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Combined Effects of NPK 0-23-19 + TE Mineral Fertilizer and NPK 11-9-41 Liquid Fertilizer on Cocoa Production in South-Central Côte d'Ivoire

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Abstract

The search for a solution to the decline in cocoa bean yields in Côte d'Ivoire remains a preoccupation. This study was carried out to evaluate the combined effects of the mineral fertilizer NPK 0-23-19 + TE and the liquid fertilizer NPK 11-9-41 on cocoa yield parameters in the locality of Divo, specifically in the villages of Troucasso and Gazaville. The experimental set-up was a Fisher block design, with 4 replications for 11 treatments. Results showed that treatments receiving mineral fertilizer combined with liquid fertilizer improved cocoa yields. Treatments T4 (300 g NPK 0-23-19 + TE + 0.045 L NPK 11-9-41) and T5 (300 g NPK 0-23-19 + TE + 0.09 L NPK 11-9-41) were more effective at Troucasso. They had actual yields of 1627.36 $kg \cdot ha^{-1}$ and 1836.61 $kg \cdot ha^{-1}$ respectively, and potential yields of 1886.62 $kg \cdot ha^{-1}$ and 2032.08 $kg \cdot ha^{-1}$. In Gazaville, on the other hand, treatments T4 (1788.68 $kg \cdot ha^{-1}$), T5 (1923.25 $kg \cdot ha^{-1}$) and T9 (150 g NPK 0-23-19 + TE + 0.18 L NPK 11-9-41) with 1642.41 $kg \cdot ha^{-1}$ had the best actual yields. The same applies to potential yield, with these treatments achieving 1920.37 $kg \cdot ha^{-1}$, 2141.21 $kg \cdot ha^{-1}$ and 1829.14 $kg \cdot ha^{-1}$ respectively. As for wilted cherelles, treatments T4, T5 and T9 had the highest values on both experimental sites.

Keywords

Mineral Fertilizer, Liquid Fertilizer, Cocoa Yield, Divo, Côte d'Ivoire

1. Introduction

Cocoa (*Theobroma cacao* Linn.) is an important cash crop in many tropical countries, given its role in their economies [1]. Africa still holds the monopoly on production, with over 70% of the world's cocoa supply [2]. Increasing production has thus become a necessity and a challenge for the main producing countries [3], including Côte d'Ivoire, the world's leading producer since 1970, which produced 2.2 million tonnes of merchantable cocoa, according to the 2022-2023 campaign [4]. Revenues from cocoa sales generate 15% of GDP and account for over 50% of export earnings [5]. Cocoa cultivation covers more than 2 million hectares of land and employs 60% of the working population [6].

However, cocoa production in Côte d'Ivoire, which is partly the result of attempts at intensification and replanting, but also of the creation of new plantations at the expense of forests, is facing a decline in yields due to a reduction in the country's forest reserves [7] [8], with the destruction of forest cover falling from 16 million hectares in 1960 to 3.4 million hectares in the last decade, the aging of orchards, diseases such as brown pod rot and swollen shoot [9], and the rapid decline in soil fertility [10] due to overexploitation. In order to be self-sufficient in food, cocoa farmers cultivate various crops, including cocoa, yams, bananas, and sometimes taro and corn, on the same land for several years. This practice, which gives the soil no respite, depletes it of nutrients. To compensate for this and maintain a certain level of productivity, cocoa farmers invest in various inputs. This is also the conclusion reached by some authors when they assert that, after several unsuccessful attempts by cocoa farmers to boost their production, they have ended up relying on the use of fertilizers, particularly foliar fertilizers first and granular fertilizers second, in the hope of restoring the vegetative system of the cocoa trees [11] [12]. Fertilizer appears to be one of the factors that could potentially revitalize the economy of an old cocoa-growing region and curb migration to remaining forests. It can play this role locally and partially [13].

But on a national scale, the logic of cocoa migration and the conquest of new forests has always prevailed. In fact, in the 2000s and 2010s, despite talk of "zero deforestation" and fertilizer as a tool for sustainability, migration and deforestation continued unabated [14]. Faced with this prevailing situation, the cocoa industry continues to advocate the use of mineral fertilizers as a sustainability tool to improve production. However, the criteria and techniques for assessing the fertility of cocoa-growing soils vary depending on their users. Some are generally based on the decrease in organic matter content, while others are based on the decline in marketable cocoa yields [15]. With a view to finding other solutions to improve cocoa production, this study, which aims to use mineral fertilizer combined with liquid fertilizer, was initiated to evaluate the effectiveness of these fertilizers.

2. Materials and Methods

2.1. Study Setting

The study was conducted in Troucasso and Gazaville, in the locality of Divo (Lôh-

Djiboua Region), in south-central Côte d'Ivoire. Divo is located 188 km from Abidjan and has the following geographical coordinates: 5˚49'59.999"N 5˚22'0.001"W. The soils of this region belong to the Ferralsols, Acrisols, Cambisols and Gleysols groups [16]. The climate is tropical, characterized by two wet seasons (May to July and September to November) alternating with two dry seasons (August and December to April). Average monthly temperatures range from 25.8˚C to 27˚C, with relatively abundant rainfall ranging from 1203.6 mm to 1392 mm per year [17], and an average annual humidity of 85%. The vegetation, once a dense semi-deciduous forest, has been reduced to a mosaic of forest relics by farming and logging [18]. However, the chemical characteristics of the soil in its initial state on the plots are recorded in the table below (**Table 1**).

Table 1. Chemical characteristics of the soil in its initial state on the plots.

Study area	Chemical characteristics of the soil	Troucasso (T0)	Gazaville (T0)
	$pH_{(eau)}$	5.65	5.72
	V (%)	46.90	44.40
	MOS ($g \cdot kg^{-1}$)	27.50	22.40
	COS ($g \cdot kg^{-1}$)	16.30	13.20
	N ($g \cdot kg^{-1}$)	1.48	1.67
Lôh-Djiboua	C/N ratio	10.80	9.90
	P_2O_5 (ppm)	86.76	91.21
	K^+ ($cmol \cdot kg^{-1}$)	5.40	5.11
	Ca^{2+} ($cmol \cdot kg^{-1}$)	4.12	3.89
	Mg^{2+} ($cmol \cdot kg^{-1}$)	4.30	4.73

2.2. Plant Material

The study material is the cocoa tree. The plots chosen for the trial are mature, with ages of 12 and 18 years.

2.3. Fertilizing Material

The fertilizing material consisted of mineral fertilizer NPK 0-23-19 + 2.5 SO3 + 3.5 MgO + 17 CaO + 0.1 B_2O_3 + 0.1 Zn (reference fertilizer), mineral fertilizer Falcacao (NPK 0-23-19 + 10 CaO + 4 S + 5 MgO), and a liquid fertilizer Caobor, which also contains 11% boron. These fertilizers were supplied by Export Trading Company (ETG).

2.4. Experimental Design

The trial was conducted using a Fisher block design with 11 treatments repeated 4 times. Each treatment (12.5 m × 12 m) consisted of 30 plants spaced 3 m apart by 2.5 m (density of 1333 plants/ha). The elementary plots (150 m^2) were separated from each other by two (2) rows of cocoa trees. The blocks were laid out parallel and spaced 6 m apart. The trial comprised 1,320 plants and was planted on 0.1 ha. The different fertilizer doses required and coded for field use correspond to treatments T0 to T10. Thus, at each fertilizer application period, *i.e.*, every six months, half a year's dose was applied. Fertilizer was applied in two stages (March-April and August-September), within a radius of 80 to 100 cm around the cocoa plant for solid fertilizer, and on the trunk and leaves for liquid fertilizer. However, fertilizer doses were determined based on the manufacturer's recommendations (**Table 2**).

Table 2. Types and doses of fertilizer applied per cocoa plant.

Treatment	Type of fertilizer	% applied	Dose (g)/plant/year
T0	0	0	0
T1	NPK 0-23-19 + TE	100	36 kg
T2	Dose 1 NPK 11-9-41	100	0.09 L
T3	Dose 2 NPK 11-9-41	100	0.18 L
T4	NPK 0-23-19 + TE	100	36 kg
	Dose 1 NPK 11-9-41	50	0.045 L
T5	NPK 0-23-19 + TE	100	36 kg
	Dose 2 NPK 11-9-41	50	0.09 L
T6	NPK 0-23-19 + TE	50	18 kg
	Dose 1 NPK 11-9-41	50	0.045 L
T7	NPK 0-23-19 + TE	50	18 kg
	Dose 2 NPK 11-9-41	50	0.09 L
T8	NPK 0-23-19 + TE	50	18 kg
	Dose 1 NPK 11-9-41	100	0.09 L
T9	NPK 0-23-19 + TE	50	24 kg
	Dose 2 NPK 11-9-41	100	0.18 L
T10	NPK 0-23-19	100	36 kg

2.5. Agronomic Parameters Measured

The agronomic parameters measured during this study were: the number of wilted cherelles, the number of healthy pods, the number of rotted pods, the average weight of fresh beans in the pod, and the yield. This yield was calculated as follows:

Rdt_real average = (PMF × 0.35 × nCabsain × 1333 × 0.001).

Rdt_potential average = (PMF × 0.35 × nCabtotal × 1333 × 0.001).

Rdt = Yield; PMF = Average weight of fresh beans.

nCabsain = number of healthy pods; nCabtotal = number of total pods.

0.35 = coefficient of transformation of a fresh bean into a dry bean; 1333 = number of cocoa plants per hectare; 0.001 = conversion of grams into kilograms.

2.6. Statistical Analysis

A one-factor analysis of variance (ANOVA) was performed using SAS 9.4 software. A comparison of means using the Newman-Keuls method was applied at the 5% probability threshold.

3. Results

3.1. Effects of Treatments on the Number of Wilted Cherelles, Healthy Pods, Rotted Pods, Gnawed Pods, Total Pods, and Average Weight of Fresh Beans at Troucasso/Divo

Analysis of variance showed significant differences between treatments in the number of wilted cherelles. For this parameter, treatments T4 (300 g NPK 0-23-19 + TE + 0.045 L NPK 11-9-41) with 135.14, T5 (300 g NPK 0-23-19 + TE + 0.09 L NPK 11-9-41) with 140.08, and T9 (150 g NPK 0-23-19 + TE + 0.18 L NPK 11-9-41) with 132.85 had the highest number of wilted cherelles. The lowest value was obtained by the T0 control treatment (38.10). There were no significant differences between treatments in terms of healthy, rotted, gnawed, and total pods, or fresh bean weight. However, the fertilized treatments had relatively higher values than the control treatment (Table 3).

Table 3. Effects of treatments on the number of cherries wilted, healthy, rotted, gnawed, Total pods and average fresh bean weight.

Treatment	Wilted cherelles	Healthy pods	Rotten pods	Rotted pods	Total pods	Average fresh bean weight
T0	36.10c	14.10a	3.05a	0.14a	17.29a	82.05a
T1	94.12b	20.05a	3.04a	1.05a	25.04a	89.71a
T2	97.58b	18.46a	2.02a	0.78a	21.26a	85.81a
T3	110.42b	20.97a	2.05a	1.21a	24.03a	90.12a
T4	135.14a	38.28a	1.82a	0.97a	42.07a	96.12a
T5	140.08a	40.12a	1.17a	3.10a	44.39a	98.12a
T6	96.82b	20.91a	1.12a	0.52a	22.55a	91.04a
T7	99.14b	22.06a	2.03a	0.51a	24.60a	90.35a
T8	103.21b	24.11a	2.09a	0.55a	26.75a	90.71a
T9	132.85a	29.68a	1.18a	3.07a	33.93a	94.10a
T10	105.13b	28.84a	3.07a	1.51a	33.42a	92.78a
Mean	104.78	25.23	2.06	1.22	28.66	90.99
CV (p.c.)	13.01	18.14	16.11	23.14	20.07	15.17
Pr > F	<0.001	0.167	0.182	0.191	0.128	0.154

The means with the same letter are not significantly different at the 5% level.

3.2. Treatment Effects on Yield at Troucasso/Divo

Analysis of variance showed significant differences between treatments in actual and potential yield. Treatments T4 (300 g NPK 0-23-19 + TE + 0.045 L NPK 11-9-41) with 1627.36 kg·ha^{-1} and T5 (300 g NPK 0-23-19 + TE + 0.09L NPK 11-9-41) with 1836.61 kg·ha^{-1} had the best actual yields. The same applies to potential yield, where these treatments achieved 1886.62 kg·ha^{-1} and 2032.08 kg·ha^{-1} respectively (Table 4).

Table 4. Effects of treatments on cocoa yields.

Treatment	Actual yield (kg·ha^{-1})	Potential yield (kg·ha^{-1})
T0	539.75e	661.87d
T1	847.58c	1048.03c
T2	739.04d	851.14cd
T3	881.69c	1010.35c
T4	1627.36a	1886.62a
T5	1836.61a	2032.08a
T6	888.15c	957.80c
T7	929.89c	1036.96c
T8	1020.35c	1132.08c
T9	1303.02b	1489.60b
T10	1248.38b	1446.63b
Mean	988.48	1232.10
CV (p.c.)	13.82	16.21
Pr > F	0.0127	0.0139

The means with the same letter are not significantly different at the 5% level.

3.3. Effects of Treatments on the Number of Wilted Cherelles, Healthy Pods, and Rotted Pods, Gnawed Pods, Total Pods, and Average Fresh Bean Weight in Gazaville/Divo

Analysis of variance showed significant differences between treatments in the number of wilted cherelles. Regarding this parameter, treatments T4 (139.35), T5 (145.08) and T9 (150 g NPK0-23-19 + TE + 0.18L NPK 11-9-41) with 134.82 obtained the highest rates of wilted cherelles. The lowest value (33.52) was recorded by the absolute control (T0). There were no significant differences between treatments in terms of healthy, rotted, gnawed, and total pods, or fresh beans weight. However, values for these parameters improved in the fertilized treatments (Table 5).

Table 5. Effects of treatments on the number of cherries wilted, healthy, rotted, gnawed, Total pods and average fresh bean weight.

Treatment	Wilted cherelles	Healthy pods	Rotten pods	Rotted pods	Total pods	Average fresh bean weight
T0	33.52c	11.62a	5.20a	1.02a	17.84a	79.20a
T1	97.62b	23.45a	2.15a	1.05a	26.65a	87.51a
T2	99.14b	21.16a	2.00a	0.41a	21.77a	85.80a
T3	107.35b	22.19a	1.16a	1.10a	24.45a	88.98a
T4	139.05a	38.71a	1.04a	1.81a	41.56a	99.04a
T5	145.08a	41.12a	1.62a	3.04a	45.78a	101.25a
T6	99.01b	24.81a	1.78a	0.29a	26.88a	90.11a
T7	102.14b	24.93a	1.99a	0.67a	27.59a	91.08a
T8	107.09b	25.06a	2.18a	1.81a	29.05a	93.17a
T9	134.82a	36.59a	2.05a	2.11a	40.75a	96.21a
T10	100.15b	25.71a	3.98a	2.16a	33.42a	92.95a
Mean	105.91	26.86	2.29	1.31	30.52	91.39
CV (p.c.)	11.18	24.02	19.04	16.41	22.83	14.08
Pr > F	<0.001	0.185	0.147	0.132	0.170	0.129

The means with the same letter are not significantly different at the 5% level.

3.4. Treatment Effects on Yield at Gazaville (Divo)

Analysis of variance showed significant differences in yield between treatments. Treatments T4 (300 g NPK 0-23-19 + TE + 0.045L NPK 11-9-41) with 1788.68 kg·ha^{-1}, T5 (300 g NPK 0-23-19 + TE + 0.09L NPK 11-9-41) with 1923.25 kg·ha^{-1} and T9 with 1642.41 kg·ha^{-1} had the highest actual yields. These treatments also had the highest potential yields with T4 (1920.37 kg·ha^{-1}), T5 (2141.21 kg·ha^{-1}) and T9 (1829.14 kg·ha^{-1}) (**Table 6**).

Table 6. Effects of treatments on cocoa yields.

Treatment	Actual yield (kg·ha^{-1})	Potential yield (kg·ha^{-1})
T0	429.37c	659.20c
T1	957.41b	1088.06b
T2	847.03b	871.45bc
T3	921.19b	1015.01bc
T4	1788.68a	1920.37a
T5	1923.25a	2141.21a
T6	1043.03b	1130.06bc
T7	1059.36b	1172.39bc

Continued

T8	1089.32b	1262.76b
T9	1642.41a	1829.14a
T10	1114.93b	1385.53b
Moyenne	1165.09	1315.92
CV (p.c.)	12.05	10.64
Pr > F	<0.001	<0.001

The means with the same letter are not significantly different at the 5% level.

4. Discussion

Sustainable cocoa production over 25 to 30 years depends largely on soil fertility, hence the importance of mineral fertilization [19]. This fertilization intensifies nutrient levels, enabling high yields (over 2 tha^{-1}) to be obtained. It must be maintained to replace the nutrients exported by the crops [20]. Thus, the results of this study indicate that cocoa trees receiving certain combined doses of mineral and liquid fertilizers have overall good production characteristics. This is reflected, among other things, in treatments T4 (300 g NPK 0-23-19 + TE + 0.045 L NPK 11-9-41), T5 (300 g NPK 0-23-19 + TE + 0.09 L NPK 11-9-41) and T9 (150 g NPK 0-23-19 + TE + 0.18 L NPK 11-9-41), which were more effective in terms of wilted cherelles and actual and potential yields. As for other parameters, notably healthy, rotted and total pods and fruit weight, there were no significant differences between the fertilized plots and the controls, notably absolute (T0) and reference (NPK 0-23-19). The increase in yield obtained on the sites would therefore be linked to the nutrients contained in the solid and liquid fertilizers. The combination of solid and liquid fertilizers enabled the cocoa trees to better absorb the mineral elements needed to boost production. In fact, the phosphorus and potassium contained in solid and liquid fertilizers are recognized as major contributors to flower proliferation and improved fruit quantity and quality. Regular use of phosphorus-based mineral fertilizers is necessary to support canopy growth and bean production [21]. As for potassium, it plays a role in facilitating assimilate transport, improving stomatal function and photosynthesis [22]-[24]. Its role also contributes to improving production yields. Previous studies have shown the positive effect of potassium on the number of pods [25]. Studies have also shown that the number of pods is even more pronounced [26] when we have the combined effect of nitrogen, phosphorus and potassium fertilization. The positive effect of fertilizers on cocoa production can be explained by an improvement in the chemical status of the soil [27]. Research conducted at the station has also shown the importance of phosphorus and potassium in improving cocoa yields [28]. Some authors also claim that after several unsuccessful attempts by cocoa farmers to boost their production, they ended up relying on the use of fertilizers, particularly foliar fertilizers first and granular fertilizers second, in the hope of restoring the vegetative system of cocoa trees [11] [12]. Fertilizer appears to be one of the factors that could potentially revitalize the economy of an old cocoa-growing region. Research carried out in cocoa plantations in eastern Côte d'Ivoire has also shown that plots that received fertilizer had a significantly higher yield than the control plots that did not receive fertilizer [29]. However, differences in yield were observed between actual yield and potential yield. This difference could be linked either to black rot of cocoa pods caused by fungal agents of the genus Phytophthora, which severely infect the pods, or to damage caused by insects such as moths, which lay their eggs on the pods, causing them to rot. These yield differences may also be linked to rodents such as squirrels, which gnaw on pods and cocoa beans. Indeed, some research conducted on cocoa trees has shown that cocoa yield losses due to pod rot can range from 15.18% to 18.25% [30].

As for the high number of wilted cherelles observed in cocoa farms, it should be stressed that the high rate of wilted cherelles strongly affects production. In fact, wilted cherelles act as a regulating factor for trees with a high number of pods, exceeding 100 pods per tree, which corresponds to around 4 tons of merchantable cocoa per hectare [31]; other studies have shown that a rise in temperature increases the number of chérelle wilt [32]. The increase in flower cover, hence the appearance of cherelles, is thought to be due to the action of the phosphorus contained in the fertilizer. The results of several trials corroborate the major role of phosphorus in stimulating flowering [33]. The work of [28] on research stations has also shown the importance of phosphorus and potassium in improving cocoa yields. Phosphorus is considered the limiting factor for plants in tropical soils [34].

5. Conclusion

In south-central Côte d'Ivoire, in the department of Divo, more specifically in Gazaville and Troucasso, the combined effect of certain doses of mineral and liquid fertilizers improved yield parameters. Treatments T4 (300 g NPK 0-23-19 + TE + 0.045 L NPK 11-9-41), T5 (300 g NPK 0-23-19 + TE + 0.09 L NPK 11-9-41) and T9 (150 g NPK 0-23-19 + TE + 0.18 L NPK 11-9-41) improved the number of wilted cherelles and yields at both sites. Treatments T4 and T5 had potential yields of 1886.62 $kg \cdot ha^{-1}$ and 2032.08 $kg \cdot ha^{-1}$ respectively at Troucasso. In Gazaville, on the other hand, treatments T4 (1920.37 $kg \cdot ha^{-1}$), T5 (2141.21 $kg \cdot ha^{-1}$) and T9 (1829.14 $kg \cdot ha^{-1}$) had the highest potential yields.

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Conflicts of Interest

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

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