PHOSPHORUS SORPTION CHARACTERISTICS OF SOME LOWLAND RICE SOILS OF THE MIDCOUNTRY WET ZONE OF SRI LANKA

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INTRODUCTION

Rice in the midcountry wet zone is grown under lowland conditions in the narrow sloping valleys and on terraced slopes. In this region, three types of rice lands namely Godakumbura (well-drained), Medakumbura (moderately to imperfectly drained) and Madakumbura (poorly drained) have been recognized by farmers. Recently, phosphorus deficiency has been found to be the major cause for the poor growth of rice observed especially in the madakumburas (Nagarajah *et al.*, 1979). The addition of phosphorus fertilizers to rice fields in this region has therefore become very important for obtaining high yields. In order to obtain a better understanding of the phosphorus requirements of these soils a study of their P sorption characteristics was considered useful.

Lowland rice is grown under flooded culture and this brings about profound chemical changes as a result of reducing conditions (Ponnamperuma, 1972). Therefore P sorption measurements should be made on flooded soils and not on air-dried soils, if meaningful data on P requirements of rice soils are to be obtained. Phosphorus sorption studies under anaerobic conditions are few, mainly because of the difficulties in sampling and analysing wet soils under such conditions. A simple method was developed to determine P sorption under flooded conditions and this paper discusses the data obtained on the P sorption of some rice soils of the midcountry wet zone using this method.

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MATERIALS AND METHODS

Soil Samples

Eleven surface soil samples (0–15 cm) were collected from traditional lowland rice fields of the midcountry wet zone of Sri Lanka where P response studies have been carried out recently (Nagarajah *et al.*, 1979). Seven samples were obtained from madakumburas and four from medakumburas. Some selected properties of these soils are given in Table 1.

Phosphorus Sorption Isotherms

In order to make a comparative study, P sorption by the air-dried and flooded samples were measured at the same pH. The pH selected was that recorded on the fourteenth day of flooding (pH_{14}, Table 1).

Flooded samples: A modification of the method used for air-dried samples by Fox *et al* (1968) was followed. The details were as follows.

Nine g of each of the eleven samples (<0.5mm) were immersed in 80 ml of water in 100 ml Erlenmeyer flasks at room temperature ($28\pm1^{0}C$) for 14 d. Ten ml of 0.9 M NaCl containing graded amounts of $NaH_2PO_4.2H_20$ was added such that the final solution has 0.1 M NaCl. Two drops of toluene were added and the soil suspensions equilibrated for a pre-determined period of 4 d by shaking for 30 min twice daily. During this period the pH of the supernatant liquid was adjusted to pH_{14}. After equilibration the soil suspensions were filtered and filtrate analysed for P by the stannous chloride-molybdenum blue method (Dickman and Bray, 1940). Phosphorus which disappeared from solution was considered to have been sorbed.

Air-dried samples: Phosphorus sorption isotherms for the air-dried samples at pH_{14} were obtained as for flooded samples, but without prior flooding, using the same quantity of soil and solution.

Extractable Fe and Al in the air-dried and flooded samples: Extractable Fe and Al in the flooded samples were determined by weighing out wet soil samples of known moisture contents after flooding the air-dried samples for 18 d and removing as much water as possible by filtration.

Portions of air-dried samples or an equivalent weight of the wet sample were extracted with 0.3 M $(NH_4)_2C_2O_4$ (Saunders, 1965). Aluminium in the extract was determined by the Aluminon method (McLean, 1965) and Fe by the o-phenanthroline method (Fortune and Mellon, 1938).

RESULTS AND DISCUSSION

P Sorption Characteristics

Phosphorus sorption data of the eleven soils under flooded and air-dried conditions fitted the Langmuir equation

$$x/m = abc / (1+bc) \quad (1)$$

where x=amount of P sorbed (μg), m=amount of soil (g), c=equilibrium concentration of P (μg/ml), b=a parameter related to the energy of sorption (ml/μg), and a=sorption maximum (μg/g).

The linear form of equation (1) which is

$$c/(x/m) = 1/ab+c/a \quad (2)$$

was used to obtain the sorption maxima (Table 2). It is evident from this Table that 14 d of flooding resulted in a marked increase in P sorption in eight of the eleven soils. In the other three soils, namely Wavekumbura, Golahanwatte and Ulapane, flooding caused very little increase in P sorption. Two typical P sorption isotherms belonging to the two groups are shown in Fig 1. The data also showed that there was no difference in the P sorption behaviour of the madakumbura and medakumbura soils.

Flooding also resulted in a remarkable increase in oxalate extractable Fe in all eleven soils. Oxalate extractable Al too increased on flooding though not to the same extent (Table 3).

The increase in P sorption and oxalate extractable Fe and Al seem to indicate that P sorption is related to oxalate extractability. In fact many workers have postulated that oxalate extractable Fe is mainly responsible for increased P sorption in lake sediments (Shukla *et al.*, 1971; Williams *et al.*, 1971) and soils under anaerobic conditions (Patrick and Khalid, 1974; Khalid *et al.*, 1977; Willett and Higgins, 1978).

Correlation coefficients expressing the relationship between P sorption maxima and different soil properties showed that while oxalate extractable Al gave significant correlation under both air-dried and flooded conditions, oxalate extractable Fe had significant effects only under flooded conditions (Table 4). Hence the increase in P sorption due to flooding observed in a majority of the soils could largely be attributed to oxalate extractable Fe, although the effects due to Al cannot be completely ruled out.

Dithionite extracts both crystalline and amorphous Fe oxides (McKeague and Day, 1966). On the other hand, oxalate extraction developed by Tamm (1922) is believed to cause dissolution of mainly amorphous and poorly

crystalline Fe and Al compounds but the exact nature of the material extracted is not well understood (Parfitt, 1978). Table 3 shows that the amount of Fe extracted by the oxalate reagent from the air-dried samples is very small compared to that extracted by dithionite. This probably is an indication that before flooding the oxides were essentially crystalline in nature. However, the increase in oxalate extractability following flooding must have been due to the conversion of some of the crystalline Fe oxides to amorphous and or poorly crystalline forms. This increase could be attributed to the reduction of the ferric hydrous oxides to ferrous forms. In fact, it is believed that the bulk of the Fe in most rice soils is ferrosoferric hydroxide ($Fe_3(OH)_8$) which is a precipitate and is poorly crystalline (Ponnamperuma *et. al.*, 1967).

Compounds of Al unlike those of Fe cannot undergo reduction. Hence increase in extractable Al cannot be attributed to reduction. However, it is possible that in the air-dried samples some of the Al could have been associated with organic matter and Fe, in the form of a complex or as coatings (Habibullah, 1972). On flooding, the organic matter and Fe (of the complex or coatings) may undergo destruction releasing Al compounds into solution. This probably accounts for the increase in oxalate extractable Al on flooding.

It is well known that amorphous Fe and Al oxides are highly reactive and sorb more P than crystalline oxides on account of their (amorphous oxides) greater specific surface areas (Colwell, 1959; Hsu, 1965; Fox *et al.*, 1968). Thus the increase in P sorption on flooding observed in most soils is very likely due to increase in amorphous material as indicated by the increased oxalate extractability on flooding.

However it must be observed that although increased P sorption by flooded soils can be largely attributed to an increase in oxalate extractable Fe the reverse may not be true, that is, increase in oxalate extractable Fe need not always result in increased P sorption. For instance, the present study revealed that in three soils namely Wavekumbura, Golahanwatte and Ulapane although the increase in oxalate extractable Fe is about the same order as that in the other soils, there was no appreciable increase in P sorption on flooding (Table 2). Khalid *et al* (1977) also found similar trends in some soils but did not offer any explanation for this behaviour.

It is probable that oxalate extracts material of varying degrees of crystallinity with varying surface areas from soils and the extent of P sorption can be expected to depend on the type and amount of these materials formed, which in turn may be governed by the nature and properties of the soil. Clay mineralogy studies of some seasonally flooded rice soils of Bangladesh have shown that the form and amount of amorphous and crystalline iron oxides vary with age of soils (Habibullah *et al.*, 1971). Furthermore, the period of flooding (hence the extent of reduction) will also affect the extent to which crystallinity has been decreased, that is, longer the period of flooding greater the amount of poorly crystalline material formed (Willett and Higgins, 1978).

In the three soils showing exceptional behaviour even though flooding for 14 d caused an increase in oxalate extractable Fe and Al the nature and degree of crystallinity of the Fe and Al compounds formed must be such that an appreciable increase in specific surface area may not have occurred to significantly increase P sorption.

P Requirements

Phosphorus sorption isotherms have been successfully used to determine P requirements of soils. For this purpose Beckwith (1965) measured sorbed phosphorus at standard equilibrium solution concentration of 0.2 ppm P (μg/ml) which value was considered sufficient for successful growth of many plant species. Fox *et al* (1968) have found that the P requirements of Hawaiian latosols determined by this method to be consistent with observed needs. It is however recognized that the value for standard equilibrium solution P concentration would vary from soil to soil and from crop to crop.

The equilibrium solution P concentration needed for optimum rice growth is not well established. Therefore in this paper Beckwith's value of 0.2 ppm was used to determine the P requirements of the soils under flooded conditions.

The standard P requirements (i.e. amounts of P required to attain 0.2 ppm P in solution) varied from 50 to as much as 600 μg P/g soil (Table 5). This implies that a single application of triple superphosphate (TSP) ranging from about 500 to 6000 kg/ha would be necessary to maintain a solution concentration of 0.2 ppm P in the soils under study.

Juo and Fox (1977) have classified the soils according to P sorption for purposes of comparing P requirements of soils as follows:

Standard P requirement $\mu g/g$ *soil*	*Scale*
<10	very low
10 — 100	low
100 — 500	medium
500 - 1000	high
>1000	very high

Based on this classification majority of the soils studied have a medium P requirement.

The high P requirement of 600 μg/g soil (equivalent to an addition of 6000 kg TSP/ha) was for the Gampolawela soil. However recent studies have shown a lack of response to P at this location (Nagarajah *et al.*, 1979). It is likely that the sorbed P in this soil is held in such a manner that rice plants are able to easily absorb them. Studies are needed to determine the validity of this concept.

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Table 1. Some selected properties of the air-dried soil samples

Soil	*Great Soil Group*[1]	*pH* (H_2O)	pH^2_{11}	*Silt* %	*Clay* %	*Texture*[3]	*Organic matter* %	*CEC* μeq/g	*Total P* %	*Olsen's P* μg/g
Kumburegama	IBL/RBL	5.6	6.8	21.6	28.6	SCL	2.5	53	0.06	7.5
Gampolawela	RBL	5.7	6.7	24.6	54.6	C	5.1	135	0.10	10.6
Kirivavula	RBL	5.1	6.3	14.6	38.6	SC	4.4	47	0.06	5.5
Kobbekaduwa	RBL	5.4	7.0	6.6	28.6	SCL	3.7	45	0.06	5.5
Nagahatenne (A)	RBL	5.4	6.2	14.6	36.6	SC	2.6	38	0.08	9.5
Nagahatenne (B)	RBL	6.2	7.5	14.6	32.6	SCL	4.5	61	0.05	3.5
Thalamurayaya	RBL	7.8	8.1	20.6	24.6	SCL	3.1	65	0.05	4.6
Wattapola	RBL	5.5	6.9	18.6	28.6	SCL	3.9	72	0.11	12.0
Wavekumbura	RBL	5.7	7.0	6.6	36.6	SC	2.6	50	0.06	6.5
Golahanwatte	RBL/RBE	6.0	6.9	5.6	32.6	SCL	2.6	36	0.04	4.5
Ulapane	RYP	5.3	6.3	18.6	45.6	C	5.8	100	0.06	5.0

[1] Refers to Great Soil Group of the surrounding upland. IBL=Immature Brown Loams, RBL=Reddish Brown Latosolic soils, RBE=Reddish Brown Earths, RYP=Red Yellow Podzolic soils.

[2] Refers to pH of the system on the fourteenth day of flooding.

[3] SCL=Sandy clay loam, SC=Sandy clay, C=Clay.

Table 2. Langmuir sorption maxima of the soils under air-dried and flooded conditions

Soil	*Sorption capacity (a)* ($\mu g/g$)	
	AD	*FL*
Kumburegama	555	776
Gampolawela	1094	1219
Kirivavula	579	912
Kobbekaduwa	409	750
Nagahatenne (A)	505	593
Nagahatenne (B)	624	949
Thalamurayaya	396	469
Wattappola	451	888
Wavekumbura	469	474
Golahanwatte	448	456
Ulapane	1160	1170

AD = Air-dried sample, FL = Flooded sample

Table 3. Extractable Fe and Al in the air-dried and flooded samples

Soil	*Dithionite-Fe* %	*Oxalate.Fe* ($\mu g/g$)		*Oxalate-Al* ($\mu g/g$)	
	AD	*AD*	*FL*	*AD*	*FL*
Kumburegama	3.35	850	3875	1150	1700
Gampolawela	4.20	525	5698	1400	2200
Kirivavula	3.12	750	6800	1200	1800
Kobbekaduwa	3.30	400	3962	475	1000
Nagahatenne (A)	3.95	400	3250	1050	1400
Nagahatenne (B)	4.07	650	3744	1050	1500
Thalamurayaya	2.80	425	3125	1050	1400
Wattappola	2.95	675	6000	525	900
Wavekumbura	3.30	450	2690	300	600
Golahanwatte	3.30	525	3000	975	1200
Ulapane	4.00	575	5100	1950	2400

Table 4. Correlation between Langmuir sorption maxima (a) and soil properties

Soil Property	*Correlation coefficient (r)*	
	AD	*FL*
pH_{14}	–0.414	–0.382
Silt	0.516	0.571
Clay	0.865**	0.660*
Organic matter	0.806**	0.900**
Cation exchange capacity	0.844**	0.768**
Dithionite extractable-Fe	0.723*	n.d.
Oxalate extractable-Fe	0.129	0.757**
Oxalate extractable-Al	0.791**	0.730*

*, **, significant at 5% and 1% respectively; n.d.=not determined.

Table 5. P sorbed at 0.2 ppm solution P concentration under flooded conditions

Soil	*P sorbed (μg/g soil)*
Kumburegama	250
Gampolawela	600
Kirivavula	220
Kobbekaduwa	50
Nagahatenne (A)	235
Nagahatenne (B)	275
Thalamurayaya	150
Wattappola	250
Wavekumbura	270
Golahanwatte	250
Ulapane	325

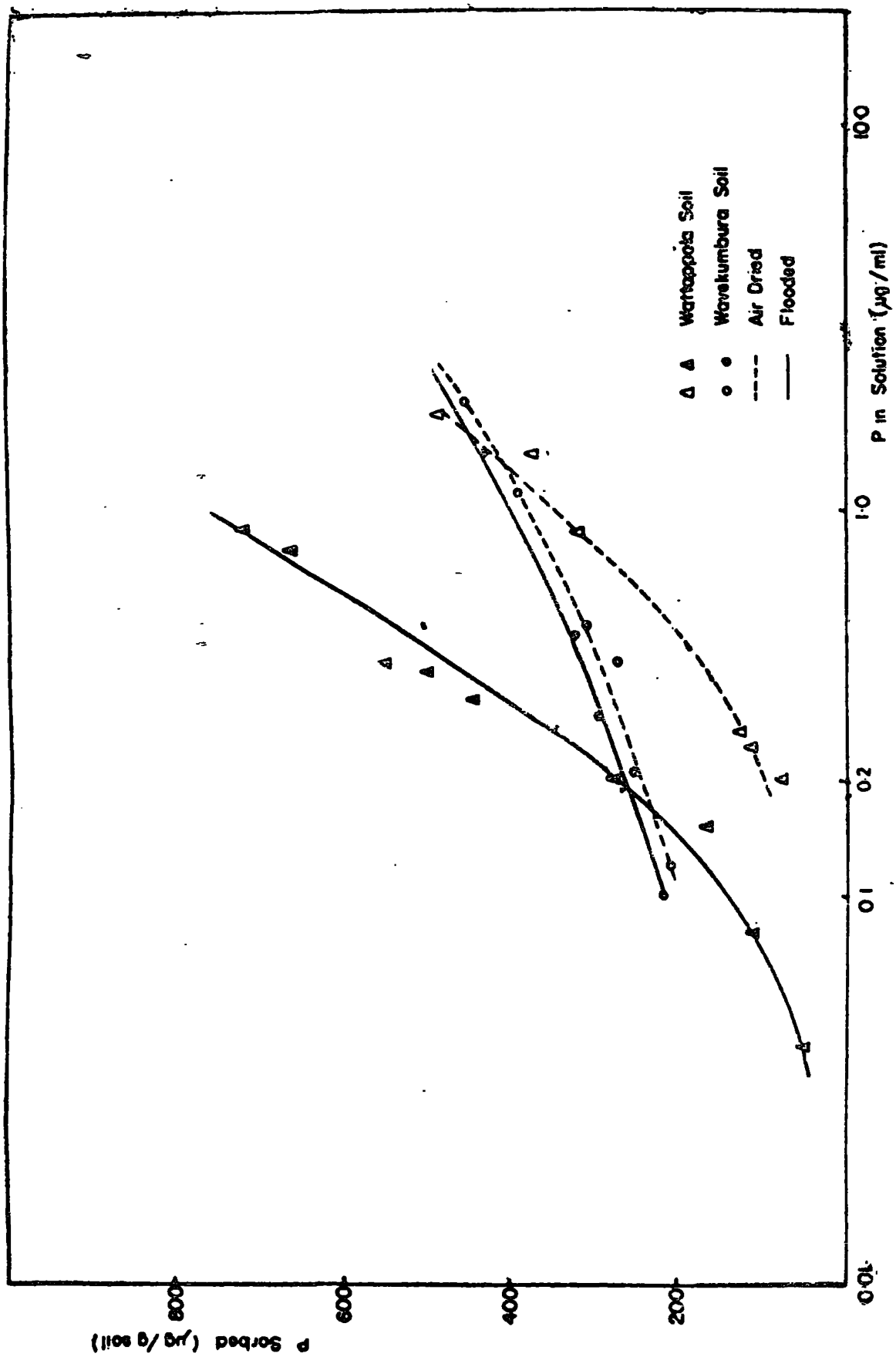

Fig. 1. P sorption isotherms of Wattappola and Wavekumbura soils under air-dried and flooded conditions