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(Research Article)

Effects of rock phosphate and PK mineral fertilizer on soil fertility and cocoa production in south-central Côte d'Ivoire

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Abstract

Côte d'Ivoire is the world's leading cocoa producer, but sustainable cocoa production is threatened by, among other things, the country's dwindling forest reserves and declining soil nutrients, mainly phosphorus. To remedy the decline in soil fertility, a study of a mineral amendment was carried out in south-central Côte d'Ivoire to ensure the sustainability of cocoa production. Specifically, the aim was to evaluate the effects of rock phosphate (RP) and PK mineral fertilizer on soil fertility and cocoa production at Divo, over three years of trials. The experimental set-up was a Fisher block design, with 4 replications for 5 treatments. The results showed that, in terms of soil fertility, treatments receiving rock phosphate generally had good assimilable phosphorus content (≥ 11.5 $Cmolkg^{-1}$), a Ca/Mg ratio of between 1 and 1.5, Mg/K≥3, (Ca+Mg)/K of between 12 and 40 and Ca/SBE x100 ≥ 68%. These ratios reflect not only good cocoa-growing soil, but also a good balance between Ca and the sum of exchangeable bases (SBE) and between K and the sum of Ca and Mg. On the other hand, all treatments had potassium deficiencies with (K/S) x100 < 8%. As for yield, treatments T1 (100%RP + 100% NPK 0-23-19) with 2953.44 $Kgha^{-1}$, T2 (90%RP + 100% NPK 0-23-19) with 2962.95 $Kgha^{-1}$ and T3 (80% RP + 100% NPK 0-23-19) with 2862.10 $Kgha^{-1}$ were the most expressive.

Key words: Mineral Amendment; Natural Phosphate; Soil Fertility; Cocoa Production; Côte d'Ivoire

1. Introduction

The cocoa tree (*Theobroma cacao* L.) is a perennial plant grown for its beans, which are used as raw material in the food, brewing and cosmetics industries. It is one of the most important cash crops grown in Africa, with global cocoa supply accounting for more than 70% of production [1]. In Côte d'Ivoire, cocoa production contributed around 15% of Gross Domestic Product (GDP) and over 50% of export earnings [2]. Cocoa plays a key role in the country's economic and social prosperity. However, cocoa farming is faced with a number of constraints that affect the sustainability of its production, leading to lower yields [3] and a fall in producers' incomes. These include the disappearance of the forest [4], and the increased decline in the fertility of cocoa-growing soils [5] due to a reduction in the main nutrients in the soil, particularly phosphorus [6]. This decline is accelerated by climatic conditions, which destroy the clay-humus complex that retains nutrients and gradually releases them to cultivated plants as required. As a result, cocoa-growing soils are depleted at an accelerated rate and yields fall continuously, jeopardising the sustainability and productivity of

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the cocoa sector. When soil acidity is very high, the plant is unable to absorb the elements such as phosphorus that are supplied for its growth, because the acidity releases metals such as aluminium (Al), iron (Fe) and manganese (Mn), which bind the phosphorus in the soil and make it unavailable. The work of [7] on a research station has shown the importance of phosphorus and potassium in improving cocoa yields. Phosphorus is considered to be the limiting factor for plants in tropical soils [8]. To remedy this problem, chemical fertilisers are applied to achieve appreciable yields, but although they are effective, they are used without mastery of their applications. Phosphate fertilisation needs to be improved to maintain the fertility of acid soils. This is the background to this study, the main objective of which is to ensure the sustainability of cocoa production in Côte d'Ivoire through rational mineral fertilisation using phosphate amendments.

2. Materials and methods

2.1. Study setting

The study was carried out in Divo, in south-central Côte d'Ivoire. Its geographical position benefits from a humid tropical climate. The rainfall regime is bimodal, with an average annual rainfall of 1,200 mm. Rainfall is characterised by two rainy seasons (March-June and September-November) and two dry seasons (July-August and November-February) according to [9]. Average temperatures are around 32°C and average annual radiation is 1650 joules/cm^2/day. Divo's vegetation cover is a dense secondary semi-deciduous forest [10]. Most of the area's soils are Ferralsols, which are highly desaturated [11, 12].

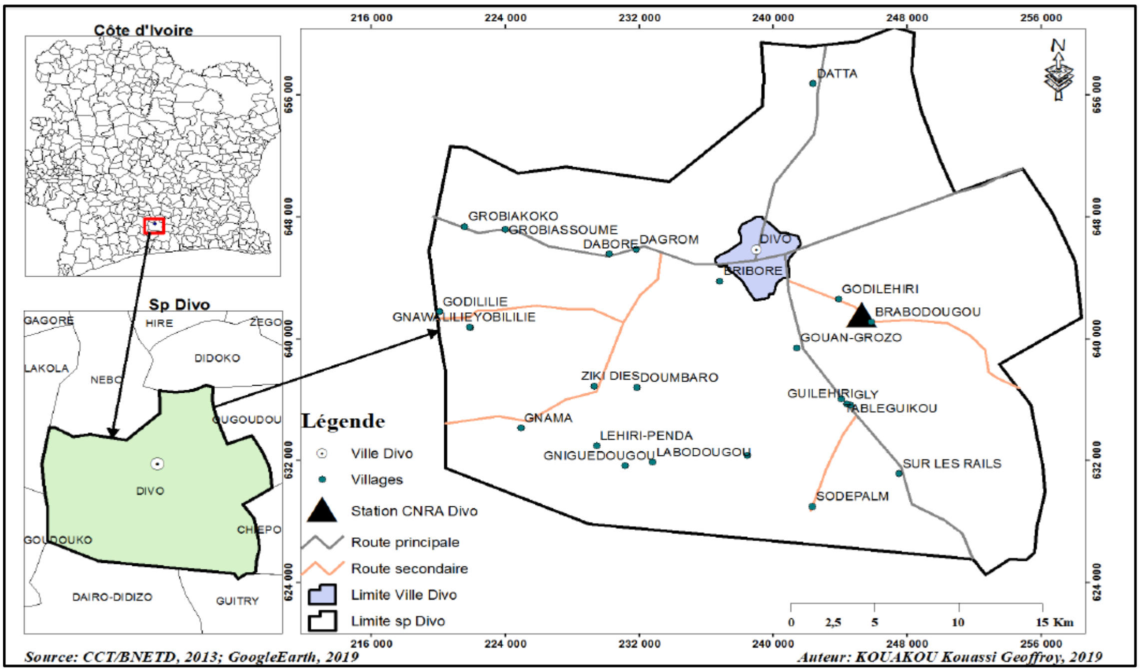

Figure 1 Geographical location of the study area

2.2. Plant material

The study material is the cocoa tree. The plot chosen for the trial is mature (11 years old).

2.3. Fertiliser

The fertiliser material consisted of NPK 0-23-19 mineral fertiliser (reference fertiliser) and phosphate mineral amendment, in particular rock phosphate. These fertilisers were supplied by the Office Chérifien of Phosphates (OCP).

2.4. Experimental set-up

The trial was conducted using a Fisher block design with 5 treatments repeated 4 times. Each treatment (15mx15m) consisted of 42 plants spaced 3m apart by 2.5m (density of 1333 plants/ha). The individual plots (225 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 840 plants and was conducted on 0.741 ha (78mx95m). The different fertiliser rates required and coded for use in the field correspond to treatments T1 to T5. Thus, at each fertiliser application period, i.e. every six months, half a year's worth of fertiliser is applied. Fertiliser was applied in two stages (March-April and August-September), within a radius of 80 to 100 cm around the cocoa plant (Table 1). However, rock phosphate was applied in a single year.

Table 1 Types and doses of fertiliser applied per cocoa plant

Treatment	Type of fertiliser	% application	Dose (g)/foot/year	Dose(g)/foot/application
T1	PR NPK 0-23-19	100 100	493 300	246,5 150
T2	PR NPK 0-23-19	90 100	444 300	222 150
T3	PR NPK 0-23-19	80 100	394 300	197 150
T4	PR NPK 0-23-19	60 100	296 300	148 150
T5	PR NPK 0-23-19	0 100	0 300	0 150

2.5. Soil sampling

Soil samples were taken before fertiliser applications and at the end of each production season (September). Soil samples were taken in the 0-30 cm soil layers from the surface [13], and 1 m from the cocoa tree, using a cylindrical sounding tube [14]. Composite samples from the 4 blocks were taken by treatment on each plot and then stored in plastic bags. 5 composite samples were obtained on site. These soil samples were analysed at the Cherifian Office of Phosphate (OCP) laboratory in Bingerville.

2.6. Analysis of soil samples

Soil organic carbon (C) was determined titrimetrically (Walkley-Black method) after oxidation with a mixture of sulfuric acid (H_2SO_4) and potassium dichromate ($K_2Cr_2O_7$). Total nitrogen was determined by the Kjeldahl method based on wet oxidation. Total phosphorus was determined colorimetrically after reaction with phosphoric acid in the presence of ammonium molybdate and ascorbic acid. Assimilable phosphorus (Olsen-Dabin method) was extracted using sodium bicarbonate ($NaHCO_3$) at pH 8.5. Exchangeable bases (K, Ca, Na and Mg) were extracted using ammonium acetate. Potassium was determined by flame photometer, while Ca and Mg were determined by atomic absorption flame spectrophotometer. pH (water) was determined using a pH meter after adding 50 ml of ionized water to 20 g of soil, followed by stirring and decanting.

2.7. 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)

0.35 = coefficient of transformation of a fresh bean into a dry bean; 1333 = number of cocoa plants per hectare; Rdt = Yield ; PMF = Average weight of fresh beans ; nCabsain = number of healthy pods; nCabtotal = number of total pods 0.001 = conversion of a gram into a kilogram.

2.8. 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 rock phosphate and mineral fertiliser (PK) on soil fertility in the Centre-South of Côte d'Ivoire

3.1.1. Effects of 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, with the exception of Na^+, CEC and water pH. With regard to assimilable phosphorus and K^+, apart from the other treatments, only T5 obtained the lowest value. For Ca^{2+}, only T3 had the lowest content. As for Mg^{2+}, T3 was the most expressive compared with the other treatments, which had low values. The average Na^+ and CEC levels were 0.73 and 13.05 $Cmolkg^{-1}$ respectively, and the pH water level was 6.08 (Table 2).

Table 2 Effects of mineral fertilisers on the absorbent complex and soil acidity

Treatment	**Cmolkg^{-1}**						
	P ass	K^+	Ca^{2+}	Mg^{2+}	Na^+	CEC	pH eau
T_1	11.59a	0.18 a	4,93a	1.17 ab	0.70 a	13.04a	5.77a
T_2	12.03a	0.17 a	3,43 a	0.82 b	0.74 a	12.77a	5.86a
T_3	11.75a	0.22 a	2,44 b	1.67 a	0.72 a	12.40a	6.18a
T_4	11.65a	0.14ab	4,02a	0.56b	0.73a	12.28a	6.60a
T_5	8.28b	0.05 b	3,92 a	0.48 b	0.74 a	12.14a	5.98a
Mean	11.06	0.15	3,75	0.94	0.73	12.58	6.08
C.V (p.c)	12.01	3.29	8.07	10.56	3.45	7.81	6.10
Pr > F	<.0001	0.0081	0.0007	0.007	0.380	0.521	0.310

Means followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.
PR : Reactive rock phosphate; T1 (100% PR + 100% NPK 0-23-19); T2 (90 % PR + 100% NPK 0-23-19) ;
T3 (80 % RP + 100% NPK 0-23-19); T4 (60 % RP + 100% NK 0-23-19); T5 (100% NPK 0-23-19).

3.1.2. Effects of fertilisers on ionic balances

The analysis of variance showed significant differences at the 5% threshold, between treatments for the parameters studied. Thus, all treatments had at least Ca/Mg ratios between 1 and 1.5, Mg/K≥3, (Ca+Mg)/K between 12 and 40 and Ca/SBE x100 ≥ 68% (optimum). In contrast, all treatments had (K/S) x 100 ratios below 8% (Table 3).

Table 3 Effects of mineral fertilizers on ionic balances

Treatment	**Ca/Mg**	**Mg/K**	**(Ca+Mg)/K**	**(Ca/S)100**	**(K/S)100**
T_1	4.21b	6.50b	33.88 b	78.75ab	2.87b
T_2	4.18b	4.78c	25.00 b	76.51ab	3.79b
T_3	1.56c	7.62b	18.68 c	42.62c	7.09a
T_4	7.18ab	3.86c	32.71 b	83.67a	3.13b
T_5	8.17a	9.60a	88.00 a	86.87	1.17c
Mean	5.06	6.47	39.65	73.69	3.61
C.V(%)	4.49	10.05	8.11	7,03	21.45
Pr > F	0.002	0.007	0.015	< 0.001	0.0062

Means followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.
PR : Reactive rock phosphate; T1 (100% PR + 100% NPK 0-23-19); T2 (90 % PR + 100% NPK 0-23-19) ;
T3 (80 % RP + 100% NPK 0-23-19); T4 (60 % RP + 100% NK 0-23-19); T5 (100% NPK 0-23-19).

3.2. Effects of rock phosphate and mineral fertiliser (PK) on yield and yield components in south-central Côte d'Ivoire

The analysis of variance showed significant differences between treatments in terms of the parameters measured. Treatments T1 (145.65) and T3 (141.77) were the most expressive in terms of Wilt, while T2 (90.31) and T5 (87.43) had the lowest values. As for healthy and total pods, T1, T2, T3 and T4 had the highest rate and T5 the lowest. In terms of average fresh bean weight, T1 had the highest rate at 150.58 g, while T2 had the lowest average fresh bean weight (112.34 g). As for yield, treatments T1 (2712.47 $Kgha^{-1}$), T3 (2600.15 $Kgha^{-1}$) and T4 (2703.97 $Kgha^{-1}$) had the highest real yields, while treatments T2 (2083.38 $Kgha^{-1}$) and T5 (2036.82 $Kgha^{-1}$) had the lowest. The same applies to potential yield, where T1 (2953.44 $Kgha^{-1}$), T3 (2962.95 $Kgha^{-1}$) and T4 (2862.10 $Kgha^{-1}$) were the most expressive, compared with T2 (2341.25 $Kgha^{-1}$) and T5 (2421.95 $Kgha^{-1}$), which obtained the lowest yields (Table 4).

Table 4 Effects of fertilizers on the number of healthy pods, total pods, average fresh bean weight, actual and potential yields

Treatment	Chérelles Wilt	Healthy pods	Total pods	average weight fresh bean	Actual yield	Potential yield
T1	145.65a	38.61a	42.04a	150.58a	2712.47a	2953.44a
T2	90.31c	39.75a	44.67a	112.34c	2083.38b	2341.25c
T3	141.77a	38.63a	44.02a	144.27b	2600.15a	2962.95a
T4	103.62b	41.04a	43.44a	141.22b	2703.97a	2862.10a
T5	87.43c	30.04b	35.72b	145.33b	2036.82b	2421.95c
Mean	113.76	37.61	41.98	138.75	2427.36	2708.34
CV (p.c.)	24.02	11.02	32,04	5.74	20.10	27.11
Pr > F	0.0011	0.0021	<.0001	<.0001	<.0001	<.0001

Means followed by the same letters in the same column are not significantly different at the 5 p.c. threshold.
PR : Reactive rock phosphate; T1 (100% PR + 100% NPK 0-23-19); T2 (90 % PR + 100% NPK 0-23-19) ; T3 (80 % RP + 100% NPK 0-23-19); T4 (60 % RP + 100% NK 0-23-19); T5 (100% NPK 0-23-19).

4. Discussion

4.1. Effects of rock phosphate and mineral fertiliser (PK) on soil fertility

4.1.1. Effects of fertilisers on the absorbent complex

The results of the effects of fertilisers on the absorbent complex showed that the assimilable phosphorus content of the soil, particularly in treatments T1, T2, T3 and T4, was higher than the standard established for cocoa production (11.5 $Cmol.kg^{-1}$) in [15]. The high assimilable phosphorus content in these treatments is due to the contribution of natural phosphorus, which slowly releases the orthophosphate ion (P_2O_5).

pH is an important soil parameter because it provides information about nutrients and the risk of toxicity. The biological activity of the soil and the availability of most nutrients depend on pH [16]. The pH of the experimental plot (5.77 to 6.60) respects the threshold required for good cocoa tree development. This is corroborated by [17] and [18], who concluded that the slightly acidic pH of the soil does not constitute a constraint for the cocoa tree. Even if the optimum pH is 7 for the best soils under cocoa trees, this plant can develop on soils with an acid pH (pH 4.5-6) or slightly basic pH (pH 6.7-7.5). However, the increase in pH towards neutrality would be due to saturation of the soil with bases.

However, in terms of average K (0.15 $Cmol.kg^{-1}$), Ca (3.75 $Cmol.kg^{-1}$) and Mg (0.95 $Cmol.kg^{-1}$) levels, all treatments showed deficits. According to [19], the average potassium content for good mineral nutrition of cocoa trees is around 0.7 $Cmol.kg^{-1}$. The low potassium levels obtained on the plots could be explained by the fact that it has been exchanged or exported or washed into the lower horizons. The same applies to magnesium and calcium, whose threshold values of between 5 and 8 $Cmol.kg^{-1}$ were higher than those obtained in the soils of the experimental plot [20, 21, 22]. These deficits in certain exchangeable cations could be due to the nature of the clays, which tend to saturate quickly, thus facilitating their leaching. With regard to CEC, all treatments had values below 12 $Cmol.kg^{-1}$ (minimum threshold), as the CEC of soils under cocoa trees must be between 12 and 30 $Cmolkg^{-1}$ [23]. These good CEC values obtained by the treatments could be due to good availability of soil organic matter.

4.1.2. Effects of fertilisers on ionic balances

The results of the effects of fertilisers on ionic balances showed that the Mg/K and Ca/Mg ratios obtained reflect soils that are favourable to cocoa production. These values fall within the ranges proposed by some researchers [24, 25], in particular Ca/Mg between 1.5 and 5 and Mg/K ≥ 3. On the other hand, all the plots showed potassium deficiencies with K/S below 8, which would indicate an imbalance between K and S [26, 27]. In this case, correction of the imbalance requires an increase in potassium for good mineral nutrition. The results also showed that all the treatments favoured a ratio of (Ca/S) x100 ≥ 68% and (Ca+Mg)/K of between 12 and 40. These values reflect a good balance between Ca and the sum of exchangeable bases (S), and between potassium and the sum of calcium and magnesium [28].

4.2. Effects of fertilisers on cocoa production

The results indicate that cocoa trees that have received phosphate fertiliser have the best production characteristics. This is confirmed by the average number of healthy pods produced per cocoa tree and the high yields of fertilised soils. Phosphorus and potassium are recognised as major elements contributing to flower proliferation and improved fruit quantity and quality. Regular use of phosphate mineral amendment is necessary to support canopy growth and bean production [29]. The positive effect of fertilisers on production can be explained by an improvement in the chemical status of soils that are chemically imbalanced and deficient in potassium [3], essential mineral elements for cocoa production [30]. With regard to the high number of chérelle wilt observed in cocoa farms, it should be stressed that the high rate of chérelle wilt has a major impact on production. In fact, chérelle wilt acts as a regulating factor for trees with a high number of pods, exceeding 100 pods per tree, which corresponds to around 4 tonnes of merchantable cocoa per hectare [31]; other studies have shown that a rise in temperature increases the number of chérelle wilt [32]. In terms of yield, we noted that the highest yields were observed in treatments that received phosphate mineral amendments, in particular T1, T3 and T4. This was confirmed by the weight of the fresh beans and the large number of healthy and total pods observed in these treatments.

5. conclusion

In the Centre-Sud region of Côte d'Ivoire, precisely at Divo, rock phosphate combined with the reference fertilizer showed that in terms of soil fertility, the treatments that received rock phosphate generally obtained, good water pH (4.5-6), assimilable phosphorus content (≥ 11.5 $Cmolkg^{-1}$), CEC (12 and 30 $Cmolkg^{-1}$), Ca/Mg ratio (1-1.5), Mg/K (≥3), (Ca+Mg)/K (12-40) and Ca/SBE x100 (≥ 68%). These ratios reflect not only good cocoa-growing soil, but also a good balance between Ca and the sum of exchangeable bases (SBE). In contrast, all treatments had potassium deficiencies with (K/S) x100 < 8%. As for yield, treatments T1 (100%RP + 100% NPK 0-23-19) with 2953.44 $Kgha^{-1}$, T2 (90%RP + 100% NPK 0-23-19) with 2962.95 $Kgha^{-1}$ and T3 (80%RP + 100% NPK 0-23-19) with 2862.10 $Kgha^{-1}$ achieved higher potential yields than the reference control T5 (100% NPK 0-23-19) with 2421.95 $Kgha^{-1}$.

These results show that rock-phosphate fertilizer combined with the NPK 0-23-19 reference control has very good potential for improving cocoa bean yields.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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