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Improvement of juvenile growth and flowering of cocoa (*Theobroma cacao* L.) by different types of fertilizers in southwestern Ivory Coast

OUATTARA Tièba Victor[1], TUO Seydou[2], ALLA Kouadio Theodore[3], EPONON Eboa Christophe Ghislain[2], KASSIN Koffi Emmanuel[4], KOKO Kan Louis Anselme[5], CAMARA Maméri[6], and DICK Acka Emmanuel[2]

[1]University of Jean Lorougnon Guédé, UFR Agroforesterie, BP 150 Daloa, Côte d'Ivoire

[2]University of Félix Houphouët-Boigny, UFR Biosciences, 22 BP 582 Abidjan 22, Côte d'Ivoire

[3]National Pedagogical Institute for Technical and Vocational Education, Department of Training of Trainers in Agricultural Professions, 08 BP 2098 Abidjan 08, Côte d'Ivoire

[4]Mondelez, 01 BP 5754 Abidjan 01, Côte d'Ivoire

[5]OCP-Africa, 01 BP 528 Abidjan 01, Côte d'Ivoire

[6]Centre National de Recherche Agronomique (CNRA) BP 808 Divo, Côte d'Ivoire

ABSTRACT: To ensure the sustainability and productivity of the cocoa crop, replanting on non-forested sites such as old orchards or young fallow lands raises the problem of the survival and establishment of seedlings, due to the low fertility of the soil, particularly in phosphorus. Thus, in order to minimize mortality and improve juvenile growth and flowering precocity of cocoa trees, organic, mineral and organo-mineral fertilizers were applied to a fallow land with low phosphate fertility, in Soubré, in the southwest of Ivory Coast. The experimental design was a partially balanced incomplete block design with 12 treatments and three replications. The treatments consisted of two fertilizer applications per year for each plant: compost (T1); phospho-compost (T2); TSP + compost (T3 and T4); NPK based on natural phosphates (T7, T8 and T9), combined with compost (T5 and T6) or phospho-compost (T10 and T11) at different doses. Growth parameters and flowering were evaluated. Treatments T2 (phosphocompost 1 kg), T3 (TSP 75 g + compost 2 kg) and to a lesser extent T11 (NPK 0-15-15 300 g + phospho-compost 1 kg) were the most efficient. They allowed a better growth, a good precocity of crowning and flowering. All the treatments tested did not impact the mortality rate of young cocoa trees. These results could allow farmers to exploit favorably soils with low fertility, with the guarantee of a good establishment of cocoa plants in the field during the juvenile stage.

KEYWORDS: Cocoa tree, fertilization, replanting, growth, flowering, Ivory Coast.

1 INTRODUCTION

In Ivory Coast, the area covered by cocoa cultivation has increased from 2,000,000 ha in 2000 to nearly 4,776,000 in 2019 [1]. This increase has been at the expense of forest reserves, worsen problems related to land scarcity due to high land pressure [2]. The growing interest in cocoa farming often leads farmers to replant on old plots and very young fallows with degraded soils, with the corollary of difficult establishment of young plants [3], [4]. Its poor soils are generally deficient in phosphorus, nitrogen, potassium and in calcium and magnesium as well [5], [6]. Potassium and nitrogen can be returned to the soil from pod husk residues in the form of compost [7] unlike phosphorus [8], [9]. Yet, the latter is essential for plant growth and productivity [10], [11]. Indeed, phosphorus deficiency in cocoa trees results in stunted growth, poor flowering and fruiting. In addition, a young cocoa tree deficient in phosphorus will not express its productivity potential at the adult stage, even in the presence of sufficient quantities of this element [12]. Phosphorus can be supplied in the form of triple superphosphate (TSP) or through mineral resources such as rock phosphates [13]. The latter used as fertilizers, have a lasting residual effect that limits their participation in the phenomenon of eutrophication [14]. With a relatively low cost, natural phosphates would be very effective on plants after composting [15]. Thus, this study was undertaken to contribute to the promotion of sustainable, ecological cocoa farming using low-cost fertilizers in southwestern Ivory Coast. The area concentrates the majority (40%) of the country's producers and has ferrallitic soils that are highly leached and not very fertile. Juvenile growth and flowering precocity were evaluated on cocoa trees replanted on relatively poor soil treated with organic, mineral and organo-mineral fertilizers.

2 Material And Methods

2.1 Study Area

The experiment was conducted on the plots of the National Center for Agronomic Research (NCAR) in Soubré, southwestern Ivory Coast. The station is located between 85 and 278 m of altitude with coordinates of 050 62.222' in north latitude and 0060 63.987' in west longitude **(Figure 1).** The area is drained by the Sassandra River and its tributaries. The average temperature is in the range of 21-33°C and the annual rainfall is 1200 mm. The soils are highly desaturated Ferrasols derived from granite [16]. The previous crop on the study plot was a fallow of about 3 years, consisting mainly of *Pueraria phaseoloides* and *Panicum maximum* vegetation

2.2 Material

2.2.1 Plant Material

The plant material used consisted of plants from seven cocoa tree (*Theobroma cacao*) hybrids certified by the Centre Of Agronomic Research (CNRA) [17]. The plants were produced in the nursery from seed and then transferred to the field at the age of 6 months for experimentation.

2.2.2 Fertilizers

The fertilizers used to make up the manures were compost made solely from pod husk residues (compost) or made with natural soft phosphates (phosphocompost), triple superphosphate (TSP) dosed at 46% and NPK 0-15-15 based on natural phosphates. For composting, cocoa and *Puerraria* sp leaves, wood ash, poultry droppings and humus soil were added to the pod husk residues.

2.3 Methods

2.3.1 Fertilizer Treatments Applied

In each elementary plot, 20 cocoa trees were selected to receive one of the treatments as shown in **Table I**. Each year, the applications were made on the surface at the foot of the cocoa trees, in the crown within 0.30 m of the collar where the absorbing roots are most active. The application was done in two periods, at the beginning of the long and short rainy season, in April and September respectively. In total, three applications were made during the experiment.

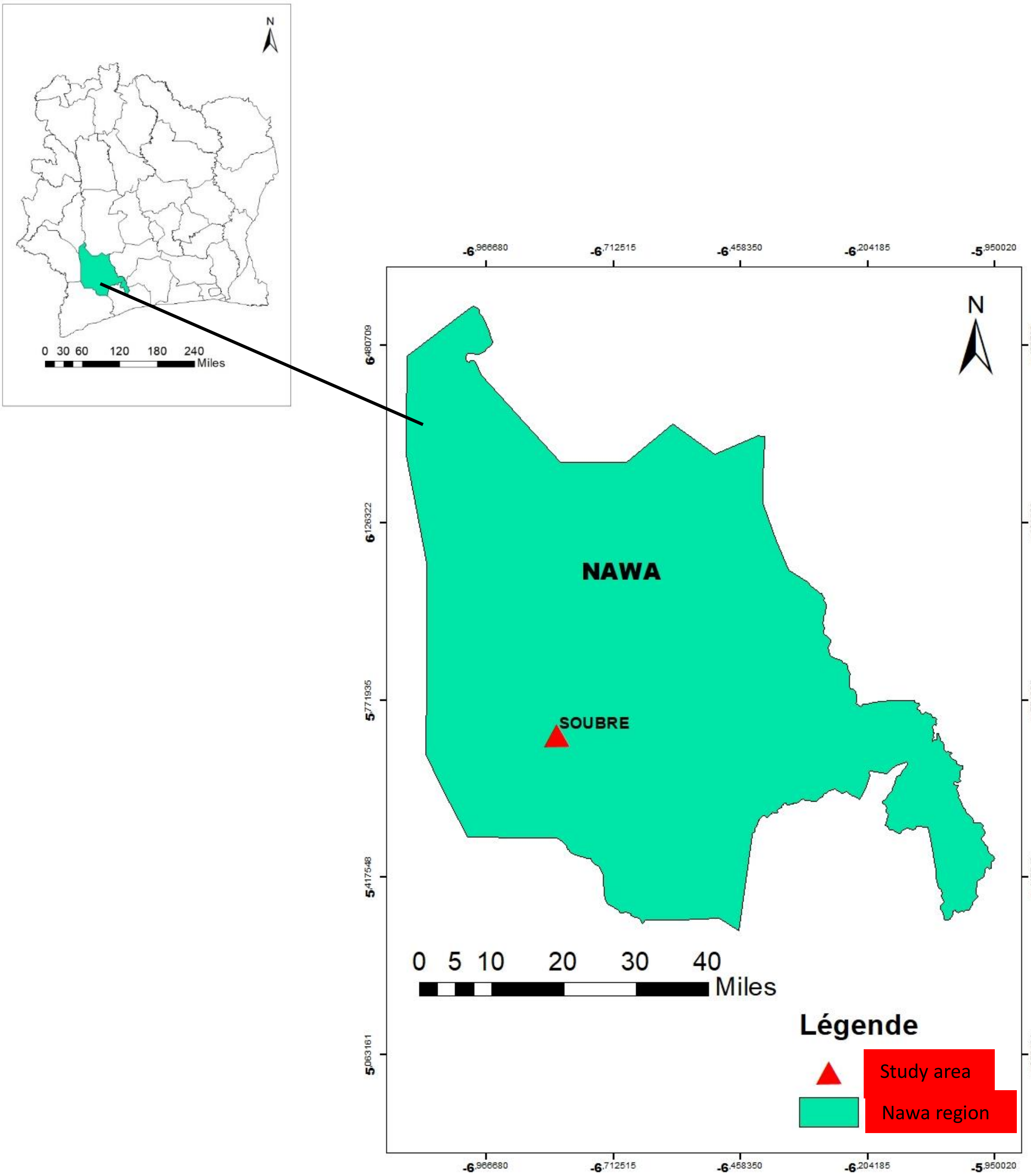

Fig. 1. Location of the study area in Ivory Coast

Table 1. Composition of fertilizer treatments and doses applied per cocoa plant

Treatments	Composition et doses
T0	Control without fertilizer
T1	Compost 2 kg
T2	Phospho-compost 1 kg
T3	TSP 75 g + compost 2 kg
T4	TSP 100 g + compost 2 kg
T5	NPK 0-15-15 225 g + compost 2 kg
T6	NPK 0-15-15 300 g + compost 2 kg
T7	NPK 0-15-15 225 g
T8	NPK 0-15-15 150 g
T9	NPK 0-15-15 300 g
T10	NPK 0-15-15 225 g + phospho-compost 1 kg
T11	NPK 0-15-15 300 g + phospho-compost 1 kg

2.3.2 Experimental Design

The trial was conducted in a partially balanced incomplete block design with 12 treatments and three replicates on an area of 0.56 ha (80 m x 70 m). Treatments were randomized in each 80 m x 7.5 m block. These blocks were arranged parallel and spaced 5 m apart. The individual plots each consisted of 20 cocoa trees with a spacing of 3 by 2.5 m (density of 1333 plants/ha), separated from each other by 4 m. Banana trees planted 8 months before the cocoa trees, in row spacing and at the same density, served as temporary shading.

2.3.3 Parameters Assessed

2.3.3.1 Chemical Characteristics Of The Soil

Prior to the implementation of the tests, an auger sampling of 30 elementary soil samples in the 0-20 cm horizon was done along the diagonals. After mixing them into a composite unit, the resulting batch was air-dried, sieved and stored in polyethylene bags.

The chemical data analyzed were organic carbon (C) determined by the [18] method, total nitrogen (N) by the [19] method and assimilable phosphorus (P.assimilable) evaluated by the Olsen-Dabin method [20]. Exchangeable bases (K, Mg and Ca) and cation exchange capacity (CEC) were determined by the method of [21]. Exchangeable aluminum (Al) was determined by the method of [22]. The pH (water) was determined using the pH meter, after addition of 50 ml of ionized water to 20 g of soil [23]. Soil trace elements (B, Zn, Cu and Fe) were obtained by standard methods [24]. The saturation rate (V) was evaluated by the quotient of the sum of exchangeable bases on the CEC reported to 100. Equilibria were calculated with the values obtained from the analyses.

2.3.3.2 Growth In Thickness And Height Of The Cocoa Tree Stem

Growth in thickness and height, as well as other cocoa parameters, were assessed per unit plot and per treatment at 6, 12 and 18 months after planting, with the exception of flowering.

Height (cm) was measured from the collar to the apical bud of the main stem, using a tape measure. Diameter at the collar (cm) was measured at 10 cm above the ground using a "Stainless Hardened" electronic caliper. Measurements were taken according to the fertilization regimes. Growth rates in thickness and height were calculated according to the following equation: (Cti-Cti-1) / (ti- ti-1) with C = growth; t = time; i = month.

2.3.3.3 Mortality And Crowning Of Cocoa Trees

The number of dead or crowned cocoa trees was counted and the rates were evaluated by relating the values obtained to the total number of plants and then multiplied by 100. In addition, the rate of crowning was determined as before according to the following formula: (TCou i - TCou i-1) / (ti- ti-1) with T = rate; Cou = crowning; i = month, t= time.

2.3.3.4 Flowering Of Cocoa Trees

Cocoa trees bearing flowers were counted 18 months after planting. The flowering rate, which reflects its intensity, was evaluated by multiplying the quotient of the value recorded by 100 over the total number of cocoa trees.

2.3.4 STATISTICAL ANALYSIS OF DATA

The collected data were subjected to analysis of variance (ANOVA) using GenStat version 9.1 software. The averages were separated using the Student-Newman-Keuls test at the 5% threshold. The transformations of the values into percentages were done according to the formula $Y=\arcsin\sqrt{X}$ and the others according to this one: $Y=\sqrt{X+0,5}$.

Comparison of independent means of cocoa tree growth in two periods (6-12 and 12-18 months) was performed using Student's unpaired t-test. A Pearson correlation between the variables studied and a hierarchical ascending classification of treatments were the multivariate analyses applied.

3 RESULTS

3.1 INITIAL SOIL FERTILITY

Soil chemistry data collected at the experimental site **(Table II)** were compared to recommended optimal values for cocoa farming [25].

For all of the following parameters C (1.4%), N (0.1%), assimilable P (4.8 ppm), CEC (3.7 cmol/Kg), Ca (2.1 cmol/Kg) and Mg (0.8 cmol/Kg) and then the equilibria SBE+6.15N (3.6), PMg (16.6%), and Ca+Mg/K (15.9), values below the thresholds were observed. However, pH (6.2), M.O (2.5%), V (82.0%), K (0.2 cmol/Kg,), C/N (14.3), Ca/Mg (2.6), Ca/K (11.5) and Mg/K (4.4) were within the recommended range. The N/available ratio (210.1), PCa (71.3%), PK (12.1%) were high compared to the optimum. For trace elements, Zn (8.1 ppm), B (0.2 ppm) and Cu (1.4 ppm) were within the acceptable range for cocoa.

However, for Al (395 ppm), the initial level was well above the toxicity threshold defined for cocoa, which is 156 ppm.

Table 2. Initial soil chemical characteristics of the experimental site and recommended values for cocoa production

Soil properties	Values	Threshold or optimal values[1]
pH water	6.2	5.0 to 7.0
N (%)	0.1	0,2
C (%)	1.4	1.7 to 3.2
M.O (%)	2.5	2.5 to 5.0
P. assimilable (ppm)	4.8	12.0 to 25.0
Absorbent complex		
CEC (cmol/Kg)	3.7	≥ 12.0
V (p.c.)	83.8	≥ 60.0
K (cmol/Kg)	0.2	0.2 to 1.2
Ca (cmol/Kg)	2.1	4.0 to 18.0
Mg (cmol/Kg)	0.8	0.9 to 4.0
Chemical Equilibrium		
C/N	14.3	9.5 to 15.0
SBE+6,15N	3.6	8.9
N/P. assimilable	210.1	10.0<N/P. assimilable<20.0
PCa (%)	71.3	68.0
PMg (%)	16.6	24.0
PK (%)	12.1	8.0
Ca+Mg/K	15.9	25.0
Ca/Mg	2.6	1.0 to 4.0
Ca/K	11.5	6.0 to 12.0
Mg/K	4.4	3.5 to 4.0
Trace elements		
Al (ppm)	395.0	<156.0
B (ppm)	0.2	≥ 0.2
Zn (ppm)	8.1	8.0 à 10.0
Cu (ppm)	1.4	>0.6
Fe (ppm)	98.5	27.0

(1): Source Snoeck et al., 2016

3.2 Growth In Thickness And Height Of The Stems Of Young Cocoa Trees

For all periods, the diameter at the collar and the monthly increase or growth rate of the stem thickness of the cocoa trees were influenced by the different fertilizer treatments applied **(Table III).** At 6, 12 and 18 months after planting, the treatments that consistently induced the highest diameters were T2, T3 and T11. The lowest values were observed in the unfertilized T0 control. On the other hand, the highest growth rates in thickness simultaneously over the two measurement periods, 6-12 and 12-18 months, were due to treatments T4 and T11.

Considering the monthly increases in thickness per treatment over the two time intervals, the values evolved upwards for T2, T6, T7, T10 and T11 in contrast to the other inputs where they remained stable.

Table 3. Growth in thickness of cocoa stems under different fertilizer treatments as a function of time after planting

Treatments	Diameters (cm)			Increases in thickness (mm/month)	
	6 months	12 months	18 months	Period 6-12 months	Period 12-18 months
T0	0.9 ± 0.5 b	1.4 ± 0.6 c	2.1 ± 1.1 d	0.7 ± 0.1 c A	0.8 ± 0.1 c A
T1	1.0 ± 0.4 ab	1.7 ± 0.6 ab	2.7 ± 1.0 bc	1.0 ± 0.0 bc A	1.2 ± 0.1 b A
T2	1.1 ± 0.4 a	1.7 ± 0.7 ab	2.9 ± 1.2 ab	1.0 ± 0.1 bc B	1.5 ± 0.1 a A
T3	1.0 ± 0.5 ab	1.8 ± 0.7 a	2.9 ± 1.1 ab	1.4 ± 0.1 a A	1.4 ± 0.1 b A
T4	0.9 ± 0.4 b	1.7 ± 0.6 ab	2.9 ± 1.3 ab	1.4 ± 0.1 a A	1.4 ± 0.1 ab A
T5	1.0 ± 0.5 ab	1.6 ± 0.5 bc	2.6 ± 0.9 c	1.0 ± 0.0 bc B	1.2 ± 0.1 b A
T6	1.0 ± 0.4 ab	1.6 ± 0.6 bc	2.8 ± 1.0 b	1.0 ± 0.1 bc B	1.4 ± 0.1 ab A
T7	0.9 ± 0.4 b	1.5 ± 0.5 bc	2.4 ± 0.9 cd	1.0 ± 0.1 bc A	1.2 ± 0.1 b A
T8	1.1 ± 0.4 a	1.7 ± 0.6 ab	2.8 ± 1.0 b	1.1 ± 0.1 b A	1.3 ± 0.1 ab A
T9	0.9 ± 0.5 b	1.6 ± 0.6 bc	2.7 ± 1.0 bc	1.1 ± 0.1 bc A	1.2 ± 0.1 b A
T10	1.0 ± 0.5 ab	1.6 ± 0.6 bc	2.7 ± 1.1 bc	1.0 ± 0.10 bc B	1.4 ± 0.1 ab A
T11	1.2 ± 0.5 a	1.9 ± 0.6 a	3.1 ± 1.1 a	1.2 ± 0.1 ab B	1.6 ± 0.1 a A
Mean	1.0	1.7	2.7	1.1	1.3
C.V. (%)	16.9	14.9	18.2	4.5	6.2
Probability	0.01	< 0.001	< 0.001	<0.001	<0.001

In a column (lower case) or row (upper case), the means followed by the same letter are statistically identical at the 5 p.c. threshold. (Student-Newman-Keuls); C.V = coefficient of variation; T0 (Controls without fertilizer); T1 (Compost 2 kg); T2 (Phospho-compost 1 kg); T3 (TSP 75 g + compost 2 kg); T4 (TSP 100 g + compost 2 kg); T5 (NPK 0-15-15 225 g + compost 2 kg); T6 (NPK 0-15-15 300 g + compost 2 kg); T7 (NPK 0-15-15 225 g); T8 (NPK 0-15-15 150 g); T9 (NPK 0-15-15 300 g); T10 (NPK 0-15-15 225 g + phosphocompost 1 kg); T11 (NPK 0-15-15 300 g + phospho-compost 1 kg)

With respect to the height of the cocoa trees (**Table IV),** the values were not affected by the fertilizer treatments during the first 12 months of planting. On average, the heights were equal to 62.6 cm (6 months) and 99.8 cm (12 months). However, at 18 months, T2 and T11 were the treatments that induced the highest values. The lowest height was observed in the untreated control. In addition, the height increment assessed for each period did not vary significantly according to the treatments performed. The averages recorded were equal to 63.1 mm/month and 42.2 mm/month, respectively in the periods from 6 to 12 months and from 12 to 18 months after planting the cocoa trees. In contrast, for each treatment, the monthly increase in main stem height decreased significantly from the 6-12 month period to the 12-18 month interval, with the exception of those observed following the application of T2 and T7, which remained stable.

Table 4. Stem height growth of cocoa under different fertilizer treatments as a function of time after planting

Treatments	Heights (cm)			Height increases (mm/month)	
	6 months	12 months	18 months	Period 6-12 months	Period 12-18 months
T0	58.1 ± 33.7 a	93.7 ± 39.6 a	116.4 ± 62.4 b	59.9 ± 5.6 a B	39.8 ± 4.1 a B
T1	63.2 ± 25.0 a	100.0 ± 36.3 a	128.4 ± 47.4 ab	60.0 ± 5.0 a A	39.1 ± 3.5 a B
T2	66.0 ± 26.9 a	105.1 ± 44.8 a	147.1 ± 57.0 a	65.1 ± 5.9 a A	52.94 ± 3.7 a A
T3	60.7 ± 27.8 a	104.1 ± 39.6 a	134.0 ± 50.5 ab	72.2 ± 5.0 a A	39.1 ± 3.7 a B
T4	58.2 ± 29.8 a	101.6 ± 38.2 a	136.0 ± 47.4 ab	72.1 ± 4.1 a A	43.8 ± 3.5 a B
T5	64.6 ± 29.3 a	99.6 ± 35.7 a	129.4 ± 43.4 ab	58.4 ± 4.6 a A	41.2 ± 3.3 a B
T6	64.0 ± 20.0 a	100.6 ± 38.8 a	131.8 ± 45.1 ab	59.1 ± 5.3 a A	41.4 ± 4.0 a B
T7	52.8 ± 25.8 a	88.9 ± 31.4 a	123.3 ± 41.6 ab	53.5 ± 4.5 a A	45.7 ± 4.2 a A
T8	64.0 ± 25.7 a	103.0 ± 30.2 a	129.8 ± 42.1 ab	65.0 ± 4.6 a A	37.0 ± 3.2 a B
T9	58.7 ± 32.6 a	102.3 ± 39.6 a	131.7 ± 50.7 ab	73.6 ± 5.3 a A	40.3 ± 3.9 a B
T10	57.7 ± 27.34 a	92.7 ± 34.5 a	123.6 ± 46.9 ab	56.5 ± 5.3 a A	41.4 ± 3.5 a B
T11	68.0 ± 29.4 a	106.5 ± 44.0 a	144.3 ± 47.5 a	62.5 ± 5.1 a A	48.0 ± 4.4 a B
Mean	62.6	99.8	131.3	63.1	42.2
C.V. (%)	32.0	21.0	23.3	33.9	35.6
Probability	0.12	0.40	0.04	0.06	0.16

In a column (lower case) or row (upper case), the means followed by the same letter are statistically identical at the 5 p.c. threshold. (Student-Newman-Keuls); C.V = coefficient of variation; T0 (Controls without fertilizer); T1 (Compost 2 kg); T2 (Phospho-compost 1 kg); T3 (TSP 75 g + compost 2 kg); T4 (TSP 100 g + compost 2 kg); T5 (NPK 0-15-15 225 g + compost 2 kg); T6 (NPK 0-15-15 300 g + compost 2 kg); T7 (NPK 0-15-15 225 g); T8 (NPK 0-15-15 150 g); T9 (NPK 0-15-15 300 g); T10 (NPK 0-15-15 225 g + phosphocompost 1 kg); T11 (NPK 0-15-15 300 g + phospho-compost 1 kg)

3.3 Crowning Of Cocoa Trees

The effects of fertilizers on the crown of cocoa trees are shown in the **table V**. Six months after planting, the fertilizers applied had no significant effect on the crowning rate of cocoa trees. The average rate obtained was equal to 4.9%. At 12 and 18 months after planting, the values recorded fluctuated significantly according to the treatments. Thus, T8 and T11 are the fertilizer treatments that were the basis of the highest crowning rates after 12 months, then T2, T3, T6 and T11 after 18 months of planting. In both cases, the control without fertilizer caused the lowest values.

With respect to the monthly crowning velocity, the values obtained in the interval 6-12 months after planting varied significantly according to the treatments applied. T2, T8 and T11 induced the highest velocity and T0 the lowest. In the 12-18 months post-planting period, the effects of treatments on the data collected were no longer significant. Considering separately the effects of the treatments during the periods 6-12 and 12-18 months, the values increased significantly with T0 and T7. They decreased significantly at T1, T8, T10 and T11. For all other treatments, the crowning velocity did not vary significantly between the two periods.

Table 5. Crowning of cocoa trees under different fertilizer treatments according to the time after planting

Treatments	Crowning rate (%)			Crowning velocity (%/month)	
	6 months	12 months	18 months	Period 6-12 months	Period 12-18 months
T0	5.0 ± 2.0 a	20.0 ± 4.0 c	60.0 ± 49.4 c	2.5 ± 1.0 b B	5.0 ± 1.0 a A
T1	5.0 ± 0.0 a	43.3 ± 5.0 ab	75.0 ± 40.0 ab	6.4 ± 1.0 ab A	4.0 ± 1.0 a B
T2	3.3 ± 1.8 a	43.3 ± 5.0 ab	90.0 ± 30.0 a	6.7 ± 1.0 a A	5.8 ± 1.0 a A
T3	8.3 ± 3.0 a	41.7 ± 5.0 ab	86.0 ± 40.0 a	5.8 ± 1.0 ab A	5.4 ± 1.0 a A
T4	5.0 ± 2.0 a	40.0 ± 5.0 ab	75.0 ± 4.0 ab	5.8 ± 1.0 ab A	4.4 ± 1.0 a A
T5	5.0 ± 0.0 a	36.7 ± 5.0 b	78.3 ± 4.0 ab	6.1 ± 1.0 ab A	5.2 ± 1.0 a A
T6	10.0 ± 3.0 a	36.7 ± 5.0 b	85.0 ± 40.0 a	5.0 ± 1.0 ab A	6.0 ± 1.0 a A
T7	5.0 ± 2.0 a	26.7 ± 4.0 bc	81.7 ± 40.0 ab	3.9 ± 1.0 ab B	6.9 ± 1.0 a A
T8	5.0 ± 2.0 a	51.7 ± 5.0 a	78.3 ± 40.0 ab	7.8 ± 1.0 a A	3.5 ± 1.0 a B
T9	5.0 ± 2.0 a	38.3 ± 5.0 b	70.0 ± 50.0 b	5.5 ± 1.0 ab A	4.2 ± 1.0 a A
T10	5.0 ± 2.0 a	41.7 ± 5.0 ab	71.7 ± 40.0 b	6.1 ± 1.0 ab A	3.7 ± 1.0 a B
T11	6.6 ± 3.0 a	50.0 ± 5.0 a	87.0 ± 30.0 a	7.2 ± 1.0 a A	4.6 ± 1.0 a B
Mean	4.9	39.2	78.1	5.8	4.9
C.V. (%)	15.2	27.6	19.1	27.6	27.6
Probability	0.37	0.03	0.00	0.01	0.07

In a column (lower case) or row (upper case), the means followed by the same letter are statistically identical at the 5 p.c. threshold. (Student-Newman-Keuls); C.V = coefficient of variation; T0 (Controls without fertilizer); T1 (Compost 2 kg); T2 (Phospho-compost 1 kg); T3 (TSP 75 g + compost 2 kg); T4 (TSP 100 g + compost 2 kg); T5 (NPK 0-15-15 225 g + compost 2 kg); T6 (NPK 0-15-15 300 g + compost 2 kg); T7 (NPK 0-15-15 225 g); T8 (NPK 0-15-15 150 g); T9 (NPK 0-15-15 300 g); T10 (NPK 0-15-15 225 g + phosphocompost 1 kg); T11 (NPK 0-15-15 300 g + phospho-compost 1 kg)

3.4 Flowering And Mortality Of Cocoa Trees

Table VI groups together the data on flowering and mortality of plants under the effect of applied fertilizers. For the first parameter mentioned, the first flowers that appeared in the 18th months after planting the cocoa trees were counted. The values recorded varied significantly according to the treatments. The largest flowers were obtained following the application of T3 (20%) and T11 (18.3%), while the smallest were induced by T0 (1.6 %) and T7 (1.7%). The other treatments caused flowering with intermediate rates.

With respect to the mortality of young cocoa trees, the treatments carried out had no significant effect at 6, 12 and 18 months after planting. The rates evaluated were respectively equal on average to 7.4%, 9.6% and 10.4%.

Table 6. Mortality rate as a function of time after planting and flowering of cocoa trees under different fertilizer treatments

Treatments	Mortality rate (%)			Flowering rate (%)
	6 months	12 months	18 months	18 months
T0	10.0 ± 3.0 a	12.3 ± 3.8 a	21.3 ± 4.0 a	1.6 ± 1.2 c
T1	11.3 ± 2.0 a	11.3 ± 2.3 a	13.6 ± 2.4 a	5.0 ± 2.0 b
T2	6.3 ± 2.0 a	8.0 ± 2.4 a	11.3 ± 3.0 a	13.3 ± 3.0 ab
T3	6.6 ± 2.0 a	6.6 ± 2.0 a	8.3 ± 2.2 a	20.0 ± 4.0 a
T4	7.6 ± 3.0 a	7.6 ± 3.0 a	7.6 ± 3.0 a	11.7 ± 3.2 ab
T5	10.0 ± 3.0 a	10.0 ± 3.0 a	11.6 ± 3.5 a	5.0 ± 2.0 b
T6	10.6 ± 1.0 a	13.9 ± 1.8 a	15.6 ± 3.0 a	6.7 ± 2.0 b
T7	8.3 ± 3.0 a	10.0 ± 2.0 a	11.6 ± 3.0 a	1.7 ± 1.0 c
T8	5.0 ± 2.0 a	5.0 ± 2.0 a	6.6 ± 3.0 a	6.7 ± 2.0 b
T9	13.3 ± 3.0 a	15.0 ± 4.2 a	16.6 ± 4.0 a	10.0 ± 3.0 ab
T10	10.0 ± 3.0 a	10.0 ± 3.0 a	10.0 ± 3.0 a	11.7 ± 3.0 ab
T11	5.0 ± 2.0 a	5.0 ± 2.0 a	5.0 ± 2.0 a	18.3 ± 4.0 a
Mean	7.4	9.6	10.4	9.3
C.V. (%)	45.1	18.7	20.5	19.7
Probability	0.27	0.18	0.22	0.00

In a column, the means followed by the same letter are statistically identical at the 5 p.c. threshold. (Student-Newman-Keuls); C.V = coefficient of variation; T0 (Controls without fertilizer); T1 (Compost 2 kg); T2 (Phospho-compost 1 kg); T3 (TSP 75 g + compost 2 kg); T4 (TSP 100 g + compost 2 kg); T5 (NPK 0-15-15 225 g + compost 2 kg); T6 (NPK 0-15-15 300 g + compost 2 kg); T7 (NPK 0-15-15 225 g); T8 (NPK 0-15-15 150 g); T9 (NPK 0-15-15 300 g); T10 (NPK 0-15-15 225 g + phospho-compost 1 kg); T11 (NPK 0-15-15 300 g + phospho-compost 1 kg)

3.5 Correlations Between The Variables Studied And Prioritization Of Fertilizer Treatments

Strong relationships between the studied parameters in young cocoa trees are observed through the Pearson correlation coefficient matrix **(Table VII).**

Thus, significant positive correlations between the diameter at the collar and stem height (0.9), flowering (0.8) and then crowning (0.7) were found. Positive correlations were also observed between height and crowning (0.8) and then flowering (0.7). However, negative correlations were also noted between mortality and growth or flowering parameters. The most significant one was the one observed with crown diameter (-0.8).

Furthermore, the hierarchical ascending classification (HAC) represented in **Figure 2** shows three main groups of fertilizer treatments. The first group, composed only of the control without fertilizer T0, is characterized by weak and late growth, as well as low flowering. The second group is made up of treatments T2, T3 and T11, with strong growth and flowering. The third group, intermediate between the first and the second, is composed of treatments T1, T4, T5, T6; T7, T8, T9 and T10.

Table 7. Correlation between growth, flowering and mortality variables of cocoa trees after fertilization

Variables	Diameter at the collar	Height	Coronation	Flowering	Mortality
Diameter at the collar	**1**				
Height	**0.9**	**1**			
Coronation	**0.7**	**0.8**	**1**		
Flowering	**0.8**	**0.7**	0.5	**1**	
Mortality	**-0.8**	-0.5	-0.5	-0.6	**1**

Values in bold are different from 0 at significance level alpha=0.05

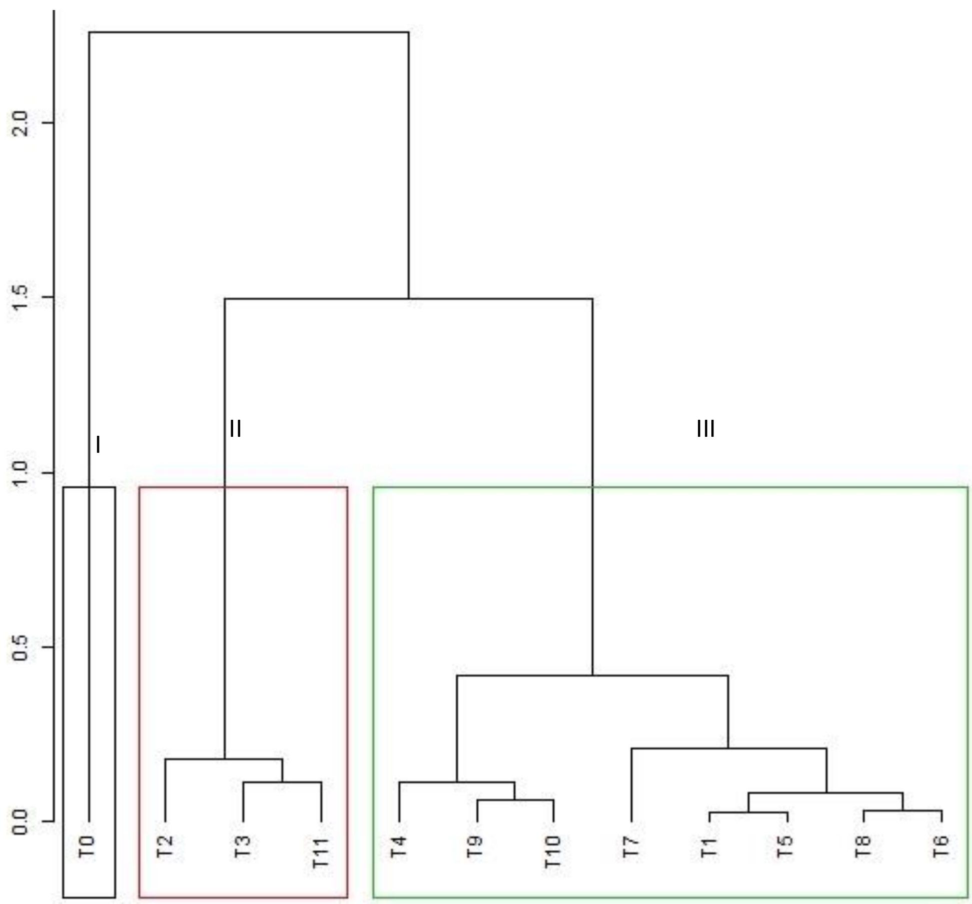

Fig. 2. Classification of fertilizer treatments into homogeneous groups according to the parameters studied

4 DISCUSSION

4.1 INITIAL SOIL FERTILITY

Initially in the soil of the experimental site, the levels of macro-nutrients important for cocoa cultivation (assimilable P, Ca, Mg, N and C) were low and the fertility indicators were generally below the recommended thresholds. The poor soil condition of the plot, which is slightly sloped, could be attributed to nutrient leaching, among other reasons. However, the abundant presence of trace elements (B, Cu and Zn) appears to be due to the leaf fall of *Pueraria phaseoloides* and *Panicum maximum,* species that have colonized the site [26].

4.2 EFFECTS OF FERTILIZER TREATMENTS ON AGROMORPHOLOGICAL PARAMETERS OF THE COCOA TREE AND POTENTIALLY ON SOIL FERTILITY

The study conducted to improve the establishment of cocoa plants in the field by fertilizing the relatively poor soil of young fallows, identified treatments T2, T3 and T11 as the most likely to contribute to this. The T2 treatment, made of phospho-compost only, the T11

treatment, which was derived from T2 with the addition of NPK based on natural phosphates, and the T3 treatment, which was made of simple compost supplemented with triple superphosphate, produced the best results overall. They caused a strong stem growth in height and thickness, a good crowning and an abundant first flowering. The results showed that during the first months after planting the cocoa trees, there was no significant effect of fertilizers on height growth. This period could correspond to the delay in the active formation of root absorbing hairs under the effect of auxins, for an efficient absorption of water and nutrients from the soil [27], [28], [29]. Phosphorus and nitrogen are known to stimulate the synthesis of phytohormone necessary for rhizogenesis; this is thought to have resulted in rapid recovery of cocoa trees after planting [30], [31].

With crowning, the monthly increase in height of the main stem slowed down following the decline of the stem meristem in favor of its thickening favored by T2 and T3 in particular.

Comparing these two treatments, the rapidity of the effect observed with T3 would be due to the solubility, and thus the availability of TSP [32]. However, for T2, a prior mineralization of the phospho-compost would be necessary. Furthermore, the abundance of the first flowering, which characterized treatments T3, T11 and incidentally T2, would depend on the bioavailability of phosphorus, as pointed out by [33]. Treatments consisting solely of compost (T1) and NPK based on rock phosphates alone or with added compost or phospho-compost (T5 to T10) did not produce the expected results. This suggests, in the latter cases, the inefficiency of natural phosphates in organo-mineral fertilization. The increase in soil pH towards neutrality or alkalinity due to the added organic matter and the liming effect of their calcium richness, would make rock phosphates ineffective [34], [35]. Conversely, composted, natural phosphates would acquire along with the organic matter, their effectiveness by the bioavailability of minerals such as phosphorus and calcium as suggested by [36], [37], [38]. Moreover, the good performance of treatments T2 and T3 could be linked to the favorable effect of mineral fertilizer on microorganisms. This would accelerate the mineralization of organic matter by making nutrients available, according to [39], [40].

Mortality of transplanted seedlings in the field after their transfer from the nursery appears to be independent of soil fertility status. Indeed, fertilizer treatments had no significant effect on the mortality rate of cocoa trees in the field. Too strong a variation in temperature, light or water deficit could have caused stress in the plants to which they would have had difficulty adapting.

5 Conclusion

In a nutshell, this study conducted to contribute to the sustainability and productivity of cocoa production, three types of fertilizers were identified that allow for better plant establishment on soils that are relatively low in fertility, especially in phosphorus. These are treatments T2, T3 and T11. They caused a good juvenile growth and an abundant first flowering compared to the other treatments. Of these, the application of T11 would be unnecessarily more expensive, as the NPK added to the phospho-compost does not induce a very significant improvement in results.

References

[1] FAOSTAT, Cocoa Bean Production Statistics in Ivory Coast. 2019.
[Online] Available: http://www.fao.org/faostat/fr/data/QC. (june 05 2019).

[2] J. Gockowski and D.J. Sonwa, «Cocoa Intensification Scenarios and Their Predicted Impact on CO2 emissions, Biodiversity Conservation, and Rural Livelihoods in the Guinea Rain Forest of West Africa,» *Environmental Management,* vol. 8, no. 2, pp. 307-321, 2010.

[3] A.A. Assiri, A. Konan, K.F. N'Guessan, B.I. Kébé, K.E.Kassin, J.Y. Couloud, AR.Yapo, G.R Yoro. and A.Yao-Kouamé, «Comparison of two cocoa replanting techniques on non-forestry crop history in Côte d'Ivoire,» *African Crop Science Journal,* vol. 23, no. 4, pp 365 – 378, 2015.

[4] Z. Konaté, A.A. Assiri, F.G. Messoum, A. Sekou, M. Camara and A. Yao-Kouamé.

[5] «Cultural history and identification of some farmer practices in cocoa replanting in Côte d'Ivoire,» *African Agronomy,* vol. 27 no. 3 pp 301-3014, 2015.

[6] K.J-C. N'Guessan, O.F. Akotto, D. Snoeck, M. Camara and A. Yao - Kouamé., «Chemical fertility potential of cocoa orchards *Theobroma cacao* L. (Malvaceae) in Côte d'Ivoire,» *International Journal of Innovation and Applied Studies,* vol. 18, no. 3, pp 868-879, 2016.

[7] E.C.G. Eponon,. «Contribution to the formulation of mineral manure rates adapted to coffee (*Coffea canephora* Pierre ex A. Froehner) in Côte d'Ivoire,» PhD thesis from the University of Félix Houphouët-Boigny, Cocody, Ivory Coast, 161 p., 2020.

[8] V.T. Ouattara, Z. Konate, D.F. Messoum, K.E. Kassin, M.G. Tahi, L.A. Koko, B. Kone, E.A. Dick, and M. Camara, «Effects of organophosphate fertilization on organic matter and adsorbent complex fertility of a ferralsol under cocoa trees in the Divo region (Ivory Coast),» *International Journal of Biological and Chemical Sciences,* vol. 12, no. 6, pp 2901- 2921, 2018.

[9] C. Nobile, «Phyto-availability of phosphorus in agricultural soils of Reunion Island fertilized with organic residues over the long term: is the application rate the only determinant to be taken into account?,» PhD thesis from the University of La Réunion, Réunion, France, 181p, 2017.

[10] T.V. Ouattara, K.E. Kassin, L.J. Koko, G.M. Tahi, M.E. Assi, G. Amari, E. Dick and M. Camara, «Effects of organophosphate fertilization on phosphorus bioavailability, aluminum content and pH of soils under cocoa trees in the Divo region of Côte d'Ivoire,».

[11] Journal of Applied Biosciences, vol. 118, pp 11754-11767, 2017.

[12] K. Ofori-Frimpong, A.A. Afrifa, and M.R. Appiah, «Effect of Nitrogen rates and Frequency of application on cocoa yield, soil, mineral composition of cocoa leaves,» *In:* 14Th International Conference on Cocoa Research, Yamoussoukro, Côte d'Ivoire, pp 239–245, 2003.

[13] L.K. Koko, K.E. Kassin, A.A. Assiri, G. Yoro, K. NGoran and D. Snoeck. «Mineral fertilization of cocoa (*Theobroma cacao* L.) in Côte d'Ivoire: popularizable achievements and research perspectives,» *Agronomie Africaine,* vo. 23, no. 3, pp 217-225, 2011.

[14] Yara, Crop nutrition: cocoa, 2021. [Online] Available:.https://www.yara.ci/fertilization/fertilization/cocoa/ (August 05 2021).

[15] L.K. Koko, «Teractiv Cacao as a new fertilizer based Reactive Phosphate Rock for cocoa productivity in Côte d'Ivoire: A participatory approach to update fertilization recommendation,» *Procedia Engineering,* vol. 83, no. 2014, pp 348-353, 2014.

[16] F. Zapata and R.N. Roy, Use of rock phosphates for sustainable agriculture, FAO.

[17] Bulletin, Fertilizer and Plant Nutrition, 151 p, 2004.

[18] K.A. Ablede, K. Koudjega and K.K. Ganyo, «Improved solubilization of low reactivity rock phosphates by manure-based phospho-composting,» *Bulletin de la Recherche Agronomique du Bénin (BRAB),* Special issue, pp 175-181, 2019.

[19] K.E. Kassin, K. Doffangui, B. Kouamé, G. Yoro and A. Assa, «Rainfall variability and prospects for cocoa replanting in west-central Côte d'Ivoire,» *Journal of Applied Biosciences,* vol 12, pp 633-641, 2008.

[20] B.I. Kébé, K.F. N'Guessan, G.M. Tahi, A.A. Assiri, L.K. Koko, N.J. Kohi, Z. Irié Bi and N. Koffi, «Growing cocoa well in Côte d'Ivoire,» CTA, Direction des programmes de recherche et de l'appui au développement, Direction des Innovations et systèmes d'information, CNRA, Abidjan, Côte d'Ivoire, 4 p 2009.

[21] A Walkley and C.A. Black, «An examination of the Degtjareff method for determining soil organic matter and a proposal modification of chromic acid situation method,» Journal of Soil Science, vol 37, no 1, pp 29-38, 1934.

[22] J. Kjeldahl, «Neue Methode zur Bestimmung des Stickstoffs in organischen Körpern,».

[23] Zeitschrift für Analytische Chemie, Vol 22, pp 66-382, 1883.

[24] B. Dabin, «On a method of analysis of phosphorus in tropical soils,» Colloque sur la fertilité des sols tropicaux, 19-25 November, Tananarive, Madagascar, vol 1, pp 99-115, 1967.

[25] H. Ciesielski and T. Sterckeman, «A comparison between three methods for the determination of cation exchange capacity and exchangeable soils,» *Agronomy,* vol 17, no 1 pp 9-16, 1997.

[26] B.W. Bache and G.S. Sharp, «Caracterisation of aluminium in acid soils,» *Geoderma* vol 15, no 2, pp 91-101, 1976.

[27] AFNOR. (Association Française de Normalisation), «Determination of pH,» iso 103.

[28] *In:* Afnor Qualité des Sols, Paris, France, p 339-348, 1981.

[29] CEAEQ (Centre d'Expertise en Analyse Environnementale du Québec), «Determination of metals, trace elements, phosphorus and sulphur by Mehlich-III extraction, hot water boron extraction and argon plasma emission spectrometry,» Ministère de l'Environnement du Québec, 19 p, 2003.

[30] D. Snoeck, L. Koko, J. Joffre, P. Bastide and P. Jagoret, «Cacao Nutrition and Fertilisation,» *Sustainable Agriculture,* vol 19, pp 155-202, 2016.

[31] A. Comeau, D. Pageau, H. Voldeng, and A. Brunelle, «Trace elements: Essential for canopy establishment in cereals,» *Field Crops,* vol 16 no 4, pp 34-36, 2006.

[32] A Bruce, S.E. Smith and M. Tester, «The development of mycorrhizal infection in *Cuncumber*: effects of P supply on root growth, formation of entry points and growth of infection units,». *New Phytologist,* vol 127, no 3, pp 507-514, 1994.

[33] M.A. Hajabbasi and T.E. Schumacher, «Phosphorus effects on root growth and development in two maize genotypes,» *Plant and Soil,* vol 158, no 1, pp 39-46, 1994.

[34] C.A. Rosolem, J.S. Assis and A.D. Santiago, «Root growth and mineral nutrition of corn hybrids as affected by phosphorus and lime,» Communications *in: Soil Science and Plant Analysis,* vol 25 no 13-14, pp 2491-2499, 1994.

[35] M. Laskowski, «Lateral root initiation is a probabilistic event whose frequency is set by fluctuating levels of auxin response,» *Journal of Experimental Botany,* vol 64, no 9, pp 2609-2617, 2013.

[36] V. Herrbach, C. Rembliere, C. Gough and S. Bensmihen, «Lateral root formation and patterning in Medicago truncatula,» *Journal of Plant Physiology,* vol 171, no 3-4, pp 301-10, 2014.

[37] B.A. Kouyate and I. Serme, «Evaluation of the effectiveness of Tilemsi phosphate rock (TNP) under different tillage practices in the Sahelian zone of Mali,» *International Journal of Innovation and Applied Studies,* vol 34 no 4, pp 845-857, 2021.

[38] L.K. Koko, T.V. Ouattara, C. Morel and D. Snoeck, «Fruiting and production precocity in cocoa: nutritional factors related to bioavailability and net P ion transfer dynamics in Côte d'Ivoire soils,» 17th International Conference on Cocoa Research, Yaoundé, Cameroon, October 15-20, 2012.

[39] A.J. Messiga, N. Ziadi, A. Mollier, L.E. Parent, A. Schneider and C. Morel, «Process based mass balance modeling of soil phosphorus availability: Testing different scenarios in a long-term maize monoculture,». *Geoderma,* vol 243-244, pp 41-49, 2015.

[40] H. Li, A. Mollier, N. Ziadi, A.J. Messiga, Y. Shi, S. Pellerin, L-E. Parent and C. Morel, «Long-term modeling of phosphorus spatial distribution in the no-tilled soil profile,». *Soil & Tillage Research,* vol 187, no 2019, pp 119-134, 2019.

[41] A.K. Kpomblekou and M.A. Tabatabaï, «Effect of organic acids on release of phosphorus from phosphate rocks,» *Journal of Soil Science,* vol 158, pp 442-453, 1994.

[42] L. Yang, S. Zhang, Z. Chen, Q. Wen and Y. Wang, «Maturity and security assessment of pilot-scale aerobic co-composting of penicillin fermentation dregs (PFDs) with sewage sludge,». *Bioresource Technology,* 204: 185-191, 2016.

[43] A Ndiaye, O. Ndiaye, B. Bamba, M. Guèye and O. Sawané, «Effects of organo-mineral fertilization on growth and yield of sanio millet (*Pennisetum glaucum* L.R.Br) in Upper Casamance, Senegal,». *European Scientific Journal,* vol 15, no 33 pp 155-170, 2019.

[44] K.H. Kouadio, A.J.A. Kotaix, Z. Konaté, K.E. Kassin, K.S. Kouakou, J.N. Ehounou, E.M. Assi, K.N. N'dri, L. Koko and S. Bakayoko, «Mineral Fertilizers from Soil Diagnosis Reduce the Decomposition Time of Cocoa Leaf Litter in the South-Western of Cote d'ivoire,». *Journal of Experimental Agriculuture International,* 43 (5): 84-95, 2021.