Hindarto, and F. Fahrurrozi, "Hubungan Kelerengan Dengan Kadar Air Tanah, Ph Tanah, Dan Penampilan Jeruk Gerga Di Kabupaten Lebong," *J. Ilmu-Ilmu Pertan. Indones.*, vol. 20, no. 1, pp. 13–18, 2018, doi: 10.31186/jipi.20.1.13-18.

[20] A. N. Sandil, M. Montolalu, and R. I. Kawulusan, "Kajian Sifat Kimia Tanah pada Lahan Belerang Tanaman Cengkeh (Syzygium aromaticum L.) Di Salurang Kecamatan Tabukan Selatan Tengah," *Soil Environ.*, vol. 21, no. 3, pp. 18–23, 2021, doi: 10.35791/se.21.3.2021.36687.

[21] Susilawati, E. Budhisurya, R. C. W. Anggono, and B. H.

Simanjuntak, "Analisis Kesuburan Tanah Dengan Indikator Mikroorganisme Tanah Pada Berbagai Sistem Penggunaan Lahan Di Plateau Dieng," *Agric*, vol. 25, no. 1, pp. 64–72, 2016, doi: 10.24246/agric.2013.v25.i1.p64-72.

[22] M. Lesmanasari and N. Barunawati, "Respon Pertumbuhan dan Hasil Tanaman Seledri (Apium graveolens L.) pada Pemberian Dosis Nitrogen dan Bahan Organik," *Produksi Tanam.*, vol. 010, no. 10, pp. 562–569, 2022, doi: 10.21776/ub.protan.2022.010.10.05.

[23] D. Kusairi, Sunarti, and Aswandi, "Improvement of Some Soil Chemical Properties Onmarginal Lands to Increase Corn Productionthrough Conservation Tillage Techniques Andorganic Fertilizers," *Int. J. Adv. Technol. Eng. Inf. Syst.*, vol. 1, no. 4, pp. 89–101, 2022, doi: 10.55047/ijateis.v1i4.483.

[24] W. R. Cookson, I. S. Cornforth, and J. S. Rowarth, "Winter soil temperature (2-15°C) effects on nitrogen transformations in clover green manure amended or unamended soils; A laboratory and field study," *Soil Biol. Biochem.*, vol. 34, no. 10, pp. 1401–1415, 2002, doi: 10.1016/S0038-0717(02)00083-4.

[25] K. C. Cameron, H. J. Di, and J. L. Moir, "Nitrogen losses from the soil/plant system: A review," *Annals of Applied Biology*, vol. 162, no. 2. pp. 145–173, 2013, doi: 10.1111/aab.12014.

[26] B. C. Braskerud, "Factors affecting phosphorus retention in small constructed wetlands treating agricultural non-point source pollution," *Ecol. Eng.*, vol. 19, no. 1, pp. 41–61, 2002, doi: 10.1016/S0925-8574(02)00014-9.

[27] B. Bar-Yosef, R. Rosenberg, U. Kafkafi, and G. Sposito, "Phosphorus Adsorption by Kaolinite and Montmorillonite: I. Effect of Time, Ionic Strength, and pH," *Soil Sci. Soc. Am. J.*, vol. 52, no. 6, pp. 1580–1585, 1988, doi: 10.2136/sssaj1988.03615995005200060011x.

[28] L. E. Alakukku and E. Turtola, "Surface runoff and soil physical properties as affected by subsurface drainage improvement of a heavy clay soil," *XVIIth World Congr. Int. Commi Biosyst. Ension Agric. gineering*, pp. 1–8, 2010, doi: 10.13031/2013.32135.

[29] B. M. Olson and L. W. Papworth, "Soil chemical changes following manure application on irrigated alfalfa and rainfed timothy in southern Alberta," *Can. J. Soil Sci.*, vol. 86, no. 1, pp. 119–132, 2006, doi: 10.4141/S05-024.

[30] L. Soumya, K. R. Poovathingal, G. P. Williams, N. Chandra D, and S. V. Kunnummal, "Evaluation of the Concentration of Phytotoxic Chemicals and Microbial Load of the Vermicompost Prepared from Coffee Processing Waste," *Univers. J. Agric. Res.*, vol. 10, no. 6, pp. 731–748, 2022, doi: 10.13189/ujar.2022.100613.

[31] N. R. Pasaribu, F. Fauzi, and A. S. Hanafiah, "Aplikasi Beberapa Bahan Organik dan Lamanya Inkubasi Dalam Meningkatkan P-Tersedia Tanah Ultisol," *Talent. Conf. Ser. Agric. Nat. Resour.*, vol. 1, no. 1, pp. 110–117, 2018, doi: 10.32734/anr.v1i1.129.

[32] R. Septianugraha and Suriadikusumah, "Pengaruh Penggunaan Lahan Dan Kemiringan Lereng Terhadap C-Organik Dan Permeabilitas Tanah Di Sub Das Cisangkuy Kecamatan Pangalengan, Kabupaten Bandung," *Agriin*, vol. 18, no. 2, pp. 158–166, 2019, doi: 10.20884/1.agrin.2014.18.2.221.

[33] C. Bayer, L. Martin-Neto, J. Mielniczuk, C. N. Pillon, and L. Sangoi, "Changes in Soil Organic Matter Fractions under Subtropical No-Till Cropping Systems," *Soil Sci. Soc. Am. J.*, vol. 65, no. 5, pp. 1473–1478, 2001, doi: 10.2136/sssaj2001.6551473x.

[34] S. Balakrishnan, M. Srinivasan, and P. Santhanam, "Interactions of nutrients, plant growth and herbivory in a Parangipettai mangrove ecosystem of the Vellar estuary, Southeast coast of India," *Reg. Stud. Mar. Sci.*, vol. 5, no. january, p. 19026, 2016, doi: 10.1016/j.rsma.2016.01.001.

[35] E. Tando, "Upaya Efisiensi Dan Peningkatan Ketersediaan Nitrogen Dalam Tanah Serta Serapan Nitrogen Pada Tanaman Padi Sawah (Oryza sativa L.)," *BUANA SAINS*, vol. 18, no. 2, pp. 171–180, 2019, doi: 10.33366/bs.v18i2.1190.

[36] M. N. Khan *et al.*, "Exogenous Potassium (K(+)) Positively Regulates Na(+)/H(+) Antiport System, Carbohydrate Metabolism, and Ascorbate-Glutathione Cycle in H(2)S-Dependent Manner in NaCl-Stressed Tomato Seedling Roots.," *Plants (Basel, Switzerland)*, vol. 10, no. 5, pp. 948–961, May 2021, doi: 10.3390/plants10050948.

[37] A. Chrysargyris, C. Panayiotou, and N. Tzortzakis, "Nitrogen and phosphorus levels affected plant growth, essential oil composition and antioxidant status of lavender plant (Lavandula angustifolia Mill.)," *Ind. Crops Prod.*, vol. 83, pp. 577–586, doi: 10.1016/j.indcrop.2015.12.067.

[38] S. Ramayana, S. D. Idris, R. Rusdiansyah, and K. F. Madjid, "Pertumbuhan Dan Hasil Tanaman Jagung (Zea Mays L.) Terhadap Pemberian Beberapa Komposisi Pupuk Majemuk Pada Lahan Pasca Tambang Batubara," *AGRIFOR*, vol. 20, no. 1, pp. 35–46, 2021, doi: 10.31293/agrifor.v20i1.4877.

[39] A. Jadeja and H. Hirpara, "Fundamentals of Soil Science first lecture," *Dep. Agric. Chem. Soil Sci. Coll. Agric. Junagadh Agric. Univ.*, pp. 1–38, 2019, doi: 10.13140/RG.2.2.20705.84325.

[40] R. Hapsari, D. Indradewa, and E. Ambarwati, "Pengaruh Pengurangan Jumlah Cabang dan Jumlah Buah terhadap Pertumbuhan dan Hasil Tomat (Solanum Lycopersicum L.)," *Vegetalika*, vol. 6, no. 3, pp. 37–49, 2017, doi: 10.22146/veg.28016.

[41] P. J. Gregory, L. P. Simmonds, and G. P. Warren, "Interactions between plant nutrients, water and carbon dioxide as factors limiting crop yields," *Philos. Trans. R. Soc. B Biol. Sci.*, vol. 352, no. 1356, pp. 987–996, 1997, doi: 10.1098/rstb.1997.0077.

[42] Raihan, "Pemupukan NPK dan ameliorasi lahan pasang surut sulfat masam berdasarkan nilai uji tanah untuk tanaman jagung," *Ilmu Pertan. (Agricultural Sci.*, vol. 9, no. 1, pp. 20–28, 2002, doi: 10.22146/ipas.58613.

[43] M. Mapegau, H. Setyaji, I. Hayati, and S. Putri Ayuningtiyas, "Efek Residu Biochar Sekam Padi Dan Pupuk Kandang Ayam Terhadap Pertumbuhan Dan Hasil Tanaman Jagung (Zea mays L.)," *Biospecies*, vol. 15, no. 1, pp. 49–55, 2022, doi: 10.22437/biospecies.v15i1.17121.

[44] A. Marvelia, S. Darmanti, and S. Parman, "Produksi Tanaman Jagung Manis (Zea Mays L. Saccharata) yang Diperlakukan dengan Kompos Kascing dengan Dosis yang Berbeda," *Bul. Anat. dan Fisiol.*, vol. XIV, no. 2, pp. 7–18, 2006, [Online]. Available:http://eprints.undip.ac.id/34480/.

[45] N. S. Isnaeni S, "Respon Tanaman Jagung Manis (Zea Mays L.) Terhadap Pemberian Pupuk Guano Kelelawar Dan Pupuk Guano Walet," *J. Agroteknologi*, vol. 11, no. 1, pp. 33–38, 2020, doi: 10.24014/ja.v11i1.9276.

[46] N. M. Rahni, "Efek Fitohormon PGPR Terhadap Pertumbuhan Tanaman Jagung (Zea mays)," *CEFARS J. Agribisnis dan Pengemb. Wil.*, vol. 3, no. 2, pp. 27–35, 2012, [Online]. Available: https://jurnal.unismabekasi.ac.id/index.php/cefars/article/view/92.

[47] T. Kendari, "The Change of Catechin Antioxidant during Vacuum Roasting of Cocoa Powder," *J. Nutr. Food Sci.*, vol. 02, no. 10, pp. 1–5, 2012, doi: 10.4172/2155-9600.1000174.

[48] S. Sarminah, Karyati, Karmini, J. Simbolon, and E. Tambunan, "Rehabilitation and soil conservation of degraded land using sengon (Falcataria moluccana) and peanut (Arachis hypogaea) agroforestry system," *Biodiversitas*, vol. 19, no. 1, pp. 222–228, 2018, doi: 10.13057/biodiv/d190130.

[49] Parveen, M. Anwar-Ul-Haq, T. Aziz, O. Aziz, and L. Maqsood, "Potassium induces carbohydrates accumulation by enhancing morpho-physiological and biochemical attributes in soybean under salinity," *Arch. Agron. Soil Sci.*, vol. 67, no. 7, pp. 946–959, 2021, doi: 10.1080/03650340.2020.1769075.

[50] A. Y. Fadwiwati and A. G. Tahir, "Analisis Faktor-Faktor yang Mempengaruhi Produksi dan Pendapatan Usahatani Jagung di Provinsi Gorontalo," *J. Pengkaj. dan Pengemb. Teknol. Pertan.*, vol. 16, no. 2, pp. 92–101, 2013, [Online]. Available:https://core.ac.uk/download/pdf/326453451.pdf.

[51] I. Anita-Sari and A. Wahyu, "Keragaan Beberapa Genotipe Harapan Kakao Mulia Hasil Seleksi di Kebun Penataran, Jawa Timur [Performance of Some Promising Genotypes of Fine-flavour Cocoa Selected at Penataran Estate, East Java]," *Pelita Perkeb.*, vol. 30, no. 2, pp. 81–91, 2014, [Online]. Available: https://pdfs.semanticscholar.org/f812/25b9f43c488377b0cdd7182861e8e683be02.pdf.

[52] M. S. Sharar, M. Ayub, M. A. Nadeem, and N. Ahmad, "Effect of Different Rates of Nitrogen and Phosphorus on Growth and Grain Yield of Maize (Zea mays L.)," *Asian J. Plant Sci.*, vol. 2, no. 3, pp. 347–349, 2003, doi: 10.3923/ajps.2003.347.349.

[53] N. S. Ruseani, W. Vanhove, A. W. Susilo, and P. Van Damme, "Clonal differences in nitrogen use efficiency and macro-nutrient uptake in young clonal cocoa *(Theobroma cacao L.)* seedlings from Indonesia," *J. Plant Nutr.*, vol. 45, no. 20, pp. 3196–3211, 2022, doi: 10.1080/01904167.2022.2057328.

[54] K. B. Kuan, R. Othman, K. A. Rahim, and Z. H. Shamsuddin, "Plant growth-promoting rhizobacteria inoculation to enhance vegetative growth, nitrogen fixation and nitrogen remobilisation of maize under greenhouse conditions," *PLoS One*, vol. 11, no. 3, pp. 0152478–0152497, 2016, doi: 10.1371/journal.pone.0152478.

[55] M. D. Staudinger *et al.*, "Biodiversity in a changing climate: A synthesis of current and projected trends in the US," *Frontiers in Ecology and the Environment*, vol. 11, no. 9. pp. 465–473, 2013, doi: 10.1890/120272.

[56] F. Bekele and W. Phillips-Mora, "Cacao *(Theobroma cacao L.)* breeding," *Adv. Plant Breed. Strateg. Ind. Food Crop.*, vol. 6, pp. 409–487, 2019, doi: 10.1007/978-3-030-23265-8_12.

[57] T. Wahyuni, Karmilasanti, S. Y. Indriyanti, and Abdurachman, "Involvement and roles of stakeholders in Mahakam delta management to support mitigation and adaptation effort of climate change in East Kalimantan," in *IOP Conference Series: Earth and Environmental Science*, 2022, vol. 976, no. 1, pp. 012028–012037, doi: 10.1088/1755-1315/976/1/012028.

[58] P. J. Kramer, "Effects of soil temperature on the absorption of water by plants," *Science (80-.).*, vol. 79, no. 2051, pp. 371–372, 1934, doi: 10.1126/science.79.2051.371.

[59] D. Chmolowska, "Higher Vulnerability of Heterotrophic Soil Respiration to Temperature Drop in Fallows than in Meadows," *J. Clim. Chang.*, vol. 7, no. 1, pp. 57–67, 2021, doi: 10.3233/jcc210005.

[60] C. Illawathure, G. Parkin, S. Lambot, and L. Galagedara, "Evaluating soil moisture estimation from ground-penetrating radar hyperbola fitting with respect to a systematic time-domain reflectometry data collection in a boreal podzolic agricultural field," *Hydrol. Process.*, vol. 34, no. 6, pp. 1428–1445, 2020, doi: 10.1002/hyp.13646.

Performance of Cocoa Fruit (Theobroma cacao L.)

ORIGINALITY REPORT

2%	4%	5%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.hrpub.org Internet Source	1%
2	"Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities", Springer Science and Business Media LLC, 2007 Publication	1%
3	tel.archives-ouvertes.fr Internet Source	1%
4	Mulatie Mekonnen, Tadissual Abeje, Solomon Addisu. "Integrated watershed management on soil quality, crop productivity and climate change adaptation, dry highland of Northeast Ethiopia", Agricultural Systems, 2021 Publication	1%

Exclude quotes	Off	Exclude matches	< 1%
Exclude bibliography	Off		