

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

Kotchi Valère¹, Tonessia D. Charlotte², Soko D. Faustin³

^{1,2,3}Department of Soils Sciences and Agriculture/Plant Physiology, University of Jean Lorougnon Guédé, Daloa, Côte d'Ivoire*
Email address: ¹vkotchie@hotmail.com, ²dolouc@yahoo.fr, ³fsoko2000@yahoo.fr

Abstract - Phosphorus (P) availability in acid soils of humid forest regions is a major constraint to the development of agriculture. In fact, the bonds between the orthophosphates and iron and aluminum oxides and hydroxides in quantity in these soils give to them abilities to fix P, reducing its availability for plant nutrition.

The inputs of P in different forms actually contribute to meeting the needs of the crops, but remain under-exploited because of the very high P binding capacity of these soils, which further increases the acidity of the soils. The addition of organic matter contributes significantly to reduce the fixing power of P and increasing the availability of this nutrient (Eastwood and Sartain, 1990). The residual substrates for mushroom production or spent mushroom substrates (SMS), in increasing quantity in the subregion due to the development of mushroom cultivation, may be an alternative. Indeed, rich in organic matter and with a near neutral pH, the add of these substrates to the soil makes it possible to reduce the sites of fixation of the metal ions, lowering the P fixation capacity and increasing its availability (Sun and al. ., 2008).

Experiment conducted for this purpose by application of two residual substrates S1 and S2 from fungi production on acid soils from two sites in the humid forest zone in Côte d'Ivoire, including Man and Abengourou respectively to the west and in the eastern part of the country has shown a decrease in the binding capacity of P. According to the results, the decrease in the fixing power of P depends on the characteristics of the substrate, including the pH but also the rate of incorporation of substrate into soil. Thus, the S2 substrate from a rice straw compost is more appropriate for lowering the ability or P-fixing ability of acid soils in moist forest regions. In fact, a contribution of 15p.c. by volume of this substrate suffices to impact the availability of P in the soils.

Keywords- Phosphorus, acidic soils, capacity of de fixation, substrates, organic matter, oxydes, hydroxydes.

I. INTRODUCTION

In the acid soils of humid forest regions, phosphorus remains one of the binding mineral element (Gervy 1970, Fardeau et Jappe 1980) as to its availability for plant nutrition in general and rice in particular. The bonds between the metal ions (oxides and hydroxides of iron and aluminum) in quantity in these soils with phosphorus (P) make this element little available (Abekoe et al., 2001, Maguire et al., 2001; Novak and Watts, 2004). Many authors believe that these chemical bonds coupled with other factors including pH, organic matter content, etc., would give to these soils the ability to fix or release P. For others authors (Pellerin et al., 2006), ability to

fix or release mineral element and particularly P would be a specific characteristic parameter to soils. Factors such as pH, nature and levels of organic matter, etc. would be likely to influence this parameter. The purpose of the present study is to determine P fixation capacities of different acid soils and above all, to test the influence of two types of Spent Mushroom Substrates (SMS) S1 and S2 on those acidic soils from humid forest regions of Côte d'Ivoire. Specifically, this study aims to i) determine the physicochemical characteristics of each soil; ii) determine for each soil the ability to fix P and iii) evaluate the influence of the add of the substrates S1 and S2 on this capacity.

II. MATERIALS AND METHOD

2.1 Materials

Field of studies

The experiments were conducted at the soil and plant laboratory of the Africa Rice Center (AfricaRice) located in Bouake in central Côte d'Ivoire.

Soils

The soils that are the subject of this study come from two sites located in Man and Abengourou, respectively in the west and east of Côte d'Ivoire. These soils are very representative of those of the humid forest zone of this country. Two SMS from the edible fungus *Pleurotus Eous* var. S1 and S2 were used. The substrate S1 is derived from a compost originally made up in volume proportion by red sawdust (63 p.c.), rice straw (9 p.c.), rice bran (2 p.c), inert lime (1 p.c.) and water (25 p.c.). The substrate S2 is derived from a compost originally made up in volume by red sawdust (22 p.c.), rice straw (50 p.c.), rice bran (2 .p.c.), inert lime (1 pc) and water (25 pc). Potassium dihydrogenphosphate (KH₂PO₃) was used as a source of phosphorus.

2.2 Method

Sampling and physico-chemical characterization of soils

In each site, a composite sample was obtained from a mixture of ten holes in the 0-20 and 20-40 cm horizons of soil with a helical auger in the immediate environment of an open profile made in effect of a soil characterization of the environment.

Explicitly, the soil samples were air-dried to 14% relative humidity and sieved (2 mm or less in diameter). On the soils passing the sieve, the particle size, the water pH and KCl (1M) were determined according to the potentiometric method in a sol /solution ratio of 1: 2.5; total phosphorus and assimilable phosphorus, according to the Bray method (Bray and Kurtz, 1945). Soils were then grouped in two according to the water pH: very acid soils (pH below 4.8), and acid soils (pH between 4.8 and 6.7).

Similarly, the levels of total nitrogen, organic carbon and metal cations, in particular aluminum and iron, were determined for each soil sample.

Determination of the fixing capacity in P

The standard method of Ozanne and Shaw (O & S) (1968) adapted to acid soils, very fixative of P, was used to determine the P fixation capacity of the soils used.

Principle of the method of Ozanne and Shaw

This method is based on the principle according to which, the average content of P in the solution of the ground is considered unless 0,2 M. Phosphorus in various doses is then brought to samples of soils in a solution of CaCl₂. The P content in the floating solution, after separation of both circles is then estimated. The P capacity of adsorption of the ground would correspond to those in which the concentration of P of the floating solution would vary between 0,25 and 0,35 mg of P/l, considered as interval of the extreme P contents, also called Ozanne and Shaw interval of the values. The capacity of adsorption of P is then the difference between the quantity of P brought to the solution and that residual in the floating solution. The implementation of the method required several stages.

Step 1. Characterization of samples o Preparation of samples

Every composite samples stemming from a site was divided into two heap, and, each heap, divided into four samples. On four samples of the first heap of the first ground, were added in weight 0; 5 p.c. ; 15 p.c. and 30 p.c. of the substrate S1. It was the same with the substrate S2 at the level of the samples of the second heap, of the same composite soil. The operation was repeated with the samples of the second ground. Each of the obtained mixtures constitutes a composite sample (E3). We get now sixteen samples of composite. A witness of eight sample of every soil was eliminated for reasons of repetition, what gives us for every

Step 2. Determination of the capacity of P fixation

- Preparation and extraction of the solutions of the composite samples

The various established samples (E3), and placed in tubes of 100 ml containing each 50 ml of a solution of CaCl₂ in 0,01M. For each series, quantities of 0; 1; 2,5; 5; 7,5; 10; 12,5; 15, 20 and 25 mg of PI⁻¹, in the form of KH₂PO₃ were added in each of the tubes. Also, some chloroform (0,25 p.c., v/v) is added in every tube, to inhibit any microbial activity. Tubes were shaken during 16 hours on a horizontal agitator, at the speed of 10 tours/min, in 25 °C, and then spin-dried at a speed of 6 000 tours/min, during 10 minutes to separate the solution of the ground.

- Analyzes and measurements performed

The pH of each composite sample was determined, as well as its P content by colorimetry, according to the method of Murphy and Riley (1962). Using graphs, the average amounts of adsorbed P were plotted against the final P content of the supernatant solution for each soil series. The adsorption band, corresponding to residual contents of P in this solution, between 0.25 and 0.35 mg of PI⁻¹, was identified on each graph. The amount of P adsorbed, corresponding to a content of 0.3 mg of PI⁻¹ in the supernatant solution, was used to estimate the adsorption capacity of P. The mathematical method of linear regression is used when no direct value corresponded to a content of 0.3 mg of PI⁻¹ of the supernatant solution.

- Data processing, factors and studies carried out

The analysis of the measurement and analysis data, especially P data, of the various composite soil samples made it possible to evaluate the influence of soil characteristics, pH and organic inputs on the absorption capacities.

III. RESULT AND DISCUSSION

3.1 Physical and Chemical Characteristics of Soils, Composite Soils and Substrates

The sites of Man and Abengourou have ferrallitic soils (Ferralsols) respectively strongly and moderately desaturated in bases. Soils are generally deep (+ 120 cm) and very acidic. The acidity of Man's soil remains higher than that of Abengourou. Similarly, both soils abound large amounts of metal ions, including Al³⁺ and Fe³⁺. Their P assimilable content remains very low, unlike the stock of P they overflow (Table I).

TABLE I. Physical and chiminal characteristics of soils in the sites

Nature analyses effectuées	Sol Man	Sol Abengourou
Partical characteristic (g.kg⁻¹)		
Clay	395	270
Fine silt	30	40
Coarse lime	180	187
Fine sand	235	240
Coarse sand	160	270
pH eau	4,4	5,9
pH (1M KCl)	3,8	4,7
pF 4,2	12,4	10,7
pF 2,5	17,3	14,9
CEC (cmol (+).kg ⁻¹)	8,30	12,4
Taux de saturation		
Bases échangeables (cmol (+).kg⁻¹)		
K	0,23	0,29
Mg	0,14	0,19
Na	0,06	0,08
Ca	0,42	0,81
Al (cmol (+).kg-1)	0,98	0,77
extractible Fe (mg/kg)	33,6	46,6
P. Bray I (mg/kg)	2,1	6,4
Total P. (mg/kg)	250	218
Organic Carbone (g/kg)	10,0	9,0
Total N (mg/kg.)	579	350
¹ m = (Al x 100) / (Al +SBE*)	48,9	35,9

The analyzes of the substrates (Table II) shows that S1 and S2 have a substantially neutral pH which is respectively 6.9 and 7.1. They are both rich in organic matter, and have a

moderately high nitrogen content. The concentration of P and K in substrates regardless of the nature remains low. The C/N ratios close to 15 (16.1 for the substrate S1 and 17.8 for the substrate S2) effectively reflect the high level of degradation of the organic matter generated by the mushroom culture. Similarly, the pH of composite soils (soils + substrate) remains acid, and the average varies from 4.3 to 5.1 with Man soils and from 5.1 to 5.8 with Abengourou soils. However, their acidity level varies according to the nature of the spent mushroom substrates used (S1 or S2) but generally decreases contrary to the increase of their incorporation rate (Table II).

The add of substrates raises the pH and improves other parameters such as: Cation Exchange Capacity (CEC), total nitrogen, organic carbon and available P. The mobilization of P is more increased in composite soils, and its average reaches to 18 mg of Pkg⁻¹ in composite soil, compared to 6.5 mg of Pkg⁻¹ in soil concerning Abengourou, and 11 mg of Pkg⁻¹ in composite soil, compared to 2.6 mg of soil Pkg⁻¹ in soil concerning Man.

TABLE II. Chemical characteristics of soils composites sample

Treatment	pH eau	Sol.P** (mg de Pkg ⁻¹)	Tot. P (mg de Pkg ⁻¹)	CEC (cmol (+).kg ⁻¹)	C (p.c.)	N total (mg/kg)
Sol Man	4,3	2,6	300	5,29	1,30	790
Sol Aben.*	5,1	6,5	248	10,3	1,20	450
SAS1-5	5,4	8,1	281	7,9	4,2	840
SAS1-10	5,6	9,7	294	10,4	5,6	890
SAS1-15	5,7	11,8	306	13,1	8,3	960
SAS1-30	5,6	12,1	328	14,3	10,6	1100
SAS2-5	5,7	9,3	269	8,4	4,6	870
SAS2-10	5,7	11,2	282	11,3	5,5	920
SAS2-15	5,8	17,6	283	15,7	8,2	1040
SAS2-30	5,7	16,2	298	16,3	10,1	1140
SMS1-5	4,6	4,9	305	6,8	5,4	520
SMS1-10	4,6	5,7	326	7,2	7,6	590
SMS1-15	4,6	8,9	335	8,9	8,9	620
SMS1-30	4,7	9,1	356	9,1	10,8	1670
SMS2-5	4,6	6,1	301	7,6	3,8	580
SMS2-10	4,7	8,3	315	8,4	7,3	650
SMS2-15	4,7	9,8	312	14,3	9,4	740
SMS2-30	5,1	10,7	341	14,2	11,1	810

	C (p.c.)	N (mg/kg)	P (p.c.)	C/N	K (p.c.)	pH eau
S1	15,6	970	0,48	16,1	0,04	6,9
S2	18,3	1030	0,67	17,8	0,12	7,1

*Abengourou
** Soluble P

3.2 Adsorption of P and P Concentration of the Supernatant Solution of the Soils Used

Generally P adsorption is higher at the soil in Man than that of Abengourou. It increases with the P concentration of the supernatant solution following two phases (figure 1). A first phase takes place between 0 and 0.4 mg of P l⁻¹, and during which the adsorption rate of P increases linearly and strongly following to the P concentrations of the supernatant

solution. The slope is higher in Man soils than that of Abengourou soils.

A second phase beyond 0.4 mg of P l⁻¹, during which there is a slowing down or stagnation of the adsorption of P as a function of P contents of the supernatant solutions.

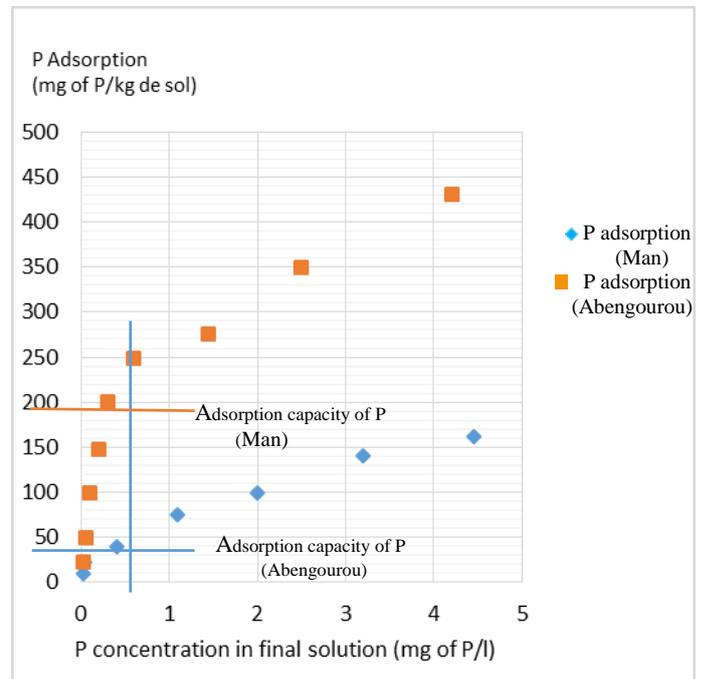


Fig. 1. Adsorption of P according to Ozanne and Shaw (1962) as a function of the P content in the final solution (mg of Pkg-1 soil)

3.3 P adsorption Capacity of Composite Soils and Soils

The average adsorption of P of both soils are high. However adsorption remains higher in Man's soil (averaging 195 mg Pkg-1 soil) than in Abengourou (averaging 28 mg Pkg-1 soil).

The adsorption capacity of P varies following to the characteristics of the soils (Man or Abengourou), in particular the pH, the nature of residual substrates used (S1 or S2) and especially their rate of incorporation.

Regarding the pH, whatever the nature of the substrate (S1 or S2), the adsorption capacity of P drops as the pH increases (Figure 2). Phosphorus fixation capacity is very high in the soil of Man than that of Abengourou.

The supply of substrate S1 raises the pH on average by 0.5 units. Specifically, this contribution increases soils pH from 5.1 to 5.7 (Figure 2a), and from 4.3 to 4.7 (Figure 2c), respectively in Abengourou and Man.

The add of substrate S2 raises the pH by 0.7 units. Specifically, this supply increases soils pH from 5.1 to 5.75 (Figure 2b), and from 4.3 to 5.1 (Figure 2d), respectively, in Abengourou and Man.

The pH increase is therefore very sensitive in more acid soils (Man's case), and with substrate S2, compared to less acid soils (Abengourou's case) and with the substrate S1. In addition, the pH variations for the 15 p.c. and 30 p.c. soil incorporated of substrate of any kind are not significantly different.

The significant correlation between P uptake capacity and pH, especially in the low pH range ($r^2 = 0.91$ *) (Figure 2a and 2b), reflects effectively the influence of pH on floors to fix P.

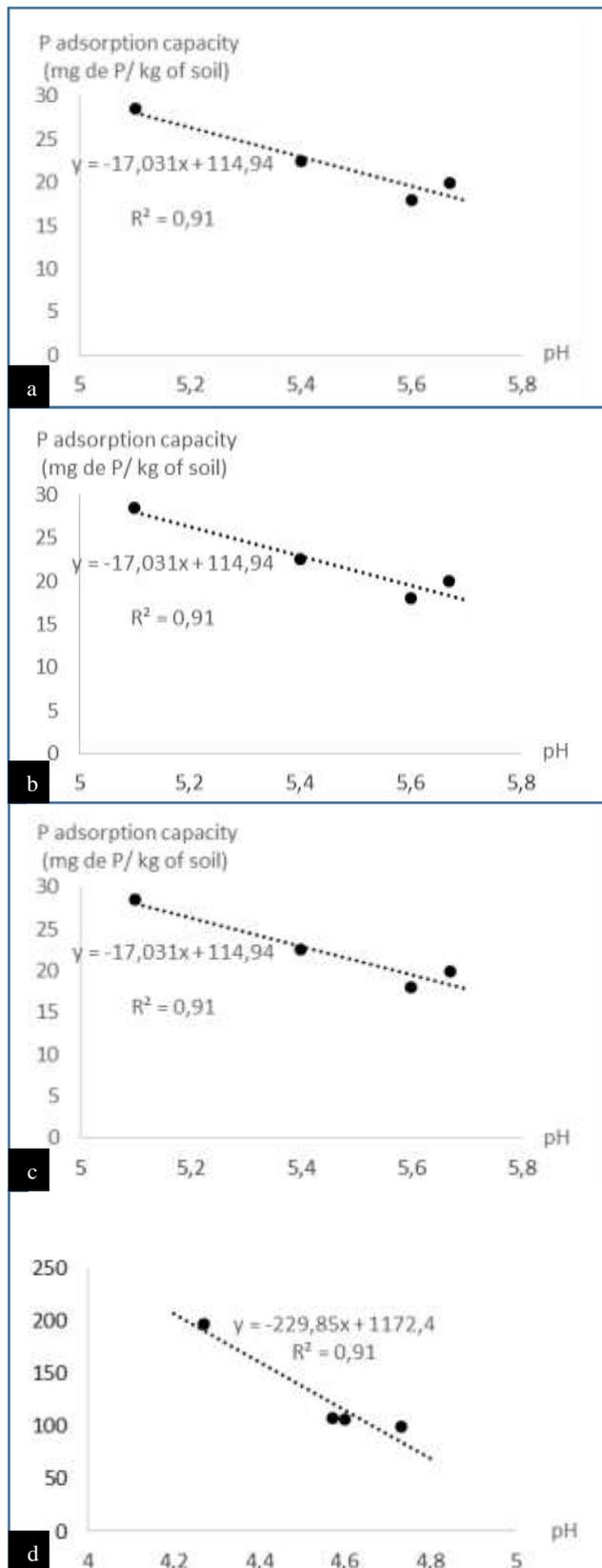


Fig. 2. P adsorption capacity following soils pH

a/ S1 + soil (Abengourou) b/ S2 + Soil (Abengourou)
c/ S1 + soil (Man) d/ S2 + Soil (Man)

Concerning the spent mushroom substrates used, P fixation decreases with their nature and their incorporated rate into the soil (Figure 3 and 4). Explicitly, adsorption capacity varies on average from 195 mg of Pkg^{-1} of soil (0 p.c. of substrate) to 93 mg of Pkg^{-1} of soil (30 p.c. of substrate), and 28.7 (0 p.c. of substrate) to 18 mg of Pkg^{-1} of soil (30 pc of substrate), respectively, for Man and Abengourou soils, and for substrate S1. It ranges from 195 (0 p.c. of substrate) to 69 mg of Pkg^{-1} of soil (30 p.c. of substrate) and 29 (0 p.c. of substrate) to 13 mg of Pkg^{-1} of soil (30 p.c. of substrate), respectively for the soils of Man and Abengourou, and for the substrate S2. The analysis of variance of the adsorption capacities shows a significant difference in the treatments. The application of LSD at the level of 5 p.c. to adsorption capacities gives to the soils, with no substrate input, the highest P uptake capacity. It also gives to the treatment (soil + 30 p.c. of substrate) the lowest adsorption capacity.

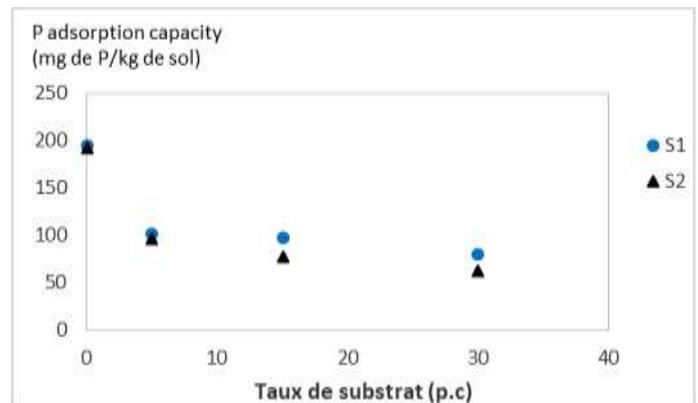


Fig. 3. P adsorption capacity following nature and rate of substrate (Man)

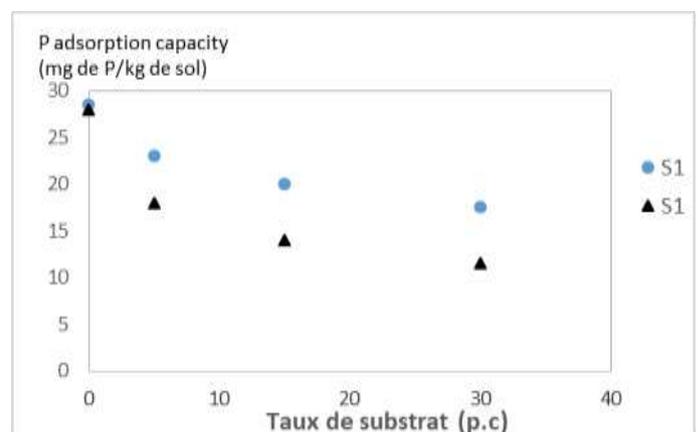


Fig. 4. P adsorption capacity following nature and rate of substrate (Abengourou)

Phosphorus availability in the soil is not the only fact of the quantities of P brought in the form of phosphated fertilizer (Brady and Weil, 2002) or organic amendments (Iratcabat M., 2000), but especially the resultant of various reactions of balances (Gervy, 1970), and the action of numerous factors (Mkhabela and Warman, 2005) in whom P would be

involved. At Man, the pH of the soils between 3,5 and 4,5 favors the solubility of aluminum oxides (Hewitt, 1952), and pulls the liberation of the ions Al^{3+} . The fixation of these ions to the phosphorus would reduce the availability of P in these very acid soils for the nutrition of plants confirming the assertions of Kuo in 1990 and Tisdale and *al.*, in 1993.

High P adsorption rate in the different soils or ratio of the amount of P adsorbed to that of P intake (60 - 85 pc), reflect the low deficiency of P in these soils (Abekoe and Sahrawat, 2001), especially those in the humid forest region sensitive to any P input (Akhtar *et al.*, 2003). In addition, the adsorption rates obtained are consistent with those obtained by Maguire *et al.* (2001) and Nguyen (2003). For indeed, while highlighting P fixation contributed by the metal ions of the soil, in particular iron and aluminum (Brady and Weil 2002, Agbenin 2003, Gielser *et al.*, 2005), attributes these high rates adsorption. to quantitative insufficiency of P related to soil acidification.

This progressive acidification of soils under influence of natural processes, plant production and cultural practices (Pernes and Tessier, 2002) leads to the management of soil acid-base status in order to reduce the rate of P fixation. Certain agricultural practices, particularly the use of fertilizers and soil improvers, can correct soil P deficiency, maintain a correct content of the main elements, avoid soil depletion, and improve soil quality, crop productivity (ENESAD, 2006). Thus, unlike organic acids resulting from biochemical reactions during the degradation of organic matter (Shen *et al.*, 2002, Lopez-Marrin and Rao, 2009), the presence of which causes a significant drop of pH to below the zone of solubility of aluminum, and consequently the reduction of P fixation by these ions (Bushman *et al.*, 2002); the contribution of spent mushroom substrate makes it possible for them to raise the pH of the composite soils because of their near-neutral pH, displacing the soils of the zones sensitive to P fixation to the metal ions this time in an opposite direction at the first displacement. This results in a decrease in the fixing capacity of the soils in P. These results confirm the work of Barrow (1983) according to which, the higher the organic matter content, the more P is available. They also confirm those of Korsaeht *et al.* in 2002 and Ibrahim *et al.*, in 2008, according to which, a true source of minerals, compost increases the cation exchange capacity (C.E.C) of the soil, and reduces the adsorption and / or P fixation capacity

IV. CONCLUSION

P availability in the acid soils of the humid forest regions depends certainly of factors that are the intensity and the quantity of the orthophosphate ions, but is mainly due to the capacity or buffer capacity of the soil with respect to these ions. (Bekett and White, 1964). Metallic ions, especially the oxides and hydroxides of iron and aluminum in quantity in these soils increase the capacity or the ability of the soil to maintain the intensity of P despite the increase in solubility resulting from inputs in different forms of orthophosphate. Additions of organic matter, especially spent mushroom substrates, while allowing the pH of the soil to be raised, thus

avoiding the solubility of the metal ions, and consequently reducing P fixation, contribute significantly to lowering the soil capacity to fix P and make it available to the plants.

The experiment conducted, which consisted in testing two spent mushroom substrates, in particular S1 and S2, showed that the decrease of P capacity of the soils depends on the nature (pH) and the rate of substrates incorporated in said substrates, but also the level of soil acidity. Thus, a contribution of 15 pc to 30 pc of substrate whatever the nature significantly reduces the capacity of the soil to fix P. According to these experiments, the decrease of these capacities is much stronger at the level of the soils relatively more acidic for the same amount of incorporated substrate. Finally, the S2 substrate from a rice straw compost is more appropriate for lowering the acid capacity or fixing capacity of acid soils of humid forest regions. Indeed, a contribution of 15% by volume of this substrate is sufficient to impact the availability of P in the soil.

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