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Mixture Effect of Rock Phosphate and Triple Superphosphate on Maize Yield in Acid Soils of Côte d'Ivoire

Akissibah Leticia Kouassi [a,b*], Djétchi Jean Baptiste Ettien [a,b] and Oi Bouadou Félix Bouadou [a,b]

[a] *University Felix Houphouët-Boigny, 01 BP 34 Abidjan 01, Côte d'Ivoire.*
[b] *Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS), 01 BP 1303 Abidjan 01, Côte d'Ivoire.*

Authors' contributions

This work was carried out in collaboration among all authors. Author ALK wrote the first draft of the manuscript and managed the literature searches. Author DJBE designed the study and wrote the protocol. Authors Oi BFB performed the statistical analysis and managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Determine the optimum rock phosphate (RP) / Triple superphosphate (TSP) ratio for improved maize yield
Study Design: The experimental design was of random blocks with 3 replications.
Place and Duration of Study: The study was carried out in central Cote d'Ivoire, in a savannah area over 3 consecutive years 2019, 2020 and 2021.

**Corresponding author: E-mail: leticiaakouassi@gmail.com, leticlever01@gmail.com;*

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Methodology: Eight treatments were tested: control T0, T0r (100 Kg urea ha^{-1} + 200 Kg NPK ha^{-1}), T1 (300 Kg RP ha^{-1}), T2 (270Kg RP ha^{-1} + 19,6 Kg TSP ha^{-1}), T3 (240 Kg RP + 39,2 Kg TSP ha^{-1}), T4 (180 Kg RP ha^{-1} + 78,4 Kg TSP ha^{-1}), T5 (60 Kg RP ha^{-1} + 156,8 Kg TSP ha^{-1}), T6 (196 Kg TSP ha^{-1}). For maintenance, 200 Kg NPK ha^{-1} and 100 Kg urea ha^{-1} were added to all treatments except control. After harvest, yields were calculated, pH levels were measured at the beginning, after three months and at the end of the trial.
Results: the effect of the RP/TSP combination was effective in the second year. Ratio T3 obtained the best yield (5.71 t ha^{-1}) and was more efficient than the treatment used for maize extension in Côte d'Ivoire (T0r). At the same time, the soil pH has become neutral, contributing to an improvement in soil fertility due to the gradual bioavailability of phosphorus from the solubilized phosphate rock.
Conclusion: Mixing RP and TSP in proportions of T3 (240 Kg RP + 39,2 Kg TSP ha^{-1}) is effective in improving maize yields.

Keywords: Acid; Cote d'Ivoire; maize; yield; rock phosphate; soil; triple superphosphate.

1. INTRODUCTION

Phosphorus is an essential nutrient for plant growth [1]. However, its deficiency and bioavailable fraction is a major constraint to crop production [2]. This is the case for most tropical soils, in particular those from Cote d'Ivoire [3].

To improve crop productivity, phosphorus inputs need to be carefully managed to increase yields while maintaining plant availability [4]. Synthetic phosphate fertilizers have proved effective in increasing the productivity. However, they are expensive for smallholders and can be harmful to the environment if their use is not regulated [2].

In a global context of high climatic variability leading to soil degradation with loss of fertility due to leaching of organic matter and phosphorus in particular, it is essential to preserve bioavailable phosphorus for plants sustainably. This requires the search for reliable alternatives to cover phosphorus deficiencies and improve its availability in soils in order to increase crop yields. Numerous studies exploring other solutions to phosphorus deficiency in tropical soils have shown that applying rock phosphate alone or with triple superphosphate to soils could be an alternative solution for restoring soil fertility. This is the case of studies conducted in Burkina Faso [5], Mali [4], Ghana [1] and Nigeria [6] on the agronomic efficiency of rock phosphates in acid soils, with rock phosphate amendment combined with soluble phosphate fertilizers or organic matter. Indeed, these researches have shown that applying rock phosphate in combination with water-soluble phosphates such as triple superphosphate (TSP) and single superphosphate (SSP) can increase the effectiveness of the rock phosphate applied [1,4,5]. Thus, the aim of this study was to determine the optimum RP / TSP ratio for best maize yield and the gradual solubilization of the rock in soil through soil pH.

2. MATERIALS AND METHODS

2.1 Study Site

The field experiment was conducted in Bringakro in central Cote d'Ivoire at the research station of Centre Suisse de Recherches Scientifiques en Côte d'Ivoire (CSRS) [2° 26'55'' N and 4° 53'16'' W] (Fig. 1.). The map of the area was generated by using ArcGIS software. The area is distinguished by a transitional equatorial climate, situated at the boundary between a humid semi-deciduous forest and a shrub savannah. Rainfall distribution follows a bimodal pattern, with two rainy seasons occurring from May to June and from September to October, separated by a brief dry season. the period between April and November is marked by a long dry season. The soil at the experimental site was categorized as ferralsol [7].

2.2 Plant Material

The maize variety (*Zea mays* L.) used is PR9131-SR, orange-yellow in color, with a 90-day cycle and an average yield of 3t/ha.

2.3 Fertilizers

Four types of fertilizers were used:

- Moroccan rock phosphate, moderately reactive with 30 % P_2O_5 (Table 1);
- Triple superphosphate (46 % P_2O_5)
- NPK (15-15-15);
- Urea (46 % N)

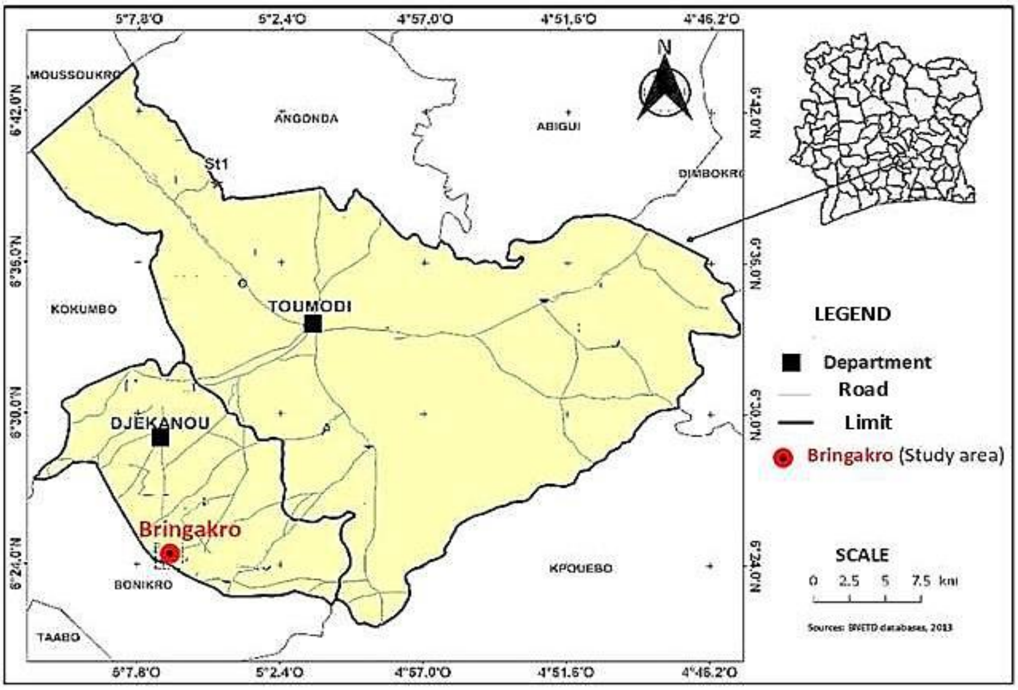

Fig. 1. Map of the study area

Table 1. Chemical composition of moroccan rock phosphate

Chemical elements	Contents (%)
BPL*	60
P_2O_5	30
CO_2	7.8
SO_3	1.68
SiO_2	8
CaO	49.93
MgO	1.46
Fe_2O_3	0.2
Al_2O_3	0.41

**Bone Phosphate Lime = P_2O_5* × 2.1853

2.4 Setting up the Experimental Design

The trial was carried out at the station over 3 consecutive years (2019, 2020 and 2021) with one cycle per year.

The randomized complete block design with three replications was implemented after the site had been manually cleaned. The trial initially comprised 7 microplots, which were extended to 8 in the second year with T0r, a fertilizer widely used on maize in Cote d'Ivoire. The microplots covered an area of 16 m² and consisted of 5 rows of seedlings spaced 0.8 metres apart. Each seeding line comprised 12 seed holes spaced 0.4 m apart (Fig. 2.) Once the experimental set-up had been installed, doses of 300 Kg. ha-1 of rock phosphate (RP) and 196 Kg. ha-1 of triple superphosphate (TSP) were applied to the top 20 cm of soil on the seed rows before sowing.

Twenty days after sowing, 200 kg. ha^{-1} of NPK and 100 kg. ha^{-1} of urea were applied between the plants in the first 20 cm of soil. These doses of NPK and urea were applied to each cycle (Table 3).

The depth of application of the treatments to the soil was 0 - 10 cm. NPK and urea were applied 20 days after sowing. When the maize reached physiological maturity (115 days after sowing), The cobs from each treatment were harvested from a yield square of 0.000192 ha, then dehulled and dried (Fig. 2.). The grains were dried at room temperature for 21 days until they reached an almost constant weight and a moisture content of 14%.

Table 2. Doses of TSP, RP, NPK fertilizer and urea

Trts	RP (kg. ha-1)	TSP (kg. ha-1)	NPK (kg. ha-1)	Urea (kg. ha-1)	Quantities of phosphorus applied (kg. ha-1)				
					P_2O_5	P_{RP}	P_{TSP}	P_{NPK}	P
T0	0	0	0	0		0	0	0	0
T0r	0	0	200	100	30	0	0	13,2	13,2
T1	300	0	200	100	120	39,6	0	13,2	52,8
T2	270	19,6	200	100	120	35,6	4	13,2	52,8
T3	240	39,2	200	100	120	31,7	8	13,2	52,8
T4	180	78,4	200	100	120	23,8	15,8	13,2	52,8
T5	60	156,8	200	100	120	8	31,7	13,2	52,8
T6	0	196	200	100	120	0	39,6	13,2	52,8

Trts: Treatments; P_{RP}: phosphorus from rock phosphate; P_{TSP}: phosphorus from superphosphate triple; P_{NPK}: phosphorus from NPK fertilizer; P: P from all phosphorus inputs

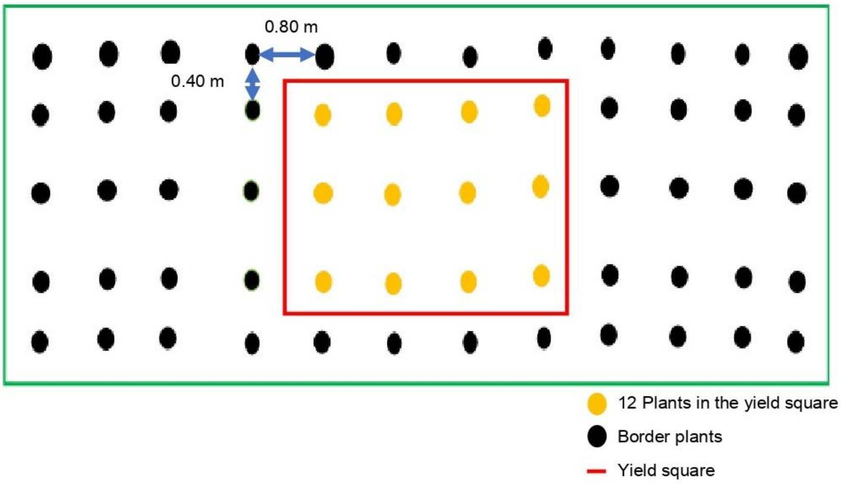

Fig. 2. Diagram of the yield square for a microplot

2.5 Parameters Measured

2.5.1 Grain yield

After drying, grains from each treatment were weighed. Grain yields were calculated from the weight obtained according to the formula:

Yield (t. ha^{-1}) = (weight of dried grains / yield square) × 10^{-2}

2.5.2 Relative agronomic effectiveness (RAE)

The relative agronomic efficiency (RAE) was calculated by was calculated by modifying the authors' formula [8].

Using yields instead of nutrient exports P: RAE = [(RDG_x-RDG_{0r}) / RDGx] x 100 [2]

RDGx represents RDG of a treatment at "Dose x" with x = T1, T2, T3, T4; T5 and T6; RDG_{0r} is the RDG of the reference control (T0r).

2.5.3 Plant height

At harvest, plant height was measured from the base of the crown to the last node using a measuring tape.

2.5.4 Soil pH

Soil pH was measured at the start, after 3 months and at the end of the experiment for each treatment using a pH meter. The depth of pH measurement was 0-10 cm in soil.

2.6 Statistical Analysis

Statistical models were developed using the lm function from the agricolae package in R software version 4.3.3 (R Core Team, 2024), with its interface RStudio (Posit Team, 2023). Data are presented as means unless otherwise indicated. Homogeneity of variances (Bartlett's test) and normality of residuals (Shapiro-Wilk test) were verified for maize grain yield. When the assumptions of normality were met, one-way analysis of variance (ANOVA) and the least significant difference (LSD) test were employed to assess differences between the various treatment response groups at each sampling point for $P < 0.05$.

3. RESULTS

3.1 Initial Soil Nutrient Content

The soil at the study site is weakly acidic (pH=5.8) with a sandy texture. The soil has low organic matter, total nitrogen, total phosphorus and CEC values. Exchangeable bases, saturation rate and C/N ratio have average levels. These chemical parameters are within the range of normative values. As for the assimilable phosphorus content of the soil is high (Table 3).

3.2 Maize Grain Yield and Relative Agronomic Effectiveness at 115 days after Sowing

In 2019, the analysis of variance (ANOVA) carried out to compare the yields of treatments T1, T2, T3, T4, T5 and T6 compared to the control (T0) and the recommended rate (T0r) revealed that there is no significant difference between treatments. However, in 2020, there is a significant difference between treatments ($P < 0.001$). Treatment T3, with an average yield of

5.71 t. ha^{-1}, was significantly different from and higher than all the other treatments. The yields obtained with treatments T0r (4.51 t. ha^{-1}), T5 (4.45 t. ha^{-1}), T6 (4.34 t. ha^{-1}), T1 (3.93 t. ha^{-1}) and T4 (3.89 t. ha^{-1}) did not differ from each other, but were all significantly higher than the control (T0) and treatment T2. Treatment T2 obtained a higher yield (2.41 t ha^{-1}) than the control (T0).

In 2021, no significant differences were observed between treatments. The type of treatment did not affect yields (Table 4).

In 2020, in terms of RAE compared with the reference control T0r, T3 had the highest value (21.0%), with the other treatments obtaining negative values.

3.3 Maize Plant Height at 115 days after Sowing

Treatment type significantly influenced plant height in the first two years of cultivation (2019 and 2020). The tallest plants were observed with treatments T6 (208.11 cm), followed by T3 (206.56 cm) and T5 (190. 69 cm), in 2019. In 2020, maize plant heights were recorded with treatments T3 (199.73 cm), T6 (183.33 cm) and T4 (179.64 cm). In contrast, in 2021, maize plant height was not significantly influenced by treatment type (Table 5).

3.4 Soil pH at three Months after Sowing and at the end of Trial

Soil pH type (initial pH, pH after three months of the experiment and soil pH at the end of the experiment) showed that there were significant differences between soil pH types ($P < 0.001$).

An analysis of soil pH revealed a significant decrease in the initial group (5.52 ± 0.393) compared with the group observed after 3 months (6.21 ± 0.477). On the other hand, a significant increase was observed in the final pH group (6.68 ± 0.503) compared with that observed after 3 months and with the initial pH (Fig. 4.).

Table 3. Initial soil (0-10cm) characteristics of the experimental site

Characteristic	**Values**	***Threshold values ****
pH H_2O	5.8	5 - 6
pH KCl	4.5	4 - 5
C ($g.kg^{-1}$)	10	12.6 - 25
N ($g.kg^{-1}$)	0.707	1.2 - 2.2
OM	1.7	3.6 – 6.5
P ($g.kg^{-1}$)	0.11	0.20 - 0.23
P_{Olsen} ($mg.kg^{-1}$)	12.5	3 - 8
Ca^{++} ($Cmol.kg^{-1}$)	3.06	5 - 8
Mg^{++}($Cmol.kg^{-1}$)	1.53	1.5 - 3.0
K^{+} ($Cmol.kg^{-1}$)	0.2	0.15 - 0.25
Na^{+} ($Cmol.kg^{-1}$)	0.5	0.3 - 0.7
Al^{++} ($Cmol.kg^{-1}$)	0.22	-
Ca^{++} : Mg^{++}	2	2 - 9
K^{+} : Mg^{++}	1 :3	0.05 - 0.1
CEC)($Cmol.kg^{-1}$)	7.6	10≤ CEC ≤20
Al^{++} : CEC (%)	5	
V(%)	80	60 ≤ V < 90
C/N	14	11 – 15
Clay (%)	12.75	-
Slit (%)	3.5	-
Sand (%)	83.75	-
Texture	Sandy	-

*N: total nitrogen; P: total phosphorus; P_{Olsen} : available phosphorus ; Ca^{++} : exchangeable Calcium ;Mg^{++} : exchangeable Magnesium ;K^{+}: exchangeable potassium ; Na^{+} : Exchangeable Sodium; Al^{++} :exchange Aluminium ; CEC : Cation Exchange Capacity; V : Bases saturation ;OM : Oragnic matter *Reference threshold values ([9]; [10]; [11]; [12])*

Table 4. Grain yield (t/ha) of maize

Treatments	2019	2020	2021
T0	3,48a	1.37d	4.46a
T0r	-	4.51b	4.90a
T1	2,53a	3.93b	4.54a
T2	3,56a	2.41c	5.15a
T3	4,85a	5.71a	5.37a
T4	3,68a	3.89b	4.22a
T5	3,02a	4.45b	5.39a
T6	4,33a	4.34b	4.36a
P	$0,32^{ns}$	< 0.01***	0.29^{ns}

*P:probability associated with the ANOVA test. Treatments with the same letter are not significantly different. *P < 0.05; **P < 0.01;*** P < 0.001; ns = not significant.*

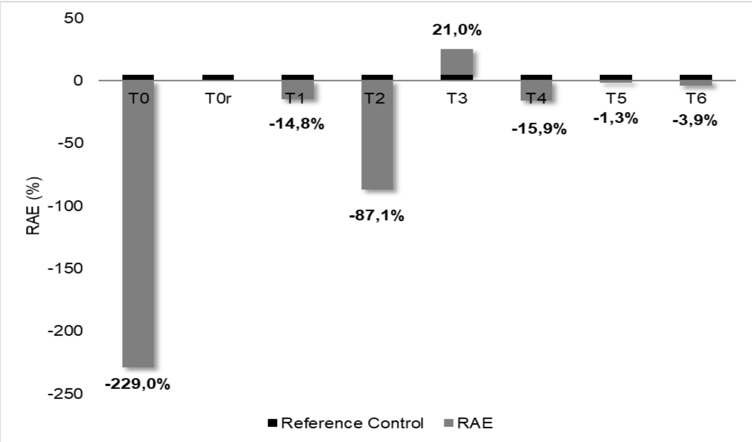

Fig. 3. Relative agronomic efficiency compared to the reference control in 2020

Table 5. Height (cm) of maize plants

Treatments	2019	2020	2021
T0	157.42a	156.98a	138.93a
T0r	-	166.66ab	131.93a
T1	171.00ab	169.28ab	127.88a
T2	181,750bc	179.77bc	134.50a
T3	206.57c	199.732d	133.61a
T4	189.33c	179.64bc	125.57a
T5	190.69c	176.76bc	137.46a
T6	208.11c	183.33c	131.03a
Average	186.76	177.01	132.96
P	< 0.001	< 0.001	0.30^{ns}

P: probability associated with the ANOVA test. Treatments with the same letter are not significantly different. ns: not significanrt

4. DISCUSSION

The soil studied is sandy. this type of soil is characterized by less than 18 % clay and more than 68 % sand in the first 100 cm of the solum and a low water retention capacity [13]. The silt/clay ratio is 0.27, suggesting that the soil is relatively young. Indeed, old or heavily leached soils have a silt/clay ratio of less than 0.15 [14]. Most of the chemical parameters have mediocre to average levels, which shows that the soil is of the moderately desaturated ferrallitic type [15]. The low cation exchange capacity and average saturation rate indicate that the soil is poorly to moderately supplied with exchangeable bases and mineral reserves [16]. These results are similar to those obtained in the author's work [17]. This author showed that the soil in the study area had low CEC values. Chemical analysis shows a low fertility state of the soil.

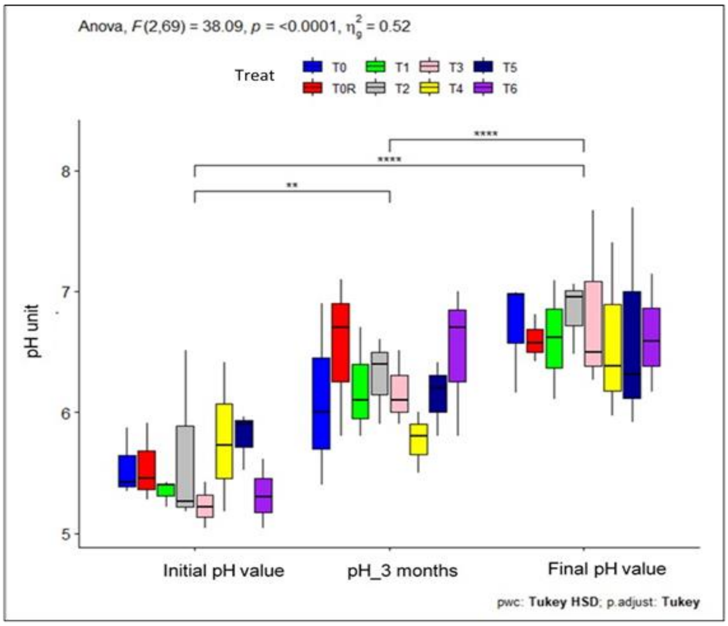

Fig. 4. Soil pH values at the start, after 3 months and at the end of the experiment (115 days after sowing)

4.1 Effect of Treatments on Maize Grain Yield and Relative Agronomic Effectiveness

It would appear that the RP/TSP combination had no effect on maize yields in the first year. The lack of response from maize is attributable to the high level of P in the soil (12.5 mg P kg^{-1}). However, this level is well below the critical level of P available to maize, which is 30 mg kg-1[18]. TSP et NPK, which are soluble fertilizers, would have helped to supply the maize's P requirements. Indeed, its high solubility of TSP helps the availability of P as soon as it is applied [19]. These results differ from those of the authors [20], who obtained a response from rice from the first year of cultivation. This difference is attributable to the P content in the soils studied, the species cultivated, the rock phosphate tested and the application rates.

In contrast to the first year of cultivation, in the second year, the RP/TSP combination affected maize yields. Treatment T3 obtained the best yield, followed by the T1, T4, T5, T6 and T0r groups, followed by T2 and finally T0. These results are similar to those of the author [2]. This could be because phosphorus release from rock P is slow and hence for annual crops it is the second or third crop which is likely to benefit most [18]. Indeed, natural phosphates have a certain agronomic efficiency, which is slow but increases over time [21]. Furthermore, organic matter deriving from the decomposition of crop residues helps to dissolve RP. Unlike TSP, the release of P from the RP occurs gradually over time. This attests to the reactivity of RP [22] and above all its residual character [19]. The dissolution of rock phosphate depends on several factors such as its reactivity, soil characteristics, climatic conditions and the crop species [23].

Although the same rate of P was applied to all treatments (52.8 kg P ha-1), with the exception of the reference and control, the effect on yields was different. It was expected that the efficacy of the RP/TSP combination would increase in proportion to the amount of water-soluble P in the mixture [24]. Thus, our results differ from those of the authors [24], who state that the phosphorus availability of RP is affected by the proportions of mixtures with water-soluble P, but not by P rates.

This could be due to the critical value of P from TSP (8 kg P ha-1). Application above this rate results in a decrease in P use efficiency [25]. These authors obtained critical values of 13 kg P ha-1 and 26 kg P ha-1 in western Kenya. This value is very interesting because it limits high P inputs for optimum yield [26]. In addition, the authors [27] reported that any phosphorus input in excess of the amount

that can be dissolved in the soil solution is followed by adsorption of a greater or lesser fraction onto soil particles.
In the third year, it seems that the combination did not affect the grain yield of the maize. The lack of response in 2021 is attributable to the enrichment of the soil in P at the end of the experiment [16].

4.2 Effect of Treatments on Maize Plant Height

Plant height was significantly influenced by the treatments in the first two years, with the best heights recorded in treatments T3, T4, T5 and T6. The combination of TSP and RP had an effect on maize above-ground biomass growth. This effect faded in the third year. This could be explained by the fact that the maize used the available nutrients in the soil to cover its needs. In fact, the bulk of these nutrients are required during the period between flowering and ear formation, i.e. from 10 days before the appearance of the male flowers to 25 to 30 days afterwards. During this period, maize absorbs 70 to 75% of its nitrogen and 2/3 of its phosphorus and potassium requirements [28].

4.3 Effect of Treatments on Soil pH

As far as soil pH is concerned, the treatments had an influence by gradually increasing it. This increase in pH is thought to be linked to the gradual dissolution of rock phosphate. Studies have shown an increase in pH as the RP dissolves [29]. This observation could be explained by the fact that apatite is the main mineral in rock phosphates, which justifies the significant presence of CaO (50%) in the chemical composition of Moroccan rock phosphate. This apatite, of the Ca-P type, therefore has the potential capacity to supply calcium under conditions favourable to its dissolution [23].

Consequently, rock phosphate could have a liming effect on the soil by releasing calcium into the rhizosphere. The authors of the study [30] pointed out that this liming effect of rock phosphate is attributable to the consumption of H+ ions in the soil solution and the release of OH- ions during the dissolution of rock phosphate. However, this increase in pH could ultimately inhibit the dissolution of rock phosphate, as acidity plays a crucial role in this process.

5. CONCLUSION

The objective of this study was to determine the optimum ratio between rock phosphate (RP) and triple superphosphate (TSP) to improve maize yield. The results of our research showed that the most beneficial optimum ratio in terms of increasing maize yields was T3 (80% RP + 20% TSP) or (240 Kg RP ha^{-1} + 39.2 Kg TSP ha^{-1}), with effects observed from the second year of cultivation.

This ratio also had a positive impact on above-ground biomass in the first and second years of cultivation, as well as on the gradual change in soil pH, thereby improving the availability of nutrients to the plant.

Treatment T3 (240 kg RP ha^{-1} + 39.2 kg TSP ha^{-1}) could therefore be considered the most effective combination for improving maize yields in the acid soil of Côte d'Ivoire.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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