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Study of phosphorus fixation capacity in *Alfisol* soil order of North-East India

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Abstract
The surface soil samples of 3 soil profiles were used in the study representing one of the dominant soil order of North-East India i.e. *Alfisol.* The physical and chemical attributes of the 3 profile soils along with the ability of the profiles to fix phosphorus (P) were determined in this investigation. The order *Alfisol* comprised of 3 profiles *viz.*, P1, P2 and P3 representing Changlang (Arunachal Pradesh), Sepahijala (Tripura) and Ri-Bhoi (Meghalaya), respectively. Results from the incubation experiment (P levels 0, 25, 50, 100, 200, 300,400, 500, 600 and 700 ppm for 24 h) indicated that phosphorus fixation capacity (PFC) (µg P g^{-1} soil) ranged from 223 to 471 for the soil profiles of *Alfisol*. The maximum PFC was obtained at the P application dose (µg g^{-1} soil) for Changlang (Arunachal Pradesh) at 500.The higher percent P fixed was in order of Ri-Bhoi, Meghalaya (94.1) > Sepahijala, Tripura (85.1) > Changlang, Arunachal Pradesh (74.4). The bulk density (BD), maximum water holding capacity (MWHC) and clay content ranged from 0.91 to 1.00 g cc^{-1}, 32.7 to 51.8% and 15 to 40%, respectively among three soil profiles. The content of soil organic carbon (SOC), soil available nitrogen, phosphorus and potassium (Avl.N, Avl.P and Avl.K, respectively) ranged from 1.4 to 1.8%, 270 to 301 kg ha^{-1}, 9.7 to 22.8 kg $ha^{-1}$and 155 to 220 kg ha^{-1}, respectively. Soil pH, exchangeable aluminium (Ex.Al), readily soluble aluminium (RS.Al), exchangeable calcium+magnesium (Ex.Ca+Mg) and base saturation (BS) ranged from 4.4 to 6.3, 0.12 to 3.59 meq 100^{-1}g soil, 18.8 to 354 mg kg^{-1} soil, 2.8 to 8.1 meq 100^{-1}g soil, 39.9 to 55.3%, respectively. The soils of Ri-Bhoi, Meghalaya showed the highest percentage of P fixation and Changlang, Arunachal Pradesh the least among the three profiles. In order to minimize the loss of phosphatic fertilizers, site-specific nutrient management is suitable and formulation of appropriate fertilizer dose should be undertaken to achieve maximum phosphorus use efficiency from these locations.

Keywords: *Alfisol*, phosphorus fixation capacity, site-specific nutrient management, phosphorus use efficiency

Introduction

The North Eastern region (NER) of India has the largest stretches of acid soils, followed by the neighbouring states of West Bengal, Bihar and Orissa; because of the climatic conditions prevailing in the region, types of rocks and minerals along with other factors being involved. It is estimated that approximately 91% soils are acidic, and nearly 65% soils are suffering from strong acidity (pH < 5.5) in NE India (Sharma *et al*., 2006) [9]. The average crop productivity in acid soil regions (ASR), particularly in NE India, is very low, lagging far behind the national average. A multitude of acidity-related fertility constraints *viz.*, the toxicities of aluminium (Al), iron (Fe) and manganese (Mn), deficiency of phosphorus (P), calcium (Ca), magnesium (Mg), zinc (Zn), molybdenum (Mo), boron (B), low base saturation, reduced biological activity and related acidity-induced soil fertility and plant nutritional problems are associated with such soils (Sarkar, 2015; Thakuria *et al*., 2016) [8, 11]. The majority soils of NE India are categorized under *Inceptisols, Entisols, Ultisols, Alfisols* and other miscellaneous orders and their respective distribution is 49.6%, 22.2%, 15.1%, 3.6% and 9.5% of the TGA of NE India (Patiram and Ramesh, 2008) [6]. Acid soils of NE India are also P deficient. Phosphorus use efficiency (PUE) is reported to be only 15–20% for most of the acid soils. More than 80% applied P fertilizer during crop production is fixed in soil due to acidity-related factors like precipitation reaction with Al and Fe resulting insoluble $AlPO_4$ and $FePO_4$ (Patiram, 1991; Sharma *et al*., 2006; Kumar *et al*., 2012) [5, 9, 3]. Phosphorus deficiency is often exacerbated by a high capacity to fix (adsorb and/or precipitate) P, making it less available to crops (Quang *et al.*, 1996) [7]. The availability of inorganic P (P_i) in soil solution is controlled by the fixation mechanism (Muralidhar *et al.*, 2005) [4].

Phosphorus fixation in soils depends upon many factors, *viz*. soil pH, organic matter content, type of clay minerals and sesquioxides, *etc*. The causes of low P-use efficiency (PUE) in highly weathered humid sub-tropical soils of NE India are Al and Fe induced P deficiency (Sharma *et al*., 2006) [9]. The process of P fixation accelerates the problem leading to low PUE in soil. Since, there lies spatial variability of P availability in soils, single blanket recommendation is not appropriate, instead site-specific nutrient management is the need of the hour.

Materials and Methods

The three representative soil profiles of the order *Alfisol* of NE India considered in this study were from different locations *viz*. Changlang, Arunachal Pradesh (P1); Sepahijala, Tripura (P2) and Ri-Bhoi, Meghalaya (P3). The soil samples from surface layer (0-15 cm depth) were collected for laboratory analysis and some basic physico-chemical properties (Soil texture, soil colour, pH, SOC, Available. N, P, K, Exchangeable Ca and Mg, Readily soluble Al, CEC, Exchangeable aluminum, Base saturation) of the soils were determined.

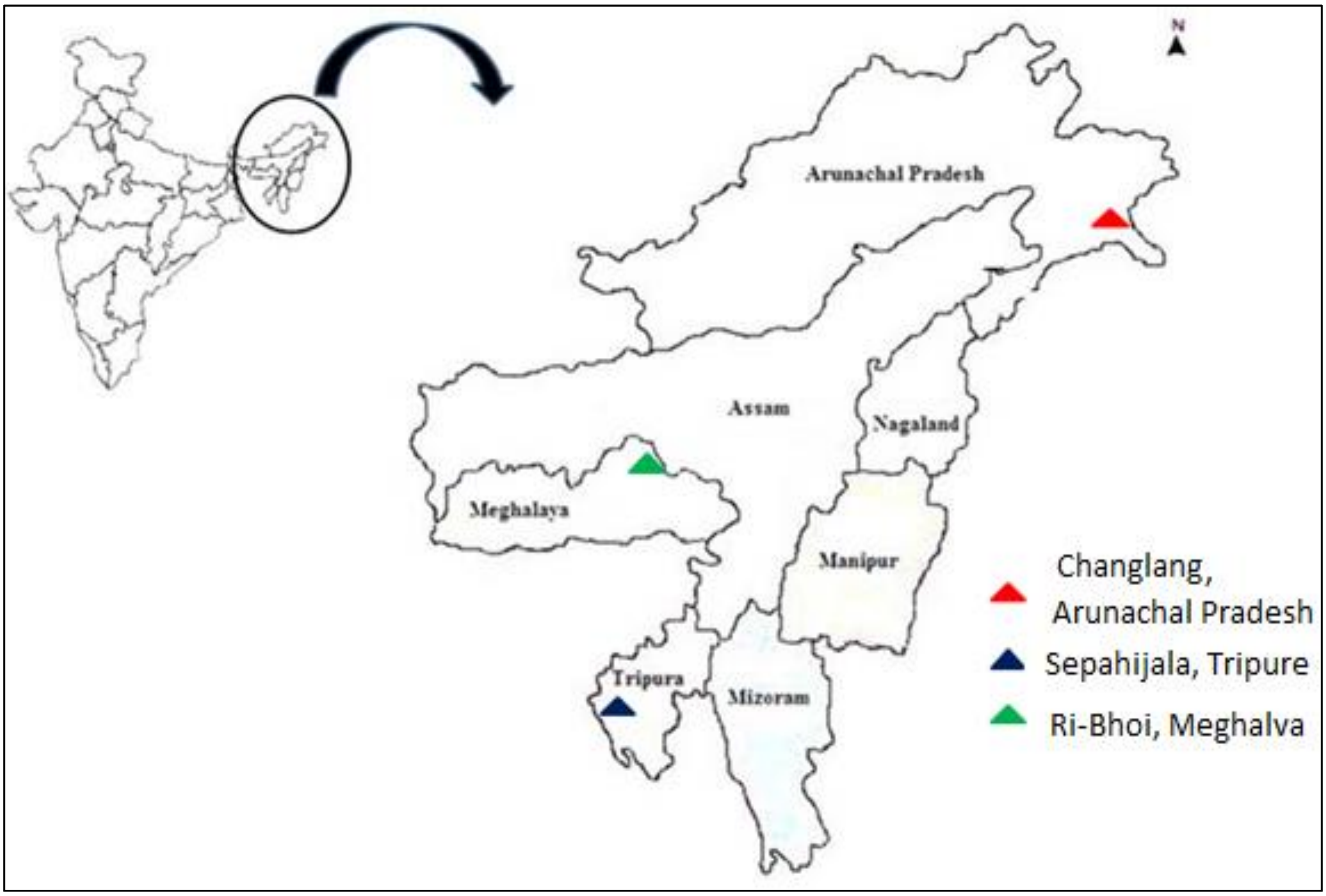

Fig 1: Sampling locations of the study area

An amount of 5 g soil was taken in each conical flask (capacity 100 ml). The graded levels of P (0, 25, 50, 100, 200, 300, 400, 500, 600 and 700mg P_2O_5 kg^{-1} soil) were imposed to each profile soil maintaining 3 replicate flasks. Immediately after addition of P levels, 25 ml of 0.01 M $CaCl_2$ solution was added to each conical flask and these flasks were incubated for 24 h in a gyratory shaker at rpm 120. After incubation, soil suspension was filtered through Whatman filter paper no. 42 and then the concentration of P in the clear supernatant was determined using stannous chloride blue colour method. The percent P fixed was calculated by dividing fixed P amount with added P amount and multiplying it with 100. The formula used to calculate percent P fixed is given below:

$$\% \text{ P fixed} = \frac{\text{Fixed P}}{\text{Added P}} \times 100$$

Qunatity of fixed P = (Quantity of P applied – Quantity of P in solution – Quantity of solution P in blank)

Statistical Analysis

Univariate statistics were performed using SPSS v12.0 (Statistical Packages for Social Science Inc., Chicago, IL, USA). Means were tested at a significant level of $P \leq 0.05$ using Tukey's HSD test for multiple pair-wise comparisons among means.

Results and discussion

Physico-chemical properties of the profiles

The colour of soils in dry conditions ranged from strong brown to yellowish brown *viz.*, 7.5 YR 4/6 to 10YR 5/6 and under moist conditions ranged from dark red to dark yellowish brown *viz.*, 2.5 YR 3/6 to 10YR 3/4. The sand content varied from 50 to 65%, clay content ranged from 15 to 40%. The maximum clay content was 40% in P2 and minimum was 15% in P1. The silt content values varied from 10-20%. The texture varied from sandy loam to sandy clay. The values of BD ranged from 0.91 to 1.00 g cc^{-1} among the 3 profiles and the highest was found in P3. Among 12 soil profiles, P2 had the least bulk density. The water holding capacity ranged from 32.7% in P3 to a maximum of 51.8% in

P1. Among all 12 soil profiles, P3 had the least capacity to hold water.

The pH of soils ranged from 4.40 to 6.33 that are from extremely acidic to slightly acidic. The pH of P3 was the highest and P2 was the lowest among *Alfisols*. Soil organic carbon varied from 1.4%- 1.8%. The content of SOC was the highest (1.8%) for P1 and the least (1.4%) was for P3. The content of soil Avl.N ranged from 270 kg ha^{-1} to 301 kg ha^{-1} and the P2 soil contained maximum SOC and minimum was for P1 soil. The content of Avl.P varied from 9.7 kg ha^{-1} to 22.8 kg ha^{-1}. The highest P was found in P1 soils and the lowest in P3 soils. The P1 soil contained maximum Avl.K (220 kg ha^{-1}) and the minimum content (155 kg ha^{-1}) for P3 soils. Exchangeable alumina (Ex. Al) ranged from 0.12 meq 100^{-1}g to 3.59 meq 100^{-1}g. The P2 soil had the highest amount and P1 had the least amount of Ex. Al. The higher content of readily soluble aluminium was due to low soil pH of the soil. The P3 soil contained the highest amount of readily soluble aluminium (354 mg kg^{-1}) and the lowest (18.8 mg kg^{-1}) was P1 soil. The content of DTPA-Fe varied from 20.0 mg kg^{-1} to 29.7 mg kg^{-1}. The content of Exch. Ca+Mg ranged from 2.8 meq 100^{-1}g soil to 8.1 meq 100^{-1}g soil. The values of CEC ranged from 8.0 to 15.6 cmol kg^{-1} and the percent BS ranged from 39.9% to 55.3% for 3 soil profiles belongs to *Alfisol*. Higher values of BS was in P1 soil due to higher CEC and high amount of Ex.Ca+Mg and the lower BS values was in P3 soil due to low CEC and low amount of Ex.Ca+Mg**.**

Table 1: Physico-chemical properties of surface soils of the three profiles of *Alfisol*

Profile		P1	P2	P3
Soil colour	Dry	10 YR 4/4	7.5 YR 4/6	10 YR 5/6
	Moist	10 YR 3/4	2.5 YR 3/6	5 YR 3/3
Coarse sand (%)		42.5	8.9	33.2
Fine sand (%)		22.5	41.1	21.8
Silt (%)		20	10	10
Clay (%)		15	40	35
Textural Class		sandy loam	sandy clay	sandy clay loam
BD (g cc^{-1})		0.92±0.006ab	0.91±0.005a	1.00±0.005c
MWHC (%)		51.8±0.84de	49.5±0.50d	32.7±2.36a
FC (%)		39.1±0.40f	37.1±0.40e	24.3±0.46a
pH		6.33±0.015g	4.40±0.060ab	5.31±0.0404d
SOC (%)		1.80±0.115de	1.70±0.115cde	1.40±0.057bcd
Avl.N (kg ha^{-1})		270±4.6e	301±5.5f	276±6.1e
Avl.P (kg ha^{-1})		22.8±0.53f	10.6±0.55c	9.70±0.519c
Avl.K (kg ha^{-1})		220±5.8a	174±1.67ab	155±2.10b
DTPA-Fe (mg kg^{-1} soil)		20.02±1.15a	22.48±1.00ab	29.74±2.52b
Ex.Al (meq 100^{-1} soil)		0.12±0.011ab	3.59±0.056g	1.06±0.036e
RS.Al (mg kg^{-1} soil)		18.8±2.32a	287±5.8b	354±2.3d
Ex.Ca+Mg [cmol (P^+) kg^{-1} soil]		8.10±0.173d	4.60±0.289b	2.80±0.231a
CEC [cmol (P^+) kg^{-1} soil]		15.6±.46de	11.8±0.52bd	8.00±0.867ab
BS (%)		55.3±1.52f	42.5±1.66e	39.9±2.51de

Values ± means, n = 3; Within a column (parameter) values followed by different letters are statistically significant as determined by one-way ANOVA incorporating Tukey's HSD test for multiple pair-wise comparisons among means. BD – bulk density, MWHC – maximum water holding capacity, FC– field capacity, SOC – soil organic carbon, Avl.N – soil available N, Avl.P – soil available P, Avl.K – soil available K, DTPA-Fe – soil available Fe, Ex.Al – exchangeable aluminium, RSA – readily soluble aluminium, Ex.Ca+Mg – exchangeable ca+Mg, CEC – cation exchange capacity and BS – base saturation.

Soil profiles and the phosphate fixation capacity

The values of maximum quantity of applied P fixed and % P fixed ranged from 223.3 to 470.7 µg P g^{-1} soil and 74.4 to 94.1%, respectively for *Alfisol* profiles P1, P2 and P3 (Fig. 2). The P dose at which maximum PFC value obtained for P1, P2 and P3 profiles were 300, 500 and 500 µg P g^{-1} soil, respectively (Fig. 2).

Table 2: The maximum quantity of applied P fixed at the P dose where the highest % P fixed in soils of the three profiles

Profile	Soil order	Maximum quantity of applied P fixed (µg P g^{-1} soil)	P fixed (%)	P dose at which max. PFC point achieved (µg P g^{-1} soil)
P1	Alfisol	223.3±1.7c	74.4	300
P2		425.6±2.9g	85.1	500
P3		470.7±5.8h	94.1	500

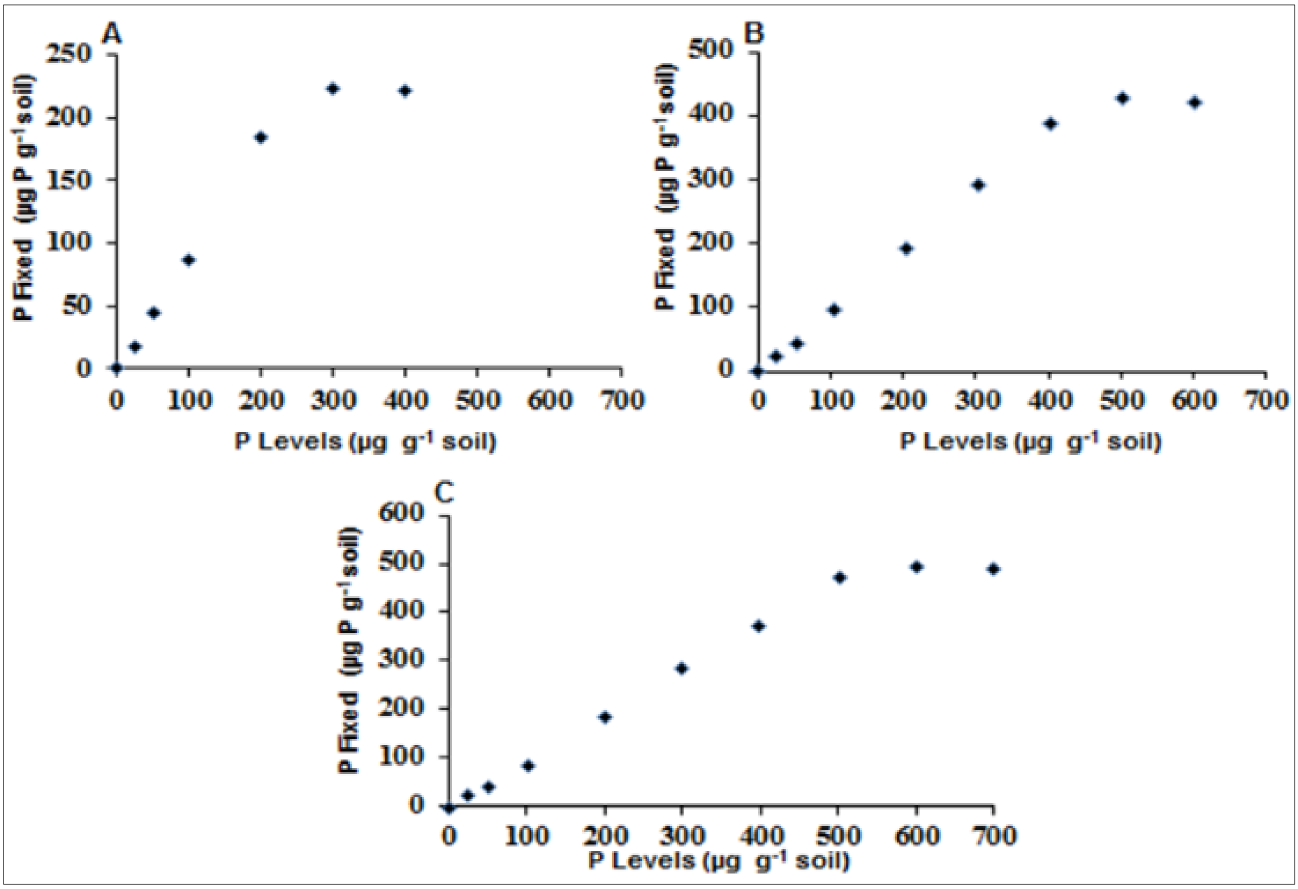

Fig 2: Phosphate fixation capacity curves of *Alfisols* representing by 3 soil profiles (A) Profile 1, (B) Profile 2, and (C) Profile 3.

Out of 3 soil profiles, P3 ranked first in terms of the maximum quantity of applied P fixed (471 µg P g^{-1} soil) and % P fixed (94.1%). The high quantity of Ex. Al (323 mg kg^{-1} soil) and RS. Al (354 mg kg^{-1} soil) might be the responsible factor. About 1 meq exchangeable Al per 100 g soil when completely hydrolyzed can sorb up to 102 mg P L^{-1} in soil solution (Tisdale *et al.*, 1990) [12] and the P adsorption is positively correlated with Ex. Al (r=0.84) (Syers *et al.*, 1971) [10]. Goundar *et al.* (2014) [2] also reported the positive correlation between P fixation and Al and Fe content of soils (R = 0.65, p = 0.04). The higher P fixing capacity of *Alfisols* in the Chotanagpur plateau region of Eastern India was also previously reported (Ghosal *et al.*, 2011) [1]. Thus, the higher P fixation capacity in *Alfisols* of NE India could be supported by the above past findings.

Conclusion

Out of three soil profiles, Ri-Bhoi (Meghalaya) possess very high PFC and Changlang (Arunachal Pradesh) possesses relatively the lowest PFC. The higher percent P fixed was in the order Ri-Bhoi, Meghalaya (94.1) > Sepahijala, Tripura (85.1) > Changlang, Arunachal Pradesh (74.4). So, the PFC findings of this study calls for an urgent need to correct the existing blanket recommended dose of phosphatic fertilizer. There is a need for formulation of suitable nutrient management practice that can improve the status of these soil attributes so as to reduce the PFC and enhancing the PUE of soil. Findings of this investigation revealed the fundamental understanding on PFC of *Alfisol* of NE India and based on which efficient P management practice needs to be formulated and tested for effectiveness against the existing blanket recommendation of P fertilizer through future trials in farmers' fields.

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