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EFFECT OF WETTING AND DRYING CYCLES ON INORGANIC P-TRANSFORMATION IN AN ACID SOIL MAINTAINED UNDER DIFFERENT MOISTURE REGIMES

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ABSTRACT
Inorganic phosphorus transformation in waterlogged soil is different from non-flooded situation. Drying-induced soil aeration and re-flooding periodically alters redox conditions and stimulate redox-sensitive processes influencing P binding forms. Available P release from indigenous rock phosphate under this situation is another area of focus in the present investigation. Drying increased available P by 5.5 and 6.15 mg kg^{-1} in soil maintained at 60% of moisture holding capacity (MHC) and waterlogged situations depending upon treatment combinations. Furthermore drying reduced its P sorption affinity. Single drying at early stage and remoistening is enough to release reductant soluble P into available pool. However, maintenance of two drying phases and remoistening to its waterlogged situation is more effective in releasing inorganic P (77.11 mg kg^{-1}) than the soil maintained at 60% MHC (66.55 mg kg^{-1}). Rock phosphate addition further accentuates the inorganic P release pattern in soil particularly where 2nd drying and remoistening phase is given. Results also pointed out that all fractions of inorganic P are closely correlated with fixation and release phenomena under both the moisture regimes.

INTRODUCTION

Phosphorus is the 2nd most important (after nitrogen) essential plant nutrient. Available P concentration in soil is generally low due to its low solubility and interacting nature. As a result P is a critical growth limiting factor in crop production (Saha *et al*., 2013). P-deficiency leads to incomplete reproductive growth, hindrance in energy transformations in metabolic and physiological processes and ultimately poor yield in terms of quantity and quality.

Chang and Jackson (1957) classified inorganic phosphate into four main groups; namely Ca-P, Al-P, Fe-P and reductant soluble phosphates which are most available to plants. Relatively less active are the occluded and reductant soluble forms of P. According to Mattson and Karlsson (1938) "Saloid bound" phosphorus is a highly available form which is held as H_2PO_4-Ca-micelle linkage over a limited pH range. These forms differ in their behaviour (binding strength, stability etc.) (Moazed *et al*., 2010).

Among the phosphatic fertilizers, superphosphate (SP) is considered to be the best which is manufactured by acidulation of high grade rock phosphates. Indian deposits of Rock Phosphates (RP) are mostly unsuitable for SP production due to low P content and high degree of impurities (Like, $CaCO_3$, Fe). A lot of experiments have been conducted to assess the feasibility of RP for direct application to soil (Kumari and Phogat, 2008).

Acid soils generally exhibit poor crop yield due to low P content. This is because such soils contain large quantities of Al and Fe hydrous oxides which can adsorb P onto their surfaces (Watham *et al*., 2014). Thus, much of the added P is 'fixed' and is not available for crops. So, more P is to be applied (as fertilizers) to raise the concentrations of available soil P to an adequate level (Sanchez and Uehara, 1980).

Changes in P-availability during drying and re-flooding have been widely studied in agricultural sites and wet lands (Zak and Gelbrecht, 2007; Gilbert *et al*., 2014). Inorganic P fractions are greatly influenced by the maintenance of moisture regimes in soils (Saleque *et al*., 1996). Generally under waterlogged condition, aluminium bound phosphate increases where as reductant soluble and iron phosphate decreases. Increase in phosphorus solubility within dried soils following their rewetting are widely reported. Furthermore, drying decreased the solubility of amorphous Fe and Al oxides (Chepkwony *et al*., 2001) and P sorption affinity (Bache, 1964).

Keeping above information in view, the present investigation was conducted to study the effect of wetting and drying cycles on changes in different fractions of inorganic P in an acid soil maintained under different moisture regimes in presence and absence of Mussoorie Rock Phosphate.

MATERIALS AND METHODS

Composite soil sample (0-15 cm depth) was collected from Regional Research Farm (BCKV) (22°27'47"N 87°0'45"E), Jhargram, Paschim Medinipur ,West Bengal, India during the

year 2014-15.The soil was air dried, powdered, passed through a 2 mm sieve. The physical and chemical properties of the initial soil were presented in Table 1. The experiment was conducted in controlled laboratory condition. Two kg air dried soils were taken in each plastic pot. As treatment material, Mussoorie Rock Phosphate (17.4% P_2O_5, supplied by West Bengal Mineral Development Corporation) at 180 kg ha^{-1} was mixed thoroughly with the soil of respective pots where the effect of drying and wetting phase(s) was studied in presence of rock phosphate. One set of soils were maintained at 60% of Moisture Holding Capacity (MHC) and another set under water logged condition. Altogether 8 treatments with 3 replications were adopted for each moisture regimes. The treatments adopted for the experiment are as follows:

T_1 = Soils were maintained at moist condition throughout the experimentation period up to 90th day of incubation.

T_2 = T_1 + Mussoorie Rock Phosphate at 180 kg ha^{-1}.

T_3 = Soils were maintained at moist condition up to 30th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 45th day and maintained up to 90th day of incubation.

T_4 = T_3 + Mussoorie Rock Phosphate at 180 kg ha^{-1}.

T_5 = Soils were maintained at moist condition up to 60th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 75th day and maintained up to 90th day of incubation.

T_6 = T_5 + Mussourie Rock Phosphate at 180 kg ha^{-1}.

T_7 = Two drying phases, one at 30th day and another at 60th day of experiment, were given and after each drying phase soils were remoistened to its pre-dried moist condition on 45th day and 75th day respectively and maintained up to 90th day of incubation.

T_8 = T_7 + Mussourie Rock Phosphate at 180 kg ha^{-1}.

Soils were sampled on 0th, 30th and 45th (which corresponds to 1st drying phase), 60th and 75th (which corresponds to 2nd drying phase) and 90th day of incubation and analyzed for inorganic P fractions (Available-P, Fe-P, Al-P, Ca-P, Saloid bound P, Occluded P, Reductantsoluble P) following the method of Jackson (1973). Fe-P, Al-P, Ca-P and Saloid-P are added together and treated as active P in the present investigation.

RESULTS AND DISCUSSION

Irrespective of treatments, available P increased with increase in the period of incubation (Table 2). The increase in available P is due to mineralization of organic P which is present in soil (Noack *et al*., 2012)and in microbial cells which rupture upon extreme drying or rapid reflooding (Turner and Haygarth, 2001) or under anoxic condition (Reddy *et al*., 1999). Addition of Mussourie rock phosphate as P source increased available P content in soil (Singh *et al*., 2014). Data further revealed that maintenance of one or two drying and rewetting phase did not remarkably change the available P content in soil. The variation observed in available P is due to reaction with other soil constituents (like Fe, Al) which are the most active phosphate fixers and thus get retained (Jokubauskaite *et al*., 2015). Results also pointed out that higher amount of available P is accumulated in both the soils maintained at 60% MHC and under waterlogged condition subjected to two drying phases. However, closer examination of the data revealed that higher amount of available P is accumulated in waterlogged soil subjected to two drying and remoistening phases.

Results in Table 3 showed that maintenance of drying and rewetting phase under waterlogged soil is effective in releasing active P in the available pool. The alteration in oxidation and

Table 1: General physical and chemical characteristics of the soil

Parameters Analyzed	Results	Methods Adopted
Sand (%)	43.50	Hydrometer (Bouyoucus, 1962)
Silt (%)	40.00	
Clay (%)	16.50	
Water holding capacity (%)	32.50	Keen Rackzaw Ski (Piper, 1942)
Bulk density (g cc^{-1})	1.43	Keen Rackzaw Ski (Piper, 1942)
Particle density (g cc^{-1})	2.32	Keen Rackzaw Ski (Piper, 1942)
pH (1:25 w/v) in water	5.13	Glass Electrode pH meter (Black, 1965)
Electrical conductivity (dSm^{-1})	0.40	Conductivity Bridge (Black, 1965)
CEC [Cmol(p^+) kg^{-1} soil]	6.61	Jackson (1973)
Oxidizable Organic carbon (%)	0.34	Walkley and Black (1934)
Total Nitrogen (mg kg^{-1})	533.32	Bremner (1965)
Available Nitrogen (mg kg^{-1})	87.91	Bremner and Keeney, 1966
Available Phosphorus (mg kg^{-1})	36.9	Bray and Kurtz (1945)
Available Potassium (mg kg^{-1})	9.20	Jackson (1973)
Inorganic P fractions (mg kg^{-1})	S-P (4.95)	
	Al-P (34.72)	
	Fe-P (74.20)	Jackson (1973)
	Ca-P (17.30)	
	O-P (91.60)	
	R-P (138.10)	

[S-P = Saloid bound P, Al-P = Aluminium P, Fe-P = Iron P, Ca-P = Calcium P, O-P = Occluded P, R-P = Reductant soluble P]

Table 2: Effect of wetting and drying cycles on increase in the amount (mg kg^{-1}) of available P over O-day in soils maintained under different moisture regimes

Treatments	Moisture regimes maintained					
	At 60% of Moisture Holding Capacity			Under Waterlogged Condition		
	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage
T_1	3.3	6.5	7.3	4.33	8.53	9.51
T_2	4.9	8.5	9.7	5.87	10.62	12.16
T_3	0.5	8.8	9.9	1.12	11.04	12.44
T_4	0.9	2.0	13.1	1.68	14.68	16.07
T_5	7.7	2.6	11.2	4.75	4.06	13.98
T_6	5.2	4.6	13.6	6.43	6.29	16.63
T_7	0.5	3.1	12.9	1.12	4.61	15.8
T_8	0.8	5.2	15.7	1.54	6.99	19.01

[T_1 = Soils were maintained at moist condition throughout the experimentation period up to 90th days of incubation. T_2 = T_1 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_3 = Soils were maintained at moist condition up to 30th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 45th day and maintained up to 90th day of incubation. T_4 = T_3 + Mussoorie Rock Phosphate at 180 kg ha^{-1}.T_5 = Soils were maintained at moist condition up to 60th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 75th day and maintained up to 90th day of incubation.T_6 = T_5 + Mussourie Rock Phosphate at 180 kg ha^{-1}. T_7 = Two drying phases, one at 30th day and another at 60th day of experiment, were given and after each drying phase soils were remoistened to its pre-dried moist condition on 45th day and 75th day respectively and maintained up to 90th day of incubation. T_8 = T_7 + Mussourie Rock Phosphate at 180 kg ha^{-1}.]

Table 3: Effect of wetting and drying cycles on increase in the amount (mg kg^{-1}) of active P (Al-P + Fe-P + Ca-P + Saloid bound P) over O-day in soils maintained under different moisture regimes

Treatments	Moisture regimes maintained					
	At 60% of Moisture Holding Capacity			Under Waterlogged Condition		
	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage
T_1	158.74	161.22	193.47	101.82	191.09	224.57
T_2	183.13	190.57	217.85	122.75	225.96	256.65
T_3	97.56	202.97	225.29	32.08	239.91	265.02
T_4	121.12	227.77	250.09	48.81	269.20	297.1
T_5	165.93	122.77	230.66	108.80	147.85	278.97
T_6	188.09	136.00	250.09	128.33	164.59	295.71
T_7	106.65	141.37	262.90	39.06	170.17	309.66
T_8	111.20	152.12	286.06	54.40	195.28	348.71

[T_1 = Soils were maintained at moist condition throughout the experimentation period up to 90th days of incubation. T_2 = T_1 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_3 = Soils were maintained at moist condition up to 30th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 45th day and maintained up to 90th day of incubation. T_4 = T_3 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_5 = Soils were maintained at moist condition up to 60th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 75th day and maintained up to 90th day of incubation. T_6 = T_5 + Mussourie Rock Phosphate at 180 kg ha^{-1}. T_7 = Two drying phases, one at 30th day and another at 60th day of experiment, were given and after each drying phase soils were remoistened to its pre-dried moist condition on 45th day and 75th day respectively and maintained up to 90th day of incubation. T_8 = T_7 + Mussourie Rock Phosphate at 180 kg ha^{-1}.]

Table 4: Effect of wetting and drying cycles on increase in the amount (mg kg^{-1}) of occluded P over O-day in soils maintained under different moisture regimes

Treatments	Moisture regimes maintained					
	At 60% of Moisture Holding Capacity			Under Waterlogged Condition		
	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage
T_1	32.24	57.05	64.49	39.05	66.95	75.32
T_2	42.17	64.49	71.93	53.00	78.11	86.40
T_3	9.92	62.01	69.45	13.95	72.53	80.90
T_4	14.88	66.97	79.37	22.31	80.90	94.85
T_5	32.24	32.24	69.45	39.05	39.05	80.90
T_6	42.17	42.17	84.33	53.00	53.00	100.43
T_7	12.40	34.72	76.89	16.74	41.84	89.27
T_8	25.73	51.16	91.77	33.12	61.72	89.62

[T_1 = Soils were maintained at moist condition throughout the experimentation period up to 90th days of incubation. T_2 = T_1 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_3 = Soils were maintained at moist condition up to 30th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 45th day and maintained up to 90th day of incubation. T_4 = T_3 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_5 = Soils were maintained at moist condition up to 60th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 75th day and maintained up to 90th day of incubation. T_6 = T_5 + Mussourie Rock Phosphate at 180 kg ha^{-1}. T_7 = Two drying phases, one at 30th day and another at 60th day of experiment, were given and after each drying phase soils were remoistened to its pre-dried moist condition on 45th day and 75th day respectively and maintained up to 90th day of incubation. T_8 = T_7 + Mussourie Rock Phosphate at 180 kg ha^{-1}.]

reduction state of the Fe and Al due to wetting and drying changed the fixing pattern of P (Fabre, 1988; de Vicente *et al*., 2010). Furthermore, maintenance of a drying phase at 60th day released comparatively higher amount of active P over

Table 5: Effect of wtting and drying cycles on increase in the amount (mg kg^{-1}) of reductant soluble P over O-day in soils maintained under different moisture regimes

Treatments	Moisture regimes maintained					
	At 60% of Moisture Holding Capacity			Under Waterlogged Condition		
	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage	At the end of 1st drying phase	At the end of 2nd drying phase	At last stage
T_1	42.17	59.53	71.93	50.22	69.74	83.69
T_2	57.04	81.84	89.29	69.74	97.64	106.01
T_3	14.88	69.44	89.29	19.53	80.90	103.22
T_4	22.32	99.21	109.13	30.69	117.17	128.13
T_5	47.13	42.17	89.29	55.80	50.22	103.22
T_6	59.52	54.56	104.17	72.53	66.95	122.76
T_7	14.88	42.16	126.49	19.53	50.22	124.93
T_8	19.84	49.6	136.41	27.90	61.37	159.01

[T_1 = Soils were maintained at moist condition throughout the experimentation period up to 90th days of incubation. T_2 = T_1 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_3 = Soils were maintained at moist condition up to 30th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 45th day and maintained up to 90th day of incubation.T_4 = T_3 + Mussoorie Rock Phosphate at 180 kg ha^{-1}. T_5 = Soils were maintained at moist condition up to 60th day where a drying phase was given and then the soils were remoistened to its pre-dried moist condition on 75th day and maintained up to 90th day of incubation. T_6 = T_5 + Mussourie Rock Phosphate at 180 kg ha^{-1}.T_7 = Two drying phases, one at 30th day and another at 60th day of experiment, were given and after each drying phase soils were remoistened to its pre-dried moist condition on 45th day and 75th day respectively and maintained up to 90th day of incubation. T_8 = T_7 + Mussourie Rock Phosphate at 180 kg ha^{-1}.]

Table 6: Correlation co-efficient among different inorganic fractions of P in soil maintained at 60% of MHC and waterlogged condition

P fractions	60 % of moisture holding capacity				Waterlogged condition			
	Red-P	Occl-P	Av-P	Active P	Red-P	Occl-P	Av-P	Active P
Red-P	1				1			
Occl-P	0.956**	1			0.967**	1		
Av-P	0.944**	0.875**	1		0.940**	0.878**	1	
Active-P	0.970**	0.910**	0.924**	1	0.971**	0.921**	0.918**	1

** Correlation is significant at the 0.01 level ; * Correlation is significant at the 0.05 level; [Red-P = Reductant soluble P, Occl-P = Occluded P, Av-P = Available P and Active P = (Al-P + Fe-P + Ca-P + Saloid bound P)]

that of the soil subjected to a drying phase at 30th day of the incubation under both the moisture regimes.

Presence of higher amount of occluded P throughout the incubation period (with low rate of increase) is due to the release of P by oxidation of iron compounds (Table 4). Red and lateritic soils with which the experiment was conducted are dominated by Fe and Al oxides. Data further showedthat the maintenance of a single drying (30th to 45th day) and rewetting phase at the early stage retained comparatively lesser amount of P in occluded form (Table 4). The drying may have facilitated formation of a crystalline structure of amorphous Fe-hydroxides in a process known as mineral aging thereby reducing sorption capacity (de Vicente *et al*., 2010). The effect of Mussourie rock phosphate is well marked at the last stage of the experiment as the rock phosphate is slowly dissolved with time (Singh *et al*., 2014).

Reductant soluble P is of highest order among all inorganic P fractions in the present investigation (Table 1). The result is at par with earlier investigation carried out by Malakar *et al*. (2015). Irrespective of treatments, reductant P is increased with increase in the period of incubation (Table 5). The release of P from the reductant form is more prominent in soils subjected to 2nd drying phase on 60th day of incubation and treated with rock phosphate. Results further showed that two cycles of wetting and drying led to shift in proportion of reductant soluble P in soil. The increase in reductant soluble P was likely due to the oxidation of Fe (II) and formation of Fe (III) oxyhydroxides, which preferentially bind P (Fox, 1989).The Fe (III) would be reduced to Fe (II) again in waterlogged condition releasing bound P (Dieter *et al*., 2015). Addition of rock phosphate increased the release of reductant soluble P in waterlogged soil (Mukhopadhyay and Saha, 1977).

Results of correlation co-efficient (Table 6) showed that saloid bound P is highly correlated with occluded P, available P and active P. It is also interesting to note that occluded P form is highly correlated with available and active P fractions of the soil. Again, available P fraction is closely related with active P. It is, therefore, clear from the correlation data that maintenance of wetting and drying cycles has a good impact on retention and release of available P which is controlled by other active components present in the soil system (Nguyen and Marschner, 2005; Gilbert *et al*., 2014).Maintenance of drying and rewetting phases changed the micro environment in soil through the alteration of oxidation-reduction states which influence fixation and release of Fe-P in soils. The results corroborate the earlier studies carried out by Han *et al*., (2005) and Zin *et al*., (2015).

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