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Phosphorus fixation capacity as a guide for phosphorus availability in *Entisol* soil order of North-East India

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Abstract
A laboratory experiment was conducted in the College of Post Graduate Studies in Agricultural Sciences, Umiam, Meghalaya. The surface soil samples of 3 soil profiles were used in the study representing the soil order *Entisol*. 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 *Entisol* comprised of 3 profiles *viz.*, P1, P2 and P3 representing Changlang (Arunachal Pradesh), North-West-1 Jorhat (Assam) and North-West-2 Jorhat (Assam), 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 103 to 577 for the soil profiles of *Entisol*. The maximum PFC was obtained at the P application dose (μg g^{-1} soil) for North-West-1 Jorhat (Assam) at 200. The higher percent P fixed was in order of Changlang, Arunachal Pradesh (68.2) > North-West-1 Jorhat, Assam (46.2)> North-West-2 Jorhat, Assam (33.3). The bulk density (BD), maximum water holding capacity (MWHC) and clay content ranged from 1.02 to 1.18 g cc^{-1}, 33.6 to 55.5% and 3.7 to 10%, respectively among the 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 0.5 to 1.2%, 122 to 226 kg ha^{-1}, 20.8 to 24.6 kg ha^{-1} and 115 to 126 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 5.8 to 7.7, 0.09 to 0.28 meq 100 g^{-1} soil, 18.4 to 22.6 mg kg^{-1} soil, 6.8 to 12.9 meq 100 g^{-1} soil, 44.4 to 71.0%, respectively. The soils of Changlang, Arunachal Pradesh showed the highest percentage of P fixation and North-West-2 Jorhat (Assam), the least among the profiles. Thus, higher phosphatic fertilizers have to be applied for Changlang district of Arunachal Pradesh to render P available for plant uptake as compared to the other profiles. Furthermore, appropriate adaptive management practices should be designed to alleviate P losses and thereby, increase the percentage of phosphorus use efficiency.

Keywords: *Entisol*, phosphate fixation capacity, phosphatic fertilizers, phosphorus use efficiency

Introduction
The challenge for agriculture over the coming decades will be to meet the world increasing demand for food in a sustainable way. Deteriorating soil fertility and mismanagement of plant nutrients have made this task more challenging (Gruhn *et al.*, 2000) [6]. Phosphorous is an essential macronutrient for plant growth and it is generally added to soil as a fertiliser and, thereby, increases the physiological efficiency of crops. When phosphatic fertiliser is applied to soil, various reactions occur between phosphate and soil constituents which eliminate P from the solution phase and make it less variable. This phenomenon is called P fixation or sorption (the two terms are frequently used interchangeably). There are two types of studies typically employed for estimating P availability: sorption studies and the use of P extractants. From such studies it has been reported that P tends to be strongly retained by soils in alkaline, as well as in acidic pH, for different reasons. In alkaline pH values, P is bound by $CaCO_3$ (Naeem *et al.*, 2013), while in acidic pH it is bound by soil oxides (Arai and Livi, 2013) [3]. Thus, P availability is dramatically reduced in soil pH values that significantly depart from neutrality.

Entisols are moderately extensive, accounting for 8 percent of the area of mapped land (Grossman, 1983) [5]. It comprises of about 80.1 Mha in India while in the NE India, *Entisols* covering 7040.54 thousand ha have been identified with 8 great groups further divided into 18 subgroups (Patiram and Ramesh, 2008) [11]. There is a void in knowledge concerning the role of the physico-chemical attributes governing the phosphorus fixation in the *Entisol* soil order of the north eastern region of India.

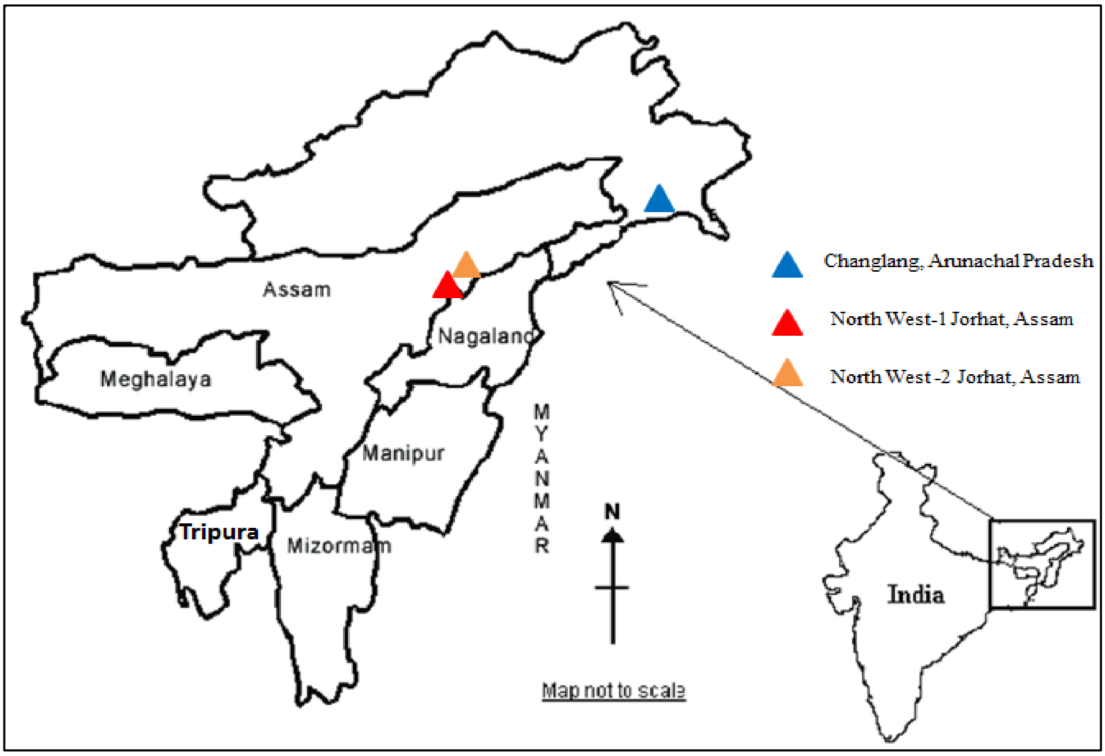

Fig 1: Sampling locations of the study area

Materials and Methods

The study was conducted in laboratory with bulk surface samples (0-30) collected from three different locations of NE India *viz*. Changlang, Arunachal Pradesh (P1); North-West-1 Jorhat, Assam (P2) and North-West-2 Jorhat, Assam (P3). Some of the basic physico- chemical properties *viz*. 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. 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 700 mg 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:

Quantity 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 v1 2.0 (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.

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

Profile		Changlang, Arunachal Pradesh (P1)	North-West-1 Jorhat, Assam (P2)	North-West-2 Jorhat, Assam (P3)
Soil colour	Dry	10 YR 5/3	2.5 Y 6/2	2.5 YR 6/8
	Moist	5 YR 3/2	5Y 4/1	10 YR 4/6
Coarse sand (%)		60.7	12.6	23.4
Fine sand (%)		14.3	82.4	51.6
Silt (%)		20	1.3	15
Clay (%)		5	3.7	10
Textural Class		loamy sand	fine sand	sandy loam
BD (g cc^{-1})		1.18±0.0054f	1.02±0.0054c	1.37±0.005g
MWHC (%)		33.6±0.64a	55.5±0.38e	34.1±0.51ab
FC (%)		25.2±0.23b	41.7±0.06g	25.6±0.12b
pH		5.81±0.049e	7.74±0.050h	6.44±0.057g
SOC (%)		1.20±0.057bc	0.90±0.057ab	0.50±0.057a
Avl.N (kg ha^{-1})		226±6.1d	122±5.9a	138±5.8a
Avl.P (kg ha^{-1})		20.8±0.21e	24.6±0.53f	23.2±0.46f
Avl.K (kg ha^{-1})		126.0±1.53f	115±2.51g	116.5±2.00g
DTPA-Fe (mg kg^{-1} soil)		26.0±1.15ab	20.5±0.90a	24.1±1.53ab
Ex.Al (meq 100^{-1} soil)		0.28±0.010bc	0.12±0.003ab	0.09±0.003a

RS.Al (mg kg^{-1} soil)	22.6±1.53a	19.6±1.00a	18.4±1.53a
Ex.Ca+Mg [cmol (P$^+$) kg^{-1} soil]	6.80±0.289c	12.9±0.72f	9.30±0.289e
CEC [cmol (P$^+$) kg^{-1} soil]	16.1±0.58de	18.7±0.68e	18.4±1.26e
BS (%)	44.4±0.45e	71.0±1.22g	52.3±0.41f

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.

Results and Discussion

Physical attributes

The colour of soils in dry conditions ranged from light brownish gray to brown *viz.*, 2.5 Y 6/2 to 10 YR 5/3 and under moist conditions ranged from dark reddish brown to dark grey *viz.*, 5 YR 3/2 to 5 Y 4/1. The sand content values varied from 75 to 95%, clay content ranged from 3.7 to 10%. The maximum clay content was 10% in P3 soil and the minimum was 3.7% in P2 soil. The *Entisol* quartzipsamment soils of Brazil had clay content less than 20% and the minimum sand content is 50% (Alovisi *et al*., 2019) [1]. The adequate supply of phosphorus (P) to crops in sandy soils is always a challenge since plants normally require low phosphorus levels compared to other nutrients such as nitrogen and potassium, but there is a need to apply high doses of phosphate fertilizers to increase crop productivity. However, nutrient amounts, including P, are not always defined based on technical criteria and, therefore, accumulation of excess P must be expected (Alovisi *et al*., 2019) [1]. The texture varied from fine sand to sandy loam. The values of BD ranged from 1.02 to 1.37 g cc^{-1} among 3 *Entisol* profiles and the highest BD values in P3 soil and the lowest BD value in P2 soil. The water holding capacity ranged from 33.6% in P1 to a maximum of 55.5% in P2.

Chemical attributes

According to Bhat *et al.* (2017) [4], higher soil pH was in order of *Entisols* > *Alfisols* > Inceptisols. The pH of the soils ranged from 5.81 to 7.74 that are from medium acidic to mildly alkaline. The pH of P2 was the highest and P1 was the lowest among *Entisols*. Lower pH conditions reduced the P adsorption capacity of purple soils throughout the soil profiles in China (Xiao *et al*., 2017) [14]. The soil organic carbon varied from 0.5%- 1.2%. The content of SOC was the highest (0.5%) for P1 and the least (1.2%) was for P3. Phosphate fixation was positively related with clay, organic carbon and Fe and Al oxide contents of soil and negatively with pH (Misra and Saithantuaanga, 2000) [10]. The content of soil Avl.N ranged from 122 kg ha^{-1} to 226 kg ha^{-1} and the P1 soil contained maximum Av. N and minimum was for P2 soil. The content of Avl.P varied from 20.8 kg ha^{-1} to 24.6 kg ha^{-1}. The highest P was found in P2 and the lowest in P1 soils. The P1 soil contained maximum Avl.K (126 kg ha^{-1}) and the minimum content (115 kg ha^{-1}) for P2 soils. Misra and Saithantuaanga (2000) [10] studied the acid soils of Mizoram and found 57% and 71% of Entisols were high in available N and available K, respectively. Exchangeable alumina (Ex. Al) ranged from 0.09 meq 100^{-1}g to 0.28 meq 100^{-1}g. The P1 soil had the highest amount and P3 had the least amount of Ex. Al within the profiles as well. A large decrease in exchangeable Al and acetate extractable A1 with increasing pH accompanied to some extent the decrease in phosphate retention (Lopez-Hernandez1 and Burnham, 1974) [9]. The lower content of readily soluble alumina was due to high soil pH of the soil. The P1 soil contained the highest amount of readily soluble aluminium (22.6 mg kg^{-1}) and the lowest (18.4 mg kg^{-1}) was P3 soil. The content of DTPA-Fe varied from 20.5 mg kg^{-1} to 26 mg kg^{-1}. The ability of the soil to adsorb added P enhances due to increase in affinity sites of clay and iron content (Idris and Ahmed, 2012) [8]. The content Exch.Ca+Mg ranged from 6.8 meq 100^{-1}g soil to 12.9 meq 100^{-1}g soil. The values CEC varied from 16.1 to 18.4cmol kg^{-1} and the percent BS ranged from 44.4% to 71.0% for 3 soil *Entisol* profiles. Higher value of BS was in P2 soil, which was also the highest among all 3 soil profiles.

Soil orders and the phosphate fixation capacity

The values of maximum quantity of applied P fixed and % P fixed ranged from 66.6 to 92.3 µg P g^{-1} soil and 33.3 to 68.2%, respectively for *Entisol* profiles P1, P2 and P3 (Fig. 2). The P dose at which maximum PFC value obtained for P1, P2 and P3 profiles were 100, 200 and 200 µg P g^{-1} soil, respectively (Fig. 2). The significant lesser PFC values and % P fixed (33.3 to 68.2) for *Entisols* could be explained by the relative higher soil pH (5.81 to 7.74), lower content of Ex.Al (8.1 to 25.2 mg kg^{-1} soil) and Rs.Al (18.4 to 22.6 mg kg^{-1} soil). Lopez-Hernandez and Burnham (1974a) [9] also reported the lowest P adsorption capacity for *Entisols*. Because *Entisols* are recently developed on river alluviums where water carried most of the clay particles and leaving behind only sand particles. This is evident from the fact that P fixation is strongly influenced by clay content of soil and is more specifically related to a large surface area for adsorption, where sand particles lacked (Sims and Pierzynski, 2005; Rayment and Lyons, 2011; Guppy *et al*., 2005) [13, 12, 7].

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	*Entisol*	68.2±2.3a	68.2	100
P2		92.3±2.3b	46.2	200
P3		66.6±2.3a	33.3	300

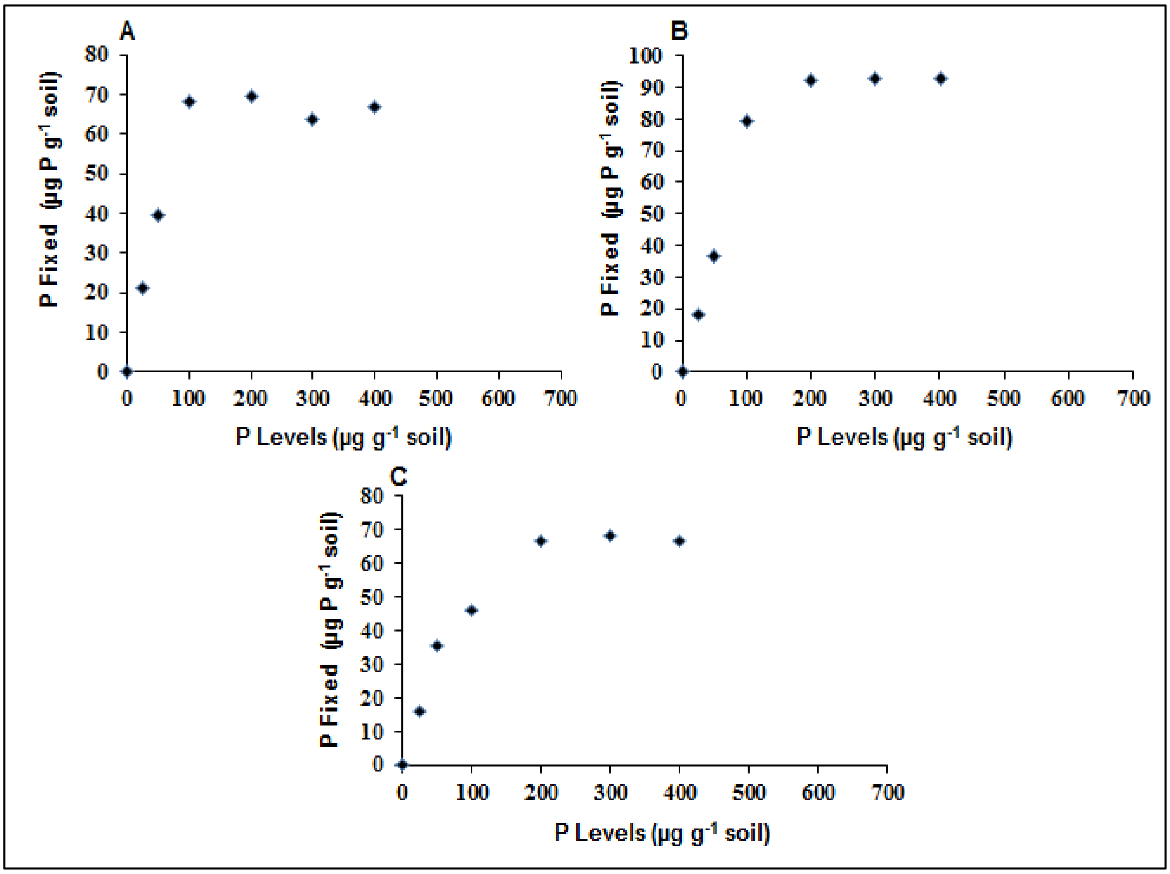

Fig 2: Phosphate fixation capacity curves of *Entisols* representing 3 soil profiles (A) Profile 1, (B) Profile 2, and (C) Profile 3.

Conclusion

Out of three soil profiles, Changlang (Arunachal Pradesh), possess very high PFC and North-West-2 Jorhat (Assam), possesses relatively the lowest PFC. The higher percent P fixed was in the order of Changlang, Arunachal Pradesh (68.2) > North-West-1 Jorhat, Assam (46.2)> North-West-2 Jorhat, Assam (33.3). For agricultural practice, the low-input strategy is recommended. Frequent applications at modest rates are more effective than less frequent applications at higher rates. 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. Effective soil phosphorus (P) management from both environmental and agronomic point of view requires the knowledge of P forms determining its availability. Through future trials in farmer's field in these regions will aid in finding the optimum dose of phosphate fertilizers and will eventually increase the phosphorus use efficiency of these soils.

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