Original Research Article

Mixture effect of rock phosphate and triple superphosphate on maize yield in acid soils of Cote d'Ivoire

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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.

Methodology: Eight treatments were tested: control T0 (zero RP and zero TSP), reference control T0r (zero RP and zero TSP +100 Kg urea $ha^{-}1$ + 200 Kg NPK ha-1), T1 (100 % RP), T2 (90 % RP + 10 %TSP), T3 (80 %RP + 20 % TSP), T4 (60 % RP +40 % TSP), T5 (20 % RP +80 % TSP), T6 (100 % TSP). 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.

Results:T3 (80 % RP+ 20 %) was the most efficient with yields of 5,767 t ha-1, 5,705 t $ha^{-}1$ and 5,365 t ha-1 respectively in 2019, 2020 and 2021 and efficiency gain of 26.52 % compared with T0r.

At the same time, the soil pH rose to neutral, reflecting an improvement in soil fertility due to the gradual bioavailability of phosphorus from the solubilized phosphate rock.

Conclusion: The mixture of RP and TSP in proportions of 80 % RP+ 20 % was efficient 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 in a sustainable way. 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. 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. MATERIAL 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 RecherchesScientifiquesen Côte d'Ivoire (CSRS) [2° 26'55'' N and 4° 53'16'' W]. 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 colour, with a 90-day cycle and an average yield of 3t/ha. This variety was obtained from Agence Nationale d'Appui au Développement Rural (ANADER), the Ivorian national agency for support to rural development in the study area.

2.3. Fertilizers

Four types of fertilizers were used:

- Moroccan rock phosphate, moderately reactive with 30% P2O5 (Table 1);

- Triple superphosphate (46 % P2O5)

-NPK (15-15-15);

- urea (46 % N)

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

2.4Setting up the experimental design

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

The randomized complete block design with three replications was set up after the site had been manually cleaned. The trial initially comprised 7 microplots, which were expanded to 8 on the second year with a reference control consisting of T0r

T0r a fertilizer widely used on maize in Cote d'Ivoire.

Once the experimental set-up had been installed, the following doses of rock phosphate (RP) and triple superphosphate (TSP) (Table I) were applied to a surface area of 0.0016 ha

- Control T0 (0 RP + 0 TSP)
- Reference control T0r (0 RP + 0 TSP + 100 Kg urea ha-1 + 200 Kg NPK ha-1)
- T1: 300 Kg RP ha-1 as 100 % RP;
- T2: 270 Kg RP ha-1 +19.6 Kg TSP ha-1 as 90 % RP +10 % TSP;
- T3: 240 Kg RP ha-1 +39.2 Kg TSP ha-1 as 80% RP + 20% TSP;
- T4 :180 Kg RP ha-1 +78.4 Kg TSP ha-1 as 60 % RP + 40 % TSP;
- T5 60 Kg RP ha-1 +156.8 Kg TSP ha-1 as 20 % RP + 80 % TSP;

- T6 196 Kg TSP ha-1 as 100 % TSP.

The depth of application of the treatments to the soil was 0 - 10 cm. Maintenance fertilizing was carried out 20 days after sowing the maize with 100 Kg urea ha and 200 kg NPK ha-1 uniformly on the sowing lines of all treatments (except the T0 control) each year in each cycle.

When the maize reached physiological maturity (115 days after sowing), the cobs from each treatment were harvested from a useful plot measuring 0.000192 ha then shelled and dried. The kernels were air-dried for 21 days to a nearly constant weight with a moisture content of 14 %.

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 / surface

2.5.2 Efficiency gain

The yield gains for the different doses compared with the T0r, T1 and T6 controls were calculated using the formula: Yield gain:

G1 (%) = [Yield at Dose - Yield at T0r] / Yield at T0r] ×100

G2 (%) = [Yield at Dose - Yield at T1] / Yield at T1] × 100

G3 (%) = [Yield at Dose - Yield at T6] / Yield at T6] ×100.

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.

Statistical analysis

The mean values of grain yields and heights for the different treatments were compared to each other for each year over the three (03) years using analysis of variance (ANOVA) with XLSTAT premium V2016.02.28451 software. Means were compared using the Turkey and Fisher test at the 5 % threshold. The pH values were analyzed using R software. They are presented as the mean + / - standard deviation.

3. RESULTS AND DISCUSSION

3.1 Effect of different Treatments on maize grain yield

Table 2 shows the effect of the different treatments on maize grain yield in the 3 years (2019, 2020 and 2021).

In 2019 (first year of cultivation), yields were not significantly influenced by the treatments. In contrast to the first year, the analysis of variance of yields in the second year (2020) shows that the type of treatment significantly influenced yields (*P*< 0.001). All treatments recorded higher yields than the T0 control. The treatments in descending order of yield were as follows: T3 > T0r > T5 > T6 > T1 > T4 > T2 > T0. Only treatment T3 was more efficient than treatment t0r (reference control) compared with the other treatments.

In the third year (2021), the treatments showed no significant difference in yields. Nevertheless, over the 3 years, 2021 showed higher yields than the first 2 years. The treatment with the highest yield over the 3 years was T3 (5.71 t ha-1) in 2020, followed by T5 (5.39 t ha-1) and T3 (5.37 t ha-1) in 2021.

Table 2. Grain yield (t/ha) of maize over three years

Treatments	2019	2020	2021
T0	3.49a	1.37d	4.46a
T0r	-	4.51b	4.90a
T1	2.53a	3.93b	4.54a
T2	3.56a	2.41c	5.15a
T3	5.77a	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
Average	3.77	3.83	4.79
P	0.06	< 0.001	0.30
Standard deviation	1.36	1.36	0.74

3.2 Effect of different treatments on efficiency gain

The efficiency gain associated with these treatments compared with T0r (the reference control), T1 (100 % RP) and T6 (100 % TSP) was calculated for yields over the three years Compared with the T0r control: in 2020 all treatments showed negative efficiency yield, except treatment T3 (26.52 %). In 2021, only treatments T5 (10.02 %), T3 (9.53 %) and T2 (5.21 %) showed positive efficiency yield. Thus, T3 was the most efficient (Table 3).

Table 3. Efficiency gain of treatments compared with the T0r control

Treatments	2020	2021
T0	-69.57	-9.86
T0r	0	0.00
T1	-12.86	-7.31
T2	-46.64	5.21
T3	26.52	9.53
T4	-13.79	-13.86
T5	-1.24	10.02
T6	-3.70	-10.96

Compared with T1 (100% RP): in 2019, positive yield gains were observed for all treatments, with T3 recording the highest (127.67 %), while in 2020, only treatments T0r (14.76 %), T3 (45.20 %), T5 (19.27 %) and T6 (71.14 %) showed positive gains, with T3 recording the highest. In 2021, positive gains were recorded with T0r, T5, T2 and T3. Treatments T3 and T5 showed the highest gains of 18.17 % and 18.70 % respectively. Therefore, over the three years, treatment T3 was the most efficient compared with the other treatments (Table 4).

Table 4. Yield gains of treatments compared with T1

Treatments	2019	2020	2021
T0	37.62	-65.08	-2.75

T0r	-	14.76	7.89
T1	0.00	0.00	0.00
T2	40.51	-38.76	13.50
T3	127.67	45.20	18.17
T4	45.36	-1.07	-7.07
T5	19.27	13.34	18.70
T6	71.14	10.51	-3.94

Compared with T6 (100 % TSP): in 2019, all treatments showed negative yield gains, except treatment T3 (33.03 %). In 2020, only treatments T0r, T3 and T5 showed positive yield gains.

In 2021, all treatments showed positive gains except treatment T4 (-3.26 %). Over the three years, treatment T3 was the most efficient compared with the other treatments (Table 5).

Table 5. Yield gains of treatments compared with the T6 control

Treatments	2019	2020	2021
T0	-19.58	-68.40	1.24
T0r	-	3.85	12.31
T1	-41.57	-9.51	4.11
T2	-17.90	-44.59	18.16
T3	33.03	31.39	23.02

T4	-15.06	-10.48	-3.26
T5	-30.31	2.56	23.57
T6	0.00	0.00	0.00

3.3 Effect of different treatments on maize plant height

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 6).

Table 6. 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
Standard deviation	36.50	37.73	25.77

3.4 Effect of different treatments on soil pH

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 (**Figure**).

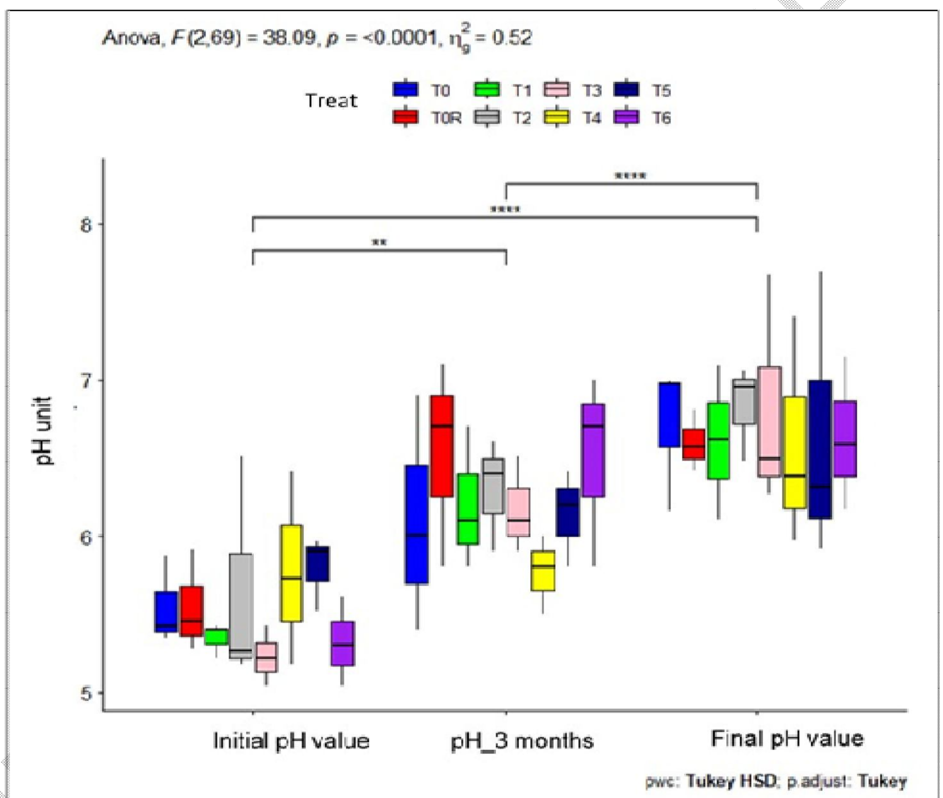

Figure 1: Soil pH values at the start, after 3 months and at the end of the experiment (115 days after sowing)

DISCUSSION

It would appear that the combination of RP and TSP did not significantly affect maize yield compared with the T0 control, regardless of the rate of RP and TSP applied in 2019. This could be attributed to the low phosphate status of the soil. Doses of TSP contained in the various treatments would have served to bring the soil fertility level to an average phosphate status. According to[7], for such soils, it would be necessary either to rectify the soil's phosphate status by applying a water-soluble phosphate fertilizer before considering direct application, or to apply a large quantity of RP (500 to 1000 kg RP ha-1), followed by regular maintenance applications. Furthermore, some soils have a very high phosphorus-fixing capacity and a greater or lesser proportion of the soluble phosphorus released by fertilizers could be blocked, especially if fertilizers are applied before the crop is sown, when root uptake is non-existent. In this way, the phosphorus (P) released by the TSP applied before sowing would have been fixed by the soil [8].

Furthermore, in terms of yield gains, all the treatments were more efficient than T1 (100 % RP) and less efficient than T6 (100 % TSP), with the exception of T3 (80 % RP + 20 % TSP). This can be explained by the fact that T6, consisting solely of TSP (water-soluble P), performed better than the other treatments. This contrasted with T1, consisted solely of RP. According to [7], low- to medium-reactivity RPs release the quantity of P they contain slowly, especially when applied at low doses.

In 2020, the significant effect of the RP / TSP combination was very visible. By the second year, the RP had had time to dissolve and gradually released the phosphorus over time, making it available to the plant. In fact, natural phosphates have a certain agronomic efficiency, which is slow but increases over time [9]. Furthermore, organic matter deriving from the decomposition of crop residues helps to dissolve RP. On this subject, [10] showed that soil organic matter content increased the dissolution of RP.

Treatment T3 (80 % RP + 20 %) proved to be the most efficient compared to other treatments. Treatments T1 (100 % RP), T4 (60 % RP + 40 % TSP), T5 (20 % RP+80 %) and the control T0r were as efficient as treatment T6 (100% TSP). In terms of yield gains, only

T3 performed better than T0r (the reference for maize extension), T1 (100% RP) and T6 (100 % TSP).These results differ from those of , [10] who showed that a mixture of North Carolina RP and TSP in a 50:50 ratio (50 % RP + 50 % TSP) was as effective as 100% TSP, applied to a limed soil (pH 6.2). This difference could be explained by the chemical composition of the rock phosphate applied and the pH of the amended soil. North Carolina rock phosphate is highly reactive and was applied to limed soil.

In the case of this study, the soil amended with Moroccan RP is acidic (pH= 5.22). According to [11],soil acidity is an important factor in the solubilization of natural phosphates. It allows the supply of protons H+ that cause the solubilization of RP. However, although the solubility of RP significantly affects the agronomic effectiveness of RP, other factors such as pH, crop species and the nature of the root system are decisive in assessing the agronomic effectiveness of RP [7].So, the use of rock phosphate by different species depends on their phosphate and calcium requirements, the way in which they absorb these two elements, the way in which they use them, the way the absorption of these elements affects the composition of the soil solution in the rhizosphere, and the nature of their root system [12].

In the third year of cultivation, the treatments had no significant effect on yield. Nevertheless, an increase in maize yield was noted in the third year of cultivation compared with the previous two years. This could be explained by the fact that the plant's uptake of phosphorus (P) from the RP had reached both its maximum and its limit. It would therefore be necessary to consider adding more RP in subsequent years in order to obtain a significant effect on maize yield. Under these conditions, it is possible to determine the phase at which plants reach the point where they have absorbed all the P available in the soil.

Recommendations for the popularization of rock phosphates for direct application in agriculture stipulate that 400 kg RP ha-1 should be applied in the first year for all crops, followed by an annual maintenance fertilizer at a dose of 300 Kg RP ha-1 for maize, supplemented by 100 Kg urea ha-1 per year , [9]. These recommendations also consider rainfall and cultivation techniques such as ploughing and the addition of organic matter , [12].

Plant heights were significantly influenced by the treatments in the first 2 years, with the best heights recorded with treatments T3, T4, T5 and T6. The combination of TSP and RP had an effect on the growth of the above-ground biomass of maize. This effect faded in the third year. This could be explained by the fact that the maize plants used would have absorbed all the phosphorus contained in the TSP for their growth. Indeed, phosphorus availability is important during the early stages of maize growth.

In terms of soil pH, 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 [10]. This observation could be explained by the fact that apatite is the main mineral in rock phosphates, justifying the significant presence of CaO in the chemical composition of Moroccan rock phosphate. This apatite, of the Ca-P type, therefore has the potential capacity to supply calcium and magnesium under conditions favourable to its dissolution[4].

Consequently, rock phosphate could have a liming effect on the soil by releasing calcium into the rhizosphere. , [13] 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 eventually inhibit the dissolution of rock phosphate, as acidity plays a crucial role in this process.

CONCLUSION

The aim of this study was to assess the effects of rock phosphate powder on the soil and on increasing maize yields through the combined application of rock phosphate (RP) and triple superphosphate (TSP). Findings generated through our research showed that the most beneficial treatment 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.

It should be noted that rock phosphate uptake reached its maximum level and saturation during the third year. To plan future applications of rock phosphate, it will be crucial to confirm this saturation phase and determine the limit, while taking into account the state of soil fertility and changes in pH over subsequent years.

The combination of triple superphosphate and rock phosphate also had a positive impact on above-ground biomass during year one and year two of cultivation, as well as on the gradual evolution of 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 as the efficient combination to improve maize yield in the acidic soil of Cote d'Ivoire.

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