Rice straw effect on phosphate rock from Morocco (PRM) - phosphate solubilizing bacterium (PSB) combination on acid soil in Man (Ivory Coast, West Africa).

Guety Thierry Philippe[1*], Affi Jeanne Bongoua-Devisme[1], Wondouet Hippolyte Kpan[1], Konan-Kan Hippolyte Kouadio[1], Franck Michael Lemounou Bahan[2]

1 Soil Science and Sustainable Agriculture branch, UFR STRM, Université FHB, Cocody, 22 BP 582 Abidjan 22, *Côte d'Ivoire*

2 National Centre for Agronomic Research (CNRA) Man, BP 4040 Man, Côte d'Ivoire

** Corresponding author: thierryguety@yahoo.fr Tel: +225 07 07786744*

Key words: *Rice straw, phosphate rock from Morocco, PSB, Acid soil, Man.*

Submitted 16/12/2023, Published online on 29/02/2024 in the *Journal of Animal and Plant Sciences (J. Anim. Plant Sci.) ISSN 2071 – 7024*

1 ABSTRACT

The study examines the problem of phosphorus (P) limited availability to plants. The experiment evaluates impact of rice straw, combined with Phosphate Solubilising Bacteria (PSB) and Phosphate Rock from Morocco (PRM) amendments, on P availability and soil chemical parameters. The results demonstrate the importance of the straw: it significantly lowers pH, to 4.80 in sterilised soil and 4.88 in non-sterilised soil. It encourages proliferation of PSB, increasing from 105 to 107 bacteria g^{-1} of dry sterile soil to 105 and 106 bacteria g^{-1} of dry non-sterile soil. The presence of straw also increased the level of dissolved phosphorus, reaching 9.77 $mg.kg^{-1}$ and 13.68 $mg.kg^{-1}$ of dry non-sterile soil compared with 5.05 $mg.kg^{-1}$ and 9.55 $mg.kg^{-1}$ of dry sterile soil. Furthermore, the introduction of straw exceeded the critical threshold for Dissolved Organic Carbon (DOC), exceeding 0.3 $mg.kg^{-1}$ of dry soil. Without rice straw, whatever the soil type, DOC remained below this threshold, while pH increased and phosphorus levels remained lower than those observed with the presence of straw. The mineralisation of rice straw acidifies the solution in the medium, increases P, encourages the proliferation of bacterial micro fauna and increases the medium's DOC. The addition of straw had a significant effect on the parameters of the growing medium.

2 INTRODUCTION

Phosphorus (P) is a crucial element in the growth and productivity of cereal crops such as rice and wheat; it is involved at different stages of development to maintain proper physiological, physiognomic and genetic functioning of plants. However, P deficiency in tropical soils leads to lower productivity and yields of plants in general and rice in particular (Kotchi *et al.,* 2010; Rehman and Qayyum, 2020). The best percentage of plant-available phosphorus in soil solution is ranges between 2 and 5 p.c. This deficit of P directly assimilable by the plant limits the activity of microorganisms specialized in the mineralization of soil organic matter, whose content is also particularly low (Rabeharisoa, 2004; Randriamanantsoa *et al.,* 2013). To alleviate this problem, soluble chemical fertilizers, at prohibitive cost for farmers, are applied to soils to achieve appreciable yields. However, poorly applied phosphate fertilizers can reduce soil fertility, through the mobilization of organic colloids (Siemens *et al.,* 2004; Ilg *et al.,* 2005); and excessive use of mineral fertilizers leads to a reduction in nutrient availability, particularly phosphorus and nitrogen, with adverse effects on the atmosphere (Aulakh and Adhya, 2005). Also, according to Taktek (2015), only 0.1 p.c of total P exists in the soluble inorganic form easily assimilated by plants. For Khan *et al,* (2007) and Servín, (2014), the majority (70-90 p.c) of phosphate fertilizers used in agriculture precipitate after application. They form metal complexes, thus limiting their effectiveness, which depends on edaphic conditions (Li and Stanforth, 2000; Riggle and Von Wandruszka, 2005; Servín, 2014). Due to its richness in nitrogen, phosphorus, potassium, sulphur and other micronutrients, Organic Matter (OM) helps to increase crop yields by improving soil fertility (Lompo *et al.,* 2009). Although OM improves the physical, chemical and biological properties of soils, the question of its availability in sufficient quantities remains problematic. Thus, one low-cost alternative is the use of phosphate rock (PR), which is a true source of phosphorus (Kotchi *et al.,* 2010). But one of the main obstacles to the direct application of phosphate rocks to soils is the insufficient release of P to support plant nutrition due to their low solubility in soil depending on soil characteristics (Smalberger *et al.,* 2010; Servín, 2014). PSBs enhance the amount of P solubilized in the soil and from Phosphate Amendments (PAs) to make it available to plants (Khan *et al.,* 2007). Also, organic P contained in organic matter can only be made available to plants after decomposition and mineralization by microorganisms (Smith *et al.,* 2003; Pereda Campos, 2008). Making P from PR available to the plant has led researchers to partially acidify PRs (Kpomblekou and Tabatabai, 2003), to manufacture phospho-composts based on organic residues and PR (Saleem *et al.,* 2013), to combine natural phosphates with water-soluble phosphate fertilizers (Mashori *et al.,* 2013) and to solubilize phosphate rocks with microorganisms (Servín, 2014; Taktek *et al.,* 2015). However, phosphate fertilization methods need to be tailored not only to plant requirements for this element, but also to the mechanisms by which it becomes available and used by plants to increase yields. This study was undertaken in order to introduce phosphate amendments (PAs), composed of different proportions of PR and TSP, to decrease soil pH and improve phosphate nutrition in plants. The aim of this study is to evaluate the effect of rice straw on mineralization process of phosphate rock from Morocco (PRM) by phosphate solubilizing bacteria (PSB) and on the physico-chemical parameters of the environment.

2 MATERIALS AND METHODS

2.1 Study site: The study site is located between latitudes 07°18' and 07°36' North and longitudes 07°27' and 7°53' West, at the National Center of Agronomic Research (CNRA®) of Man, in western Côte d'Ivoire (West Africa). The climate is humid tropical and the rainfall regime is unimodal, with a rainy season from March to October followed by a dry season from November to February. Our site has a ferralitic soil highly desaturated in bases with a strongly acid pH.

2.2 Chemical and natural materials: Two types were used of inputs: chemical inputs such as TSP (Triple Superphosphate), a granulated fertilizer with a water pH between 1 and 3, a minimum solubility of 90% in water and containing 30 p.c P_2O_5, and two natural inputs such as phosphate rock from Morocco (PRM), also containing 30 p.c P_2O_5 with a solubility of 3 p.c in water, and rice straw collected from farmers' plots. PRM and TSP were supplied by OCP-Africa (Office Chérifien des Phosphates). The chemical composition of the PRM is given in Table 1, and the chemical composition of the straw in Table 2.

Table 1: Chemical composition of phosphate rock from Morocco

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

Table 2: Concentration of N, P, K, Ca, Mg and C in rice straw

Nutriment	Concentration ($g.kg^{-1}$)
N	140
P	1.6
K	26.2
Ca	1.7
Mg	2.8
C	448.2

2.3 Biological material: The biological material consisted of a bacterial isolate from the soil at the study site. It was selected following isolation tests based on the characteristics described by Sharma and al. in 2011. The results of the isolation tests are reported in Table 3.

2.4 Conducting the tests

2.4.1 Soil sampling: In the field, soil samples were taken along the diagonals of the plot at different points at a depth of 0-20 cm and mixed to obtain a composite sample representative of the study site. The composite sample was divided into three parts. The first part was kept in a freezer for culturing and counting the microorganisms, and then for isolating the phosphate-solubilising bacterial strains. The second part was air-dried and used for the physico-chemical characterisation of the plot before setting up the experiment. The third part was used for batch testing.

2.4.2 Isolation of strains: Isolation was carried out in three stages: pre-culture, selection and purification of bacterial strains on solid Pikovskaya medium (PVK).

Pre-culture consisted of inoculating the wells of microplates containing liquid PVK medium with soil suspensions for 7 days of incubation. The optical densities (OD) of each well were then determined using a spectrophotometer. The results were processed by a statistical programme to determine the Most Probable Number (MPN) of bacteria present in the sample, expressed as CFU (Number of Colony Forming Units) per gram of dry soil. The selection consisted of using the positive wells for inoculation and incubation for 7 days of petri dishes on solid PVK medium according to the morphological diversity of the strains. Morphological distinction of colonies was based on criteria described by Sharma et al (2011). These include shape, colony colour, appearance, colony diameter and solubilisation halos, followed by the solubilisation index. Purification consisted of isolating bacterial strains according to their shape, colony colour, appearance, colony diameter and solubilisation halos. We used isolates with an IS >2 to reseed petri dishes containing solid PVK medium (Figure 1). This procedure was repeated five (05) times until pure bacterial strains were obtained. The strain with the highest solubilisation index was used to set up our batch experiment.

The diameter of the colony and the surrounding halo were measured to determine the solubilisation index (SI) according to the following formula:

$$IS = \frac{Colony\ diameter + Halo\ diameter}{Colony\ diameter}$$

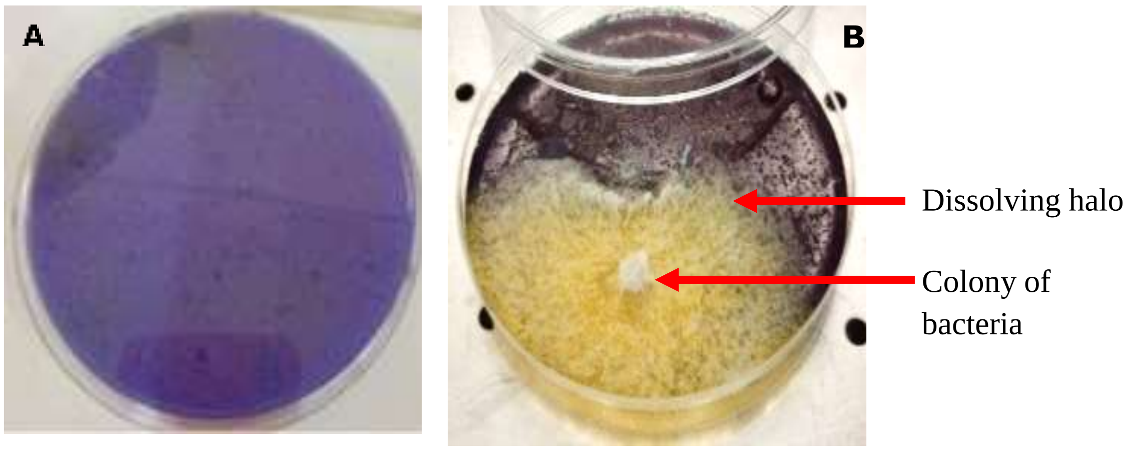


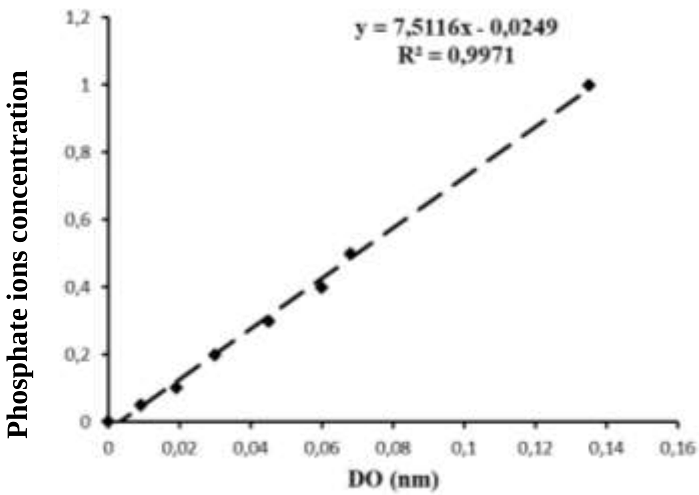
Figure 1: Uninoculated control microplate (A) and inoculated microplate showing a halo of solubilisation around a colony (B) (Source: Kpan, 2019).

2.5 Batch experiments: To complete the study on the capacity of the selected bacterial strain to effectively solubilise phosphate, a batch experiment was carried out in the laboratory in which the soil sample was divided in two and then one part was sterilised by heat treatment (autoclave) at a temperature of 120°C for 15 minutes on three (03) occasions at one (01) day intervals. In each pot of 400 cm^2 surface area, 30g of sterile or non-sterile tray soil was introduced. Then 1.2 g (300 $kg.ha^{-1}$) of phosphate amendments composed of different proportions of phosphate rock (PR) and/or triple super phosphate (TSP) to give 0.144g P /pot or 90 kg $P_2O_5.ha^{-1}$ and finally 300 ml of sterilised distilled water to give a moisture content of 80 p.c were added, then homogenised. The treatments received 250 µl of bacterial isolate, corresponding to 108 bacteria per pot. The pots were shaken and incubated for sixty (60) days in a randomised complete block design with 4 blocks. The treatments applied are shown in Table 3.

Table 3: Content of the various treatments

Type of soil	Inputs ($kg.ha^{-1}$) PRM+TSP	P_2O_5	Quantity of straw supplied ($t.ha^{-1}$)	Inoculum (I)
SterileSoil	300	90	0	+ I
SterileSoil	300	90	0.15	+ I
Non-Sterile Soil	300	90	0	+ I
Non-Sterile Soil	300	90	0.15	+ I

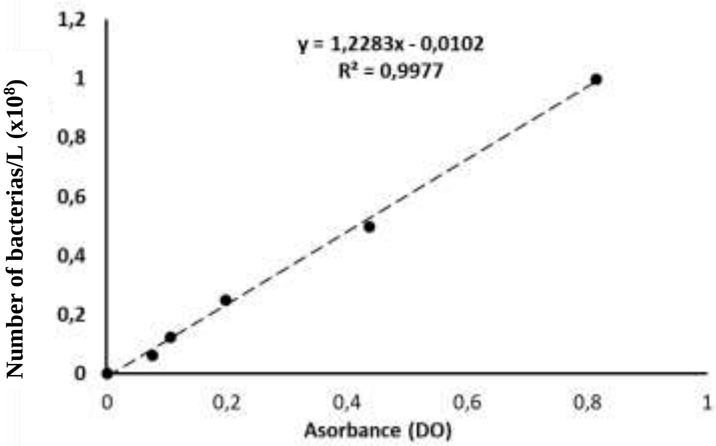
2.6 Data collection: After 0, 10, 20, 30, 40, 50 and 60 days of incubation, 5 ml of the different solutions were taken from each pot and centrifuged at 4,000 rpm for 15 minutes. The supernatant obtained was then used to determine changes in the parameters (pH, P, dissolved organic carbon (DOC) and number of bacteria) of the culture medium. The pH was determined electrometrically using a pH meter with a glass electrode (744 pH metermetrohm). Total organic carbon was determined by the Walkley-Black method using oxidation in a mixture of potassium dichromate and sulphuric acid. This method assumes that the quantity of oxygen consumed is proportional to that of the carbon to be determined. Phosphorus in solution was determined spectrophotometrically using the Spectroquant phosphate kit, a method based on the determination of orthophosphate ions. In a sulphuric solution, orthophosphate ions form phosphomolybdic acid with molybdate ions. This is reduced by ascorbic acid to blue phosphomolybdenum (BPM), which was measured photometrically and the absorbance was measured at 790 nm and then converted to mg.kg^{-1} using the established standard range (Figure 2).



Y = Phosphorus content; X = Optical density or Absorbance of the sample; R² = Coefficient of determination

Figure 2: Standard curve for phosphorus

From the measurement of the optical density (OD) of dilutions (100 to 108) of bacterial cultures, a calibration curve of bacterial growth as a function of OD was established (Figure 3). The number of bacteria in the lowest dilution was determined using the Thomas cell, giving the straight line y = ax + b (where y = number of bacteria and x = OD). Once the ODs of the culture media have been determined, the values are used to determine the number of bacteria using the pre-established standard curve (Figure 3).



Y = Number of bacteria; X = Optical Density or Absorbance of the sample; R² = Coefficient of determination;

Figure 3: Standard curve for the isolate (strain 1) used in the pot experiment.

2.7 Statistical analysis: Using SAS 9.0 software, analyses of variance (ANOVA) were performed using the Student Newman_Keuls (SNK) test to determine the significance of the different treatments on the mean levels of solubilised P, dissolved organic carbon (DOC), the number of bacteria and pH, using the least significant difference (LSD) method at the 5 p.c significance level.

3 RESULTS

3.1 Physico-chemical characteristics of the soil: The soil has a sandy – silty – clay loam texture, moderately acid with a pH water of 5.2 and a pHkcl = 3.6. The variation in pH (ΔpH= pHwater - pHkcl) is ΔpH >1. The soil contains a small amount of nitrogen (less than 100 mg.kg^{-1}) and its carbon and phosphorus contents are 143 mg.kg^{-1} and 5 mg.kg^{-1} respectively. However, although it's organic matter content is high (246 mg.kg^{-1}), there is little decomposition of organic matter, resulting in a high C/N ratio (C/N>10) (Table 4). The CEC is low (1.54 cmol^{+}.kg^{-1}), and the saturation rate (18.23 p.c) shows that the soil is desaturated in exchangeable cations such as calcium, magnesium, potassium and sodium, with respective values of 1.00 cmol^{+}.kg^{-1} ; 0.32 cmol^{+}.kg^{-1} ; 0.11 cmol^{+}.kg^{-1} ; 0.11 cmol^{+}.kg^{-1} (Table 4).

Table 4: Physico-chemical characteristics of the soil in the 0 - 20 cm horizon before experimentation

Soil characteristic	Value
Argile (%)	28.65
Limon (%)	16.35
Sable (%)	55
pHeau	5.2
pH_{KCl}	3.6
P assi (mg.kg^{-1})	5
C organique (mg.kg^{-1})	143
N total (mg.kg^{-1})	13
MO (mg.kg^{-1})	246
C/N (mg.kg^{-1})	11
K^+ (cmol^{+}.kg^{-1})	0.11
Na^+ (cmol^{+}.kg^{-1})	0.11

Ca^{++} ($cmol^{+}.kg^{-1}$)	1.00
Mg^{++} ($cmol^{+}.kg^{-1}$)	0.32
CEC ($cmol^{+}.kg^{-1}$)	1.54
S/T (%)	18.23

3.2 Macroscopic characteristics of isolated strains: Overall, four (04) bacterial strains were identified on solid PVK medium from the Plateau soil sample. The macroscopic study of the bacterial strains showed that the diameters of the halo zone varied from (0.2 to 1cm) and the solubilisation indices (SI) (from 0.6 to 3.6) (Table 4). The colour of the strains identified is green-yellow (S1), brown (S2), brown-green (S3) and green (S4) and they have a rounded (S3 and S4) and subangular (S1 and S2) shape but they all have a cottony appearance. Furthermore, only strain S1 obtained a solubilisation index IS>2, which is equal to 3.6 (Table 4).

Table 4: Macroscopic characteristics of the BSPs found on the Man plateau soil.

Isolates	Morphological characteristics	Halo diameter (cm)	IS
S1	Cotton aspect, green-yellow colour, subangular shape	1.03±0.15	3.6±1.2
S2	Cotton aspect, brown colour, subangular shape	0.2±0.01	0.6±0.04
S3	Cotton aspect, brown-green colour, rounded shape	0.7 ± 0.02	1.2 ±0.3
S4	Cotton aspect, green colour, rounded shape	0.4 ±0.03	1.5 ±0.5

SI = Solubilisation index

3.3 Changes in culture medium parameters in Batch studies

3.3.1 Changes in pH: The evolution of the medium parameters during the batch experiments shows that on sterilised soil, the initial pH values (day 0) vary according to the presence or absence of straw. The pH on the first day in the absence of straw was 5.7 compared with 6.57 in the presence of straw. From the 1st to the 10th day after the start of the experiment, the pH in the presence of straw in the medium fell rapidly and reached 5.53, while the pH in the absence of straw remained constant. From the 10th to the 60th day of the experiment, the pH in the presence of straw fell progressively to reach a value of 4.8, while the pH in the absence of straw remained constant until the 50th day before increasing to reach 6 on the 60th day (Figure 4). On non-sterile soil, at the start of the experiment, the pH in the presence of straw (pH = 5.6) and in the absence of straw (pH = 5.72) were low compared with the pH under sterile soil. The pH trend is identical to that of the sterile soil. However, variations from the 1st to the 50th day of the experiment were significantly lower than in the sterile soil. Between days 50 and 60, the pH in the presence of straw fell sharply to 4.88, while in the absence of straw it rose rapidly to 6.02 (Figure 4).

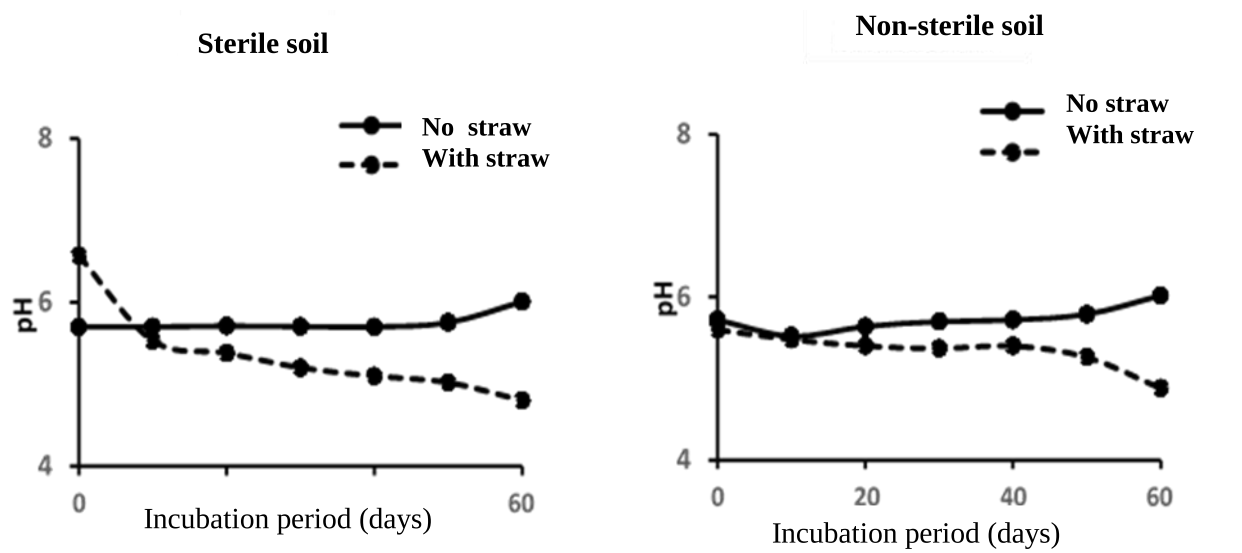


Figure 4: pH evolution during incubation times in the presence or absence of rice straw in sterilized and none sterilized soil

3.3.2 Changes in P content: Generally speaking, P levels increased in both types of soil (sterile and non-sterile), whether or not straw was present in the medium from day 1 to day 60 of the experiment. However, the P content of the non-sterile soil was higher, fluctuating between 9.77 $mg.kg^{-1}$ and 13.68 $mg.kg^{-1}$ of dry soil in the absence of straw, compared with 11.18 $mg.kg^{-1}$ and 17.2 $mg.kg^{-1}$ of dry soil in the presence of rice straw. The P content of sterile soil in the presence of rice straw varied between 5.05 $mg.kg^{-1}$ and 9.55 $mg.kg^{-1}$ of dry soil without straw, compared with 6.24 $mg.kg^{-1}$ and 10.27 $mg.kg^{-1}$ of dry soil in the presence of rice straw (Figure 5). Despite this general gradual increase, the P content of the sterile soil that had received the straw increased rapidly from day 1 to day 10 and from day 40 to day 50 of the experiment (Figure 5).

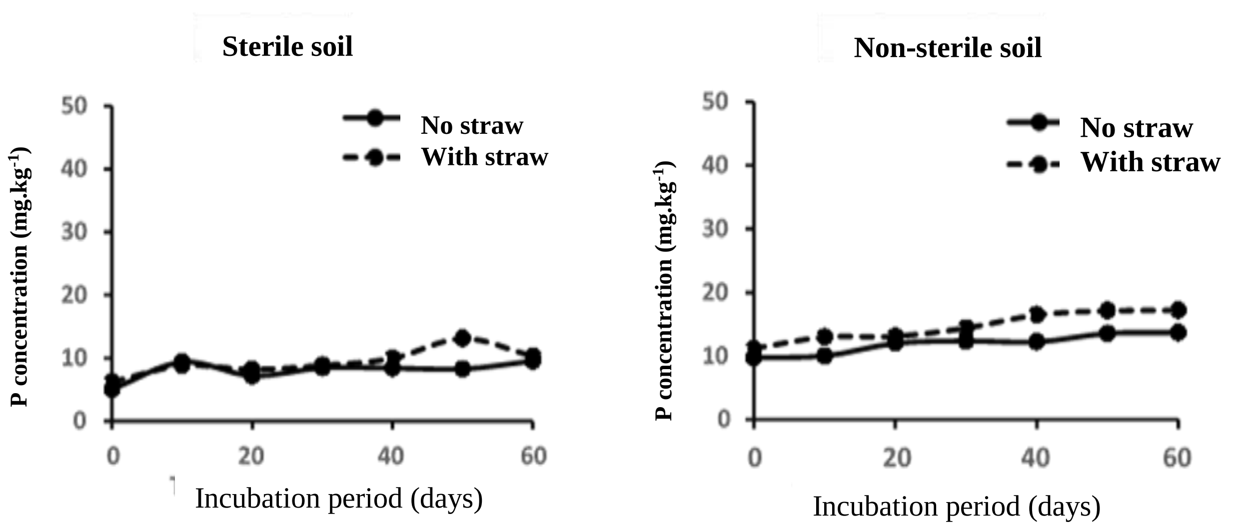


Figure 5: P content evolution during incubation times in the presence or absence of rice straw in sterilized and none sterilized soil

Journal of Animal & Plant Sciences (J.Anim.Plant Sci. ISSN 2071-7024)
Vol.59(2) : 10843 -10855 https://doi.org/10.35759/JAnmPlSci.v59-2.1

3.3.3 Changes in the number of PSB and DOC: The number of bacteria on the non-sterile soil was higher than the number of bacteria on the sterile soil from the beginning to the end of the experiment. However, on the sterile soils the number of bacteria increased significantly over the course of the experiment (from 105 to 107 bacteria g^{-1} of dry soil in the presence of rice straw, whereas in the absence of straw the number fluctuated between 105 and 106 bacteria g^{-1} of dry soil). On non-sterile soils, the number of bacteria increased progressively in the presence or absence of rice straw up to day 20. But from day 20 to day 60, compared with the medium with rice straw, the number of bacteria in the absence of rice straw was higher, with a peak of 4.06.108 bacteria g^{-1} of dry soil on day 30. After 60 days, the non-sterile soil with straw contained an average of 3.65.108 bacteria compared with an average of 3.9.108 bacteria in the non-sterile soil without straw (Figure 6). In the absence of rice straw in the growing medium, dissolved organic carbon (DOC) was below the threshold (<0.3 $mg.kg^{-1}$) for all soil types. But in the presence of rice straw in the medium, on infertile soils we obtained 1.39 $mg.kg^{-1}$ DOC compared with 1.14 $mg.kg^{-1}$ DOC on infertile soils (Table 5).

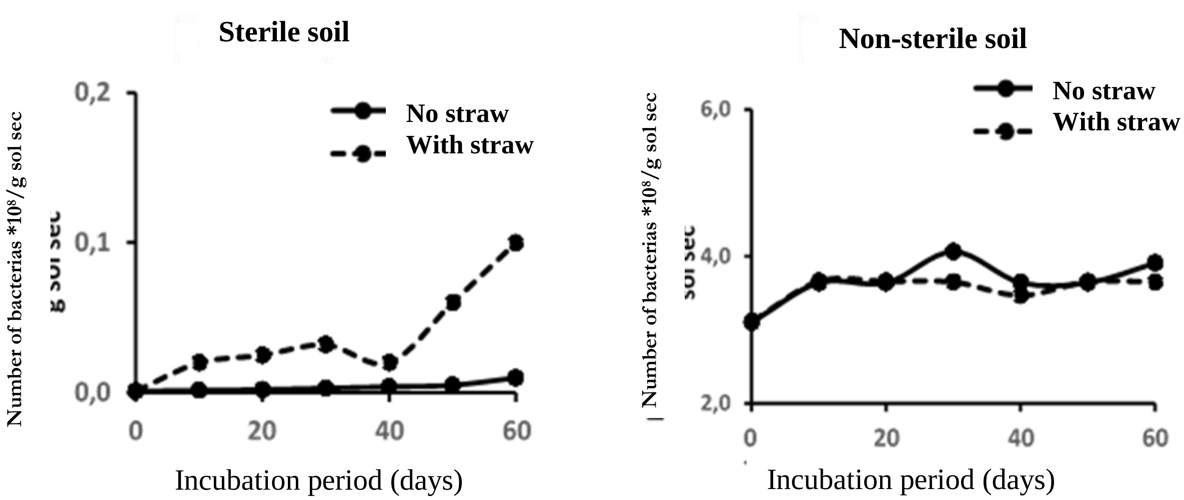


Figure 6: Bacteria number evolution during incubation times in the presence or absence of rice straw in sterilized and none sterilized soil

The ANOVAs carried out on the pH values, phosphorus content, number of bacteria and dissolved organic carbon indicate a drop in soil pH (4.81 and 4.86) highly significant at $P = 0.0001$ after 60 days of incubation in the presence of straw and an increase in pH (5.74 and 6.13) highly significant at $P = 0.0001$ after 60 days of incubation in the absence of straw (Table 5), regardless of the type of soil (sterile or non-sterile). There was a highly significant increase in phosphorus content and DOC at $P<0.05$ after 60 days of incubation in the presence of straw compared with the treatment without straw (Table 5) on both sterile and non-sterile soil. The number of bacteria was significantly greater at $P<0.01$ in the presence of straw than in the absence of straw on the sterile soil. But on the non-sterile soil, bacterial proliferation under the straw treatment was not significantly different from that without straw (Table 5).

Table 5: Statistical test for changes in environmental parameters with or without rice straw

	Non sterile				Sterile			
Treatments	pH	P ($mg.kg^{-1}$)	PSB	DOC ($mg.kg^{-1}$)	pH	P ($mg.kg^{-1}$)	PSB	DOC ($mg.kg^{-1}$)
Rice straw	4.8b	17.40a	16.10^8a	1.39a	4.86b	13.80b	$4.3.10^5$a	1.14a
Without Rice straw	6.13a	9.72b	15.10^8b	<0.3b	5.74a	9.58a	$3.7.10^5$a	<0.3b
CV (%)	3.43	7.87	42.92	19.79	3.768	12.204	11.45	8.95
Pr>F	0.001^{*}	0.0009^{**}	0.01^{*}	0.0002^{**}	0.006^{**}	0.022^{*}	0.17^{ns}	$<0.0001^{***}$

*The values in the table are the averages of the parameters measured during the follow-up of the experiment. Data in the same column followed by the same letter are not significantly different according to the Newman-Keuls test p<0.05. (0.3 is the COD detection threshold) *** very highly significant at the p<0.05 threshold; ** very significant at the p<0.05 threshold; * significant at the p<0.05 threshold;*

4 DISCUSSION

4.1 Effect of rice straw on the pH, bacterial count and DOC of the medium:

The analysis showed that the addition of rice straw to the growing medium led to a gradual drop in pH from the beginning to the end of the experiment compared with the medium without rice straw, while the number of bacteria in the medium increased from the beginning to the end of the experiment. These two phenomena are thought to be linked by the fact that the rice straw added to the medium was a source of nutrients for soil-dwelling organisms (Lompo *et al.,* 2009). In fact, the processes of decomposition and mineralisation of rice straw by soil microorganisms lead to acidification of the environment through the release of acids such as oxalic, citric and tartaric acids and organic carbon (DOC) into the environment (Caribou, 2013; Plassard *et al.,* 2015). This rice straw decomposition activity allows soil microorganisms to proliferate. These results are in line with those of Bongoua *et al.,* 2012, who observed a drop in soil pH and an increase in the number of bacteria after application of organic amendment in rice field soils in Thailand, affected by salinity problems, probably due to the reducing Ferri activities of bacteria. The increase in pH in the absence of rice straw is thought to be due to the mineralisation of the P contained in the treatments applied during the experiment. RPM contains 49.54 p.c Ca, whose release into the environment would create a liming effect that reduces the H^+ concentration of the soil solution and increases the pH (Traoré, 2009; Hartemink and Barrow, 2023).

4.2 P content and number of bacteria:

The initial pH of the soil used for the experiment predisposed it to better solubilisation of the RPM contained in the treatments applied at the start of the experiment, which helped to increase the quantity of P in the medium. This result is in line with those of Plassard et al. 2015, whose work on the involvement of plants and biological processes in the bioavailability of phosphorus revealed that an acid soil favours the solubilisation of Ca phosphates, while reducing the solubility of iron and aluminium phosphates. The low CV values (<15 p.c) in the ANOVAs indicate that environmental P has another source. This increase in environmental P would also be induced by mineralisation of soil OM and rice straw by soil microorganisms. The degradation of rice straw, which has a high phosphorus content (1.6 $mg.kg^{-1}$), or of soil OM in the absence of rice straw, will promote the mineralisation of soil phosphorus and consequently increase the soluble P content of the medium (Koulibaly *et al.,* 2010). For Plassard *et a*l. (2015), the addition of organic matter as a source of carbon in the medium stimulated the mineralisation of P in the soil and in the straw. In 2011, a study by Oburger *et al.* showed that in tropical soils with acid pH, most of the Pi is bound to clay and Fe and Al oxy (hydr) oxides. This quantity of Pi could be released as a result of variations (increase or decrease) in the pH of the environment acting on the sites of P fixation by the OM or clay in the soil (Devau *et al.,* 2009). Our results also show that a variation in pH can favour the availability of P in the environment, as demonstrated by the work of Devau *et al,* (2011).

5 CONCLUSION

The addition of straw to the growing medium affects the pH of the medium, mineralised P and DOC. The presence of straw in the medium favoured the proliferation of PSBs, which in turn favoured the solubilisation of PAs present in the growing medium. The mineralisation of rice straw acidifies the solution in the medium, increases P, encourages the proliferation of bacterial microfauna and increases the medium's DOC. The addition of straw had a significant effect on the parameters of the growing medium. The combination of rice straw, PSB and PRM is therefore very promising as an alternative to chemical fertilisers for improving soil properties and increasing the efficiency of PR use. However, field trials are needed to confirm the agronomic and economic profitability of applying this combination.

Conflicts of interest: The authors declare that there are no conflicts of interest.

Authors' contributions : Guety Thierry Philippe, Affi Jeanne BONGOUA-DEVISME and Wondouet Hippolyte KPAN took part in setting up and conducting the laboratory tests, in the design, then in the writing and formatting of the article; Konan-Kan Hippolyte KOUADIO and Franck Michael Lemounou BAHAN were the supervisors at all stages of this work.

6 ACKNOWLEDGEMENTS

We would like to sincerely thank OCP-Africa for supplying the fertilizers that were used, and the National Centre for Agronomic Research (CNRA) of Man for approval to use samples from their plot in this study.

7 BIBLIOGRAPHY

Aulakh MS. and Adhya TK: 2005. Impact of agricultural activities on emission of greenhouse gases – Indian perspective. In 'International Conference on Soil, Water and Environmental Quality – Issues and Strategies. *Indian Society of Soil Science: New Delhi*. pp. 319-335.

Bongoua J, Mustin C. and Berthelin J: 2012. Salinity, rhizosphere and organic amendment impact on iron reducing bacterial activity in paddy rice field (Thailand*)*. *Pédosphère*. Volume 22, Numéro 3, juin 2012, pages 375-393 https://doi.org/10.1016/S1002-0160(12)60024-1

Chaibou Z :2012. Effet du phospho-compost sur la production de mil (Pennisetum glaucum : cas de la commune urbaine de Niamey. Mémoire de Master, Niamey, Niger. p28.

Devau N, Hinsinger P, Le Cadre E, Colomb B. and Gerard F : 2011. Fertilization and pH effects on processes and mechanisms controlling dissolved inorganic phosphorus in soils. Geochimica et Cosmochimica Acta 75, 2980-2996.

Devau N, Le Cadre E, Hinsinger P, Jaillard B. and Gerard F : 2009. Soil pH controls the environmental availability of phosphorus: Experimental and mechanistic modelling approaches. *Applied Geochemistry* 24, 2163-2174.

Hartemink AE. and Barrow NJ : 2023. Soil pH – nutrient relationships : the diagram. *Plant and Soil*. 486, 209-215.https://doi.org/10.1007/s11104-022-05861-z

Ilg K, Siemens J. and Kaupenjohann M: 2005. Colloidal and Dissolved Phosphorus in Sandy Soils as Influenced by Phosphorus saturation. J. Environ. Qual. 34 : pp. 926 – 935. DOI: https://doi.org/10.2134/jeq2004.0101

Jones DL, Oburger E. and Wenzel WW : 2011. Phosphorus saturation and pH differentially regulate the efficiency of organic acid anion-mediated P solubilization mechanisms in soil. *Plant and Soil* 341, 363- 382.

Khan ZR, Midega CAO, Wadhams LJ, Pickett JA. and Mumuni A : 2007. Evaluation of Napier grass (*Pennisetum purpureum*) varieties for use as trap plants for the management of African stemborer (*Busseola fusca*) in a push–pull strategy. Entomol. Exp. Applic., 124 (2): 201–211. https://doi.org/10.1111/j.1570-7458.2007.00569.x

Kotchi V, Yao-Kouamé A. et 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). pp. 1895–1905.

Koulibaly B, Traoré O, Dakuo D, Zombré PN. et Bondé D : 2010. Effets de la gestion des résidus de récolte sur les rendements et les bilans culturaux d'une rotation cotonnier- maïs-sorgho au Burkina Faso. *Tropicultura* 28 (3), 184-189.

Kpomblekou K. and Tabatabai MA : 2003. Effect of low-molecular weight organic acids on phosphorus release and phytoavailability of phosphorus in phosphate rocks added to soils, *Agriculture Ecosystem and Environment*., 100, 275–284.

Lompo F, Segda Z, Gnankambary Z. et Ouandaogo N : 2009. Influence des phosphates naturels sur la qualité et la bio- dégradation d'un compost de pailles de maïs. *Tropicultura*, *27*(2), 105–109.

Mashori NM, Memon M, Memon KS. and Kakr H : 2013. Maize dry matter yield and P uptake as influenced by rock phosphate and single super phosphate treated with farm manure, *Soil Envi- ronm.*, 32, 130–134.

Pereda and Campos MV : 2008. Contribution à l'étude des transporteurs de phosphate de la famille PHT1 chez le Peuplier (Populus trichocarpa Torr. & Gray) et le champignon ectomycorhizien Laccaria bicolor (Maire) P. D. Orton. Thèse doctorat. Université Henri Poincaré, Nancy I (France). P 141.

Plassard C, Robin A, Cadre E, Le Marsden C, Trap J, Herrmann L. et Hinsinger P : 2015. Améliorer la biodisponibilité du phosphore : comment valoriser les compétences des plantes et les mécanismes biologiques du sol ? *Innovations Agronomiques*, *43*(January), 177–186.

Rabeharisoa L : 2004. Gestion de la fertilité et de la fertilisation phosphatée des sols ferrallitiques des Hautes Terres de Madagascar. Thèse de Doctorat d'Etat ès-Sciences Naturelles. Université d'"Antananarivo, Faculté des Sciences, Département de Biologie et Ecologie Végétales. 199 p.

Randriamanantsoa L, Morel C, Rabeharisoa L, Douzet JM, Jansa J. and Frossard E : 2013. Can the isotopic exchange kinetic method be used in soils with a very low water extractable phosphate content and a high sorbing capacity for phosphate ions ? Geoderma Volume 200 et 201, juin 2013, pages 120-129. DOI : http://dx.doi.org/10.1016/j.geoderma.2013.01.019.

Rehman RA. and Qayyum MF : 2020. Co-composts of sewage sludge , farm manure and rock phosphate can substitute phosphorus fertilizers in rice-wheat cropping system. Journal of Environmental Management, 259p (April). https://doi.org/https://doi.org/10.1016/j.jenvman.2019.109700

Servín PM: 2014. Development of an Inoculant of Phosphate Rock-Solubilizing Bacteria To Improve Maize, pp 1-10. DOI : http://hdl.handle.net/20.500.11794/24965

Sharma S, Kumar V. and Tripathi RB: 2011. Isolation of phosphate solubilizing microorganism (PSMs) from soil. *Journal of Microbiology and Biotechnology Research*. 1:90-95

Siemens J, Ilg K, Lang F. and Kaupenjohann M:2004. Adsorption controls mobilization of colloids and leaching of dissolved phosphorus. European Journal of Soil Science 55: pp. 254 - 263. https://doi.org/10.1046/j.1365-2389.2004.00596.x

Smalberger SA, Chien SH, Singh U. and Henao J :2010. Relative agronomic effectiveness of phosphate rock compared with triple superphosphate for initial canola, wheat, or ryegrass, and residual wheat in two acid soils. *Soil Science*. 175(1): 36-43.

Smith SE, Smith FA. and Jakobsen I :2003. Mycorrhizal fungi can dominate phosphate supply to plants irrespective of growth responses. *Plant Physiology*, 133: 16-20. Summerson,

Taktek S : 2015. Dissolution biologique des phosphates : Interaction bactéries - mycorhizes. Thèse de doctorat, Université LAVAL, Québec, Canada. pp. 1-10

Taktek S, Trépanier M, Servin PM, St-Arnaud M, Piché Y, Fortin JA. and Antoun H :2015. Trapping of phosphate solubilizing bacteria on hyphae of the arbuscular mycorrhizal fungus Rhizophagus irregularis DAOM 197198. *Soil Biology and Biochemestry*. 90 : 1-9

Traoré B : 2009. Effets des techniques de gestion de la fertilité sur le sol et sur les systèmes de culture à base de mil. Université de Bamako.

Walkley A and Black IA : 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science. 37 : 29–38.