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Effects of Organic and Inorganic Fertilizers on Peasant Cocoa Farms Evaluated: The Case of Two Agro-Ecological Cocoa Growing Districts in Ghana

Nana-Osei Agyeman Prempeh[1], Collins Kuffour[2*], Samuel Novor[3], Khalid Aziz Abdul[3], Kwadwo Gyasi Santo[3]

[1]Cocoa Health and Extension Division, COCOBOD, Techiman, Ghana
[2]Department of Environmental Health and Sanitation Education, Faculty of Environment and Health Education, Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Asante Mampong, Ghana
[3]Department of Horticulture and Crop Production, School of Agriculture and Technology, University of Energy and Natural Resources, Sunyani, Ghana
Email: *ckuffour@aamusted.edu.gh

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Abstract

Cocoa (*Theobroma cacao*) is an important cash crop for small-scale farmers, which affects livelihoods in more than fifty countries, including Ghana. This study aimed to evaluate the effects of various fertilizers [poultry manure (988.42 kg ha^{-1}), Cocofeed (370.66 kg ha^{-1}), Vitazyme (1482.63 mls ha^{-1}), Sidalco (296.53 mls ha^{-1}), and a control with no fertilizer] on yield attributes, quality of cocoa beans, and soil chemical properties. The study conducted from April to November 2022 using a Randomized Complete Block Design with three replications, the results uncovered that the use of Vitazyme produced the highest total number of cocoa pods per plot (2662 and 3087), pod weight (113.60 kg and 131.73 kg), total number of pods per tree (24.33 and 28.00), and total beans per pod (35.33 and 36.00) in Techiman and Adabokrom, respectively. Soil chemical properties improved notably, with Cocofeed enhancing soil pH (7.26 and 6.86) in both locations. Sidalco treatment resulted in the highest total soil nitrogen (0.32 and 0.34%) and Vitazyme produced the highest total available phosphorus (25.07 and 25.29 mg kg^{-1}). The control plots exhibited the highest percentages of defects in cocoa beans (6.30 and 6.00%) and all other defects (4.30 and 4.33%). In effect, the application of Vitazyme markedly improved yield parameters, while the control treatment reflected the highest cocoa bean purity. Soil chemical properties were notably influenced by Cocofeed, Sidalco, and Vitazyme across both experimental sites.

Keywords

Cocoa Production, Organic Fertilizers, Inorganic Fertilizers, Soil Chemical Properties, Cocoa Bean Quality

1. Introduction

Cocoa (*Theobroma cacao*) is a vital cash crop for small-scale farmers playing a significant livelihood support role across more than fifty countries in Africa, Latin America, the Caribbean, and Asia [1]. In Ghana, cocoa farming is essential for millions of farmers, providing a substantial portion of their income and contributing positively to the national economy [2]. Available literature [3] detailed that approximately 794,129 rural households in Ghana rely on cocoa cultivation as the primary source of revenue and employment.

Cocoa production requires soils that are rich in nutrients and organic matter [4]. The fertile soil required for cocoa growth is characterized by rich materials of chemical compounds such as NPK, microbial activity and adequate water and air, which are all essential for cocoa plant health [5]. Organic and mineral fertilizers have been found to improve soil fertility and boost cocoa yields when applied correctly [5] [6]. While many cocoa growers utilize inorganic fertilizers such as sulfate of ammonia, organic fertilizers are gaining recognition for their role in improving soil physical qualities and enhancing cocoa yield and quality [5] [7]. Organic fertilizers have been shown to improve soil tilth and increase water retention capacity, hence supporting better cocoa growth [8].

Despite the strategic programs implemented by the Ghana Cocoa Board (COCOBOD) to enhance cocoa output over the recent years, many farms in Ghana still report low yields, averaging between 234 - 400 kg/ha, far below the potential yields of over 2500 kg/ha [9]. This disparity has been hugely attributed to poor nutrient availability and other factors like diseases and pests [10]. However, the effectiveness of various fertilizer types, particularly foliar and granular fertilizers and poultry manure, remains inadequately explored among peasant cocoa producers. This study aims to evaluate the effects of organic and inorganic fertilizers on cocoa performance by addressing three specific objectives: (i) examining the effects of these fertilizers on yield and yield components of cocoa, (ii) determining their impact on soil chemical properties, and (iii) evaluating their influence on the quality of cocoa beans.

2. Materials and Methods

2.1. Experimental Site

The trial took place from April to November 2022 on 10-year experimental farms in Techiman and Adabokrom. Techiman, located in central Ghana's forest-savanna transition zone (7˚35'13'' N, 1˚56'06'' W) [11], features open woodland, gallery forests, and grasslands. It has bimodal rainfall, with the main season from

April to July and a minor one from September to October, receiving 1200 - 1500 mm annually [12]. The fertile Ferric Luvisols and Ferric Acrisols support diverse agriculture, including cocoa, oil palm, maize, yams, plantains, vegetables, and livestock farming [13]. Adabokrom, located in the Wet Semi-Deciduous Forest zone of Western North Region, Ghana, lies at 6.8217˚ N, 3.0185˚ W. It features tropical rainforest and woodland, with an annual rainfall of 1500 - 2500 mm, peaking in May, June, and September [14]. Temperatures are stable, averaging 24 - 28˚C. The soils, mainly Oxisols and Ultisols, vary in nutrient levels [15].

2.2. Experimental Design and Treatments

A Randomized Complete Block Design (RCBD) was used for the study with three replications. This was to ensure effective control of environmental variations during the study. Each block had five (5) plots, which occupied a land area of 15175.725 m^2. The various treatments comprised organic (988.42 kg/ha of poultry manure (PM), 370.66 kg/ha of Cocofeed) and inorganic (1482.63 mls/ha of Vitazyme, 296.53 mls/ha of Sidalco) and a control treatment (CON).

In both locations, well-decomposed poultry manure (988.42 kg/ha) and Cocofeed (370.66 kg/ha) were broadcast evenly across plots two weeks after slashing. Sidalco (296.53 ml/ha) and Vitazyme (1482.63 ml/ha) were mixed with water and applied separately using a motorized machine, two weeks post-slashing. These liquid treatments were administered monthly for six months throughout the trial.

2.3. Determination of Yield Parameters

The selection of the 20 tagged cocoa trees within each plot was conducted using a systematic approach. Each plot was initially divided into equal sections based on the total number of trees present. A random starting point within the first section was employed to select every 3rd tree based on a predetermined interval, ensuring that the selection process was consistent across all plots. This method not only minimized selection bias but also allowed for a representative sample of the cocoa trees in each plot, reflecting the overall health and productivity of the cocoa farms. The underlisted formulae numbered "a to d" were used to determine the yielding parameters of the peasant cocoa farms studied.

a. ***Total number of cocoa pods per tree*** =

$$\frac{\text{The sum of cocoa pods from the 20 tagged trees}}{20}$$

b. ***Total number of cocoa pods per plot*** =

$$\frac{\text{The sum of cocoa pods from the 20 tagged trees}}{20} \times 105$$

where: 105 is the total number of cocoa trees in a plot.

c. ***The weight of the cocoa pod*** =

$$\frac{\sum(\text{individual weights of the 20 selected cocoa pods})}{20}$$

d. ***The number of cocoa beans per pod*** =

$$\frac{\text{Total number of cocoa beans from 20 plants}}{20}$$

2.4. Determination of Soil Chemical Parameters

For the collection of soil data, using the transect sampling technique. Multiple transects, each measuring 100 meters in length and 10 meters in width, were established within the various plots. Each transect was divided into four sections, referred to as meshes, measuring 50 meters in length and 5 meters in width. To ensure representative sampling, one manual drill was placed at the center of each mesh. Soil samples were taken at a depth of 0 - 30 cm from each of these designated sampling points [16].

soil pH

Assuming 1:2.5 soil-to-water proportions, the soil pH was evaluated using a Suntex pH (mv) Sp meter [17]. A 20 g soil sample was measured into a 100 ml mug and 50 ml purified water was introduced. The suspension was agitated for 20 minutes continuously after which it was permitted to stand for 15 minutes. The pH meter was calibrated with buffer solvents of pH 4.0 and 7.0. The pH was recorded by submerging the electrode into the upper portion of the suspension.

Total nitrogen, phosphorus, and potassium contents

Soil samples were collected from a depth of 0 - 30 cm in each treatment unit during both seasons and analyzed at the University of Ghana's Soil Science Lab. The samples were air-dried, sieved through a 2 mm mesh, thoroughly mixed, and labeled for analysis. Total nitrogen content in the soil was determined using a CNS Macro Elemental Analyzer (Elementar Analysen Systeme GmbH, Germany) following the combustion method at 1350˚C [18]. Phosphorus levels were measured using the Bray 1 method [19], while potassium levels were assessed with the ammonium acetate method and analyzed using an Atomic Absorption Spectrometer (AAS) [20].

2.5. Determination of Cocoa Bean Quality

The cocoa beans' quality was physically determined by the cut test method on dried cocoa beans [21]. The cut test was performed on 300 beans of cocoa in every given sample. The 300-bean cut test was replicated with sub-samples taken from each plot to enhance the robustness of the bean-quality analysis. Specifically, three sub-samples per plot were collected randomly, ensuring that each sub-sample was selected from different areas within the plot to minimize bias and represent the overall quality of the beans accurately. Beans were cut lengthwise via the middle to expose the cotyledon's surface. After cutting the beans lengthwise, the beans were placed on a whiteboard to be examined and graded. Beans were thoroughly examined for any form of the following defect.

a. $$\textit{Percentage of slaty cocoa beans} = \frac{\textit{Number of slaty cocoa beans}}{300\ \textit{cocoa beans}} \times 100\%$$

b. $$\textit{Percentage of all other defects} = \frac{\textit{Number of all other defects except slaty cocoa beans}}{300\ \textit{cocoa beans}} \times 100\%$$

c. $$\textit{Percentage defects of cocoa beans} = \frac{\textit{Number of all other defects} + \textit{slaty cocoa beans}}{300\ \textit{cocoa beans}} \times 100\%$$

d. $\textit{Percentage purity of cocoa beans} = \dfrac{\textit{Number of defects free cocoa beans}}{300\ \textit{cocoa beans}} \times 100\%$

2.6. Data Analysis

The R software package (2010) version i386 3.6.0 was used for the data analysis. A two-way ANOVA model was used to evaluate the effects of different fertilizers on cocoa yield and quality. The fixed factors in the model included the type of fertilizer (poultry manure, Cocofeed, Vitazyme, and Sidalco) and the Agro-ecological district (Techiman and Adabokrom). The random factor was the plot within each district, allowing us to account for variability among plots.

To ensure the validity of the ANOVA results, normality and homoscedasticity assumptions were checked. Normality was assessed using the Shapiro-Wilk test, while homoscedasticity was evaluated with Levene's test. Both tests confirmed that the data met the necessary assumptions for ANOVA.

3. Results

3.1. Treatment Effects of Fertilizers on Cocoa Pods

As shown in **Table 1**, the total number of cocoa pods varied significantly ($p < 0.05$) due to fertilizer application in both locations. The highest (2662 and 3087) total number of cocoa pods was recorded in plots treated with Vitazyme while the control treatment had the lowest (1723 and 1835) in Techiman and Adabokrom respectively. In Techiman, the highest total number of cocoa pods was obtained in plots treated with Vitazyme fertilizer, which was similar to the Sidalco treatment but differed significantly, from all the other treatments. All the other treatments recorded a similar total number of cocoa pods. In Adabokrom, Vitazyme fertilizer treatment was significantly higher ($p < 0.05$) relative to all other treatments. Likewise, the control plot obtained the least number of cocoa pods, which was significantly ($p < 0.05$) different from all the other treatments. However, the number of cocoa pods recorded by poultry manure and Cocofeed treatments was statistically similar.

Table 1. Treatment effects of fertilizers on cocoa pods.

Fertilizers	Techiman	Adabokrom
Effect of fertilizers on the total number of cocoa pods		
Control	1723 ± 14.19^{b}	1835 ± 30.83^{d}
Poultry Manure	1923 ± 153.86^{b}	2119 ± 183.19^{c}
Vitazyme	2662 ± 259.37^{a}	3087 ± 103.97^{a}
Cocofeed	1967 ± 101.15^{b}	2200 ± 180.08^{c}
Sidalco	2406 ± 140.87^{a}	2633 ± 184.50^{b}
Effect of fertilizers on the weight of cocoa pods		
Control	73.07 ± 2.69^{d}	77.33 ± 3.00^{d}

Continued

Poultry Manure	81.97 ± 6.69^{cd}	90.37 ± 7.84^{c}
Vitazyme	113.60 ± 11.07^{a}	131.73 ± 4.46^{a}
Cocofeed	83.90 ± 4.35^{c}	93.83 ± 7.67^{c}
Sidalco	102.60 ± 6.05^{b}	112.33 ± 7.84^{b}
Effect of fertilizers on the number of cocoa pods per tree		
Control	15 ± 0.58^{d}	16 ± 1.00^{d}
Poultry Manure	17 ± 1.53^{c}	19 ± 2.08^{c}
Vitazyme	24 ± 2.08^{a}	28 ± 1.00^{a}
Cocofeed	18 ± 1.00^{c}	20 ± 1.53^{c}
Sidalco	22 ± 1.00^{b}	24 ± 1.73^{b}
Effect of fertilizers on the number of cocoa beans per pod		
Control	17 ± 1.53^{c}	20 ± 1.00^{d}
Poultry Manure	21 ± 1.53^{b}	23 ± 1.00^{c}
Vitazyme	35 ± 3.51^{a}	36 ± 2.00^{a}
Cocofeed	24 ± 1.53^{b}	30 ± 1.00^{b}
Sidalco	32 ± 2.08^{a}	33 ± 2.08^{b}

Averages with identical alphabet within a column are not significantly distinct at 5% *probability measure.*

The weight of cocoa pods was significantly ($p < 0.05$) influenced by the type of fertilizer used. The application of Vitazyme resulted in the highest pod weights and the control plot had the lowest pod weight in both locations. In Techiman, the use of Vitazyme resulted in a pod weight of 113.60 kg, which was significantly ($p < 0.05$) higher than the pod weight of all other fertilizers. However, the control and poultry manure treatments recorded similar pod weights. In Adabokrom, the use of Vitazyme resulted in a pod weight of 131.73 kg, which was also significantly ($p < 0.05$) higher than the pod weight of all other fertilizers. The application of poultry manure and cocofeed resulted in a similar effect but varied from all the other treatments.

The results further showed that the use of different fertilizers significantly ($p < 0.05$) affected the total number of cocoa pods per tree in both locations. In both locations, the highest total number of cocoa pods per tree was recorded in the plot treated with Vitazyme, which was significantly ($p < 0.05$) different from all the other treatments. Plots treated with poultry manure and Cocofeed recorded a similar number of cocoa pods per tree but varied from the control treatment. The application of Sidalco fertilizer resulted in a significantly ($p < 0.05$) higher number of cocoa pods per tree than all the other treatments, except the Vitazyme treatment. The application of Vitazyme recorded the highest (24.33 and 28.00) total number of cocoa pods per tree, while the control treatment had the lowest (15.33 and 16.00) in Techiman and Adabokrom, respectively.

Finally, on the treatment effects of fertilizer on cocoa pods, the number of cocoa beans per pod was significantly ($p < 0.05$) affected by the application of fertilizer. In both locations, the application of Vitazyme was significantly higher than all the other treatments in the number of cocoa beans per pod, whereas the lowest number was recorded in the control treatment. In Techiman, plots treated with Vitazyme and Sidalco resulted in a similar effect on the number of cocoa beans per pod, however, both varied from all the other treatments. Also, the effects of the application of Poultry manure and Cocofeed were similar, but both differed from all the other treatments. In Adabokrom, plots treated with Cocofeed and Sidalco resulted in a similar effect on the number of cocoa beans per pod, however, both varied from all the other treatments. The application of Poultry manure differed significantly from the control treatment. The application of Vitazyme recorded the highest (35.33 and 36.00) total number of beans per pod, while the control treatment had the lowest (17.33 and 20.00) in Techiman and Adabokrom, respectively.

3.2. Treatment Effects of Fertilizer on Soil Chemical Properties

It is observed from Table 2 that the soil pH differed significantly ($p < 0.05$) due to fertilizer application in both locations of the study. The soil pH was highest in plots treated with Cocofeed, while plots without fertilizer had the lowest soil pH in both locations. A similar soil pH effect was recorded in the control plot, poultry manure plot, and Vitazyme plot, but neither of them differed significantly ($p < 0.05$) from the Cocofeed treatment in both locations.

Table 2. Treatment effects of fertilizer on Soil chemical properties.

Fertilizers	Techiman	Adabokrom
Effect of fertilizers on soil pH		
Control	5.48 ± 0.25^{c}	6.12 ± 0.00^{c}
Poultry Manure	5.80 ± 0.17^{bc}	6.19 ± 0.04^{bc}
Vitazyme	5.78 ± 0.28^{bc}	6.05 ± 0.07^{c}
Cocofeed	7.26 ± 0.32^{a}	6.86 ± 0.22^{a}
Sidalco	6.40 ± 0.15^{b}	6.40 ± 0.15^{b}
Effect of fertilizers on total soil nitrogen		
Control	0.22 ± 0.01^{c}	0.25 ± 0.02^{c}
Poultry Manure	0.27 ± 0.02^{b}	0.31 ± 0.00^{ab}
Vitazyme	0.27 ± 0.02^{b}	0.28 ± 0.02^{bc}
Cocofeed	0.22 ± 0.01^{c}	0.25 ± 0.02^{c}
Sidalco	0.32 ± 0.06^{a}	0.34 ± 0.06^{a}
Effect of fertilizers on soil available phosphorus		
Control	8.01 ± 2.03^{b}	8.73 ± 2.24^{c}
Poultry Manure	19.33 ± 2.12^{a}	18.96 ± 1.23^{ab}

Continued

Vitazyme	25.07 ± 1.85[a]	25.29 ± 3.13[a]
Cocofeed	19.11 ± 1.00[a]	17.01 ± 0.00[b]
Sidalco	23.08 ± 7.16[a]	23.69 ± 6.66[ab]
Effect of fertilizers on soil exchangeable potassium		
Control	0.08 ± 0.02[c]	0.11 ± 0.00[c]
Poultry Manure	0.29 ± 0.03[ab]	0.26 ± 0.07[ab]
Vitazyme	0.33 ± 0.07[a]	0.33 ± 0.09[a]
Cocofeed	0.20 ± 0.05[b]	0.22 ± 0.06[b]
Sidalco	0.32 ± 0.14[a]	0.34 ± 0.14[ab]

Averages with identical alphabet within a column are not significantly distinct at 5% *probability measure.*

More so, fertilizer treatments significantly ($p < 0.05$) affected total soil nitrogen in both locations of the experiment. In Techiman, the effect of the application of Sidalco was significantly ($p < 0.05$) higher than the other treatments. The control treatment and Cocofeed did not differ from each other in terms of total soil nitrogen, but either of them was significantly ($p < 0.05$) lower than the other treatments. The use of poultry manure and Vitazyme recorded a similar effect. In Adabokrom, no significant ($p > 0.05$) variation was revealed for total soil nitrogen content among Vitazyme, Cocofeed, and control treatments. The application of Sidalco did not significantly vary from poultry manure, but it differed significantly ($p < 0.05$) from all other treatments. The use of Sidalco resulted in the highest (0.32 and 0.34%) total soil nitrogen, while the control treatment recorded the lowest (0.22 and 0.25%) in Techiman and Adabokrom respectively.

Soil available phosphorus differed significantly ($p < 0.05$) due to fertilizer application in both trial locations. In Techiman, all the applied treatments recorded similar effects, except the control. In Adabokrom, applying Sidalco, Cocofeed, and poultry manure resulted in a similar effect, but differed from the control treatment. Likewise, applying Sidalco, Vitazyme, and poultry manure resulted in a similar effect, but differed from the control treatment. The control plot varied significantly ($p < 0.05$) from all other treatments. The use of Vitazyme resulted in the highest (25.07 and 25.29 mg kg^{-1}) total available phosphorus, while the control treatment recorded the lowest (8.01 and 8.73 mg kg^{-1}) in Techiman and Adabokrom, respectively.

Soil exchangeable potassium differed significantly ($p < 0.05$) due to the application of fertilizer in both locations of the trial. In Techiman, the application of Vitazyme and Sidalco recorded similar effects, but neither of them was significantly ($p < 0.05$) higher than the control treatment. Also, Cocofeed and poultry manure had similar effects, but neither of them was significantly ($p < 0.05$) higher than the control treatment. In Adabokrom, the application of Vitazyme, poultry manure, and Sidalco recorded a similar effect, but neither of them was significantly ($p < 0.05$) higher than the control treatment. The use of Cocofeed, poultry manure, and Sidalco recorded similar effects, but neither of them was significantly ($p < 0.05$) higher than the control treatment (Table 2).

3.3. Determination of Cocoa Bean Quality

Observed from Table 3, the percentage of slaty cocoa beans in the cocoa pods differed significantly ($p < 0.05$) among all the fertilizer treatments in both locations. The use of poultry manure and Cocofeed recorded similar ($p > 0.05$) percentages of slaty cocoa beans, however, neither of them was significantly ($p < 0.05$) higher than the other treatments. All other treatments were similar ($p > 0.05$) in both locations.

Table 3. Effect of fertilizers on the percentage of slaty cocoa beans.

Fertilizers	Techiman	Adabokrom
Effect of fertilizers on the percentage of slaty cocoa beans		
Control	2.0 ± 0.00^{a}	1.7 ± 0.00^{a}
Poultry Manure	1.8 ± 0.17^{a}	1.8 ± 0.19^{a}
Vitazyme	1.0 ± 0.00^{b}	0.8 ± 0.19^{b}
Cocofeed	1.9 ± 0.17^{a}	1.7 ± 0.34^{a}
Sidalco	1.1 ± 0.17^{b}	1.0 ± 0.00^{b}
Effect of fertilizers on the percentage of all other defects		
Control	4.30 ± 0.00^{a}	4.33 ± 0.00^{a}
Poultry Manure	3.77 ± 0.40^{a}	3.67 ± 0.35^{ab}
Vitazyme	1.77 ± 0.40^{c}	1.00 ± 0.33^{c}
Cocofeed	2.57 ± 0.51^{b}	3.03 ± 0.92^{b}
Sidalco	2.43 ± 0.23^{bc}	1.54 ± 0.40^{c}
Effect of fertilizers on the percentage of defects in cocoa beans		
Control	6.30 ± 0.00^{a}	6.00 ± 0.00^{a}
Poultry Manure	5.57 ± 0.51^{a}	$5.47 \pm 0.50a^{b}$
Vitazyme	2.77 ± 0.40^{d}	2.00 ± 0.88^{c}
Cocofeed	4.47 ± 0.50^{b}	4.70 ± 0.61^{b}
Sidalco	3.67 ± 0.06^{c}	2.54 ± 0.40^{c}
Effect of fertilizers on the percentage purity of cocoa beans		
Control	93.70 ± 0.00^{d}	94.00 ± 0.00^{c}
Poultry Manure	94.43 ± 0.51^{d}	$94.53 \pm 0.50b^{c}$
Vitazyme	97.23 ± 0.40^{a}	97.78 ± 0.69^{a}
Cocofeed	95.53 ± 0.50^{c}	95.30 ± 0.61^{b}
Sidalco	96.47 ± 0.21^{b}	97.47 ± 0.40^{a}

Averages with identical alphabet within a column are not significantly distinct at 5% probability measure.

Additionally, the percentage of all other defects of the cocoa beans varied significantly ($p < 0.05$) with fertilizer treatments. In Techiman, the control and poultry manure treatments resulted in similar effects, which were significantly ($p < 0.05$) higher than the other treatments. The treatment effects of Sidalco, Vitazyme, and Cocofeed were similar, but neither of them differed from poultry manure and the control treatments. In Adabokrom, the application of poultry manure resulted in a similar ($p > 0.05$) percentage of all other defects as the control and Cocofeed treatments did but varied significantly ($p < 0.05$) from Vitazyme and Sidalco treatments.

In both locations, the percentage defects of cocoa beans varied significantly ($p < 0.05$) with fertilizer treatments. In Techiman, the control and poultry manure treatments had similar effects, which were significantly ($p < 0.05$) higher than the other treatments. The use of Sidalco, Vitazyme, and Cocofeed varied significantly ($p < 0.05$) from the control treatment. In Adabokrom, the application of poultry manure resulted in a similar ($p > 0.05$) percentage defects of cocoa beans as the control and Cocofeed treatments did, but varied significantly ($p < 0.05$) from Vitazyme and Sidalco treatments.

The percentage purity of cocoa beans differed significantly ($p < 0.05$) with fertilizer treatments in both locations. In Techiman, the control and poultry manure treatments recorded a similar percentage purity of cocoa beans, which were significantly ($p < 0.05$) lower than the other treatments. The use of Sidalco, Vitazyme, and Cocofeed varied significantly ($p < 0.05$) from the control treatment. In Adabokrom, the application of poultry manure resulted in a similar ($p > 0.05$) percentage purity of cocoa beans as the control and Cocofeed treatments did, but varied significantly ($p < 0.05$) from Vitazyme and Sidalco treatments.

4. Discussion

4.1. Effects of Fertilizers on Yield Parameters

The plot treated with Vitazyme fertilizer recorded the highest total number of cocoa pods, similar to the Sidalco treatment but significantly different from all other treatments. Both Vitazyme and Sidalco fertilizers likely enhanced pod formation by supplying essential nutrients or plant growth regulators. Bio-stimulant fertilizers like Vitazyme have been shown to boost crop growth and production by accelerating physiological processes, promoting nutrient absorption, and enhancing plant performance [22]. In both locations, the Vitazyme-treated plots produced the highest number of cocoa pods, confirming their effectiveness in promoting cocoa pod production. The control treatment had the lowest number of pods, likely due to the absence of fertilizer. These findings align with previous studies that show fertilizer use increases cocoa output [23]. Cocoa pod numbers from the poultry manure and Cocofeed treatments were similar in both locations, suggesting that these organic fertilizers are viable alternatives to synthetic ones. Organic fertilizers like poultry manure improve soil fertility, nutrient availability, and microbial activity, which enhances plant growth and yield [24]. Similarly, Cocofeed, derived from coconut husks, supports sustainable cocoa farming by providing essential nutrients [25].

The use of Vitazyme, with its enzymes and natural growth regulators, significantly increases nutrient uptake and pod weights in cocoa plants compared to conventional fertilizers. This aligns with [7], who found that plant growth promoters enhance nutrient absorption and yield. Control plots without fertilizer had the lowest pod weights, highlighting the necessity of adequate nutrients for optimal growth. Nitrogen, phosphate, and potassium deficiencies can hinder cocoa development and reduce yields [26]. Organic fertilizers like poultry manure and Cocofeed also improved pod weights by providing a steady nutrient supply, enhancing soil fertility, nutrient availability, and structure, thereby boosting plant growth and harvests [27].

Commercially available Vitazyme, a synergistic mixture of natural enzymes, vitamins, and minerals, stimulates plant growth [28]. It has been shown to improve the growth, nutrient uptake, and stress resistance of various plants [29]. Vitazyme enhances cocoa pod yield by improving nutrient availability and absorption. Its organic components and enzymes help decompose organic matter, enabling cocoa tree roots to absorb necessary nutrients [30]. This nutrient availability improves overall tree health, leading to earlier flowering and increased pod production [30]. The control plots produced the lowest cocoa pod yield due to insufficient nutrient availability, resulting in fewer pods per plant and fewer seeds per pod. This study underscores the importance of effective nutrient management in optimizing cocoa production [5]. Treating plants with poultry manure or Cocofeed significantly increased the number of cocoa pods per tree compared to the control. Poultry manure, a popular organic fertilizer rich in nitrogen, phosphorus, and potassium, provides slow-release nutrients and enhances soil fertility [31]. Both poultry manure and Cocofeed boosted cocoa pod output by increasing nutrient availability. Additionally, fertilizing with Sidalco significantly increased cocoa pod production compared to the control group. Sidalco, a well-known commercial fertilizer, offers a balanced mix of macro and micronutrients [32]. It likely promoted blooming and fruiting in cocoa plants by enhancing nutrient intake [33].

The application of Vitazyme consistently led to the highest number of cocoa beans per pod, outperforming all other treatments at both locations. This aligns with “reference [34], who reported that fertilizers enhance cocoa bean production and quality. Fertilizers promote overall tree growth, thereby increasing yield per pod [34]. Vitazyme’s unique formulation likely improved nutrient absorption and balance, resulting in better pod growth and higher yields [34]. Similarly, poultry manure and Cocofeed also increased cocoa bean yield per pod by enhancing soil fertility and nutrient availability, which boosts plant health and vitality [35]. Further evidence of Vitazyme’s effectiveness is seen in the significantly higher total number of cocoa pods per tree after treatment. These findings suggest that Vitazyme can significantly boost cocoa production by promoting pod formation and growth. This is consistent with available literature [36] [37], which showed that both inorganic and organic fertilizers improve cocoa output, bean quality, and pod characteristics.

4.2. Effects of Fertilizers on Soil Parameters

The content and action of applied fertilizers are key to the observed soil pH differences. Cocofeed increased soil pH the most, indicating it likely contains alkaline substances. In contrast, the control plot, which received no fertilizer, had the lowest pH. Compared to Cocofeed, the soil pH in the control, poultry manure, and Vitazyme plots showed minimal change, suggesting these fertilizers had a minor impact due to lower or absent alkaline substances [38]. Fertilizer-induced pH changes affect nutrient availability and soil fertility, as soil pH influences nutrient solubility and plant uptake [39]. Maintaining an optimal soil pH is essential for nutrient absorption and crop yield, varying with crop type and nutritional needs [40]. Studies indicate that certain fertilizers can alter soil acidity. Available literature [41] indicated that alkaline-based fertilizers improved the pH of acidic soils. Organic amendments like poultry manure can also influence soil pH [42]. These findings align with our study, supporting the idea that different fertilizers affect soil pH.

Total soil nitrogen was significantly higher in Sidalco-treated plots in Techiman, confirming its beneficial impact on soil nitrogen [33] [43]. No significant difference was found between the control and Cocofeed treatments, likely due to Cocofeed's lower nitrogen content and the control's lack of nitrogen [44]. Both poultry manure and Vitazyme increased total soil nitrogen in Techiman. Poultry manure boosts soil nitrogen due to its high content [45], while Vitazyme enhances nitrogen mineralization and availability [30]. In Adabokrom, total soil nitrogen did not significantly differ between Vitazyme, Cocofeed, and control treatments, possibly due to soil type and microbial activity [46]. Sidalco showed differences from poultry manure but not from other treatments in Adabokrom, indicating it as a viable alternative for boosting soil nitrogen levels [33].

The Vitazyme treatment resulted in the highest levels of soil-available phosphorus, while the control treatment had the lowest at both trial sites, highlighting the positive impact of fertilizer application. Several factors contribute to this increase in soil-available phosphorus. Poultry manure, rich in phosphorus and other organic compounds, aids in the mineralization and release of phosphorus, making it more accessible to plants [31]. Similarly, commercial biofertilizers like Vitazyme, which contain phosphorus-solubilizing microorganisms, enhance phosphorus solubility and availability [47]. The Cocofeed and Sidalco treatments also boosted soil-available phosphorus compared to the control. These fertilizers likely added phosphorus compounds to the soil, improving nutrient supply [33]. Additionally, their effects on soil pH and microbial activity may have indirectly increased phosphorus availability [48]. The lowest phosphorus levels were observed in the control treatment, underscoring the importance of fertilizer application for maintaining soil fertility and nutrient availability. This emphasizes the role of fertilizers in supporting plant growth and sustaining soil health.

Research shows that fertilizers boost exchangeable potassium levels due to their nutrient content. Poultry manure, rich in potassium, significantly enhances soil exchangeable potassium [49]. Similarly, the commercial biofertilizer Vitazyme, containing beneficial microbes and organic matter, increases soil nutrients by breaking down minerals and releasing potassium [28]. Vitazyme's organic matter also improves soil cation exchange capacity, aiding potassium retention [50]. Cocofeed, derived from coconut coir, also contributes to higher exchangeable potassium due to its high potassium retention (Koranteng, 2016). Sidalco, containing potassium sulfate, acts as a nutrient booster, raising soil exchangeable potassium levels efficiently [33]. These treatments, rich in potassium, provide direct sources to improve soil potassium content.

4.3. Effect of Fertilizer Treatments on the Quality of Cocoa Beans

The use of fertilizers significantly influences the physiological and biochemical processes in cocoa plants, affecting the proportion of slaty cocoa beans. Organic additives like poultry manure and Cocofeed can enhance soil fertility by increasing nutrient availability, promoting root growth, and improving nutrient absorption efficiency [51]. This suggests that fields treated with poultry manure or Cocofeed had fewer slaty cocoa beans due to improved growth conditions. In contrast, control and Vitazyme treatments produced more slaty beans, likely due to the lack of supplemental nutrients [5]. This supports previous findings on the positive impact of organic amendments like poultry manure on cocoa yield and quality [51]. Cocoa plants flourish in soils enriched with organic amendments, which improve soil structure, nutrient availability, and water retention, ultimately reducing the incidence of slaty beans [52] [53].

Treatment with poultry manure consistently showed a positive impact by reducing the prevalence of abnormalities at both sites. This effect can be attributed to poultry manure's ability to enhance soil fertility and nutrient availability for cocoa plants, due to its rich organic matter and nutrients. Organic additions like poultry manure can improve soil structure, nutrient retention, and microbial activity, resulting in healthier plants and fewer defects [54]. Differences in nutrient concentration, release rates, and action mechanisms among the fertilizers could explain the observations. Specific nutrients or bioactive substances provided by Vitazyme, Cocofeed, and Sidalco likely supported cocoa tree growth, leading to fewer defects. These fertilizers are linked to increased nutrient uptake, improved root growth, and enhanced plant vigor, reducing the plants' susceptibility to various faults [55]. The control treatment, which showed significantly higher defect rates, underscored the importance of good nutrient management in cocoa production. The lack of fertilizer application left the control plants nutrient-deficient, hampering their growth and productivity [37]. This highlights the necessity of effective fertilizer use to maximize cocoa output and minimize defect incidence [56].

Differences in fertilizer types can impact the percentage of defects in cocoa beans. Poultry manure, rich in organic matter, may increase bean defects despite its positive effects on soil fertility [57]. This increase may be due to higher susceptibility to insect and disease infestations [58]. In contrast, chemical fertilizers like Sidalco and Vitazyme, which contain specific macro and micronutrients, may reduce defects by promoting healthy growth and reducing pest and disease vulnerability [59]. The effects of fertilizers on cocoa bean defects can also be influenced by soil, climate, and management practices [55] [60]. Several studies support these findings. For example, [61] reported that organic fertilizers like poultry manure might increase the risk of cocoa bean deformities. Conversely, [62] found that chemical fertilizers improved cocoa bean quality and reduced defects.

Vitazyme and Sidalco treatments significantly outperformed the control in terms of percentage purity. The unique nutrient compositions and mechanisms of these fertilizers likely contributed to this effect. Vitazyme, which contains natural enzymes, amino acids, and bioactive components, has been shown to enhance nutrient absorption and plant metabolism, improving overall plant health [63]. Sidalco, with its organic matter and beneficial microbes, increases nutrient availability and soil fertility [1]. Conversely, the control and poultry manure treatments resulted in lower purity. The control treatment's lack of fertilizer indicated that the soil's natural fertility was insufficient for high-quality cocoa beans. Notably, there were no significant differences in purity between the Cocofeed and control treatments at both locations, suggesting that cocofeed's nutritional profile or application rate did not significantly improve cocoa bean purity.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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