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Response of lowland rice to phosphate amendments in three acidics agroecological zones of Côte d'Ivoire: Man-Gagnoa-Bouaké

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***Abstract*— *The need to achieve self-sufficiency in rice led producers to overexploit soils and to use excessively chemical fertilizers, which deplete soils and make phosphorus unavailable to crops. As an alternative, eight phosphate amendements made from phosphate rocks from Morocco (MPR), Triple Superphosphate (TSP) and NPK (T0a (0%MPR + 0%TSP without NPK); T0 (0%MPR + 0%TSP+ NPK); T1 (100%MPR + 0%TSP+ NPK); T2 (90%MPR + 10%TSP+ NPK); T3 (80%MPR + 20%TSP+ NPK); T4 (40%MPR + 60%TSP+ NPK); T5 (20%MPR + 80% TSP + NPK); T6 (0%MPR + 100%TSP+ NPK) were applied to the field and their agronomic efficiencies were evaluated in Man (very acidic soil). Gagnoa (moderately acidic soil) and Bouaké (weakly acidic soil). After three cultivation cycles, results designate Man and Gagnoa as more productive zones with respectively 5.04 t ha^{-1} and 4.36 t ha^{-1} grain yield (GY), comparatively to Bouaké (3.74 t ha^{-1}). Likewise, straw yields (SY) are 9.68 t ha^{-1} at Man and 6.06 t ha^{-1} at Gagnoa, comparatively to Bouaké (5.85 t ha^{-1}). Treatments T3 and T4 were more productive in all zones with respectively GY of 7.50 t ha^{-1} and 6.50 t ha^{-1} in Man, 5.54 t ha^{-1} and 5.91 t ha^{-1} in Gagnoa and 5.55 t ha^{-1} and 4.84 t ha^{-1} in Bouaké. This disparity is due to the chemical properties of the soils. In Man, Gagnoa and Bouaké, the combination 80% MPR + 20% TSP and 40% MPR + 60% TSP seem to improve better the yield of lowland rice.*

Keywords*— *Acid soil, Lowland rice, Man-Gagnoa-Bouaké, Phosphate amendments, phosphate rock of Morocco, Triple Superphosphate

I. INTRODUCTION

In West Africa, about 80 % of rice production surface accounted for upland rainfed rice cultivation (Koné et al. 2013). With increasing land shortages, the length of fallow between periods of cultivation has declined from 12 years in the 1980s to less than two years at present (Koné et al. 2013). This intensification of land use in the low-input systems causes declining yield levels, which are associated with a reduced soil fertility and an enhancement of soil acidification (Koné et al. 2016; Vitousek et al. 2010). These high acidity of soils favors high available P fixation by iron (Fe) and aluminum (Al) oxides and hydroxides (Koné et al., 2013). Therefore, low P concentration and P deficiencies are commonly observed. This is a major soil constraint to sustainable rice production in the tropical humid agroecosystems (Sahrawat et al. 2001). Phosphate fertilization is, therefore, strongly recommended to increase crop yields. Chemical fertilizers used until then, such as triple superphosphate (TSP), although effective for to remedy this problem are prohibitively expensive for small African farmers. An alternative and cheaper source of P is Morocco phosphate rock (MPR), which abounds in West Africa (Asuming-Brempong and Anipa, 2014). Morocco

Phosphate rock (MPR) adoption by smallholder farmers is, however, limited particularly because of the large quantities required due to its low solubility, thus making its use impossible for farmers (Debrah 2000). Numerous studies have been conducted to increase the availability and solubility of P from native sources PR. Among these, organic amendments, including animal manure, plant residues and green manure (Adesanwo et al. 2 012), composts (Saleem et al. 2013), bacterial inoculation (Abbasi et al. 2015) and the combined application of water-soluble P fertilizers (Koné et al. 2011; Mashori et al. 2013) are considered beneficial for improving the P efficiency. However, the MPR dissolution and P solubilization and availability is influenced to a large extent by physico-chemical and biological properties of the soil (Richardson et al. 2009). The aim of this study was to evaluate the agronomic effectiveness of different types of phosphates amendments resulting to the combinaison of differents proportions of Morroco phosphate rock (MPR) and of triple super phosphate (TSP) on rice yield in acidic soils in three agroecological zones.

II. MATERIALS AND METHODS

2.1. Experimental site

The experiment was conducted in Ivory Coast from 2019 to 2021 in three agroecological localities where soils pH were acidic (pH <6): Man (strongly acidic), Gagnoa (moderately acidic) and Bouaké (weakly acidic) (TABLE 1). The experiment was an on-farm study carried out in the Center (Bouaké : 6°41'37"N. 5°01'49"O), Center-West (Gagnoa 6°07'54"N. 5°57'02"W) and West (Man : 7°24'45"N. 7°33'13"W) part of Ivory Coast. Man and Gagnoa are in tropical humid forest agro-ecosystem with a mono modal and a bimodal rainfall pattern respectively. While Bouake is in tropical humid savannah with a mono modal rainfall pattern. In each locality, five fields were selected per agroecological zones for expérimentation.

Table 1. Physical and chemical characteristics of soils at 0-20 cm depth before experimention.

Parameters	**Man**	**Gagnoa**	**Bouaké**
Clay (%)	23.70	28.50	12.50
Silt (%)	24.10	22.50	15.00
Sand (%)	52.20	49.00	72.50
pHwater	4.93	5.18	6.11
pH_{KCl}	4.21	4.70	5.42
Total P (mg kg^{-1})	300.53	286.43	313.60
Assimilable P (mg kg^{-1})	20.96	12.55	21.15
Total N (g kg^{-1})	2.11	2.17	2.31
Organic C (g kg^{-1})	24.40	23.15	24.30
Organic matter (g kg^{-1})	41.97	39.82	41.80
C/N (mg kg^{-1})	11.56	10.67	10.52
K^+ ($mmol^+$ kg^{-1})	5.37	3.33	8.34
Na^+ ($mmol^+$ kg^{-1})	0.19	0.90	0.13
Ca^{++} ($mmol^+$ kg^{-1})	47.51	30.22	29.20
Mg^{++} ($mmol^+$ kg^{-1})	1.76	1.05	3.20
Al^{+++} ($mmol^+$ kg^{-1})	5.28	2.83	0.49
CEC ($mmol^+$ kg^{-1})	36.68	28.99	34.91

2.2. Plant material

The plant material is the WITA 9 rice variety also called Nimba. It was developed in 1984 by the International Institute of Tropical Agriculture (IIAT) by mixing the variety HI 2042-178-1 and the variety CT19 is an improved variety which was chosen mainly for its short cycle (90 days). It's average yield of 6 t ha^{-1} and its potential yield of 10 t ha^{-1}. The seed of WITA 9 provided in National Center of Agricultural Research (CNRA) in Man.

2.3. Chemical and natural materials

We used two types of phosphate amendments provided by OCP-Africa (Office Chérifien des Phosphates): TSP (Triple Superphosphate) a chemical fertilizers containing 30% P_2O_5, and a natural fertilizer Morocco phosphate rock (MPR) containing 30% of P_2O_5 with a solubility of 3% in water. Another chemical fertlizers such as Urea 46% N and NPK 15/15/15 were used in this study. The chemical composition of the MPR is presented in TABLE 2.

Table 2. *Chemical composition of Morocco phosphate rock*

Chemical	P_2O_5	CO_2	SO_3	SiO_2	CaO	MgO	Fe_2O_3	Al_2O_3	F	H_2O
Contents (%)	30	6.44	1.29	6.64	49.54	1.16	0.2	0.41	2.21	2.13

2.4. Field Experimentation

Fallow land of 500 m^2 was cleaned and tilled manually every year (2019 to 2021). The following eight treatments resulting to the combination of different proportions of MPR and TSP were implemented on-field before planting rice cultivar sativa : Absolute control (T0a : 0 % MPR and 0% TSP without NPK) ; reference control (T0 : 0% MPR and 0% TSP + NPK) ; T1 (100% MPR and 0% TSP+ NPK) ; T2 (90% MPR and 10% TSP + NPK) ; T3 (80% MPR and 20% TSP + NPK) ; T4 (40% MPR and 60%TSP + NPK) ; T5 (20% MPR and 80%TSP + NPK) ; T6 (0% PR and 100%TSP + NPK). In field a randomized complete block design with five replications was considered, with each field as a replicate. The MPR-TSP combination was designed to provide 90 kg ha^{-1} of P_2O_5 or 300 kg ha^{-1} of MPR or TSP. Each treatment was applied to an elementary plot of 25m² (8m × 3.13m) which included 600 pockets spaced 20cm apart from each other. Three yield squares of 1m² each were demarcated by processing along a diagonal of each elementary plot. One-meter canals separated the elementary plots framed by bunds formed to avoid contamination due to overflowing water in the event of rain.

Two days before sowing the 15-day-old rice plants, NPK 15-15-15 (200 kg ha^{-1}) and the different treatments were applied, as background fertilizer for each plot except for the absolute control. The transplanting was carried out at a rate of 02 plants per pocket 100 kg ha^{-1} of 46%N urea were spread in two stages: 50 kg ha^{-1} at the tillering stage and 50 kg ha^{-1} at the bolting stage. TABLE 3 gives the composition of the different treatments applied. In order to avoid competition between rice and weeds, a layer of water 10 to 15 cm high was maintained until heading and manual weeding was carried out if necessary. No insecticide or fungicide was applied to the plots. The transplants were carried out according to the cultural calendar of each study area. At maturity the agronomic parameters were measured.

- Plant height (H)

Heights (cm) were measured using a measuring rod from the base to the limit of the highest leaf of each plant located in the yield squares. i.e. seventy-five pockets per elementary plot due to twenty-five plants per square (IRRI, 2014). An average of the values obtained for each treatment was taken.

- Number of tillers (Til) and Number of panicles (Pan)

Tilling density is the number of tillers formed by a rice plant. The total number of tillers and the number of panicles are determined simultaneously with the harvest by counting on each plant the twenty-five pockets located in each yield square. An average of the values obtained per m² is made by multiplying the average by the number of pockets.

- Straw yield (SY)

On each site and for each treatment the biomass consisting of panicle straw tillers and leaves from the three yield squares was collected and dried in the open air then weighed in order to determine the straw yield (SY) per m².

- Grain yield (GY)

Grain yield (GY) was determined after drying the grains in the open air then in an oven at 65°C for 72 hours. Grain yield (GY) was calculated after reducing grain weights to 14% moisture (Koné et al. 2010; Akassimadou et al. 2017).

$$GY\,(14\%) = \frac{P1\,(100-h1)}{100-14} \qquad (1)$$

- Harvest Index (HI)

HI is defined as the ratio between grain yield and the sum of GY and SY.

$$HI(\%) = \frac{GYx}{GYx + SYx} \times 100 \qquad (2)$$

GYx is the Grain Yield of a treatment at a given x dose; SY: Straw yield of the same treatment at x dose.

- Yield gain (Yg)

Yield gain (Yg) of the GY of each treatment compared to the control treatment T0 was determined by modifying the formula of Morel and Fardeau (1991) using yields instead of P exports (Koné et al. 2010) :

$$Yg = \frac{GYx-GY0}{GY0} \times 100 \qquad (3)$$

Yg were calculated in relation to the T0 treatment in order to be able to subtract the share of NPK + Urea in the yields.

2.6. Statistical analyzes

Analyzes of variance were carried out using SAS (Statistical Analysis System) software using mixed models on the data from each campaign. Following linear models, the average values of each measured variable were determined depending on the treatment and the experimental site. Student Newmann_Keuls (SNK) test was used to compare these means using the least significant difference (ppds) method at the 5% significance level.

Table 3. *Treatments composition and values of fertilizers and nutrients applied on plots*

	Quantities of fertilizer applied (kg ha^{-1})					**Quantities of each nutrients (kg ha^{-1}) in each treatments**		
Treatments	**MPR**	**TSP**	**NPK**	**Urea**	**Total quantities of fertilizer**	**N**	**P**	**K**
T0a (soil potential)	0	0	0	0	0	0	0	0
T0 (reference control)	0	0	200	100	200 NPK + 100 Urea	76	13.2	24.9
T1	300	0	200	100	300 MPR + 200 NPK + 100 Urea	76	52.8	24.9
T2	270	30	200	100	270 MPR + 30 TSP + 200 NPK + 100 Urea	76	52.8	24.9
T3	240	60	200	100	240 MPR + 60 TSP + 200 NPK + 100 Urea	76	52.8	24.9
T4	120	160	200	100	120 MPR + 180 TSP + 200 NPK + 100 Urea	76	52.8	24.9
T5	60	240	200	100	60 MPR + 240 TSP + 200 NPK + 100 Urea	76	52.8	24.9
T6	0	300	200	100	300 TSP + 200 NPK + 100 Urea	76	52.8	24.9

III. RESULTS

3.1. Effect of treatments on the agro-morphological parameters of lowland rice

3.1.1. Tillers and panicles

TABLE 4 shows that panicle production is proportional to tiller production. Ours results indicated that all treatments amended with phosphate amendments (PAs) produced very hight significantly ($p<0.0001$) more tillers and panicles than control treatments T0 and T0a Treatments. However, when PAs contains more than 80% of TSP (T5 and T6), le number of tillers and panicles is significantly lower than when phosphate amendments (PAs) were enriched with Morroco phosphate rock (MPR) e.g. T1, T2, T3 and T4. Generally, the number of tillers and panicles are highest under T3 (339.76 to 564.9 m^{-2} for tillers and 291.78 to 519.0 m^{-2} for panicles) and T4 (316.1 m^{-2}to 557.6 m^{-2} for tillers and 291.8 m^{-2} to 499.4 m^{-2}) whatever the study site. However, ours results showed that le number of tillers and panicles produced in very (Man : 404.6 tillers and 362.7 panicles per m^{2}) or moderately (Gagnoa : 264.1 tillers and 231.8 panicules per m^{2}) acidic soils are higher than in weakly acidic soil (Bouaké) with 263.6 tillers and 226.9 panicules per m^{2} (TABLE 4).

3.2.2. Plant height

Whatever the agroecological zone, a significant ($p<0.05$) increase of height have been observed, when the soils are amended with MPR and/or TSP, comparatively to soils unamended (T0 and T0a) (TABLE 4). However, the rice plants heights are significantly lower (80 to 89 cm), when soils are amended with TSP only (T6) or with 80% TSP+20%MPR (T5) than the height of plant when soils are amended with more than 40% MPR (T1, T2, T3, T4) with an average 99.3 to 109.1 cm (TABLE 4). Likewise, regardless of treatment applied, rice plants height are higher in very acidic soil (Man : 95.34 cm) than in moderately acidic soil (Gagnoa : 89.8 cm) and than in weakly acidic soil (Bouaké : 88.5 cm) (TABLE 4).

Table 4. Effect of treatments on number of tillers and panicles, and plants height in each agroecological zone after three cultural cycles

	Tillers /m^2			Panicles s /m^2			Heigtht (cm)		
Treatments	Man	Gagnoa	Bouaké	Man	Gagnoa	Bouaké	Man	Gagnoa	Bouaké
T0a	165.9^c	155.1^c	148.9^c	124.2^c	113.8^c	110.0^c	80.4^b	64.0^c	62.6^c
T0	237.6^c	194.6^{cb}	241.1^b	203.6^c	180.8^b	160.5^{cb}	84.4^b	74.7^c	72.4^c
T1	483.2^a	321.2^a	308.9^a	444.4^a	275.86^a	285.9^a	101.2^a	99.3^{ba}	100.4^{ba}
T2	531.9^a	322.5^a	312.7^a	491.9^a	287.4^a	281.8^a	105.8^a	103.2^a	100.3^{ba}
T3	564.9^a	343.4^a	339.8^a	519.0^a	313.6^a	303.2^a	109.1^a	108.2^a	105.9^a
T4	557.6^a	329.4^a	316.1^a	499.4^a	291.8^a	292.8^a	108.2^a	107.6^a	104.4^a
T5	357.2^b	229.4^b	219.0^b	319.2^b	199.62^b	195.4^b	89.1^b	81.0^b	80.8^b
T6	340.1^b	216.9^{cb}	222.3^b	300.0^b	193.6^b	187.0^b	84.6^b	80.4^b	81.2^b
Means	404.8	264.1	263.6	362.7	231.8	226.9	95.3	89.8	88.5
CV (%)	24.3	21.4	18.5	26.6	22.9	24.8	19.6	14.1	18.8
Lsd$_{.05}$	92.57	53.28	29.78	90.72	52.93	32.6	16.0	16.7	8.0
Pr	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***

*Values in the tables are means values of agronomic parameters mesured during experiments. Means within the same row with different superscripts letters are different (p<0.05) as indicated by Student Newman-Keuls test. *** probability very highly significant at 0.05;*

3.3. Yields and Harvest Index

3.3.1. Paddy rice grain yields (GY), straw yield (SY) and Harvest Index (HI)

The ANOVA carried out on yield data indicates a very highly significant effect of phosphate amendments (p<0.0001) on grain yields (GY) and straw yield (SY) of rice under soils amended (4.95 to 7.5 t ha^{-1} for GY and 9.11 to 11.76 t ha^{-1} for SY), comparatively to soil unamended (controls treatments T0 and T0a) with 1.52 to 3,49 t ha^{-1} for GY and 2.49 to 8.76 t ha^{-1} for SY, whatever the agroecological zone (TABLE 5). On the other hand, when soils are amended with phosphate amendments enriched with TSP (T5 and T6), grain yield and straw yield are significantly lower than when it's amended with phosphate amendments enriched with MPR (T1, T2, T3 and T4). The high GY and SY appeared under T3 and T4 Treatments whatever the the agroecological zone (TABLE 5). HI values follow the same trends as GY and SY for each treatment. Thus, the lowest HI values are obtained in Bouaké compared with Man and Gagnoa (TABLE 5). Irrespective of the agro-ecological zone, the treatments have a highly significant effect on HI. Treatments T3 and T4 achieved the highest HIs in Man (T3: 0.43 and T4: 0.41) and Gagnoa (T3: 0.4 and T4: 0.39), while in Bouaké the HIs under treatments T3 and T4 were 0.38 and 0.36 respectively (TABLE 5).

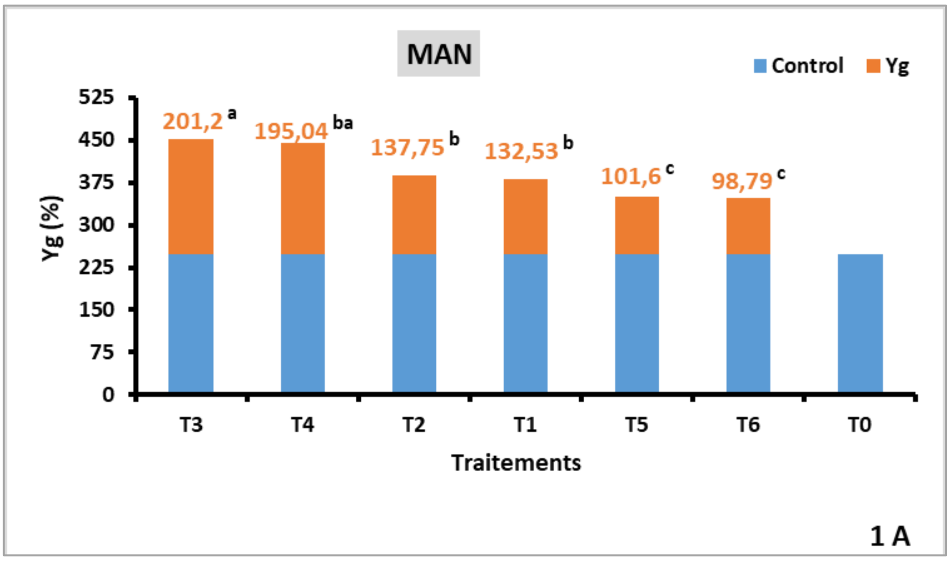
3.3.2. Yield gain

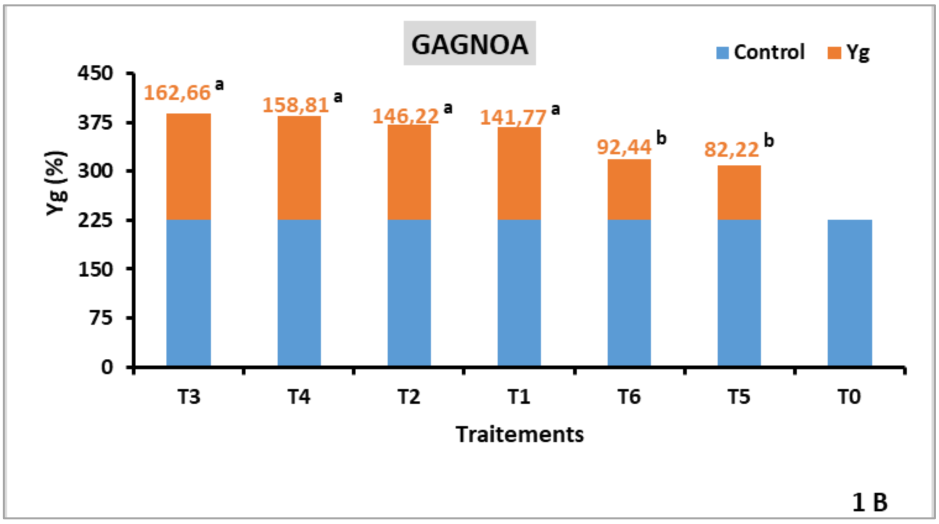
The analysis of Fig.1 shows that yield gain values vary depending on each treatment and the agroecological zones. But the greatest gains are obtained on the strongly acidic soils of Man (138.8%) followed by the moderately acidic soils of Gagnoa (130.66%) then come the weakly acidic soils of Bouaké (115.27%). We also note that Yg under T3 and T4 in Man (T3: 201.2%, T4: 195.04%) and Gagnoa (T3: 162.66%. T4: 158.81%) are greater than Yg under T3 and T4 in Bouaké (T3: 173.39%, T4: 169.44%). On the same agroécological zone, treatments rich in MPR (T1, T2, T3 and T4) significantly increased yields compared to control T0 and compared to treatments T5 and T6 enriched in TSP (Fig.1).

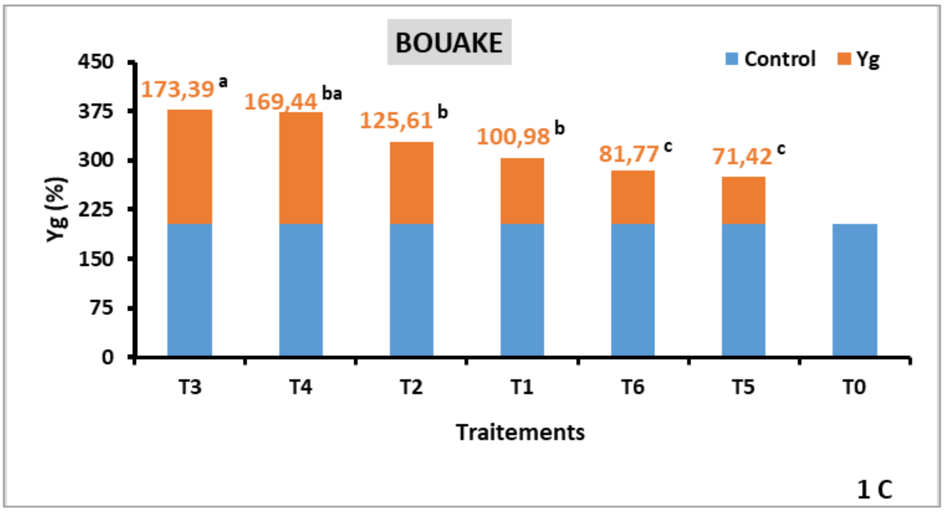
Table 5. Effect of treatments on GY. SY and HI of rice in each agroecological zone after three cultural cycles

	GY (t ha^{-1})			SY (t ha^{-1})			HI		
Treatments	Man	Gagnoa	Bouaké	Man	Gagnoa	Bouaké	Man	Gagnoa	Bouaké
T0a	2.17^{d}	1.52^{d}	1.69^{d}	4.12^{e}	2.49^{c}	3.36^{e}	0.28^{f}	0.3^{d}	0.22^{e}
T0	3.49^{d}	2.67^{d}	2.03^{d}	8.76^{d}	4.38^{c}	4.04^{ed}	0.3^{e}	0.33^{c}	0.27^{d}
T1	5.79^{bc}	5.54^{ba}	4.08^{bc}	10.99^{b}	7.24^{a}	6.15^{bc}	0.38^{c}	0.39^{a}	0.34^{b}
T2	5.92^{bc}	5.68^{ba}	4.58^{bac}	11.34^{a}	7.86^{a}	6.92^{bac}	0.4^{b}	0.39^{a}	0.34^{b}
T3	7.50^{a}	5.91^{a}	5.55^{a}	11.76^{a}	8.21^{a}	8.17^{a}	0.43^{a}	0.4^{a}	0.38^{a}
T4	6.50^{b}	5.82^{a}	4.84^{ba}	11.5^{a}	7.95^{a}	7.35^{ba}	0.41^{ba}	0.39^{a}	0.36^{ba}
T5	5.02^{c}	4.33^{bc}	3.69^{bc}	9.88^{c}	5.88^{b}	5.47^{dc}	0.37^{c}	0.36^{b}	0.33^{b}
T6	4.95^{c}	4.10^{c}	3.48^{c}	9.11^{c}	5.52^{b}	5.34^{dc}	0.35^{d}	0.32^{c}	0.31^{c}
Means	5.17	4.45	3.75	9.68	6.19	5.85	0.37	0.36	0.32
CV (%)	26.63	24.97	25.87	22.04	21.60	22.09	15.4	8.13	8.62
Lsd$_{.05}$	0.91	0.83	1.02	1.21	1.67	1.23	0.031	0.027	0.031
Pr	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	<0.001***	0.002**	<0.001***	<0.001***

*Values in the tables are means values of agronomic parameters mesured during experiments. Means within the same row with different superscripts letters are different (p<0.05) as indicated by Student Newman-Keuls test. *** probability very highly significant at 0.0 ;*







Values in the graphic are means values of agronomic parameters mesured during experiments. Means within the same row with different superscripts letters are different (p<0.05) as indicated by Student Newman-Keuls test.

Fig.1. Yield gain under treatments compared to control T0 after three cultural cycles

IV. DISCUSSION

4.1. Soil properties

The acidic pH of soils in the 0-10 cm horizon constitues a favorable factor for the solubilization of the MPR contained in applied treatments. The high levels of assimilable P (Passi > 20 mg kg^{-1}) and N (2‰ < N < 3‰) in the soil indicate that these two elements cannot be considered as a limiting factor in the assimilation of nutrients by rice plants. The fairly high percentages of clay in soils of Man (23.7%) and Gagnoa (28.5%) coupled with their so-called average ECE (10 meq.100g^{-1} < EC < 25 meq.100g^{-1}) indicate that these clay levels could constitute nutrient reserves. However the low clay content (12.5%) of soil of Bouaké could be a limit to water retention as well as nutrient retention (Kaboré et al. 2020).

4.2. Efficiency of PAs on agro-morphological parameter of rice

Statistical tests carried out showed that treatments increased not only the production of tillers and panicles of the cultivated rice but also the height of rice plants. This increase which is greater on more acidic soils of Man and Gagnoa than that of Bouaké. demonstrates that MPR is more effective in acidic soils. These results show that the more pronounced acidity of the soils of Man and Gagnoa favored the solubilization of the MPR as well as the provision of the released P for the nutrition of rice plants (Wafaa et al. 2011). Obtaining larger plants as well as high number of tillers and panicles produced under treatments (T1, T2, T3 and T4) richer in MPR indicates that the higher the percentage of MPR in the fertilizer the more the plants are larger and the higher their biomass production. In fact the phosphorus released after dissolution of the PRM is involved in vegetative growth (Wafaa et al. 2011; Kotchi et al. 2018). These results agree with those of several authors such as Useni et al. (2012) and Sanogo et al. (2020) who showed that high doses of phosphorus induce elongation of rice plants. Sanogo et al. (2020) also demonstrated that the number of tillers in lowland rice is increased by high doses of phosphate and nitrogen fertilizers. A study conducted by Saito et al. (2029) from 2014 to 2015 showed that the application of phosphate fertilizer increases production of tillers, panicles and the height of rice plants of the WITA 9 variety used in our study. The highest production of panicles per m^2 and larger rice plants under T3 and T4 in Man (very acidic soil) and in Gagnoa (moderately acidic soil) shows that their production would be influenced by pH and doses of MPR applied. This highest production would also be under the influence of other chemical parameters of the soil such as the initial values of N, P, K, Ca and Mg as demonstrated by Yang and Zhang (2010), Koné et al. (2013).

Treatments rich in TSP (T5, T6) produced shorter plants fewer tillers and panicles per m^2 compared to treatments rich in MPR. It is because the greater aqueous solubility of TSP favors the quick release of P for rice nutrition compared to PRM but its effect fades quite quickly over time because the majority of this released P forms complexes with Fe^{2+}, Al^{3+} (Wafaa et al. 2011; Aallam et al. 2023).

4.3. Yield parameters

Yield parameters subjected to analysis of variance indicate that the contributions of treatments on the different plots favor the productivity of lowland rice compared to controls (T0 and T0a). This productivity in terms of grain (GY) and straw (SY) which is even higher under T1, T2, T3 and T4 which contain between 50 and 100% MPR is the result of the provision of P contained in MPR after dissolution. In fact P intervenes during rice growing phase to promote flowering and consequently grain production as indicated by Mollier (2016) who states that 65% of the P supplied to crops in the form of fertilizer is found grains. Thus P is assimilated in large quantities by rice which like wheat is a very voracious crop in nutrients to satisfy its needs (Bihari et al. 2021). Therefore to maintain good rice productivity it would be necessary to add fertilizer annually or at each rice cultivation cycle because meeting its nutritional needs tends to considerably reduce soil nutrients (Nayak et al. 2022). This explain the low productivity of rice in treatments T5 and T6 richer in TSP because P released by this chemical fertilizer applied all at once is not enough to satisfy the nutritional needs of rice over a long period. This low grain and straw productivity can also be linked to the complexation of a large part of the P released by the TSP as highlighted by Wafaa et al. (2011). The large production of straw and grain observed on strongly acidic soils of Man and moderately acidic soils of Gagnoa compared to the weakly acidic soil of Bouaké demonstrates that MPR is more effective in an acidic environment (Kotchi et al. 2010; Maharana et al. 2020) because the application of PR on acidic soils allows the release of hydrogen ions which promote the conversion of P into forms assimilable by plants during more than one year (FAO, 2004). Treatments T3 and T4 which stand out from other treatments by their higher GY and SY indicate that it would be advantageous to constitute treatments composed of 60 to 80% MPR to increase the yields of lowland rice. But beyond the pH and fertilizer doses taking into account the interaction between the chemical elements of the soil proves necessary in order to make the application of phosphate fertilizers agronomically profitable.

Due to their highest Yg an HI under treatments rich in MPR and on strongly acidic soils of Man and those moderately acidic of Gagnoa compared to the weakly acidic soils of Bouaké show that application of MPR on plots favors rice productivity as demonstrated by Sanogo et al. (2020).

Treatments T3 (80%RP+ 20%TSP) and T4 (60%RP+ 40%TSP) having obtained the highest Yg rate shows that a fertilizer in the proportions of 240 kg ha^{-1} RPM + 60 kg ha^{-1} TSP in proportions of 180 kg ha^{-1} RPM + 120 kg ha^{-1} TSP would be best suited to considerably increase rice grain production in Man Gagnoa and Bouaké (Alam et al. 2009; Elkheir et al. 2018). However thus proportions are low compared to 300 kg ha^{-1} of phosphate from Tilemsi used by Koné et al. (2010) to produce 2.5 t ha^{-1} of rice. Our results corroborate those of Taktek (2015) who asserted that it is neccesary to reduce about 50% of phosphate rock to improve the productivity of rice. All this disparities between production in each agroecological zone bear out that the efficiency of phosphate rock varie depending to soils characteristic.

Treatments T3 and T4 which have produced more GY, SY and Yg appear to be appropriate to improve lowland rice cultivation in Man Gagnoa and Bouaké.

V. CONCLUSION

Amendment of lowland soils with MPR combined with TSP is more effective than applying MPR or TSP alone to lowland soils for rice cultivation. The treatments resulting from the MPR-TSP combination considerably increased the production of tillers panicles as well as the GY and SY of rice especially under those rich in MPR (T1, T2, T3 and T4). After three cultivation cycles treatments T3 and T4 are those which increase the GY more compared to the control T0 whatever the agroecological zone with respective GYs of 7.50 t ha^{-1} and 6.50 t ha^{-1} to Man; 5.54 t ha^{-1} and 5.91 t ha^{-1} in Gagnoa then 5.55 t ha^{-1} and 4.84 t ha^{-1} in Bouake. But the consideration of chemical (initial N, P, K, Ca and Mg contents) and biological (BSP) factors is necessary to recommend the MPR-TSP combination adapted to each type of rice soil.

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REFERENCES

[1] Aallam. Y.. Tarkka. M.. Dhiba. D.. Rasafi. T. El. Hamdali. H.. Abbas. Y.. & Haddioui. A. (2023). Scientia Horticulturae Assessment of two endemic rock phosphate solubilizing Streptomyces spp. on sugar beet (Beta vulgaris L .) growth under field conditions. *Scientia Horticulturae*. *316*(June). https://doi.org/https://doi.org/10.1016/j.scienta.2023.112033

[2] Akassimadou. F. E.. Hien. M. P.. Bouadou Oi. F. B.. Bolou Bi. E. B.. Bongoua. J. A.. Ettien. J.-B. D.. & Yao-kouame. A. (2017). Efficiences Des Nutriments P Et K En Riziculture Irriguée Dans Un Bas-Fond Secondaire En Zone De Savane Guinéenne De La Côte d’Ivoire. *European Scientific Journal*. *13*(36). 432. https://doi.org/10.19044/esj.2017.v13n36p432

[3] Alam. M. M..Amin. A. K. M. R., Ali. M., Ruhul. A.. & Hasanuzzaman. M. (2009). Yield Attributes. Yield and Harvest Index of Three Irrigated Rice Varieties Under Different Levels Phosphorus. *Biological Research*. (August 2014).

[4] Asuming-Brempong. S.. & Anipa. B. (2014). The use of rock phosphate and phosphate solubilising fungi (Aspergillus niger) to improve the growth and the yield of upland rice on typic Kandiudalf. *West African Journal of Applied Ecology*. *22*(1). 27–39.

[5] Aulakh M.S.. Adhya T.K. (2005). Impact of agricultural activities on emission of greenhouse gases – Indian perspective. In 'International Conference on Soil. Water and Environmental Quality – Issues and Strategies. pp. 319-335 (*Indian Society of Soil Science: New Delhi*).

[6] Bihari. B.. Singh. Y. K.. Shambhavi. S.. Mandal. J.. Kumar. S.. & Kumar. R. (2021). Nutrient use efficiency indices of N . P . and K under rice-wheat cropping system in LTFE after 34th crop cycle. *Journal of Plant Nutrition*. *0*(0). 1–18. https://doi.org/10.1080/01904167.2021.1943674

[7] Elkheir. A.. H.. Musa. Y.. Muslimin. M.. Sjahril. R.. Riadi. M.. & Gunadi. H. (2018). Harvest index and yield components of aerobic rice (Oryza sativa) under effect of water . varieties and seed priming. *Earth Environnement Sciences*. *157*. https://doi.org/10.1088/1755-1315/157/1/012021

[8] FAO (2004). Utilisation des phosphates naturels pour une agriculture durable. http://www.fao.org/3/y5053f/y5053f00.htm#Contents. consulté en ligne le 04 0ctobre 2022.

[9] Firmin K. K.. Brahima K.. Yves N. K.. Traoré N. K. Y. N. K. R.. Joachim T. M.. Yao Z. F.. … Albaert. Y. (2017). Yield Gap as Occurring in Lowland Rice Cropping under Guinea Savanna Ecology : Spatial and Temporal Diagnosis for Fixing Research Priority. *Journal of Agriculture and Crops*. *3*(August). 51–64. Retrieved from http://arpgweb.com/?ic=journal&journal=14&info=aims

[10] Ilg K.. Siemens J. and M. Kaupenjohann. (2005). Colloidal and Dissolved Phosphorus in Sandy Soils as Influenced by Phosphorus saturation. *Journal of Environmental Quality*. 34 : pp. 926 - 935

[11] Kaboré. F.. Hien. E.. Mare. T. B.. Ouattara. K.. & Zombre. P. N. (2020). Caractéristiques morpho-pédologiques et potentialités agricoles de sols développés sur roches dolomitiques dans le bassin de Taoudéni au Burkina Faso. *International Journal of Biological and Chemical Sciences*. *14*(August). 2333–2351. DOI : https://dx.doi.org/10.4314/ijbcs.v14i6.32

[12] Koné. B.. Fatogoma. S.. & Chérif. M. (2013). Diagnostic of mineral deficiencies and interactions in upland rice yield declining on foot slope soil in a humid forest zone. *International Journal of Agronomy and Agricultural Research (IJAAR)*. *3*(7). 11–20.

[13] Koné. B.. Yao-Kouamé. A.. Sorho. F.. Diatta. S.. Sié. M.. & Ogunbayo. A. (2011). Long-term effect of Mali phosphate rock on the grain yield of interspecifics and saltiva rice cultivars on acid soil in a humid forest zone of Côte d'Ivoire. *International Journal of Biological and Chemical Sciences*. *4*(3). 563–570. https://doi.org/10.4314/ijbcs.v4i3.60451

[14] Kotchi. V.. Charlotte. T. D.. & Faustin. S. D. (2018). Influence of the Use of Spent Mushroom Substrates of Pleurotus Eous var. on the Availability of Phosphorus in Acid Soils of Humid Forest Regions of Côte d ' Ivoire. *International Research Journal of Advanced Engineering and Science*. *3*(4). 256–261.

[15] Kotchi. V.. Yao-Kouamé A.. Diatta S. (2010). Réponse de cinq variétés de riz à l'apport de phosphate naturel de Tilemsi (Mali) sur les sols acides de la région forestière humide de Man (Côte d'Ivoire). *J. Ap. Biosci*. pp 1895–1905

[16] Kouassi. A. D.. Paul-martial. K. K.. & Casimir. B. Y. (2018). Effets d'une lutte intégrée contre les adventices sur les performances agronomiques du riz pluvial en zone pré-forestière ivoirienne. *Journal of Animal & Plant Sciences*. *38*(1). 6175–6189.

[17] Maharana D.. Saha M.. Dar J. Y.. Rathore C.. Sreepada R. A.. Xu X-R.. Koongolla J. B.. Li H-X. (2020). Assessment of micro and macroplastics along the West coast of India : abundance. distribution. polymer type and toxicity. https://doi.org/10.1016/jchemosphere.2019.125708

[18] MINESUDD. (2014). L'agriculture Intelligente face au Climat en Côte d'Ivoire: état des lieux et besoins d'appui pour mieux intégrer l'Agriculture Intelligente face au Climat (AIC). Communication pays.

[19] Mishra. J.S. and Singh V.P. (2007). Integrated weed management in zero till direct seeded rice (Oryza sativa L)-wheat (Triticum aestivum) cropping system. *Indian Journal of Agronomy*. 52 (3):198-203

[20] Mollier. A. (2016). La modélisation du transfert sol-plante du phosphore dans les agroécosystèmes. Mémoire présenté pour obtenir l ' Habilitation à Diriger des Recherches La modélisation du transfert sol-plante du phosphore dans les agroécosystèmes. Université de Bordeaux. Sciences agricoles. 37p. DOI : https://hal.inrae.fr/tel-02801015

[21] Nayak. H. S.. Silva. J. V.. Parihar. C. M.. Krupnik. T. J.. Sena. D. R.. Kakraliya. S. K.. … Sapkota. T. B. (2022). Interpretable machine learning methods to explain on-farm yield variability of high productivity wheat in Northwest India. *Field Crops Research*. *287*(July). https://doi.org/10.1016/j.fcr.2022.108640

[22] Reddy. M. S.. Kumar. S.. Babita. K.. Reddy. M. S. (2002). Biosolubilization of poorly soluble rock phosphates by Aspergillus tubingensis and Aspergillus niger. Bioresource Technology 84. pp. 187-189.

[23] Rodenburg. J.. Saito. K. (2022). Towards sustainable productivity enhancement of rice-based farming systems in sub-Saharan Africa. *Field Crops Research*. *287*(July). 108670. https://doi.org/10.1016/j.fcr.2022.108670

[24] Sahrawat. K. L. (2000). Elemental composition of the rice plant as affected by iron toxicity under field conditions. *Com. Soil Sci. Pl. An. 31*(17–18). 2819–2827. DOI : https://doi.org/10.1080/00103620009370630

[25] Saito. K.. Touré. A.. Arouna. A.. Fiamohe. R.. Silué. D.. Manful. J.. … Efisue. A. A. (2019). Multidisciplinary assessment of agricultural innovation and its impact: a case study of lowland rice variety WITA 9 in Côte d'Ivoire. *Plant*

Production Science. *22*(4). 428–442. https://doi.org/10.1080/1343943X.2019.1667834

[26] Sanogo Souleymane. Paul A. K.. Zoumana K.. Mameri C. (2020). Evaluation de l ' effet de doses d ' azote et de phosphore sur des paramètres agro-morphologiques et du rendement du riz : cas de la variété Djoukèmin dans un bas-fond fond de la région de Gagnoa. *Journal International de la Recherche Scientifique*. *1*. 8–16.

[27] Taktek. S. (2015). Dissolution biologique des phosphates : Interaction bactéries - mycorhizes. Université LAVAL. Québec. Canada.

[28] United States Department of Agriculture Foreign Agricultural Service. (2016). Production. supply and distribution. Washington. DC: Author. Retrieved from http://apps.fas.usda.gov/psdonline/psdquery.aspx

[29] Useni S. Y.. Baboy L. L.. Nyembo K. L.. Mpundu M. M. (2012). Effets des apports combinés de biodéchets et de fertilisants inorganiques sur le rendement de trois variétés de Zea mays L. cultivées dans la région de Lubumbashi. *Journal of Applied Biosciences*. 54 : 3935-3943.

[30] Vitousek P.M.. Porder M.. Houlton B.J.. Chadwick O. A. (2010). Terrestrial phosphoruslimitation: mechanisms. implications. and nitrogen–phosphorus interactions.Ecological Applications 20: pp. 5-15.

[31] Wafaa. El-Etr T.. Osman. M. A.. Mahmoud. A. A. (2011). Improving phosphorus use effeciency and its effect on the productivity of some crops. *Journal of Soil Sciences and Agriculture Engineering*. *2*(9). 1019–1034.

[32] Yang. J.. & Zhang. J. (2010). Crop management techniques to enhance harvest index in rice. *Journal of Experimental Botany*. *61*(12). 3177–3189. https://doi.org/https://doi.org/10.1093/jxb/erq112

[33] Ying. M.. Wang. H.. Yu. S.. Liu. Z.. Zhao. C.. & Tao. Y. (2014). Effect of biochar on nitrogen forms and related microorganisms of rhizosphere soil of seedling maize. *Chinese Journal of Eco-Agriculture*. *22*(3). 270–276. https://doi.org/10.3724/sp.j.1011.2014.30750