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Effect of Biofertilizers on the Agromorphological Parameters of Three Okra Cultivars in Southern Côte d'Ivoire

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Abstract

Okra (*Abelmoschus esculentus* L.) is an herbaceous plant of the Malvaceae family. In Côte d'Ivoire, okra production is estimated to be over 193,000 tons. This low production is largely due to poor soils and hardly covers the needs of the population. To remedy this, growers systematically use mineral fertilizers. However, these fertilizers pollute the environment. To find an alternative to chemical fertilization and increase production, the effect of biofertilizers (Spaawet, Retone, Super Gro) compared with NPK mineral fertilizer was evaluated on *Divo*, *Teriman*, and *Djonan F1* cultivars. The trial was set up in a factorial block design with three replications. Plant height, number of functional leaves, and crown diameter were assessed at 60 days after sowing (DAS). The time to 50% flowering, production time, and fruit yield were calculated. The results showed that the biofertilizer Retone induced the highest heights and number of functional leaves, with averages of 61.89 cm and 29.88 leaves, respectively. The diameter at the crown (17.77 mm) was highest with the NPK mineral fertilizer, and the shortest 50% flowering time, with an average of 47.61 days, was also obtained with the biofertilizer Retone. The NPK mineral fertilizer produced the longest production time, with an average of 35.25 days. The highest yields were obtained using Retone (11.07 t/ha) and NPK (9.52 t/ha) fertilizers. The "Divo*Retone" interaction produced the highest yield with an average of 12.19 t/ha. The biofertilizer Retone could therefore be used as an alternative fertilizer to chemical fertilization in okra crops, given its effect on the parameters assessed.

Keywords

Biofertilizer, Retone, Mineral Fertilizer, Okra, Yield, Côte d'Ivoire

1. Introduction

The global demand for agricultural products is constantly increasing because of the rapid growth of the human population [1]. The global population is projected to reach 10 billion within the next 50 years [2] [3] [4]. To meet the challenges posed by food scarcity due to population growth, farmers are looking for innovative approaches to optimize agricultural yields. These approaches use synthetic chemical fertilizers and pesticides. However, the misuse of these products raises many public concerns about their sustainability, impact on food safety and human and animal health [5]. Growing okra (*Abelmoschus esculentus* L., Moench) is no exception to this rule. In Côte d'Ivoire, okra production is estimated to be over 193 thousand tons. It is an exceptional plant with a wide range of uses in food, medicine, handicrafts, and even industry with high carbohydrate and protein contents [6] [7]. It also contains vitamins and minerals, which contribute to the body's proper physiological functioning [8]. Currently, okra also represents a significant source of income for disadvantaged communities because of its high sales potential in rural and urban markets. Despite its importance, this crop faces some constraints, including abiotic constraints, of which soil infertility is of particular concern. This situation affects national production, which falls below national requirements. A lack of sufficient quantities of nutrients required for plant growth can lead to poor development, resulting in low yields [9] [10] [11]. Therefore, it is essential to consider products with diverse organic compositions that are a source of nutrients and can be incorporated as fertilizers. Because of their low content of synthetic chemical elements, they can be safely used in large quantities to improve soils and boost plant growth [12]. Therefore, it is essential to consider the impact of the products involved in fertilization; hence, there is a need to look for environmentally-friendly solutions. Thus, biofertilizers, play a crucial role in sustainable agriculture [3], and represent a promising approach from this perspective. Therefore, this study was initiated with the aim of finding an alternative to chemical fertilization and increasing production by evaluating the effect of biofertilizers on the agromorphological parameters of okra cultivars.

2. Materials and Methods

2.1. Material

2.1.1. Plant Material

The plant material used in this assessment consisted of three okra cultivars: *Divo* (V_1), *Djonan F1* (V_2), and *Teriman* (V_3). The choice of these cultivars was based on their adaptation to hot, humid climates [13].

2.1.2. Fertilizer

The biofertilizers Retone (F_1), Spaawet (F_3) whose compositions are indicated in Table 1 were used. The biofertilizer Super Gro (F_4) and the ternary mineral fertilizer (F_2) NPK (12-22-22) coupled with urea (46% N) were also used. However a tap water was used as a control without fertilizer (F_0). Super Gro is a natural, liquid foliar fertilizer which, according to the manufacturer, contains three primary macro-nutrients (N, P and K). It acts directly on plant leaves, tree bark and roots.

2.2. Methods

2.2.1. Study Area

The study was conducted at Félix HOUPHOUËT-BOIGNY University in Cocody's commune on an experimental plot with geographical coordinates between latitudes 4˚10 and 5˚30 North and longitudes 3˚50 and 4˚10 West (Figure 1). The soils are essentially ferritic and ferruginous [13]. The commune is characterized by an average annual rainfall exceeding 1700 mm [13]. The Université Félix HOUPHOUËT-BOIGNY site is located in a humid tropical climate zone characterized by a highly contrasting rainfall and temperature regime. The climate is subdivided into four seasons: a long and short rainy season from May to July and October to November, respectively, followed by a long and short dry season from December to April and August to September, respectively. The average monthly temperatures in Abidjan range from 25.02˚C to 28.70˚C in 2022 [13].

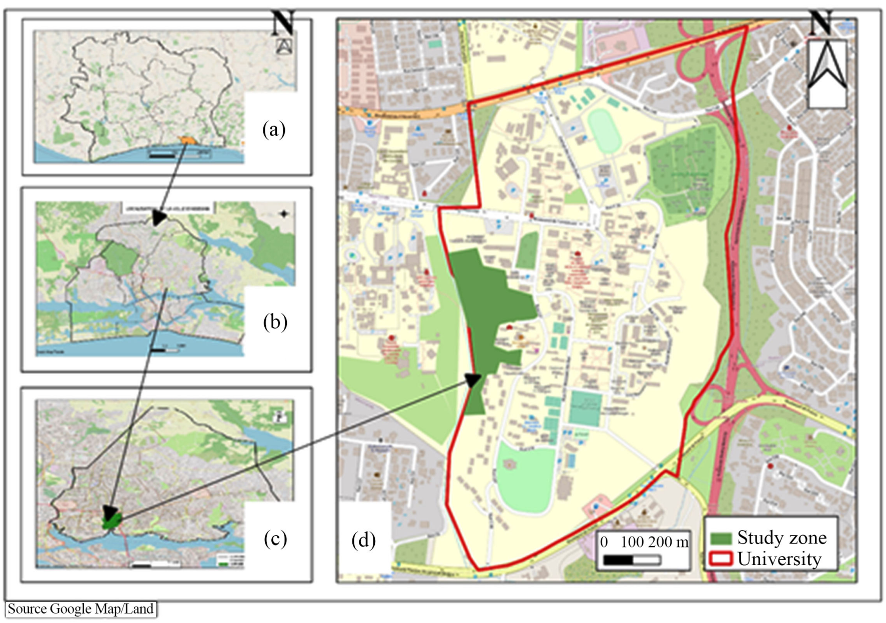

Figure 1. Study area. (a) Map of Côte d'Ivoire showing the town of Cocody; (b) Map of the city of Cocody showing Felix Houphouët-Boigny University; (c) Map of Felix Houphouët-Boigny University; (d) Experimental site.

Table 1. Composition of retone and spaawet biofertilizers.

Biofertilizers	Parameters	Values
Retone (F_1)	pH	8.30
	Organic matter (%)	16.00
	Organic carbon (%)	9.00
	Potassium (%)	4.70
Spaawet (F_3)	pH	6.50
	Emulsifiable concentrate (μ/S)	260.00
	Viscosity at 25˚C (m^2/S)	38.40
	Surface tension (mN/m)	20.70
	Density	1.08

Source: Spaa Agro Technology, Nashik (India).

2.2.2. Analysis of Soil Samples

The physicochemical analysis of the soil samples covered particle size, organic carbon (C), total nitrogen (N), hydrogen potential (pH), electrical conductivity (EC), exchangeable bases (Mg^{2+}, K^+), and cation exchange capacity (CEC). Thus, three samples were taken at random and repeated three times to obtain a composite sample. Granulometry in five fractions was performed according to the AFNOR NF X31-107 standards using the Robinson pipette method [13]. Soil texture was classified according to the USDA (United States Department of Agriculture) texture triangle. Total carbon and nitrogen were analyzed using the methods described in international standards NF ISO 10694 for carbon, and NF ISO 13878, for nitrogen. The C/N ratio used to assess soil biological activity [13] was calculated. The water pH and KCl concentrations were determined in accordance with the international standard NF ISO 10390 [13]. The cation exchange capacity was measured [14]. K^+, Mg^{2+} content was determined by the fluoro-nitro-perchloric method and the Total phosphorus and assimilable phosphorus were determined [14].

2.2.3. Experimental Design

The assessment was conducted in October 2022 and replicated in March 2023. The trial was set up in a factorial block design with three replications. The factors were variety (V) and fertilizer (F). Blocks were spaced 1.5 m apart. Each block consisted of 15 microplots to which cultivars and fertilizers were assigned. Each microplot consisted of an okra cultivar and fertilizer application represented by two rows of 10 plants arranged on either side, for 20 plants in the experimental unit (**Figure 2**). In total, each block consisted of 300 okra plants, with a row spacing of 0.6 m, giving a semi-density of 27,778 plants per hectare (**Figure 2**).

2.2.4. Trial Monitoring and Maintenance

Manual weeding and watering were performed regularly when necessary. The crop was protected against insects by applying a synthetic chemical insecticide

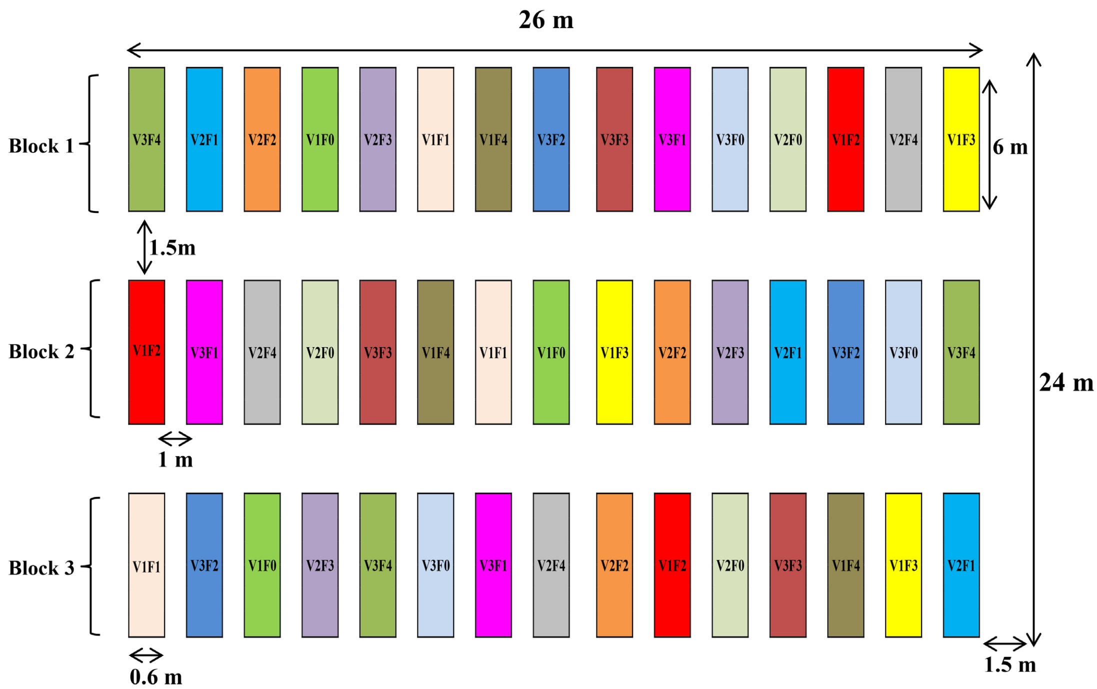

Figure 2. Study design. V1: *Divo* variety; V2: *Djonan F1* variety; V3: *Teriman* variety; F1: Retone biofertilizer; F2: NPK fertilizer; F3: Spaawet biofertilizer; F4: Super Gro biofertilizer; F0: Control without fertilizer; V1F1: *Divo* variety + Retone biofertilizer application.

(Deltamethrin + acetamepride) at a dose of 30 g/l using a 16-liter backpack sprayer. This insecticide protection was applied every 15 days, from the emergence of the okra plants until the end of the experiment. The biofertilizers Retone, Spaawet, and Super Gro were applied to the leaves at a dose of 1 ml/L using a hand sprayer every 15 days, from plant emergence to flowering, along with the control without fertilizer (water). NPK mineral fertilizer (12-22-22) was applied at a rate of 200 kg/ha at sowing, whereas urea was applied at the same rate 30 days after sowing (DAS). Biofertilizers were applied during the last hours of the day to facilitate penetration of the product into the plant stomata.

2.2.5. Growth Parameters

In this study, plant height, number of functional leaves, and crown diameter were assessed at 60 days after sowing (DAS) on 12 okra plants randomly selected by treatment. Height was measured using a tape measure. This measurement was taken from the stem collar to the tip of the tallest leaf for plants in the vegetative stage. At maturity, height was measured from the stem collar to the tip of the last apical bud. The diameter of the plant collar was measured using a conventional digital caliper from 150 mm to 2 cm above ground level. Plant leaves were counted according to the different fertilizers applied.

2.2.6. Physiological Parameters

During the trial, the dates of 50% flowering were recorded according to the different treatments. The first and last harvest times were also recorded. These data were used to assess the production duration, which was defined as the number of days elapsed between the first and last harvests of the cultivars.

2.2.7. Agronomic Parameters

When the plants reached maturity, the fruits were harvested. Harvesting was performed manually for each treatment, and began three days after the first flowers. Harvesting was continued regularly every three days until the end of each cultivar's growing cycle. The weight of the harvested fruit was obtained using a Sartorius balance (model MSE 10202S). Thus, after each harvest, the fruits were weighed by treatment and by cultivar. Evaluations were performed on 12 okra plants randomly selected by treatment for 540 plants. Yield was obtained using fruit weight (W) and plant density (D) according to the following formula:

$$R = W \times D$$

R: yield, W: fruit weight, D: plant density.

2.2.8. Statistical Analysis

The collected data were subjected to analysis of variance 2 (ANOVA) using STATISTICA software version 12.5. The Newman-Keuls test at the 5% threshold was used to compare averages in the event of rejection of the H_0 hypothesis.

3. Results

3.1. Physicochemical Characteristics of the Experimental Plot Soil

There was a significant difference in the granulometric composition of the soil. The soil was significantly richer in sands which represent 76.87% and the silts are estimated by 17.73% and poorer in clays that were 5.39% (Table 2). The soils in the experimental plot were therefore sandy-loamy in texture. The soil analyze also showed that the soil was slightly acidified, with pHwater (6.55) and pHKCl (6.50) below 7. Organic carbon (2.78%), total nitrogen (5.33%), and assimilable potassium (3.33%) levels were low. The total organic matter content was 5.01%. The carbon/nitrogen (C/N) ratio were 0.52 (C/N < 15), so the nitrogen requirements were not met. The low levels of nitrogen, phosphorus, and potassium, essential mineral elements for good crop growth reflect the poor state of the soil in the experimental plot.

3.2. Growth Parameters

3.2.1. Height of Okra Plants

The plant height data collected at 60 DAS revealed a significant difference ($p < 0.05$) between fertilizers (Table 3). The Retone biofertilizer induced the best growth in plant height, with an average of 61.89 cm, followed by the NPK mineral fertilizer treatment, which induced an average height of 56.86 cm. However, the lowest averages were observed with Super Gro (32.56 cm).

3.2.2. Neck Diameter of Okra Plants

Statistical analysis showed a significant difference ($p < 0.0001$) between fertilizers. NPK mineral fertilizer produced the highest crown diameter, with an average of 17.77 mm, followed by Retone biofertilizer, which induced an average diameter of 15.93 mm. However, the smallest average diameter (14.41 mm) was obtained using the biofertilizer Super Gro 60 DAS (Table 3).

3.2.3. Number of Functional Leaves in Okra Plants

Analysis of the collected data revealed a significant difference ($p < 0.0001$) between fertilizers. The highest number of functional leaves was recorded with Retone (29.88 leaves) and NPK (29.31 leaves) fertilizers. In contrast, the Super Gro biofertilizer and the no-fertilizer control induced the lowest numbers of functional leaves, with averages of 26.10 and 24.69 leaves per plant, respectively (Table 3). Spaawet induced an average of 27.87 functional leaves per plant.

Table 2. Physicochemical characteristics of soil in the experimental plot.

Types of analysis	Parameters	Values
Particle size	Sand (%)	76.87
	Silt (%)	17.73
	Clay (%)	5.39
Physicochemical	pH water	6.55
	pH KCl	6.50
	MO (%)	5.01
	CO (%)	2.78
	N (ppm)	5.33
	C/N	0.52
	P (ppm)	183.57
Adsorbent complex	Conductivity (mS/cm)	0.17
	Mg ($cmol \cdot kg^{-1}$)	0.28
	K (ppm)	3.33

Table 3. Plant height, Neck diameter and number of functional leaves by fertilizers.

Fertilizers	Plant height (cm)	Neck diameter (mm)	Average number of functional leaves
Control	46.59 c	14.79 cd	24.69 c
Retone	61.89 a	15.93 b	29.88 a
NPK	56.86 b	17.77 a	29.31 a
Spaawet	35.82 d	15.18 c	27.87 ab
Super Gro	32.56 e	14.41 d	26.10 b
Average	46.74	15.61	27.57
Coefficient of variation (%)	27.00	20.62	35.79
Probability	<0.0001	<0.0001	<0.0001

In the same column, the values followed by the same letter do not differ significantly according to the Newman-Keuls test at 5% threshold.

3.3. Effect of Fertilizers on the Time to 50% Flowering and Production of Okra Cultivars

The effect of fertilizers on 50% flowering time and production time showed a highly significant difference between treatments (**Table 4**). The average durations of 50% flowering time and production time were 52.06 and 29.68 days after sowing (DAS), respectively. The Super Gro biofertilizer induced the longest 50% flowering time, with an average of 57.73 DAS, whereas the Retone biofertilizer produced an average of 47.61 DAS. The earliest harvests occurred at 52.94 DAS and were obtained with the Retone biofertilizer, whereas the Super Gro biofertilizer induced the latest harvests with an average of 61.16 JAS. The time to last harvest was the longest with NPK (90.97 DAS) and Super Gro (89.85 DAS) fertilizers, whereas the shortest time was obtained with the no-fertilizer control (77 DAS). The effect of fertilizers on production time varied from 21.82 to 35.25 JAS. The NPK fertilizer produced the longest production time, with an average of 35.35 DAS, whereas the no-fertilizer control produced the shortest production time, with an average of 21.82 DAS (**Table 4**).

3.4. Effect of Fertilizers on the Mass and Yield of Different Okra Cultivars

Analysis of variance revealed a highly significant difference ($p < 0.0001$) between okra cultivars for fruit mass and yield (**Table 5**). The *Divo* cultivar produced the highest fruit weight (266.94 g) and yield (7.41 t/ha), whereas the *Teriman* cultivar produced the lowest average mass (246.85 g) and yield (6.85 t/ha). On the other hand, the cultivar *Djonan F1* produced intermediate masses and yields, with respective averages of 262.40 g and 7.28 t/ha (**Table 5**).

Table 4. Phenological parameters of by fertilizers.

Fertilizers	Time to 50% flowering (Days)	Time to first harvest (Days)	Time to last harvest (Days)	Production time (Days)
Control	50.34 c	55.18 c	77.00 d	21.82 d
Retone	47.61 d	52.94 d	85.21 c	32.28 b
NPK	51.27 c	55.72 c	90.97 a	35.25 a
Spaawet	53.37 b	57.29 b	87.64 b	30.35 bc
Super Gro	57.73 a	61.16 a	89.85 a	28.69 c
Average	52.06	56.46	86.14	29.68
Coefficient of variation (%)	8.49	7.86	8.66	27.62
Probability (p)	<0.001	<0.001	<0.001	<0.001

In the same column, the values followed by the same letter do not differ significantly according to the Newman-Keuls test at 5% threshold.

Table 5. Fruit weight and yield by okra cultivar.

Cultivars	Fruit weight (g)	yield (t/ha)
Divo	266.94 a	7.41 a
Djonan F1	262.40 b	7.28 b
Teriman	246.85 c	6.85 c
Average	258.73	7.18
Coefficient of variation (%)	37.31	37.30
Probability (p)	<0.0001	<0.0001

In the same column, the values followed by the same letter do not differ significantly according to the Newman-Keuls test at 5% threshold.

3.5. Effect of Fertilizers on Fruit Weight and Yield

Statistical analysis of the data revealed that fertilizers had a significant effect ($p < 0.0001$) on mass (g) and fruit yield (t/ha), as shown in **Table 6**. NPK and Retone showed the best results. The Retone biofertilizer produced an average fruit mass of over 398 g for a yield of over 11 t/ha. Similarly, the mineral fertilizer NKP produced statistically similar results, with an average fruit mass of 342.70 g for a yield of 9.51 t/ha. However, the biofertilizers Spaawet, Super Gro, and the untreated control induced the lowest average fruit weight and yields. The average fruit masses were 199.45, 191.75, and 161.12 g, respectively, for the Spaawet biofertilizer, no-fertilizer control, and Super Gro biofertilizer. Yields of 5.54, 5.32, and 4.47 t/ha were observed with the Spaawet biofertilizer, control, and Super Gro biofertilizer (**Table 6**).

3.6. Effect of the Interaction between Fertilizers and Okra Cultivars on Fruit Weight and Yield

Recorded fruit mass and yield significantly affected the interaction between fertilizers and okra cultivars. Fruit mass varied from 145.04 to 439.10 g. Yield varied from 4.02 to 12.19 t/ha. The highest weight and yield were observed with "*Divo**Retone" interaction, with respective averages of 439.10 g and 12.19 t/ha, whereas the lowest averages were obtained with "*Divo**Super Gro" interaction, which induced respective averages of 145.04 g and 4.02 t/ha. However, yields of over 10 t/ha were obtained with the interactions "*Teriman**Retone", "*Divo**NPK" and "*Djonan F1**Retone", whereas the interactions "*Teriman**Spaawet" and "*Teriman**Super Gro" presented average yields of less than 4.50 t/ha (**Table 7**).

4. Discussion

The study of the effect of fertilization on the agromorphological parameters of okra enabled us to evaluate the influence of fertilizers on three varieties of okra in Côte d'Ivoire. The physicochemical characteristics of the soil in the experimental plot revealed a sandy-loam texture. Indeed, over 76% of the plot's soil is sandy, which could be explained by the fact that the plot is located in the twin

Table 6. Fruit weight and yield by fertilizers.

Fertilizers	Fruit weight (g)	Yield (t/ha)
Retone	398.51 a	11.07 a
NPK	342.70 a	9.52 a
Spaawet	199.45 b	5.54 b
Control	191.75 b	5.32 b
Super Gro	161.12 b	4.47 b
Average	258.73	7.19
Coefficient of variation (%)	9.56	9.60
Probability	<0.0001	<0.0001

In the same column, the values followed by the same letter do not differ significantly according to the Newman-Keuls test at 5% threshold.

Table 7. Effect of cultivar*fertilizer interaction on the fruit weight and yield.

Interaction Culivars*Fertilizers	Weight (g)	Yield (t/ha)
*Divo**Retone	439.10 a	12.19 a
*Teriman**Retone	392.83 b	10.91 b
*Divo**NPK	375.35 c	10.42 c
*Djonan F1**Retone	363.65 d	10.10 d
*Teriman**NPK	327.38 e	9.09 e
*Djonan F1**NPK	325.36 f	9.03 f
*Djonan F1**Spaawet	253.25 g	7.03 g
*Teriman**Control	203.13 h	5.64 h
*Divo**Control	190.38 i	5.28 i
*Djonan F1**Super Gro	187.99 j	5.22 j
*Divo**Spaawet	184.84 k	5.13 k
*Djonan F1**Control	181.72 l	5.04 l
*Teriman**Spaawet	160.59 m	4.46 m
*Teriman**Super Gro	150.34 n	4.17 n
*Divo**Super Gro	145.04 o	4.02 o
Average	258.73	7.18
Coefficient of variation (%)	0.34	0.34
Probability	<0.0001	<0.0001

In the same column, the values followed by the same letter do not differ significantly according to the Newman-Keuls test at 5% threshold.

slope valley. Therefore, the transport of granulometric elements during water runoff on the soil surface on either side of the slopes could favor this high proportion of sand. In addition, physicochemical analysis revealed a slight acidity (pH < 7) and low organic matter content in the soil, which could be explained by the nature of the soil in the study area. Similar results have been observed, showing that the soil in the autonomous district of Abidjan is acidic and poor in organic matter [13]. The fertilizers tested had a significant effect on the agro-morphological parameters of the different okra cultivars. The Retone, NPK, and Spaawet fertilizers outperformed the unfertilized controls, unlike the Super Gro biofertilizer. Furthermore, the highest plant heights were obtained using plants treated with Retone and NPK fertilizers. This result could be explained by an improvement in soil mineral elements, which in turn favored an increase in plant height growth and collar diameter [15] [16]. The use of Retone biofertilizer resulted in the highest plant heights. This action of the Retone biofertilizer could be justified by the fact that it releases minerals gradually, which could ensure their availability when the plant needs them [17]. Indeed, Retone biofertilizer is made up of compounds of various plant auxins, vitamins, enzymes, algae, amino acids, and humus, thus increasing vegetative plant growth. This ability of the Retone biofertilizer would justify the better results observed after its application. Plant growth is linked to the simultaneous release of nutrients and their uptake by plants [18]. The results obtained using Retone biofertilizer and NPK mineral fertilizer are due to mineralization and the continuous release of nutrients to the plant during its life cycle. Fertilizer application influenced leaf area, collar diameter, fruit mass, and yield. Previous studies have shown that organic and mineral fertilizers accelerate the increase in leaf area [19]. The highest averages for the above agromorphological parameters were obtained using the biofertilizer Retone and the mineral fertilizer NPK. The cultivar *Divo* obtained the highest average yield. This result could be explained by the fact that the *Divo* cultivar is better adapted to the pedoclimatic conditions of the study area, which is characterized by high rainfall. This difference could be due to varietal characteristics [20] [21], these authors demonstrated that the yield differences observed between chili and maize varieties could be justified by their genetic potential. Retone and NPK fertilizers induced the longest production times and highest yields. Indeed, the gradual release of mineral elements into the soil over time in response to plant needs could explain these results [22]. The results relating to NPK mineral fertilizer can be explained by the fact that mineral fertilizers have a greater agronomic efficiency because mineral elements are directly available and easily absorbed by plants. As for the biofertilizer Retone, after its application, it is said to increase plant tolerance to abiotic stresses, which in turn may enhance their immune powers and chlorophyll content. Indeed, good photosynthetic capacity is a function of leaf chlorophyll content [23]. Similarly, a positive correlation was observed between leaf chlorophyll content and rice grain yield by the authors [24]. In addition, 90% of yield comes from photosynthetic activity in the leaves, which in turn depends on good chlorophyll content [25]. Consequently, the higher yields observed with the biofertilizer Retone would result from its ability to induce good chlorophyll content in okra plants, coupled with its capacity to increase resilience to abiotic stresses. The lowest averages recorded for the various parameters assessed were obtained using Spaawet and Super Gro biofertilizers and the no-fertilizer control. These results may be explained by the fact that Spaawet biofertilizer is a polyether trisiloxane-modified agricultural adjuvant that possesses surface-active properties and considerably reduces water surface tension. It acts as an adhesion and penetration product, and is a good gas pedal for water in the soil [26]. Therefore, it facilitates the transport of water in the soil and does not provide the minerals that plants need for their development. However, this product could be combined with other fertilizers, to optimize crop production. Its use alone, without having been combined with other types of fertilizer, could justify the low averages observed after its application. Also, better results were observed on maize agromorphological parameters following the application of Super Gro biofertilizer along with NPK mineral fertilizer [27]. Super Gro would be a natural, liquid, foliar fertilizer containing N, P, and K that acts directly on the leaves, bark, and roots of plants [27]. However, its combination with other fertilizers would constitute an additional agronomic mechanism favoring better production. Furthermore, Super Gro would be a biostimulate that must complements fertilizers and crop protection products but cannot substitute them [28], which would justify the poor results observed after its application without being combined with another fertilizer.

5. Conclusion

This study evaluated the effect of four fertilizers on the productivity of three okra cultivars in Côte d'Ivoire. The results show that productivity varied from one fertilizer to another and had a significant effect on the agromorphological parameters of okra. The Retone biofertilizer produced the best results in terms of growth and yield parameters. In addition, the study showed that NPK mineral fertilizer was also effective, but with results below those of Retone biofertilizer. The Divo cultivar exhibited the best yields. The interaction between the cultivar Divo and the biofertilizer Retone also produced the best yields. Therefore, Retone biofertilizers could be an alternative to synthetic chemical fertilizers.

Author's Contributions Statement

The project's conception and experimental design were the brainchild of GNB, NMP and SS, while the execution of the experiment was carried out by GNB. GNB took charge of statistical analysis and manuscript writing.

KNP and KDSF analyzed the soil samples. KEYG and DJP read and re-read the draft article. KD and FS wrote the discussion section and proofread the manuscript. All authors read and approved the final manuscript.

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Conflicts of Interest

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

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