

Fixation and Recovery of Added Phosphorus and Potassium in Different Soil Types of Pulse-Growing Regions of India

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Abstract: Fixation and recovery of added phosphorus (P) and potassium (K) were studied in different soil types of pulse-growing regions. Amounts of P and K fixed increased in all the soils irrespective of type and texture. With the increase in levels of added P and K, maximum P fixation was observed at lower levels of added P (50 mg kg⁻¹). Alfisols showed maximum P-fixation capacity (92.7%), followed by Vertisols (86.5%) and Inceptisols (76.6%) at 50 mg kg⁻¹ added P. However, K fixation increased with increasing levels of added K up to 200 mg kg⁻¹, and thereafter fixation either decreased or was maintained at similar levels. Vertisols showed higher K fixation than Inceptisols and Alfisols. Fertilizer P requirement per unit increase in available P in soil was highest in Bangalore (3.23) and lowest in Delhi (2.38). Fertilizer K requirement per unit increase in available K in soil was highest in Raipur and Gulbarga (1.75) and lowest in Ranchi (1.28).

Keywords: Fixation, recovery, P and K, pulse growing regions, soil types

Received 23 February 2004, Accepted 18 April 2005

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INTRODUCTION

Most of the added nutrients to soils, particularly phosphorus (P) and potassium (K), are fixed in soil in temporarily plant-unavailable forms (Kanwar, Goswami, and Kamath 1982). The type and extent of these fixation reactions in soil are influenced by a number of factors such as soil pH, type and amount of clay, and chemical composition of soil (Shaviv et al. 1985). India is the world's largest grower of pulse crops (food legumes) covering about 23.0 million hectares and producing about 14.8 million tons. Pulses are mostly grown under rain-fed conditions on marginal and submarginal lands, covering different types of soils. Additions of P to various pulse crops are recommended at the rates of 40 to 80 kg P₂O₅ ha⁻¹ and K at 20 to 40 kg K₂O ha⁻¹. Fixation studies provide information on the reaction rates and fate of the added P and K, thereby helping to formulate strategies for better management of P and K and compute optimum P and K requirements of these pulse crops. The present study examines the fixation of added P and K and the recovery in different soil types of pulse-growing regions of India.

MATERIALS AND METHODS

Soils

Soil samples (15-cm interval) were collected from 10 locations: four Inceptisols (Kanpur, Faizabad, Delhi, and Varanasi), three Vertisols (Sehore, Raipur, and Gulbarga), and three Alfisols (Hyderabad, Ranchi, and Bangalore) covering seven states and major soil groups. The soil samples were processed and analyzed for different chemical properties (Jackson 1973). Total iron (Fe) and aluminum (Al) were determined by following procedures outlined in Jackson (1973) after digesting the soil by microwave digestion system (model MLS 1200) (Table 1).

Phosphorus-Fixation Capacity

Two grams of surface soil samples (<2 mm) were equilibrated with 20 mL of 0.01 M calcium chloride (CaCl₂) solution containing graded levels of calcium phosphate [Ca(H₂PO₄)₂·H₂O]. The P levels used were 0, 50, 100, 200, 400, 800, and 1600 mg P kg⁻¹. Two drops of toluene were added to each flask and incubated for 96 h at room temperature (25°C) (Waugh and Fitts 1966). After incubation, P was extracted by Olsen's reagent (Olsen et al. 1954) for neutral and alkaline soils and by Bray's one reagent (Bray and Kurtz 1945) for acidic soils. The P concentration in the soil extracts was determined in the aliquot colorimetrically. Fixed P was computed by the difference between the initial and the equilibrium P concentrations (Fox and Kamprath 1970).

Table 1. Locations and properties of soils

Soil location	State	EC dSm ⁻¹	pH (1:2.5)	Org. C (%)	CaCO ₃ (g kg ⁻¹)	Clay (%)	CEC (cmol (p ⁺) kg ⁻¹)	Total Fe and Al oxides (%)
Inceptisols								
Kanpur	Uttar Pradesh	0.38	7.6	0.30	1.25	20.6	7.5	15.5
Faizabad	Uttar Pradesh	0.43	9.3	0.35	1.65	24.6	9.8	20.1
Delhi	Delhi	0.22	7.6	0.42	1.85	18	10.2	22.1
Varanasi	Uttar Pradesh	0.25	7.6	0.31	1.52	23.5	11.8	24.0
Vertisols								
Sehore	Madhya Pradesh	0.23	7.9	0.46	6.50	61.5	49.5	25.9
Raipur	Chattisgarh	0.12	7.3	0.41	8.50	65.5	51.5	27.6
Gulbarga	Karnataka	0.25	7.7	0.38	9.51	70.6	59.7	42.2
Alfisols								
Hyderabad	Andhra Pradesh	0.07	5.3	0.36	0.88	32.6	13.5	48.6
Ranchi	Jharkhand	0.09	6.2	0.28	0.81	25.3	8.6	24.4
Bangalore	Karnataka	0.06	5.3	0.32	0.52	36.6	14.4	36.2

Potassium-Fixation Capacity

Two grams each of surface soil samples (<2 mm) were incubated with 2 mL of K solution varying in levels for 72 h at room temperature (Verma and Verma 1970). The K levels used were 0, 50, 100, 200, 400, and 800 mg K kg⁻¹. After incubation, 8 ml of 1 N ammonium acetate solution was added and shaken for 5 min (Hanway and Heidel 1952). Potassium was estimated by flame photometer. Fixed K was computed using the formula

$$\text{K fixed} = \text{K applied} - (\text{Extractable K in treated soil} \\ - \text{extractable K in control}).$$

RESULTS AND DISCUSSION

Soil Properties

All the soils were low in organic carbon (<0.50%) despite long-term pulse cultivation on these soils (Table 1). Soils from Hyderabad, Ranchi, and Bangalore were acidic, and the rest of the soils were alkaline in reaction. Electrical conductivity was normal in all the soils except in that from Faizabad, where a slightly higher EC was observed. Black soils from Sehore, Raipur, and Gulbarga were calcareous, and the rest were noncalcareous in nature. The Vertisols were clay in texture, Alfisols were sandy clay loam, and Inceptisols were loam to silty loam. The total Fe and Al oxide (sesquioxide) content ranged from 15.5 to 24.0% in Inceptisols, 25.9 to 42.2% in Vertisols, and from 24.4 to 48.6% in Alfisols.

Phosphorus Fixation

Amount of P fixed in the different soils with P levels increasing from 50 to 1600 mg kg⁻¹ (Table 2) showed that at all the levels of added P, Alfisols fixed greater amounts of P followed by Vertisols, and then Inceptisols. The highest percent of P fixation occurred at lower levels of added P (50 mg kg⁻¹) in all the soils, and it gradually decreased with increasing P levels. The mean percent P fixation among soil types at lower levels of added P is shown in Figure 1. These lower levels of P are the levels generally recommended for different pulse crops. At 50 mg kg⁻¹ (112 kg P ha⁻¹) the percent P fixation was highest in Alfisols (87) and lowest in Inceptisols (77). At 100 mg kg⁻¹ of added P, similar levels of fixation were observed in different soil types, but with further increase in added P, the percent fixation decreased. However, the amount of added P fixed increased with increasing levels of added P. The increase in amount

Table 2. Phosphorus fixation characteristics of different soil types of pulse growing regions of India

Soil type/ location	Added P											
	50		100		200		400		800		1600	
	(%) ^a	(mg kg ⁻¹) ^b	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)	(%)	(mg g ⁻¹)
Inceptisols												
Kanpur	82	41	81	81	79	158	72	286	65	520	62	986
Faizabad	77	39	76	76	73	146	68	272	62	498	60	963
Delhi	75	37	75	75	70	140	67	268	60	481	59	952
Varanasi	76	38	75	75	70	140	67	268	61	491	60	958
Verkisols												
Sehore	81	40	80	80	80	160	72	286	65	519	62	998
Raipur	85	43	88	87	88	174	75	299	68	541	66	1058
Gulbarga	90	45	91	89	91	178	79	315	70	562	67	1071
Alfisols												
Hyderabad	93	47	92	89	92	178	80	320	71	570	68	1082
Ranchi	90	45	91	89	91	178	82	326	70	560	67	1070
Bangalore	96	48	95	90	95	181	85	340	75	600	70	1020

^aPercent of added P fixed.^bAmount of added P fixed.

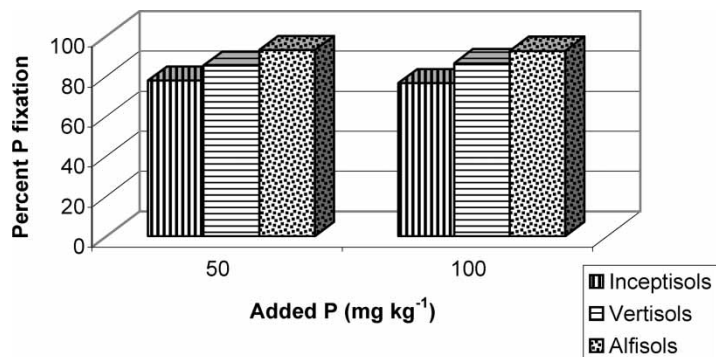


Figure 1. Percent P fixation at various levels of added P in different soil types.

of P fixation with the increase of added P might be attributed to the increase in ionic strength generated by addition of P. It has been reported that the increased ionic strength lowers the activity coefficient, which may raise the concentration of reaction products in soils per the solubility product principle (Sanyal and De-Datta 1991). The adsorbed P serves as a reservoir for regeneration of solution P, the concentration of which influences the diffusion of phosphate to plant roots, followed by its absorption by plants (Barrow 1979).

Among Inceptisols, soils of Kanpur showed maximum P fixation of 82% followed by the soils from Faizabad (77%), Varanasi (76%), and Delhi (75%) at 50 mg kg⁻¹ of added P. At higher levels of added P (1600 mg kg⁻¹) the difference in percent fixation among four Inceptisols reduced considerably, ranging from 60 to 62. Among Vertisols at 50 mg kg⁻¹ of added P, percent fixation was the highest in Gulbarga soil (90%), followed by Raipur soil (85%); the lowest was in Sehore soil (81%). A similar trend was observed at the highest level of added P. Among Alfisols, with a pretreatment of 50 mg kg⁻¹, Bangalore soils had the highest P fixation of 96% followed by soils from Hyderabad (93%); the lowest was in Ranchi (90%). The clay fraction in the Alfisols, predominantly containing kaolinite and accessory oxide and hydrous oxides of Fe and Al, played an active role in sorption (Milap-Chand, Randhawa, and Vig 1995). In general, in each soil type, the percent P fixation varied according to the amount of clay content in the soil. Among Vertisols, soils of Gulbarga, with 71.6% clay, showed the maximum percent P fixation at all the levels of added P as compared to soils of Sehore (clay: 61.5%). Relationships established between the P-fixation factor obtained from a regression equation connecting increases in available P with added P suggested that a P-fixation factor had a significant positive correlation with Fe oxides (0.74*) and nonsignificant positive relationship with Al oxide content in soil (0.62). However, when Fe and Al (sesquioxides) were taken together, the *r* values improved to 0.77* (Figure 2). The positive correlation between total oxides of Fe and Al with P fixation may be due to the

formation of insoluble phosphates of Fe and Al. The relationship of P fixation factor with pH was negative (-0.78^*), which could be due to gradual dissolution of Fe and Al oxides and their subsequent precipitation as phosphates with lowering of pH values (Mallikarjuna et al. 2003). Clay content showed a significant relation to the P fixation factor in all the soil types, but the extent of correlation was much higher in Alfisols (0.94^{**}) than Vertisols (0.92^{**}) and was lowest in Inceptisols (0.68^{NS}). Significant correlation of phosphate sorption parameters with clay content has been reported by several workers (Tomar and Gautam 1996; Toor, Ball, and Viag 1997), and this may be a mere reflection of the effect of specific surface area (Sanyal and De-Datta 1991). Milap-Chand, Randhawa, and Vig (1995) reported that CEC and clay were the predominant determinants of phosphate sorption.

Potassium Fixation

Irrespective of soil type and clay content, amount of K fixed increased with increasing K additions ranging from 50 mg kg^{-1} to 800 mg kg^{-1} (Table 3). In general, Vertisols and Inceptisols showed higher amounts of K fixation than Alfisols. Most of the soils showed the highest percent K fixation when K was added between 50 to 200 mg kg^{-1} , and thereafter, either similar levels or a decrease in percentage of K fixation was observed. However, mean percentage of K fixation in all the soils types increased between 50 and 100 mg kg^{-1} of added K (Figure 3). This differential K-fixation capacity of soils could be attributed to the variability in soil texture and mineralogy. In studies reporting on fixation characteristics of mineralogically different benchmark soils of India, Srinivasarao et al. (2000) indicated that smectitic Vertisols and Vertic subgroups showed greater K-fixation capacity followed by illitic

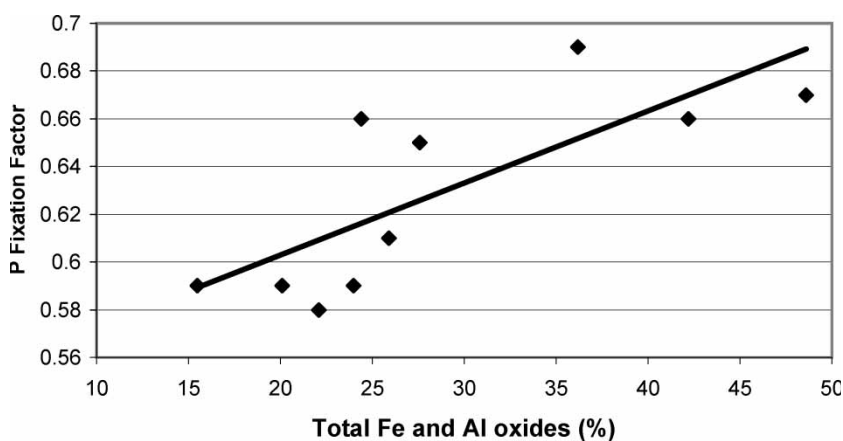


Figure 2. Relationship between total Fe and Al oxides and P-fixation factor in pulse growing soils.

Table 3. Potassium fixation characteristics of different soil types of pulse growing regions of India

Soil type/ location	Added K									
	50		100		200		400		800	
	(%) ^a	(mg kg ⁻¹) ^b	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)	(%)	(mg kg ⁻¹)
Inceptisols										
Kanpur	30	15	42	42	41	82	41	162	41	324
Faizabad	36	18	46	46	44	88	43	170	42	335
Delhi	26	13	32	32	28	56	31	122	25	198
Varanasi	34	17	45	45	43	86	43	170	42	332
Vertisols										
Sehore	36	18	46	46	44	88	44	175	43	340
Raipur	40	20	42	42	40	80	45	175	42	336
Gulbarga	48	24	49	49	47	94	46	180	44	348
Alfisols										
Hyderabad	24	12	28	28	30	59	30	118	23	184
Ranchi	20	10	25	25	27	54	27	107	21	171
Bangalore	26	13	30	30	31	62	32	128	24	194

^aPercent of added K fixed.^bAmount of added K fixed.

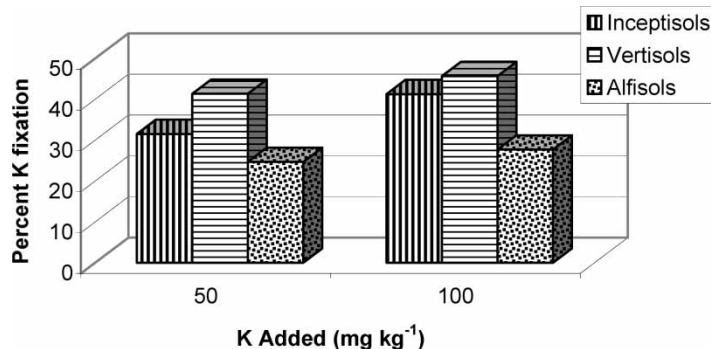


Figure 3. Percent K fixation at various levels of added K in different soil types.

and kaolinitic soils. In Inceptisols, the highest K fixation was observed in soils of Faizabad (46%), followed by Varanasi (45%), Kanpur (42%), and Delhi (32%). Soils with finer texture such as Faizabad (24.6%) and Varanasi (23.5%) showed higher K fixation compared to light-textured Delhi soils (clay: 18.0%). Among Vertisols, the highest percentage K fixation was observed in soils of Gulbarga (49%). The K fixation at higher levels of added K in Sehore soils is higher than Raipur despite its lower clay contents, which might be due to variation in associated clay minerals. Higher K fixation in Gulbarga soils could be due to larger amounts of clay content (70.6%) compared to other soils with relatively lower clay. Relationships established between clay content and the K-fixation factor showed significant positive correlation in all the soil types: Inceptisols (0.87), Vertisols (0.84*), and Alfisols (0.99**). Srinivasarao et al. (2000) showed that the variations in K-fixation capacity among benchmark soil series were mainly due to differences in clay content in soils.

Among Alfisols, soils of Hyderabad and Bangalore showed similar levels of K fixation, ranging from 24 to 32%, whereas in Ranchi soils K fixation ranged between 20 and 27%. Lower clay contents in Ranchi soil as compared to Hyderabad and Bangalore soils might have contributed to lower levels of K fixation. Fixation of added K and its retention in a slowly available form is beneficial in light-textured sandy soils, which otherwise is leached down to deeper layers. Because many studies have established that crop K needs were mostly met from nonexchangeable or fixed K (Mengel 1985; Srinivasarao, Subba Rao, and Rupa 2001), fixing of added K in light-textured soils would act as a reserve source of K in soil.

Recovery of P and K

Recovery rates of added P and K were computed based on regression equations connecting increase in available nutrients with the amount of

added nutrients (Table 4). Recovery of added P was highest in Inceptisols (0.40–0.42), followed by Vertisols (0.34–0.39); the lowest was for Alfisols (0.31–0.34). On the other hand, P fixation per unit of added P was higher in Alfisols than in Vertisols and Inceptisols. Based on recovery rate, unit of P fertilizer rate required per unit increase in available P in soil was calculated. Requirement of P in Alfisols varied from 2.94 to 3.23, Vertisols from 2.56 to 2.94, and Inceptisols from 2.38 to 2.50 units per unit increase in available P content in soils. Mean levels of required P units for different soil types are presented in Figure 4, indicating the highest requirement of P in Alfisols (3.07) as compared to Vertisols and Inceptisols.

Table 4. Recovery of P and K, fixation, and unit fertilizer rate required for unit increase in available nutrient in different soil types of pulse growing regions of India

Soil/location	Equation connecting increase in available P or K with added P or K (X)	P or K recovery rate/unit	P or K fixation rate/unit	Unit fertilizer P or K rate required per unit increase in available P or K
Phosphorus				
Inceptisols				
Kanpur	$Y = -2.83 + 0.41X$	0.41	0.59	2.43
Faizabad	$Y = -2.16 + 0.41X$	0.41	0.59	2.43
Delhi	$Y = -1.93 + 0.42X$	0.42	0.58	2.38
Varanasi	$Y = -94 + 0.42X$	0.41	0.59	2.43
Vertisols				
Sehore	$Y = -2.67 + 0.39X$	0.39	0.61	2.56
Raipur	$Y = -2.84 + 0.35X$	0.35	0.65	2.86
Gulberga	$Y = -3.42 + 0.34X$	0.34	0.66	2.94
Alfisols				
Hyderabad	$Y = -3.49 + 0.33X$	0.33	0.67	3.03
Ranchi	$Y = -3.64 + 0.34X$	0.34	0.66	2.94
Bangalore	$Y = -3.80 + 0.31X$	0.31	0.69	3.23
Potassium				
Inceptisols				
Kanpur	$Y = -1.33 + 0.59X$	0.59	0.41	1.69
Faizabad	$Y = -1.88 + 0.58X$	0.58	0.42	1.72
Delhi	$Y = -7.75 + 0.75X$	0.75	0.25	1.33
Varanasi	$Y = -1.13 + 0.58X$	0.58	0.42	1.72
Vertisols				
Sehore	$Y = -1.45 + 0.58X$	0.58	0.42	1.72
Raipur	$Y = -1.95 + 0.57X$	0.57	0.43	1.75
Gulberga	$Y = -5.79 + 0.57X$	0.57	0.43	1.75
Alfisols				
Hyderabad	$Y = -9.12 + 0.77X$	0.77	0.23	1.29
Ranchi	$Y = -7.04 + 0.78X$	0.78	0.22	1.28
Bangalore	$Y = -10.33 + 0.76X$	0.76	0.24	1.31

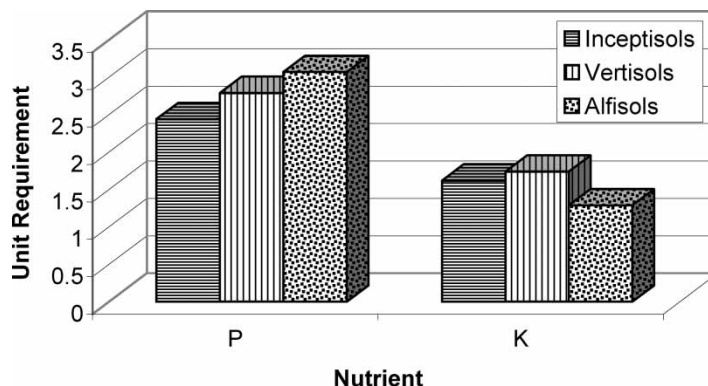


Figure 4. Mean units of fertilizer P or K rate required per unit increase in available P or K in different soil types.

In the case of K, lower recovery was observed in Vertisols and Inceptisols, whereas Alfisols showed higher recovery. The fixation rates of added fertilizer ranged from 0.25 to 0.42 in Inceptisols, 0.42 to 0.43 in Vertisols, and 0.22 to 0.24 in Alfisols. Based on mean values, Vertisols required the highest units (1.74), followed by Inceptisols (1.62) and Alfisols (1.29) (Figure 4). Rubio and Gil-Sotres (1996) stated that the proportion of clay contributes to K fixation, and therefore the K requirement rates increased with increases in fineness of the soil.

These results suggest that considerable variations in P and K fixation were found among different soil types as well as within each soil type of pulse-growing regions. Alfisols showed the highest P-fixation capacity, whereas Vertisols had the highest K-fixation capacity. As most of the pulse-growing soils are medium to high in available P and low to high in available K (Srinivasarao et al. 2002), knowledge about fixation/recovery of added P or K may help in formulating the precise fertilizer recommendation for pulse crops.

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