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Effects of mineral fertilisers (PK) on soil fertility and cocoa production in South-West Côte d'Ivoire

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Abstract

A study on reasoned mineral fertilisation has been carried out in the south-west of Côte d'Ivoire in order to ensure the sustainability of cocoa production. Specifically, the aim was to evaluate the effects of mineral fertilisers (PK) on soil fertility and cocoa production in Soubré, Méagui and Mayo. Thus, on each site, the experimental set-up was in Fisher block, with 4 replications for 4 treatments. The results showed that in terms of soil fertility, all the treatments favoured a good soil organic matter content (≥ 3%), a good pH (6.66-7.18), a good CEC (12 <CEC<30 cmolkg^{-1}), an assimilable phosphorus content greater than 100 mg kg^{-1} and a ratio of (Ca/S) x100 ≥ 68%, which reflects a good balance between Ca and the sum of exchangeable bases (S). On the other hand, all the treatments had deficiencies in Potassium with (K/S) x100 < 8% and Magnesium with (Mg/S) x100 < 24. Finally, with the exception of the T2 treatment (NPK 0-15-15), the other treatments obtained a good balance between N and S, with (S+6.15) / N > (8.9). In terms of real yield, treatment T1 (NPK 0-23-19) had the best rate (1160.53 kgha^{-1}), compared to T4 (NPK 0-18-9) and T2 (NPK 0-15-15) which had 951.92 and 730.59 kgha^{-1} respectively.

Keywords: reasoned fertilisation, soil fertility, cocoa production, East, Côte d'Ivoire

Introduction

Cocoa farming in Côte d'Ivoire is currently marked by the disappearance of the forest, which is naturally used by producers as the ideal cultural precedent for cocoa cultivation [1]. Benefiting from the good fertility of forest soils in the past, cocoa farmers had adopted a long practice of exploiting their cocoa plantations without fertilization. Today, the increasing decline in the fertility of these cocoa soils [2] and their impoverishment pose a threat to cocoa production. Unsustainable production methods impoverish the soil. However, cocoa farmers can no longer abandon their depleted land, which has become more or less acidic. For there are hardly any forests left and many countries have introduced legislation against deforestation. The impact of climate change is also being felt and is getting stronger and stronger. For cocoa production, this means a reduction in land suitable for cocoa production and a considerable drop in yield [3]. Given global competition, increasing cocoa production is a necessity and a challenge for the major producing countries [4], in particular for Côte d'Ivoire, the world's largest producer [5]. Faced with this situation, there is increasingly a shift in behaviour on the part of producers using inputs to increase the yields of their cocoa production. As advocated by research, they are opting for the application of mineral fertilizers that are essential for cocoa production, to see if these would be more suitable for identifying cocoa soil fluctuations [3]. Most trials have shown the importance of Phosphorus and Potassium in improving cocoa yields [6]. Calcium and Magnesium in small amounts have also been found to be important. In Côte d'Ivoire, current recommendations are based on a single formula regardless of soil type and chemical characteristics. This is the case of the cocoa fertilizer NPK 0-23-19 with some Ca and Mg. In the current pedoclimatic context of Côte d'Ivoire, mineral fertilization of cocoa trees requires an updating of the formulas and doses of fertilizer, so that it is maintained to replace the nutrients exported by the crops [7]. This has therefore been taken a step further and fertilizer formulas based on soil diagnosis have been proposed to the Centre National de Recherche Agronomique (CNRA) in order to assess their effectiveness in ensuring the sustainability of cocoa production in Côte d'Ivoire through rational mineral fertilization.

Materials and Methods

Framework of the study

The study was conducted in a farming environment in Soubré, Méagui and Mayo in the south-western region of

Côte d'Ivoire. The climate of this region is sub-equatorial with two rainy seasons (April-June and September-November) alternating with two dry seasons (July-August and December-March). Rainfall varies between 1203.6 mm and 1392 mm and the average annual temperature varies between 25.8 and 26.3° C [8]. Relative air humidity varies from 44% in January and reaches 85% between July and August. The soils in the study area are ferrallitic (Ferralsols) reworked or typical with induration from various granitoids and migmatites [9, 10, 11].

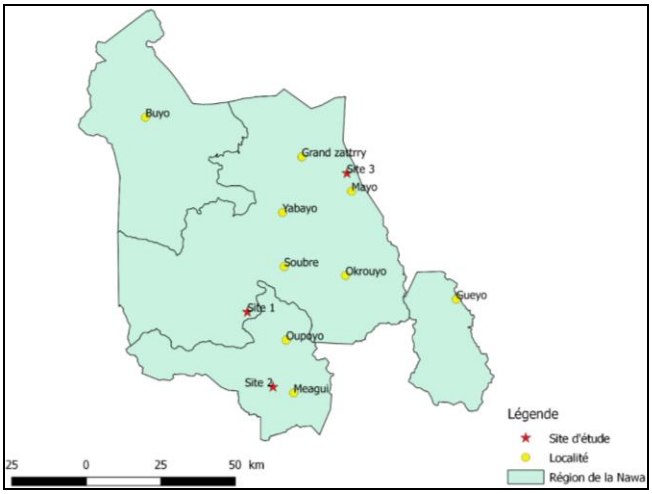

Fig 1: Map of the location of the study sites in the South-West of Côte d'Ivoire

Plant material

The study material is the "all-coming" cocoa tree. The plots chosen for the trial are mature, with an age between 15 and 17 years.

Fertilizing material

Four types of mineral fertilizers were used on the plots, including three new formulas (NPK 0-15-15; NPK 4-10-10 and NPK 0-18-9) from the soil diagnostic and the standard fertilizer formula recommended in Côte d'Ivoire (NPK 0-23-19). These new fertiliser formulas are rich in P_2O_5 based on Reactive Phosphate, while the reference fertiliser formula (recommended) is rich in P_2O_5 based on TSP.

Experimental device

The trial was conducted using a Fisher block experimental design on three sites, with 4 treatments and 4 replicates, over an area of 0.53 ha (74 m x 72 m). The treatments (T1, T2, T3, T4) were randomly distributed in each block of 888 m^2 (74 m x 12 m). These blocks were arranged parallel and 6 m apart and the elementary plots of 150 m^2 (12.5 m x 12 m) each, were each made up of 30 cocoa trees spaced 3 m by 2.5 m (density of 1333 plants/ha). In each of the elementary plots, materialised by a specific colour or treatment, 30 plants were fertilised, but observations were made on 20 plants making up the useful plot. The fertilizers were applied at their half-dose around the cocoa plant in two steps (March-April and August-September), within a radius of 80-100 cm (Table 1).

Table 1: Types and rates of fertilizer applied per cocoa plant

Treatment	Formulas	Annual fertiliser dose/cocoa tree stand	1st application March-April	2nd application August-September
T1	NPK 0-23-19	400 g	200 g/tree	200 g/tree
T2	NPK 0-15-15	400 g	200 g/tree	200 g/tree
T3	NPK 4-10-10	800 g	400 g/tree	400 g/tree
T4	NPK 0-18-9	400 g	200 g/tree	200 g/tree

Soil sampling

Soil samples were taken before fertiliser was applied and at the end of each production season (September). Soil samples were taken in the 0-30 cm layers of the soil from the surface [12], and at 1 m from the cocoa tree, using a cylindrical sounding tube [13]. Composite samples from the 4 blocks were made up by treatment on each plot and then stored in plastic bags. 5 composite samples were obtained per block, or 15 samples for the three sites. These soil samples were analysed at the laboratory of the Chérifiens Phosphates Office (OCP) in Bingerville.

Analysis of soil samples

The parameters analysed are soil organic carbon (C) determined by titrimetry (Walkley-Black method) after oxidation using a mixture of sulphuric acid (H2SO4) and potassium dichromate (K2Cr2O7). Total nitrogen was determined by the Kjeldahl method based on wet oxidation. Total phosphorus was determined by colorimetry after reaction with phosphoric acid in the presence of ammonium molybdate and ascorbic acid. Assimilable phosphorus (Olsen-Dabin method) was extracted using sodium bicarbonate (NaHCO3) at pH 8.5. The exchangeable bases (K, Ca, Na and Mg) were extracted with ammonium acetate. The potassium was determined using a flame photometer, While Ca and Mg were determined using the atomic absorption flame spectrophotometer. The pH (water) was determined using the pH meter after adding 50 ml of ionised water to 20 g of soil followed by agitation and settling.

Agronomic parameters measured

The agronomic parameters measured during this study are: the number of wilted cherries, the number of healthy pods, the number of rotten pods, the average weight of fresh beans from the pod and the yield. This yield was calculated as follows:

$$Rdt_{medium} real = (PMF * 0.35 * nCabsain * 1333 * 0,001)$$

Root = Yield; MFP = Average weight of fresh beans; $nCabsain$ = number of healthy pods; 0.35 = dry weight of a cocoa bean after percentage drying; 1333 = number of cocoa plants per hectare; 0.001 = conversion from gram to kilogram.

Statistical analysis

An analysis of variance with one factor (Anova) was performed using SAS 9.4 software. A comparison of means by the Newman-Keuls method was applied to the 5% probability threshold.

Results

Effects of Mineral Fertilisers (Pk) On Soil Fertility in South-West Côte D'ivoire

Effects of mineral fertilisers on soil organic matter

The analysis of variance showed a significant difference at the 5% threshold between the treatments concerning carbon, organic matter and C/N ratio. On the other hand, these treatments did not have a significant difference in total nitrogen. The T1 (NPK 0-23-19) and T2 (NPK 0-15-15) treatments had the best soil organic matter (3.03-3.32%) and C/N ratio ranging from 11.12 to 13.68 (Table II).

Table 2: Effects of mineral fertilisers on soil organic matter

Treatments	COS (%)	MO (%)	N total (%)	C/N
T1	1.78ab	3,03a	0,16a	11,12b
T2	2.60a	3,32a	0,19a	13.68a
T3	1.73ab	2.98b	0,17a	10.17b
T4	1,40b	2.46b	0,14a	10.43b
Average	1.88	2.45	0,16	11.35
C.V. (p.c)	9.09	9.16	12.06	13.48
Pr > F	0.0132	0.0041	0.1322	0.0012

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of mineral fertilisers on the absorbent complex and soil acidity

The analysis of variance showed a significant difference at the 5% threshold between treatments for the parameters observed, except for pH water. The highest levels were generally obtained by treatments T1 (NPK 0-23-19) and T2 (NPK 0-15-15). The average contents of P ass, K+, Ca2+, Mg2+, CEC and the sum of the exchangeable bases (S) were 58.33; 0.40; 7.59; 1.61; 18.50 and 9.63 cmolkg-1 respectively, and that of the water pH was 6.97 (Table III).

Table 3: Effects of mineral fertilizers on the absorbent complex and soil acidity

Treatment	cmolkg^{-1}						pH water
	P ass	K+	Ca^{2+}	Mg^{2+}	CEC	S	
T1	95.67a	0,49a	8.69a	1.65a	20.53a	10.82a	7.17a
T2	17.33c	0,37b	7.97a	1.66a	18.58ab	10.03ab	6,86a
T3	35.00b	0,33b	7.37b	1.76b	18.53ab	9.49ab	7.18a
T4	85.33ab	0.41ab	6.32a	1.35ab	16.38b	8.17b	6,66a
Average	58.33	0,40	7.59	1.61	18.50	9.63	6.97
C.V. (p.c)	21.71	8.91	10.02	7.41	4.11	5.41	7,12
Pr > F	<.0001	0.0001	<.0001	<.0001	<.0001	<.0001	0,421

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of mineral fertilisers on ionic balances

The analysis of variance showed significant differences at the 5% threshold between treatments for the parameters studied. Thus, all the treatments had ratios of (Ca/S) x100 greater than 68% (optimum). On the other hand, all the treatments had ratios of (Mg/S) x 100 and (K/S) x 100, lower than 24 and 8% respectively. Finally, the T1, T3 and T4 treatments obtained ratios of (S+6.15) / N higher than the threshold value (8.9) (Table IV).

Table 4: Effects of mineral fertilisers on ionic balances

Treatment	(Ca/S) 100	(Mg/S) 100	(K/S) 100	(S+6.15)/N
T1	80.31a	15.25b	4.53a	10.61a
T2	79,46a	16.55b	3.68b	8.52b
T3	77,87b	18.54a	3.48b	9.20b
T4	77,36b	16.52b	5.02a	10.23a
Average	78.75	16.71	4,18	9.64
C.V. (%)	4,49	12,01	7,03	9,15
Pr > F	0,002	0,017	0,038	0,008

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of Mineral Fertilisers (Pk) On Real Yield and Its Components in South-West Côte D'ivoire

Analysis of variance showed significant differences between the different treatments for the number of wilted cherries, healthy pods, average fresh bean weight and yield. Treatment T1 (reference control) had the highest rate of wilted cherries (27.90), healthy pods (15.70), average fresh bean weight (951.92 g) and actual yield (1160.53 Kgha^{-1}). The T4 treatment (NPK 0-18-9) with 658.31 Kgha^{-1} had the second best yield (Table V).

Table 5: Effects of mineral fertilisers on the number of wilted cherries, healthy pods, rotten pods, average weight of fresh beans and actual yield

Treatment	Chérelles wiltées	Healthy pods	Rotten pods	Average weight of fresh beans (g)	Yield (Kgha^{-1})
T1	27.90a	15.70a	0.61a	158.60a	1160.53a
T2	22.32b	10.78c	0.68a	144.84c	730.59c
T3	24.31b	9.91c	0.56a	143.34c	658.31c
T4	24.57b	13.46b	0.61a	151.08b	951.92b
Average	24.83	12.52	0.62	149.62	880.43
CV (p.c.)	30.42	42.75	52.48	3.84	45.45
Pr > F	0.0007	<.0001	0.2924	<.0001	<.0001

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of Mineral Fertilisers (Pk) On Real Yield and Its Components by Locality in South-West Côte D'ivoire

Effects of mineral fertilizers on actual yield and its components in Soubré

The analysis showed significant differences at the 5% threshold between treatments at Soubré for the number of wilted cherries, healthy pods, average weight of fresh beans and yield. In this locality, the T1 treatment had the highest rate of wilted cherries (21.49) and healthy pods (17.87). On the other hand, the T4 treatment had the highest average weight of fresh beans (154.22). Finally, the T1 treatment with 1227 kgha^{-1} and the T4 treatment with 1079 kgha^{-1} obtained the highest yields of merchantable cocoa (Table VII).

Table 6: Effects of mineral fertilisers on the number of wilted cherries, healthy pods, rotten pods, average weight of fresh beans and yield at Soubré

Treatment	Chérelles wiltées	Healthy pods	Rotten pods	Average weight of fresh beans (g)	Yield (Kgha^{-1})
T1	21.49a	17.87a	0.49a	146.84b	1227.8a
T2	17.79b	12.57b	0.28a	140.89c	825.9b
T3	17.84b	11.64b	0.47a	124.87d	679.2b
T4	18.73b	14.89ab	0.31a	154.22a	1079.9a
Average	19.01	14.31	0.39	141.71	957.643
CV (p.c.)	21.42	43.38	52.90	2.19	45.84
Pr > F	0.0145	0.0016	0.9019	<.0001	<.0001

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of mineral fertilizers on yield and its components in Méagui

In Méagui, the analysis of variance showed significant differences at the 5% threshold between treatments in terms of the average weight of fresh beans and yield. With regard to the average weight of fresh beans, treatments T1 and T3 with 159.12 g and 159.31 g had the highest fresh bean weights respectively. As for the yield of merchant cocoa, treatments T1 and T4 with respectively 942.2 kgha^{-1} and 902.2 kgha^{-1} obtained the highest values (Table VIII).

Table 7: Effects of mineral fertilisers on the number of wilted cherries, healthy pods, rotten pods, average weight of fresh beans and yield at Méagui

Treatments	Chérelles wiltées	Healthy pods	Rotten pods	Average weight of fresh beans	Yield (Kgha^{-1})
T1	21.18a	12.68a	0.84a	159.12a	942.2a
T2	19.23a	9.08a	0.42a	133.89c	569.1b
T3	17.67a	10.21a	0.18a	159.31a	762.1ab
T4	17.89a	13.33a	0.50a	145.61b	902.2a
Average	19,03	11,40	0,49	149,76	800,61
CV (p.c.)	25,64	42,75	54,26	2,06	45,75
Pr > F	0,1388	0,0595	0,1809	<.0001	0,0105

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Effects of mineral fertilizers on yield its components in Mayo

The analysis showed significant differences at the 5% threshold between treatments in Mayo for the number of wilted cherries, healthy pods, average fresh bean weight and yield. In this locality, the T1 treatment had the highest values of wilted cherries (40.70), healthy pods (16.29), average weight of fresh beans (170.20 g) and merchant cocoa yield (1293.5 kg ha^{-1}); (Table IX). In addition, there was no significant difference in treatments for rotten pods.

Table 8: Effects of mineral fertilisers on the number of wilted cherries, healthy pods, rotten pods, average weight of fresh beans and yield in Mayo

Treatments	Chérelles wiltées	Cabosses healthy	Cabosses rotten	Average weight of fresh beans (g)	Yield (kgha^{-1})
T1	40.70a	16.29a	0.54a	170.20a	1293.5a
T2	29.17b	10.49bc	1.29a	157.58b	773.0bc
T3	36.32ab	7.96c	0.96a	148.05d	549.8c

T4	36.51ab	12.17b	1.00a	153.02c	871.5b
Average	35,68	11,75	0,95	157,32	874,32
CV (p.c.)	29,05	41,08	50,17	0,73	43,88
Pr > F	0,003	<0,0001	0,569	<.0001	<.0001

The averages followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.

Discussion

Effects of mineral fertilisers (PK) on soil fertility

Effects of mineral fertilisers on organic matter

The results showed that the organic matter content of soils in the different treatments is above the threshold value defined for cocoa production, which is 3% [14]. This demonstrates the abundant presence of the activity of microorganisms present in the soil. The mineralisation of organic matter in the three localities was characterised by a C/N ratio that was generally higher than 9 and lower than 15. These values obtained confirm very good mineralisation according to [15]. According to this author, a C/N ratio lower than 9 resulted in a too fast release of nitrogen into the environment (nitrogen loss) and a C/N ratio higher than 15 would qualify a slow mineralisation (nitrogen deficit). This good supply of nitrogen to the plants is confirmed by the determined levels that are above the established threshold of 0.03% [16]. This observation on the good mineralisation of organic matter is confirmed by [17]. This author had demonstrated that nitrogen was available in the soils of south-western Côte d'Ivoire.

Effects of mineral fertilisers on the absorbent complex

The results of the effects of fertilizers on the absorbent complex showed that the soil levels of assimilable phosphorus were above 100 $mgkg^{-1}$ in all treatments. This value is the threshold for good nutrition of cocoa trees [18]. However, in spite of potassium inputs, all soils showed deficits in this element. Indeed, the average potassium content for good cocoa tree mineral nutrition is 0.7 $cmolkg^{-1}$ [16]. As potassium is an exchangeable cation, it is retained in the leaves of the clays or by organic matter. Consequently, there is a loss of potassium through leaching, which explains the low potassium levels in these soils. As for calcium, all treatments have reached threshold values between 5-8 $cmol.kg^{-1}$ [19, 20, 21]. On the other hand, for magnesium, all the treatments had levels below the threshold value established at 2.45 $cmolkg^{-1}$ [16], hence a deficiency in this element. This magnesium deficiency could be due to a strong leaching of these exchangeable cations.

With regard to CEC, all treatments had values above 12 cmol (+) kg^{-1} (minimum threshold), indicating good mineral nutrition, as the CEC of soils under cocoa trees should be between 12 and 30 cmolkg-1 [15]. These good CEC values obtained through treatments could be due to the good availability of organic matter in these soils (≥ 3%). The applied treatments also obtained satisfactory soil pH values (6.66 - 7.18), corroborating those of [22]; [23]. Indeed, according to these authors, a slightly acidic soil pH is not a constraint for the cocoa tree because, even if the optimum is pH 7 for the best soils under cocoa trees, this plant can grow on soils with an acidic pH (pH 4.5- 6) or slightly basic pH (pH 6.7-7.5). Soil pH conditions biological activity, the availability of most nutrients and the risk of toxicity of certain elements in the soil [24].

Effects of mineral fertilisers on ionic balances

The results showed that all treatments favoured a ratio of (Ca/S) x100 ≥ 68% [25]. This reflects a good balance between Ca and the sum of the exchangeable bases (S). On the other hand, all the treatments had deficiencies in potassium with (K/S) x100 < to 8% and in magnesium with (Mg/S) x100 < 24 [26], explaining an imbalance between K and S, on the one hand, and between Mg and S, on the other hand. Correcting this imbalance requires an increase in potassium and an increase in magnesium for good mineral nutrition. Finally, apart from the T2 treatment (NPK 0-15-15), the other treatments have achieved a good balance between N and S, with (S+6.15) / N > (8.9). The balance (SBE + 6.15)/N makes it possible to define the requirements in terms of nitrogen or exchangeable bases in soils under cocoa trees. Thus, according to [27], soils where the ratio (SBE + 6.15)/N was less than 8.9, indicate that nitrogen is probably not essential, either because the soil is poor in exchangeable bases (in this case, the cocoa trees will respond to an increase in the levels of exchangeable bases), or because the nitrogen is in sufficient quantity (in this case, an additional supply of nitrogen may even be toxic for the cocoa trees).

Effects of mineral fertilisers (PK) on cocoa production

The results indicate that cocoa trees that have received phosphate and potassium fertilizer have the best production traits. This is confirmed by the average number of healthy pods produced per cocoa tree and the high yields of fertilized soils. Indeed, phosphorus and potassium are recognised as major elements contributing to the proliferation of flowers and the improvement of the quantity and quality of the fruit. The regular use of mineral phosphate fertilizer is necessary to support canopy growth and bean production [28]. The positive effect of fertilizers on production can be explained by an improvement in the chemical status of soils with chemical imbalances as well as deficiencies in potassium, essential mineral elements for cocoa production [29]. With regard to the high number of wilted cherries observed in cocoa farms, it should be pointed out that the high wilt rate strongly affects production. Indeed, the wilt cherry acts as a regulating factor for trees with a high fruit content, exceeding 100 fruits per tree, which corresponds to about 4 tonnes of merchantable cocoa per hectare [30]; other studies have shown that a rise in temperature increases the number of wilted cherries [31]. For yield, we noted that the highest yields were observed in treatments that received fertilizers with more phosphorus and potassium, notably T1, T2 and T4. Indeed, this is confirmed by the large number of healthy pods observed in these treatments.

Conclusion

In south-west Côte d'Ivoire, the new fertiliser formulas resulting from the soil diagnosis and the reference fertiliser have shown better soil fertility characteristics. Indeed, all the treatments favoured a good soil organic matter content (≥ 3%; minimum threshold). The mineralisation of this organic matter was normal for all the sites studied with C/N ratio values that respected the recommended values for cocoa production. Concerning acidity (pH (water)) and the absorbent complex (S, CEC, assimilable phosphorus), the soils of the different sites generally respected the established chemical standards. In terms of chemical balances, there was a good balance between calcium and the sum of exchangeable bases (S) with (Ca/S) x100 $\geq$ 68%. On the other hand, the treatments on all the plots had deficiencies in potassium with (K/S) x100 < to 8% and magnesium with (Mg/S) x100 < 24. Finally, apart from one of the new fertilizer formulas proposed in this trial (NPK 0-15-15), the other fertilizers obtained a good balance between N and S, with (S+6.15) / N > (8.9). As for the production of cocoa beans, the reference control T1 (NPK 0-23-19) had the best real yield (1160.53 $kgha^{-1}$), compared to T4 (NPK 0-18-9) and T2 (NPK 0-15-15) which obtained 951.92 and 730.59 $kgha^{-1}$ respectively.

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