Effect of phosphorus fertilizer application on some forms of phosphorus in selected Ghanaian cocoa-growing soils

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SUMMARY

Changes in the forms of phosphorus present in Ghanaian cocoa- growing soils incubated at 25 °C for up to 56 days in the presence of added cocoa leaf litter and/or phosphorus fertilizer are described. The addition of organic litter alone had little effect on bicarbonate-extractable inorganic phosphorus but large initial increase of the inorganic phosphorus occurred with the litter and phosphorus fertilizer added in combination, followed by a decrease especially in the phosphorus deficient soils. The addition of the litter without phosphorus fertilizer increased microbial biomass phosphorus content in all the soils, the increase being between 15 and 70 per cent in the soils without the litter addition and thus suggesting that the litter, among others, might be a possible source of the increased microbial biomass phosphorus in these soils. When litter and phosphorus fertilizer were added together, there was an initial rapid incorporation of phosphorus into the microbial biomass in the soils with low initial available phosphorus content. The phosphorus content of the microbial biomass should, therefore, be considered in determining the trend of organic phosphorus mineralization in soils.

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RÉSUMÉ

OFORI-FRIMPONG, K., POWELL, D. L. & APPIAH, M. R.: *L'effet de l' application d'engrais de phosphore sur quelques formes de phosphore dans les sols de la culture cacao sélectionnés du Ghana.* Les changements dans les formes de phosphore présent dans les sols ghanéens incubés à 25 °C jusqu' à 56 jours en présence de la litiére à feuilles de cacao ajoutée et/ou l'engrais de phosphore sont décrits. L' addition de la litiére organique seulement avait peu d' effet sur le phosphore inorganique du bicarbonate inextractible mais une grande augmentation initiale du phosphore inorganique se produisait avec la litière et l'engrais de phosphore ajouté en combinaison, suivi par une diminution surtout dans les sols faibles en phosphore. L' addition de la litière sans l'engrais de phosphore augmentait le contenu du phosphore de microbien de biomasse dans tous les sols, l'augmentation étant entre 15-70 pour cent dans les sols sans l'addition de la litière et suggérant alors que, la litière pourrait être parmi d' autre, une source possible du phosphore de microbien de biomasse augmenté dans ces sols. Lorsque la litière et l'engrais de phosphore étaient ajoutés ensemble, il y avait une incorporation initiale rapide du phosphore à la biomasse microbienne dans les sols avec un contenu bas du phosphore initial disponible. Le contenu phosphore de la biomasse microbienne devait donc être considéré en déterminant la tendance de la minéralization du phosphore organique dans les sols.

Introduction

The most suitable soils for cocoa-growing in Ghana are normally of low available phosphorus content. This may be attributed to high phosphorus retention capacity of the soils (Ahenkorah, 1968; Owusu-Bennoah & Acquaye, 1989) and a greater part of the total phosphorus being in the organic form (Appiah, 1975). Acquaye (1963) and Appiah (1975) reported a range of 15-52 and 5-35 mg P 100 g^{-1} soil respectively for organic P contents of Ghanaian cocoa-growing soils, representing 42-69 per cent of the total phosphorus. It, therefore, appears that under tropical and peasant farming conditions where little phosphate fertilizer is applied, organic P may be an important source of replenishing plant available phosphorus in the soil. However, since plants obtain their phosphorus mainly in the inorganic form, the rates of turnover of the organic phosphorus may influence the available phosphorus status of the soils and may probably be of more importance than the total amounts.

There is ample evidence that in tropical soils uptake of phosphorus by crops is significantly correlated with amounts of mineralized phosphorus (Adepetu & Corey, 1977; Mueller-Harvey, Juo & Wild, 1985). Much of the mineralized phosphorus is taken up by the microbial biomass, and the annual flux has been estimated to be high in some soils (Jenkinson & Ladd, 1981; Brookes, Powlson & Jenkinson, 1984). With the faster decomposition rates in the tropics, annual fluxes will also be high. The role of the microbial biomass in phosphorus transformations in soils under cocoa has not been studied but it is possible that when cocoa litter enters the soil ecosystem, much of the mineralized inorganic phosphorus can be rapidly assimilated by the microbial biomass.

With the high interest now shown by peasant cocoa farmers in the use of phosphorus fertilizers in Ghana, it is important to study the effects of added fertilizer phosphorus on the transformations of phosphorus in the cocoa litter. McLaughlin & Alston (1986) have shown that the amount of applied phosphorus assimilated by microbial biomass was equal to that taken up by plants. Under cocoa ecosystem where available phosphorus is generally low but with a large litter fall, significant microbial immobilization of phosphorus is likely to occur. This paper reports on the effects of phosphorus fertilizer application on changes in some phosphorus forms in selected cocoa growing soils of Ghana.

Materials and methods

Soils

Surface samples (0 - 15 cm) of some Ghanaian cocoa-growing soils classified as Rhodic Ferralsols (FAO/UNESCO, 1973) were collected from different locations of experimental plots of the Cocoa Research Institute of Ghana (CRIG). These samples were from the following locations and different treatments: Nankese phosphorus fertilized, Nankese control and Bechem control plots. All the soils were under mature cocoa of the mixed Amazon variety. The Nankese phosphorus fertilized plot had received triple superphosphate fertilizer at 25 kg P ha^{-1} yr^{-1} for 16 years including the year of soil sampling. The Nankese and Bechem control plot soils had not received any fertilizer. The soils were air-dried, sieved (2 mm) and pre-incubated at 40 per cent of their maximum water holding capacity for 21 days to minimize the initial biological flush when dry soil is rewetted.

Leaf sample

Recently-fallen cocoa leaf litter from the Nankese control plot was collected and air-dried at room temperature (26 °C). The litter was milled to pass through a 1mm sieve, bottled and stored at room temperature until required.

Incubation method

Moist soil samples equivalent to 20 g oven dry soil were weighed into 100 ml beakers and further treated as follows:

(a) soil alone (S)
(b) soil plus litter (S + L)
(c) soil plus litter with phosphorus fertilizer (S + L + P)

The litter was added as 0.1 g milled sample per 20 g soil and thus providing 3 mg P kg^{-1} soil, rate equivalent to 10 tonnes of dry litter fall per hectare per year. The phosphorus addition was 0. 3 ml solution of 1mg P per ml as KH_2PO_4 providing 15 mg P kg^{-1} soil, a rate equivalent to approximately 30 kg P per hectare per year. All the soils were brought to 50 per cent of water-holding capacity by adding distilled water and then incubated at 25 °C in 1 litre Kilner jars with sealed tops. The containers were aerated for 15 min every 3 days by removing the caps of the jars.

Periodic weight checks were done on the samples and the weight lost was brought back to the original by spraying distilled water on them. Each treatment had three replications which were randomly arranged in the incubation room. At time zero, that is, the first day the incubation was set up, and at the end of 7, 14, 28 and 56 days of incubation, three samples of each treatment from each of the three soils were removed for analyses.

Chemical analyses

$NaHCO_3$ extractable P. Moist soil equivalent to 2 g oven-dry soil was shaken with 50 ml of 0.5 *M* $NaHCO_3$ solution at *p*H 8.5 for 30 min at room temperature of 25 °C (Olsen *et al.*, 1954). The inorganic P was analysed by the ammonium molybdate-ascorbic acid method as described by Murphy & Riley (1962).

Microbial biomass P. Moist soil equivalent to 4 g oven-dry soil was chloroform-fumigated as described by Jenkinson (1966). The P content of the fumigated soil was extracted with 0.5 *M* $NaHCO_3$ solution at *p*H 8.5. The extracts were then digested with 70 per cent $HClO_4$ and the P analysed as above. Microbial biomass P content of soil was then calculated as the difference between total P (fumigated) and total P (unfumigated) divided by an assumed *kp* factor of 0.4 to account for the fraction of the soil biomass P extracted after fumigation (Brookes, Powlson & Jenkinson, 1982).

Other soil properties and leaf litter composition. Other chemical analyses included organic carbon determined by wet digestion, total N by the Kjeldahl method, total P after perchloric acid digestion followed by colorimetric determination of P (Fogg & Wilkinson, 1958), *p*H on 1:2.5 soil : water ratio by glass electrode, extractable Fe and Al by the Dithionite-Citrate-Bicarbonate extraction method of Jackson (1958). Particle size distribution was determined by the pipette method. For the cocoa leaf litter, total C, total N and total P were determined by the procedures of Tinsley (1950), Bremner (1965) and Cavell (1955) respectively.

Results and discussion

Some physical and chemical properties of the soils and leaf litter composition of the cocoa leaf litter used are presented in Tables 1 and 2. The Nankese phosphorus fertilized soil was six times higher in bicarbonate inorganic P content than the Nankese and Bechem control soils. The Nankese phosphorus fertilized and Nankese control soils had almost the same organic P contents but higher than that of the Bechem control soil.

TABLE 1

Some Physical and Chemical Properties of the Soils Used

	Nankese control	*Nankese P fertilized*	*Bechem control*
Clay (per cent)	38	41	17
*p*H, 1:2.5 in water	6.0	6.3	5.4
Organic C (per cent)	2.2	2.6	2.0
$NaHCO_3$ extractable P (mg kg^{-1})	4.0	24.7	4.9
Organic P (mg kg^{-1})	262	283	132
Total P (mg kg^{-1})	297	523	155
Total N (g kg^{-1})	1.8	2.2	1.2
Extractable Fe (mmol kg^{-1})	612	561	195
Extractable Al (mmol kg^{-1})	106	106	37

TABLE 2

Composition of the Cocoa Leaf Litter Used

	Per cent of oven-dry material
Total C	36.4
Total N	0.97
Total P	0.06

$NaHCO_3$-Pi

The effects of soil alone (S), soil plus litter (S + L), and soil plus litter with phosphorus fertilizer (S + L + P) treatments on the $NaHCO_3$ extractable inorganic P ($NaHCO_3$-Pi) in the three soils are shown in Fig. 1. In the treatments without P fertilizer (S and S + L), there was an increase in the concentration of $NaHCO_3$ - Pi with time of incubation in the Bechem control soil. The $NaHCO_3$-Pi in the Nankese control soil did not change initially but tended to decrease at the end of the incubation. In the Nankese phosphorus fertilized soil, there was an

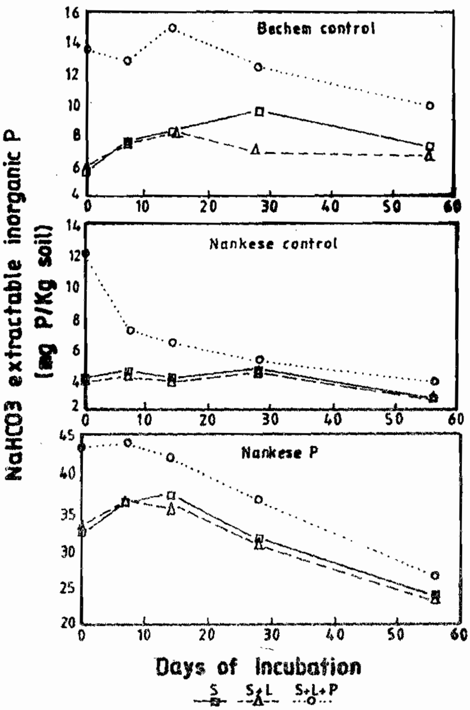

Fig. 1. Changes in $NaHCO_3$ extractable inorganic P in soil alone (S), soil plus litter (S+L), and soil plus litter with P fertilizer (S+L+P) treatments

initial increase followed by a steady decrease in the $NaHCO_3$-Pi.

Since there was no addition of fertilizer in these treatments, the release of inorganic P from the soil during the incubation depends, among others, on the available P in the soils, the composition of the soil organic matter and the litter. The addition of the litter to all the soils increased the C/P ratios of the soil organic matter to 411:1, 336:1 and 450:1 for Nankese control, Nankese P fertilized and Bechem control soils respectively. These ratios are above the critical ratio of 200:1 for net mineralization of P (Dalai, 1977) and that might have resulted in the immobilization of P in the soil plus litter treatments causing decrease in $NaHCO_3$-Pi in the Nankese control and Nankese phosphorus fertilized soils. The net gains of $NaHCO_3$-Pi in the Bechem control soil at the end of the incubation, in spite of the increase in the C/P ratio of the soil organic matter, suggests that other factors influence the availability of P in cocoa-growing soils. Halm & Ahenkorah (1978) and Owusu-Bennoah & Acquaye (1989) have shown that clay and also iron and aluminium intimately associated with organic matter can sorb more P than the same amount of free Fe_2O_3 and Al_2O_3 in Ghanaian cocoa growing soils. Bechem control soil has lower amounts of organic matter, extractable iron and aluminium and clay content than the other soils (Table 1). It is, therefore, likely that less of the mineralized P from the soil organic matter was chemically fixed in the Bechem control soil. In the litter with P fertilizer treatments (S + L + P), initial increases in $NaHCO_3$-Pi as a result of the added P fertilizer occurred but decreased towards the end of the incubation in all the soils. Enwezor (1966) and Chauhan, Stewart & Paul (1981) made similar observations and attributed the decrease in available P to immobilization of the added P in both the fertilizer and that earlier mineralized from the organic matter as a result of increased microbial activity caused by the extra energy source. The smaller change in $NaHCO_3$-Pi in the soil plus litter treatments during the first 14 days implies that

TABLE 3

Analysis of Variance of the Effect of Treatments (T), Periods of Incubation (P) and Soil Type (S) on $NaHCO_3$-Pi Content

Source	*df*	*F-value*
S	2	14327***
T	2	296.9***
P	4	205.4***
S×T	4	12.9***
S×P	8	92.6***
T×P	8	12.3***
Error	29	

*** $P<0.001$

(a) Soil means : S.E.D. 5 per cent = 0.19

Bechem	Nankese control	Nankese P fertilized
9.85	5.07	34.9

(b) Treatment means: S.E.D. 5 per cent = 0.24

S	S+L	S+L+P
14.7	14.2	19.4

not much P was being mineralized in these soils. The P fertilizer may, therefore, have supplied enough P needed to increase microbial activity with a concomitant increase in consumption of P present by the microorganisms. Irrespective of the treatments, differences in $NaHCO_3$- Pi among the soils were highly significant ($P < 0.001$) (Table 3).

Microbial biomass P

The effects of the soil alone (S), soil plus litter (S + L) and soil plus litter with phosphorus fertilizer (S + L + P) treatments on the microbial biomass P content in the soils are presented in Fig. 2. Regardless of phosphorus fertilizer additions, microbial biomass P increased initially in Bechem control and Nankese control soils with the addition of the litter. The addition of litter without phosphorus fertilizer (S + L) caused larger increases in microbial biomass P in all the soils than when phosphorus fertilizer was added especially at the latter period of incubation. The significant difference between the soils with respect to microbial biomass P (Table 4) with Nankese phosphorus fertilized > Nankese control > Bechem control soils appears to be related to the initial available P content of the soils.

The greater gains of microbial biomass P in the litter without P fertilizer treatments in the soils suggest that in the absence of P fertilizer the P present in the litter may be of importance in the mineralization and immobilization processes occurring in the soils. The failure of microbial biomass P to increase significantly in the Nankese P fertilized soil in spite of its higher initial $NaHCO_3$-Pi and the added P fertilizer also suggests that the uptake of P by micro-organisms is inversely related to their P status. These results are in agreement with those of some workers. Thus, Acquaye (1963) found that the increase in extractable inorganic phosphorus due to incubation of cocoa soils of Ghana was greater in the presence of inorganic phosphorus than in the controls. Kaila (1962) observed that decrease in organic phosphorus during incubation became more pronounced with an increase in the amount of superphosphate applied. The P content of the microbial biomass is, therefore, important in deter-

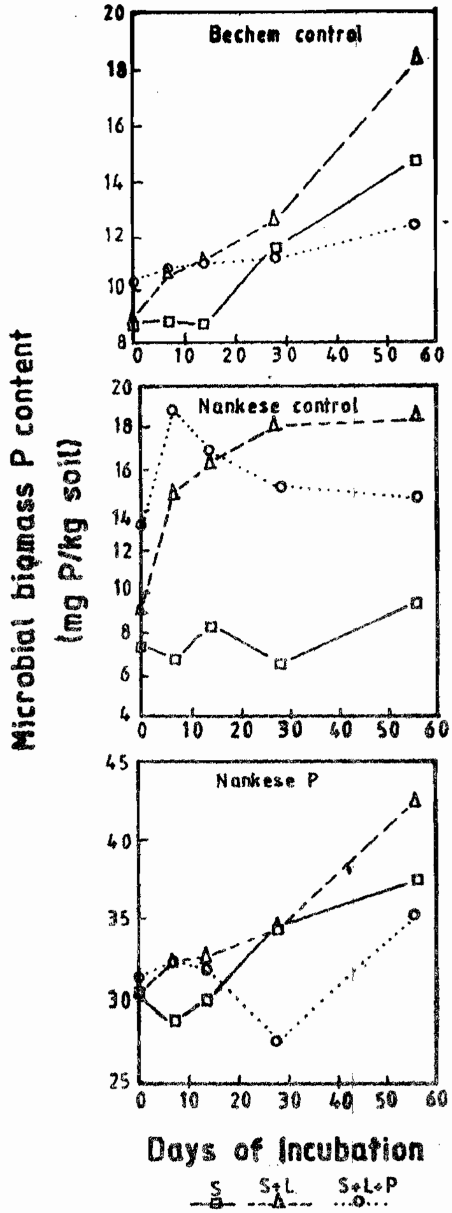

Fig. 2. Changes in microbial biomas P in soil alone (S), soil plus litter (S+L), and soil plus litter with P fertilizer (S+L+P) treatments

TABLE 4

Analysis of Variance of the Effect of Treatments (T), Periods of Incubation (P) and Soil Type (S) on Microbial Biomass Content

Source	*df*	*F-value*
S	2	545.6***
T	2	4.6***
P	4	8.7***
S×T	4	3.0***
S×P	8	1.8NS
T×P	8	1.3NS
Error	29	

*** $P<0.001$, NS=Not significant

(a) Soil means : S.E.D. 5 per cent = 0.69

Bechem	Nankese control	Nankese P fertilized
11.4	13.4	32.3

(b) Treatment means: S.E.D. 5 per cent = 0.90

S	S+L	S+L+P
16.9	20.6	19.5

mining the trend of organic P mineralization. The results from this study in practical terms indicate that phosphorus fertilizer applications would result in a decrease in the quantity of P that would be tied up in the microbial biomass which is temporarily unavailable for cocoa. One possible explanation for this observation may be an enhancement of the mineralization of organic phosphorus in the presence of added inorganic P. Further work is, therefore, needed to study the optimum combinations of litter and added P fertilizer at which the cocoa can benefit from the mineralized organic P, thus reducing cost on the P-fertilizer in any future cocoa fertilization programme.

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