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Relative Efficiency of Udaipur Rock Phosphate Combined with Amendments in Acid Soils of Odisha, India

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ABSTRACT

A pot culture study was conducted during February, 2014 to evaluate the effect of organic manure, PSB or lime on Udaipur Rock Phosphate (URP) dissolution, P and Ca availability and biomass yield of hybrid napier grass in three different acid soils (Typic Halpludalf) in Odisha, India. The experiment was conducted in a completely randomized design (CRD) with three replications and 18 treatments consists of 3 low pH soils - S_1 (pH-4.15), S_2 (pH-5.03), S_3 (pH-5.82) and six rock phosphate treatments - T_1-Control, T_2-200%P through URP, T_3-50%P through URP+50%P through SSP, T_4- 100%P through URP +FYM @5 tha^{-1}, T_5-100%P through URP +PSB @ 10 kg ha^{-1} and T_6-100% P through URP + lime @ 0.2 LR (Lime Requirement). The URP namely sourced from FCI Aravali Gypsum and Minerals India Limited (FAGMIL), Jodhpur contains 7.8% total P, 25.6% Ca, 0.26% Mg and 0.24% K indicating a moderate reactive material. Application of URP alone or with amendments increased soil pH significantly, attained its peak at 4th cutting and then decreased gradually, but remained above the initial value at the end of 8th cutting. Among the treatments, URP + lime (T_6) recorded highest pH value followed by 200% URP(T_2) and URP + SSP(T_3) in all soils. Available P in control decreased gradually during the growth period. In other treatments, P content increased and attained its peak at 2nd cutting, there after declined but remained above the initial value at the end of 8th cutting irrespective of the soils. P build up in sole URP (200% P) treatment was maximum (11 – 14.5 kg ha^{-1}) followed by URP +SSP (8.9 – 12.3 kg ha^{-1}) and URP + lime (6.8-9.0 kg ha^{-1}). Exchangeable calcium content in control is decreased by 52-58% over the initial value due to crop removal. Combined application of URP + SSP recorded highest exchangeable calcium content followed by URP + lime and URP alone. Sole application of URP recorded highest biomass yield in S_1 (44%) and S_2 (41%) whereas, URP+SSP recorded highest yield in S_3 (47%) might be due to the dissolution of URP got slower with increased in soil pH (S_3). The relative agronomic effectiveness (RAE) of URP was higher when it was applied at higher dose (T_2) in low pH soil viz. S_1 (107%) and S_2 (108%) but the efficiency decreased in S_3(76%). The efficiency of URP is greatly influenced by soil pH and exchangeable calcium content of soils.

Introduction

Acid soils in India occupy about 90 million ha (Mha) out of which 49 Mha have pH less than 5.5. The supply of soil phosphorus has been a major limiting factor in crop production due to high P fixation when a water soluble phosphate fertilizer is added to soil, a series of chemical reaction may take place. The dissolved P reacts with dissolved Ca (in high pH soils) or dissolved Fe and Al (in low pH soils) becomes more stable, forming precipitation with Fe, Al, Ca that are less available to plants (Barrow, 1983). In acid soils much of P is adsorbed by reacting with Fe, Al and clay minerals or Al that is associated with organic matter (Huges and Gilkes, 1994). All these reactions can resulted in decreasing P availability over time (Hedley and McLaughlin, 2005; Syers *et al.,* 2008). The direct use of phosphate rocks may be an economically viable alternative source of P-fertilizers in tropics. The developing countries like India can save huge amount of foreign exchange if phosphate rock (PR) can be used alone or with P-fertilizer in acid soils.

The PR deposits in India including all grades and types is of 260 million tonnes out of which 15.27 million tonnes of high grade. The low grade PR is unacceptable to P-fertilizer industry due to its low P_2O_5 and high $CaCO_3$ content. This low grade PR could be a cheaper P source for small and marginal farmers in acid soil regions. The efficiency of phosphate rock depends on its solubility which is influenced by chemical and mineralogical characteristics of rocks, soil properties, crops and climatic conditions (White, 1988b).The dissolution of phosphate rocks depend on the H^+ ion supply power of soils (Wheeler and Edmeades, 1984), activities of Ca^{2+} and $H_2PO_4^-$ ions in soil solution (Kirk and Nye, 1986b). Mishra and Pattanaik (1997), Pattanaik (1988), Dash *et al.,* (1988) evaluated the efficiency of several Indian phosphate rocks with North Carolina, Gafsa, Florida, Morocco and found all the Indian phosphate rocks showed lower efficiency as compared to North Carolina with respect to yield and P availability.

Liming of acid soils is a common practice to raise soil pH and decrease Al toxicity for optimal crop growth. However, the higher pH and increased exchangeable Ca resulting from liming are detrimental to PR dissolution (Hammond *et al.,* 1986b; Mishra and Pattanaik, 1997). Hence, lime rates should be carefully chosen to alleviate the Al toxicity problem and, at the same time, to avoid adverse effects on PR dissolution in acid soils (Chien and Friesen 1992). Application of phosphate solubilising biofertilizer (PSB) enhances dissolution of PR through production of organic acid and chelating substances (Sanyal and Saha, 1988; Adhya *et al.,* 2015). Organic manures supplies plant nutrients such as P through decomposition and the organic acids produced in this process chelate P-fixing elements in the rhizosphere or decomposition system. Several studies showed that application of SSP and PR mixture in 1:1 ratio increased the dry matter yield and P, Ca and Mg uptake by maize, groundnut, and linseed in acid soils (Mitra and Mishra, 1991; Das *et al.,* 1990; Dwivedi and Dwivedi, 1990).

Although sizeable informations are available on rate of PR dissolution either alone or in combination with different amendments, such information is still lacking in published work dealing with direct use of Udaipur rock phosphate in acid soil region of Odisha, India.

In view of the above said knowledge gaps, a pot culture study was carried out to evaluate the effect of organic manure, PSB or lime on URP dissolution, P and Ca availability and biomass yield of hybrid napier grass in three different acidic laterite soils.

Materials and Methods

Three acidic laterite soil samples in bulk from plough layers (0-15cm) were collected from farmer's field having maize-groundnut cropping system from Dhenkanal block of Dhenkanal district, Odisha. The collected soil samples were air dried, processed and used for pot culture experiment and laboratory analysis. Particle size was determined by Bouyoucos hydrometer method (Bouyoucos, 1962), pH by glass electrode with Calomel as standard (Jackson, 1973). Organic carbon was determined by wet digestion method of Walkley and Black (1934).The cation exchange capacity was determined by Schollenberger and Simon (1945). Nitrogen content in soil samples and organic manure was determined by Kjeldhal digestion method as described in AOAC (1995). Exchangeable Ca and Mg was determined by EDTA (Versenate) titration method (Gupta, 2007), exchangeable acidity and Al by the procedure outlined by McLean (1965). Available N in soils was determined by modified alkaline permanganate method (Subbiah and Asija, 1956), available P by Bray's 1 method (Bray and Kurtz, 1945) and available K by ammonium acetate method (Hanway and Heidel, 1952). The lime requirement value was determined by Woodruff Buffer method (Woodruff, 1948).

A pot culture experiment was carried out during February, 2014 in the green house of Department of Soil Science and Agricultural Chemistry, Orissa University of Agriculture and Technology, Bhubaneswar, Odisha. The experiment was conducted in a completely randomized design (CRD) with three replications and 18 treatments consists of 3 low pH soils - S_1 (pH-4.15), S_2 (pH-5.03), S_3 (pH-5.82) and each soil was superimposed with six rock phosphate (PR) treatments- T_1-Control, T_2-200%P through URP, T_3-50%P through URP+50%P through SSP, T_4- 100%P through URP +FYM @5tha^{-1}, T_5-100%P through URP +PSB @ 10 kg ha^{-1} and T_6-100% P through URP + lime @ 0.2 LR (Lime Requirement).

The polyethylene lined earthen pots were rinsed in 0.1N HCl followed by deionised water. Seven kg of soil was transferred into each pot. Each pot received a common dose of N @40 kg ha^{-1} through urea and K_2O@40 kg ha^{-1} through mutate of potash. Phosphate @40kgP_2O_5 ha^{-1} was applied through Udaipur rock Phosphate or SSP as per the treatments. Well decomposed FYM was added @ 5tha^{-1} in T_4. In T_6, pure $CaCO_3$ was added @ 0.2LR. The LR for different soil was: S_1-5.8qha^{-1}, S_2-4.8qha^{-1}, and S_3-3.3 qha^{-1}. On soil weight basis, the fertilizers, FYM and PSB were calculated, mixed thoroughly with 7kg of soil before planting. One slip of Bajra napier hybrid grass (*Pennisetum glaucum*) × (*Pennisetum purpureum*) was planted in each pot, watering with deionised water and plant protection measures were taken as and when necessary. The first cut was made after 60 days after planting and subsequently seven cuts were made at an interval of 45 days. Soil samples were collected from each treatments during cutting. After each cut, each pot received N@ 40kg ha^{-1} through urea solution. After recording the dry mass yield of grass at each cut, the samples were washed with acidified solution, rinsed with deionised water, dried at 65 degree centigrade in a hot air oven, grinded and kept for analysis. The dry powdered grass samples were digested with diacid mixture on a hot plate and filtered through Whatman No. 42 filter paper for estimation of P, Ca and S. The soil samples were air dried sieved through 8 mesh sieve and analysed for pH, available P and exchangeable Ca. Simple correlation was carried out to establish the relationships between biomass yield and soil properties.

Results and Discussion

Characteristics of soil, rock phosphate and farmyard manure used in study

The Alfisols used in this study were very acidic having pH: S_1-4.15, S_2-5.03 and S_3-5.82. The soil texture varied from sandy loam to sandy clay loam. The soils had low to medium in organic carbon content, available P but low in available N and cation exchange capacity. Available K was medium to high (Table 1).

The samples of URP used namely sourced from FCI Aravali Gypsum and Minerals India Limited (FAGMIL), Jodhpur had 7.8% total P, 25.6% Ca, 0.26% Mg and 0.24% K, indicating a moderate reactivity of the material (Table 2).

The farmyard manure sample had 1.2% N, 0.006% P and 0.045% Ca indicating a higher sink for P and Ca during dissolution of rock phosphate (Table 3).

Effect of URP with SSP, FYM, PSB or lime on soil properties

Soil pH

In all treatments soil pH increased significantly from its initial value, attained the peak at fourth cutting and then decreased gradually upto eighth cutting (Table 4 and Fig. 1). At the end of 8^{th} cutting, soil pH in control treatment attained its initial values or slightly higher in all soils whereas, in other treatments, it was higher than the in initial value, highest being in T_2. On the other hand, combined application of URP+ lime@0.2LR recorded peak pH value at 3^{rd} cutting, the values were higher than all other treatments upto 6^{th} cutting. Addition of FYM or PSB with URP recorded lower pH value as compared to URP+ SSP (T_3) treatment in all cuttings.

Soil available phosphorus at different stages of cutting

The available phosphorus content in control pot generally declined with progress of growth of hybrid napier grass. The magnitude of depletion was highest (5.51 kg ha^{-1}) in S_3 (pH-5.82) followed by 3.83 kg ha^{-1} in S_2 (pH-5.03) and 2.71 kg ha^{-1} in S_1 (pH-4.15) might be due to P uptake by grass (Table 5 and Fig. 2). The available P content in other treatments increased over the initial value, attained its peak at 2^{nd} cutting, there after declined but remained above the initial value at the end of 8^{th} cutting. This indicates that application of URP with SSP, FYM or PSB could meet crop requirement in long run. Sole application of URP at higher dose (200%P) was better than URP+FYM or URP+PSB treatment but can be compared with URP+SSP treatment in long run. Higher soil P content in T_2 (200% P through URP) treatment resulted in higher dissolution of URP in low pH soils varying from 4.15 to 5.82. Combined application of URP+SSP (T_3) seems to be better than URP+ lime treatment since, water soluble SSP meet the crop requirement P at initial stage and dissolution of URP build up the P status and also meet crop requirement in long run. On the other hand, inclusion of lime increased the soil pH that lower down dissolution rate of URP although calcium in lime decreases Al toxicity and helps better crop growth and biomass production. Inclusion of FYM with URP was better than URP+ PSB treatment. Since, FYM increases available P in soil through chelation and decomposition.

Available P build up in different treatments was calculated as final P minus initial P. The data showed that irrespective of the soils, the P build in T_2 (200% P through URP) was highest followed by URP + SSP (T_3) and URP + lime (T_6).

Soil exchangeable calcium at different stages of cutting

During dissolution of rock phosphate, calcium is released and the soils with high calcium content would slow down the dissolution of rock phosphate. The acid alfisol used in this study had low exchangeable calcium varying from 1.32 to 1.50 c mol (P^+) kg^{-1} (Table 1).

Table.1 Physical and chemical properties of the soil

Soil type	Sand (%)	Silt (%)	Clay (%)	Textural class	pH	Exch. Acidity c mol (P+) kg-1	Exch. Al c mol (P+) kg-1	Exch. Ca c mol (P+) kg-1	Exch. Mg c mol (P+) kg-1	CEC c mol (P+) kg-1	OC (%)	Av. N (k g ha-1)	Av.P (k g ha-1)	Av.K (kg ha-1)	LR (CaCO 3) (q ha-1)
S1	81.4	7.0	11.6	Sandy loam	4.15	0.86	0.55	1.32	0.32	3.2	0.47	137.5	8.9	200.5	58.0
S2	74.6	7.8	17.6	Sandy loam	5.03	0.40	0.22	1.37	0.40	3.8	0.45	125.0	12.2	162.1	48.0
S3	75.8	4.1	20.1	Sandy clay loam	5.82	0.36	0	1.50	0.48	4.5	0.58	158.5	15.7	323.6	33.0

Table.2 Chemical composition of Udaipur rock phosphate (URP) used in this study

Parameter	**Magnitude (%)**
P	7.8
S	1.2
Ca	25.6
Mg	0.26
K	0.24

Table.3 Chemical composition of farmyard manure used in this study

Parameter	Magnitude(%)
N	1.2
O.C.	0.75
P	0.006
K	0.25
Ca	0.045

Table.4 Change in soil pH at different cuttings

Soils	Treatments	Soil pH								
		1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**Mean**
S_1 (Initial soil pH-4.15)	S_1T_1=control P	4.08	4.16	4.25	4.27	4.27	4.29	4.30	4.31	4.24
	S_1T_2=200%P(URP)	4.93	5.58	5.47	5.63	5.51	5.36	5.29	5.16	5.37
	S_1T_3=50%P(URP)+50%P(SSP)	4.61	5.67	5.66	5.52	5.32	5.18	5.01	4.68	5.21
	S_1T_4=100%P(URP)+OM	4.79	5.22	5.32	5.27	5.31	5.23	4.94	4.77	5.11
	S_1T_5=100%P(URP)+Biof	4.68	5.13	5.29	5.22	5.25	5.16	4.91	4.72	5.05
	S_1T_6=100%P(URP)+Lime	5.12	5.76	5.91	5.85	5.67	5.43	5.26	4.92	5.49
S_2 (Initial soil pH-5.03)	S_2T_1=control P	4.95	5.19	5.11	5.17	5.12	5.09	5.17	5.16	5.12
	S_2T_2=200%P(URP)	5.87	6.33	6.35	6.41	6.34	6.25	6.04	5.88	6.18
	S_2T_3=50%P(URP)+50%P(SSP)	5.56	6.44	6.59	6.42	6.21	6.02	5.81	5.59	6.08
	S_2T_4=100%P(URP)+OM	5.96	6.08	6.14	5.81	5.62	5.49	5.37	5.62	5.76
	S_2T_5=100%P(URP)+Biof	5.78	5.8	5.85	5.73	5.56	5.34	5.31	5.54	5.61
	S_2T_6=100%P(URP)+Lime	5.94	6.28	6.43	6.40	6.27	6.12	6.06	5.77	6.16
S_3 (Initial soil pH-5.82)	S_3T_1=control P	5.75	5.97	5.95	6.04	6.05	5.94	5.97	5.93	5.95
	S_3T_2=200%P(URP)	6.74	6.99	7.03	7.14	7.12	6.97	6.79	6.58	6.92
	S_3T_3=50%P(URP)+50%P(SSP)	6.13	7.17	7.22	7.27	6.92	6.68	6.43	6.28	6.76
	S_3T_4=100%P(URP)+OM	6.46	6.72	6.83	6.78	6.57	6.54	6.47	6.35	6.59
	S_3T_5=100%P(URP)+Biof	6.37	6.53	6.66	6.63	6.51	6.48	6.44	6.29	6.49
	S_3T_6=100%P(URP)+Lime	6.87	7.18	7.29	7.15	6.89	6.95	6.87	6.44	6.96
CD(0.05)	S	0.09	0.15	0.23	0.18	0.15	0.15	0.13	0.15	-
	T	0.13	0.21	0.32	0.25	0.21	0.21	0.18	0.21	-
	SXT	NS	NS	NS	NS	NS	NS	NS	NS	-
C.V.(%)		1.99	2.89	4.40	3.47	2.87	3.03	2.63	3.07	-

Table.5 Change in soil available phosphorus(kg ha^{-1})at different cuttings

Soils	Treatments	Available (kg ha^{-1})									
		1st	2nd	3rd	4th	5th	6th	7th	8th	Mean	P build up (kg ha^{-1})
S_1(pH=4.15) (Initial Av.P=8.92 kg ha^{-1})	S_1T_1=control P	8.49	7.92	7.47	7.14	7.08	6.86	6.57	6.21	7.22	-2.7
	S_1T_2=200%P(URP)	12.11	21.54	20.24	21.93	23.49	22.21	20.89	19.97	20.30	11.0
	S_1T_3=50%P(URP) +50%P(SSP)	13.74	25.79	22.63	20.81	23.87	22.65	20.18	17.81	20.94	8.9
	S_1T_4=100%P(URP) +OM	11.53	19.68	17.33	16.27	17.48	17.92	15.39	14.66	16.28	5.7
	S_1T_5=100%P(URP) +Biof	11.26	19.23	16.98	16.03	17.34	17.24	14.56	13.72	15.80	4.8
	S_1T_6=100%P(URP) +Lime	13.85	24.87	23.79	19.86	21.84	19.59	16.05	15.75	19.45	6.83
S_2(pH=5.03) (Initial Av.P=12.17 kg ha^{-1})	S_2T_1=control P	11.71	10.76	10.23	9.53	9.21	8.77	8.61	8.34	9.65	-3.8
	S_2T_2=200%P(URP)	15.85	27.72	25.91	28.82	32.29	30.29	27.77	26.69	26.92	14.5
	S_2T_3=50%P(URP)+ 50%P(SSP)	17.94	32.89	29.04	27.55	30.69	29.13	25.3	24.48	27.13	12.3
	S_2T_4=100%P(URP) +OM	14.63	25.37	22.28	21.5	23.59	23.7	20.36	19.76	21.40	7.6
	S_2T_5=100%P(URP) +Biof	14.28	24.94	20.51	21.49	25.43	25.07	20.37	18.55	21.33	6.4
	S_2T_6=100%P(URP) +Lime	18.1	33.71	32.14	26.11	30.01	27.9	21.33	21.16	26.31	9.0
S_3(pH=5.82) (Initial Av. P=15.74 kg ha^{-1})	S_3T_1=control P	14.63	13.42	12.71	12.45	11.89	11.47	10.83	10.23	12.20	-5.5
	S_3T_2=200%P(URP)	19.18	31.37	29.55	31.48	35.12	33.65	30.11	28.54	29.88	12.8
	S_3T_3=50%P(URP)+ 50%P(SSP)	23.32	40.63	36.16	32.54	33.64	32.26	28.7	27.18	31.80	11.4
	S_3T_4=100%P(URP) +OM	18.94	30.67	28.25	27.52	29.21	28.41	25.13	22.49	26.33	6.8
	S_3T_5=100%P(URP) +Biof	18.43	29.89	28.49	26.51	27.31	26.75	22.85	20.38	25.08	4.6
	S_3T_6=100%P(URP) +Lime	21.67	33.52	31.34	28.79	30.74	30.41	27.36	23.87	28.46	8.1
CD(0.05)	S	0.91	0.87	1.01	0.64	0.93	0.81	0.72	0.52	0.55	-
	T	1.28	1.23	1.43	0.91	1.31	1.15	1.02	0.73	0.78	-
	SxT	NS	2.13	2.49	1.57	2.27	1.99	1.77	1.27	1.36	-
C.V.(%)	-	6.82	4.02	5.13	3.41	4.52	4.12	4.23	3.20	3.02	-

Table.6 Change in exchangeable calcium (cmol $(p)^{+}kg^{-1}$) of of soil at different cuttings

Soils	**Treatments**	**Exchangeable calcium (cmol $(p)^{+}kg^{-1}$)**								
		1st	2nd	3rd	4th	5th	6th	7th	8th	Mean
S_1(pH=4.15) (Initial Ex.Ca=1.32)	S_1T_1=control P	1.28	1.06	0.95	0.87	0.75	0.68	0.64	0.56	0.85
	S_1T_2=200%P(URP)	1.53	1.37	1.39	1.38	1.41	1.55	1.57	1.46	1.46
	S_1T_3=50%P(URP)+50%P(SSP)	1.89	1.54	1.48	1.41	1.52	1.57	1.46	1.42	1.54
	S_1T_4=100%P(URP)+OM	1.46	1.19	1.26	1.17	1.28	1.30	1.27	1.22	1.27
	S_1T_5=100%P(URP)+Biof	1.38	1.11	1.21	1.09	1.19	1.19	1.23	1.15	1.19
	S_1T_6=100%P(URP)+Lime	1.67	1.59	1.53	1.47	1.41	1.39	1.40	1.34	1.48
S_2(pH=5.03) (Initial Ex.Ca=1.37)	S_2T_1=control P	1.31	1.09	0.94	0.85	0.88	0.77	0.75	0.61	0.90
	S_2T_2=200%P(URP)	1.61	1.46	1.43	1.40	1.48	1.61	1.64	1.55	1.52
	S_2T_3=50%P(URP)+50%P(SSP)	2.02	1.61	1.51	1.44	1.63	1.66	1.52	1.51	1.61
	S_2T_4=100%P(URP)+OM	1.53	1.22	1.32	1.12	1.23	1.34	1.28	1.24	1.29
	S_2T_5=100%P(URP)+Biof	1.44	1.16	1.23	1.07	1.17	1.25	1.19	1.18	1.21
	S_2T_6=100%P(URP)+Lime	1.75	1.64	1.57	1.51	1.44	1.47	1.43	1.45	1.53
S_3(pH=5.82) (Initial Ex.Ca=1.50)	S_3T_1=control P	1.42	1.27	1.16	1.06	0.91	0.89	0.87	0.71	1.04
	S_3T_2=200%P(URP)	1.70	1.39	1.23	1.38	1.43	1.56	1.68	1.63	1.50
	S_3T_3=50%P(URP)+50%P(SSP)	2.15	1.67	1.59	1.51	1.71	1.78	1.86	1.75	1.75
	S_3T_4=100%P(URP)+OM	1.61	1.30	1.35	1.17	1.26	1.31	1.33	1.37	1.34
	S_3T_5=100%P(URP)+Biof	1.55	1.27	1.29	1.10	1.20	1.23	1.21	1.26	1.26
	S_3T_6=100%P(URP)+Lime	1.85	1.76	1.69	1.61	1.55	1.52	1.55	1.50	1.63
C.D.(0.05)	S	0.09	0.08	NS	NS	NS	NS	0.08	0.09	0.03
	T	0.12	0.12	0.11	0.10	0.10	0.13	0.11	0.12	0.04
	SxT	NS	NS	NS	NS	NS	NS	NS	NS	0.07
C.V.(%)	-	6.16	7.25	6.69	6.87	6.58	8.30	6.91	8.00	2.37

Table.7 Dry weight of hybrid napier grass (g pot^{-1}) at different cuttings

Soils	Treatments	Dry matter yield(g pot^{-1})										
		1st	2nd	3rd	4th	5th	6th	7th	8th	Total	% increase in yield over control	RAE (%)
S_1(pH=4.15)	S_1T_1=control P	8.44	7.81	5.93	5.78	6.53	6.10	4.83	3.18	48.54[a]	-	-
	S_1T_2=200%P(URP)	11.27	9.49	8.12	8.09	10.40	9.31	7.47	5.67	69.80[fgh]	43.7	107
	S_1T_3=50%P(URP)+50%P(SSP)	11.55	10.05	8.85	7.27	10.01	9.03	6.64	4.97	68.35[fg]	40.7	100
	S_1T_4=100%P(URP)+OM	10.93	9.04	7.61	6.92	9.17	8.21	6.11	4.42	62.38[cde]	28.4	70
	S_1T_5=100%P(URP)+Biof	10.63	8.63	7.46	6.56	8.61	7.80	5.82	4.33	59.82[cd]	23.2	57
	S_1T_6=100%P(URP)+Lime	12.55	11.95	8.15	6.84	9.87	8.57	6.34	4.66	68.89[fgh]	41.8	103
S_2(pH=5.03)	S_2T_1=control P	9.94	8.61	6.35	6.52	6.76	6.94	5.27	3.37	53.73[b]	-	-
	S_2T_2=200%P(URP)	12.61	10.35	9.45	8.94	10.11	9.70	8.17	6.30	75.61[ij]	40.7	108
	S_2T_3=50%P(URP)+50%P(SSP)	13.41	10.80	10.21	7.89	9.62	9.54	7.27	5.31	74.02[hij]	37.7	100
	S_2T_4=100%P(URP)+OM	12.56	9.76	8.35	7.54	9.13	8.69	6.46	4.74	67.21[ef]	25.1	60
	S_2T_5=100%P(URP)+Biof	12.20	9.44	8.23	7.34	8.72	8.23	6.20	4.37	64.71[def]	20.4	54
	S_2T_6=100%P(URP)+Lime	13.89	12.70	9.61	7.47	9.45	9.01	6.71	4.95	73.77[ghij]	37.3	99
S_3(pH=5.82)	S_3T_1=control P	10.22	9.14	8.08	6.61	7.27	7.09	5.80	3.48	57.68[bc]	-	-
	S_3T_2=200%P(URP)	12.78	10.85	11.24	8.88	9.49	9.80	8.57	6.65	78.24[ij]	35.7	76
	S_3T_3=50%P(URP)+50%P(SSP)	14.58	13.39	12.95	8.13	10.17	10.32	9.04	6.08	84.64[k]	46.7	100
	S_3T_4=100%P(URP)+OM	13.22	11.35	11.70	7.70	9.08	9.01	8.21	5.11	75.36[ij]	30.6	66
	S_3T_5=100%P(URP)+Biof	12.86	11.11	12.20	7.24	8.83	8.50	8.09	4.51	73.33[ghi]	27.1	58
	S_3T_6=100%P(URP)+Lime	14.16	13.07	11.85	7.52	9.14	9.17	8.44	5.81	79.14[j]	37.2	80
CD(0.05)	S	0.58	0.64	0.55	0.51	NS	0.53	0.59	0.36	2.04	-	-
	T	0.27	0.90	0.78	0.73	1.09	0.76	0.83	0.51	2.89		
	SXT	NS	NS	NS	NS	NS	NS	NS	NS	NS		
CV(%)		5.54	7.08	6.99	8.05	9.97	7.19	9.74	8.57	3.47	-	-

Fig.1 Change in soil pH at different cuttings

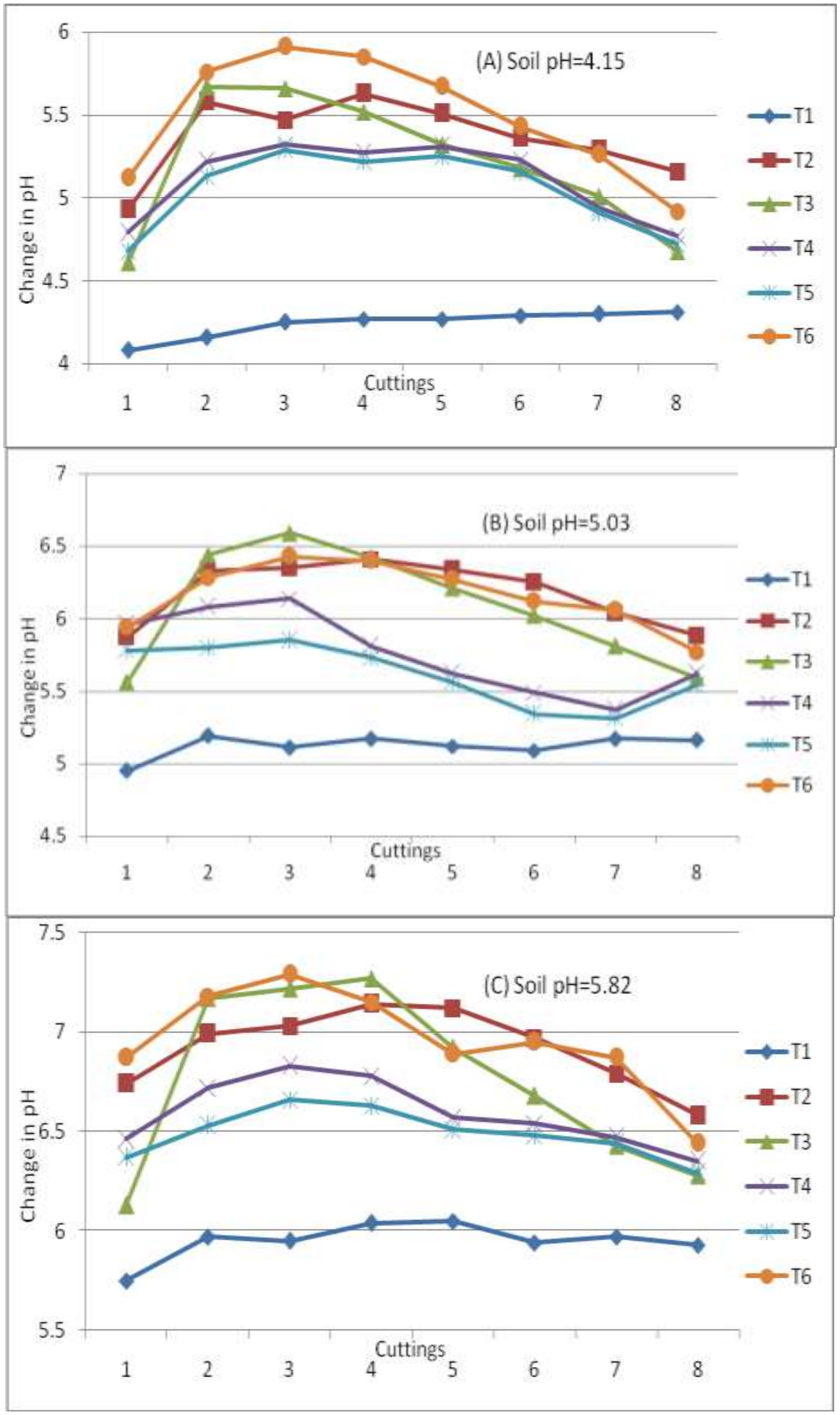


Fig.2 Change in available phosphorus of soil at different cuttings

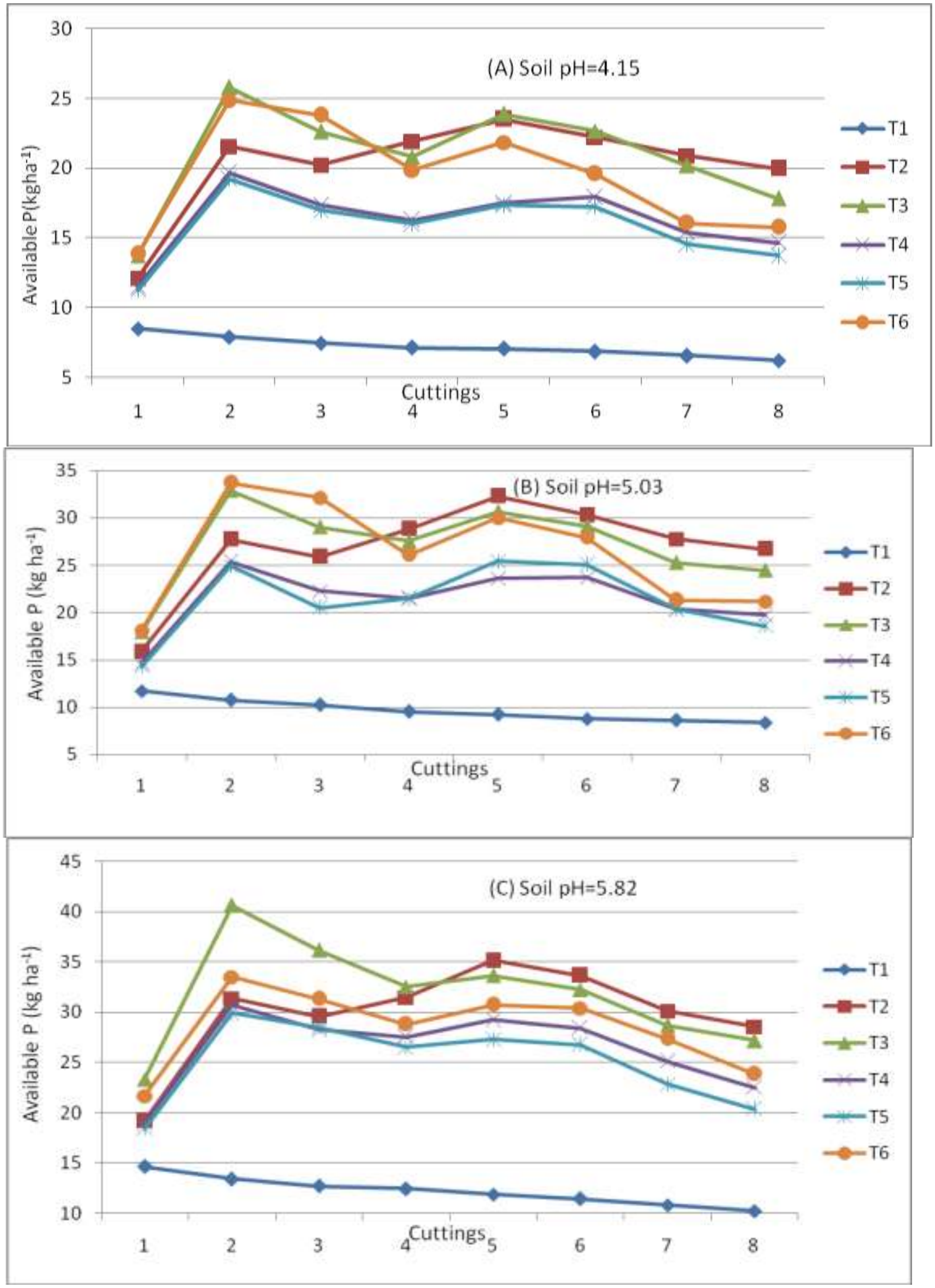


Fig.3 Change in exchangeable calcium of soil at different cuttings

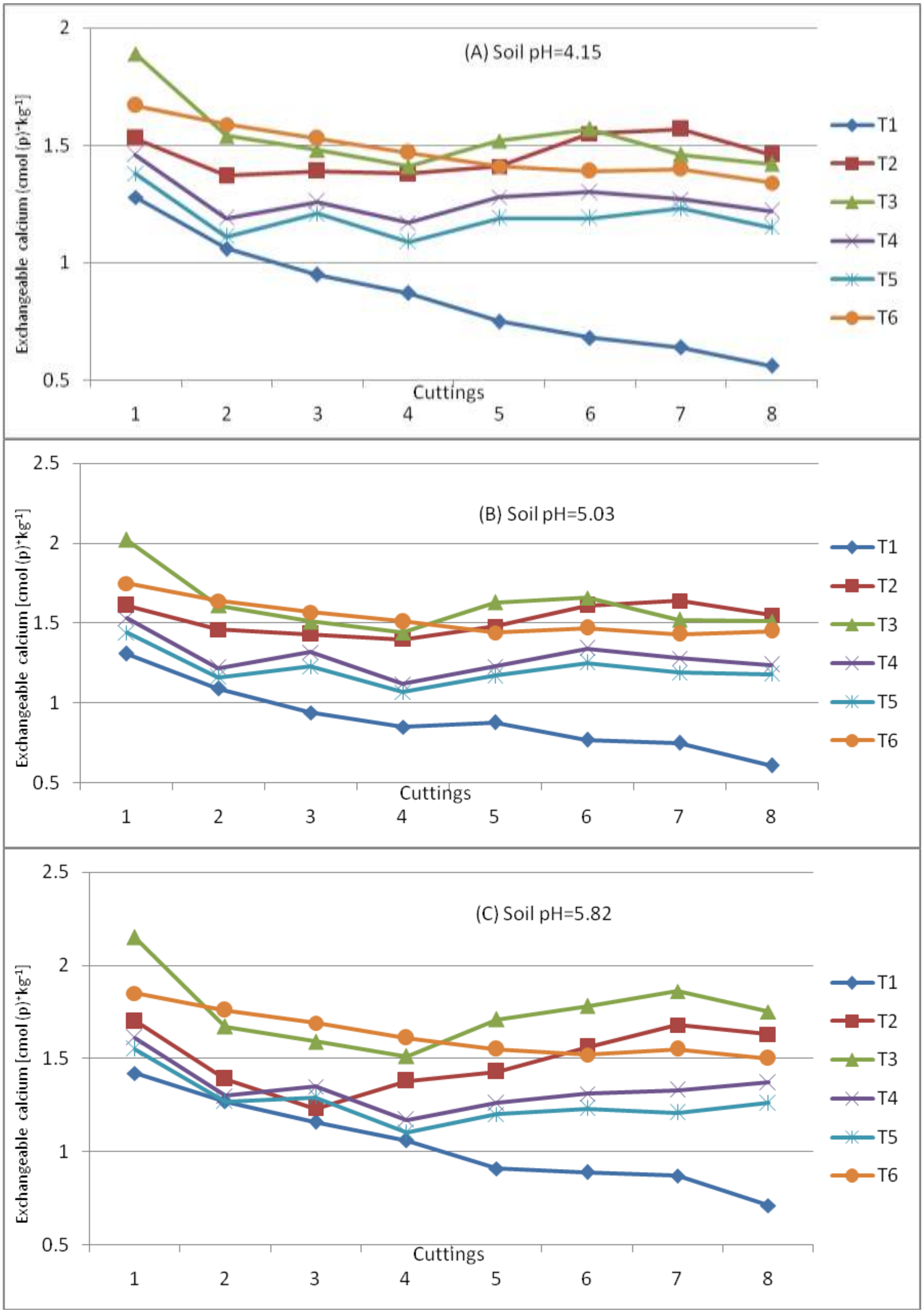


Fig.4 Effect of treatments on cumulative biomass yield of hybrid napier grass(g pot^{-1}

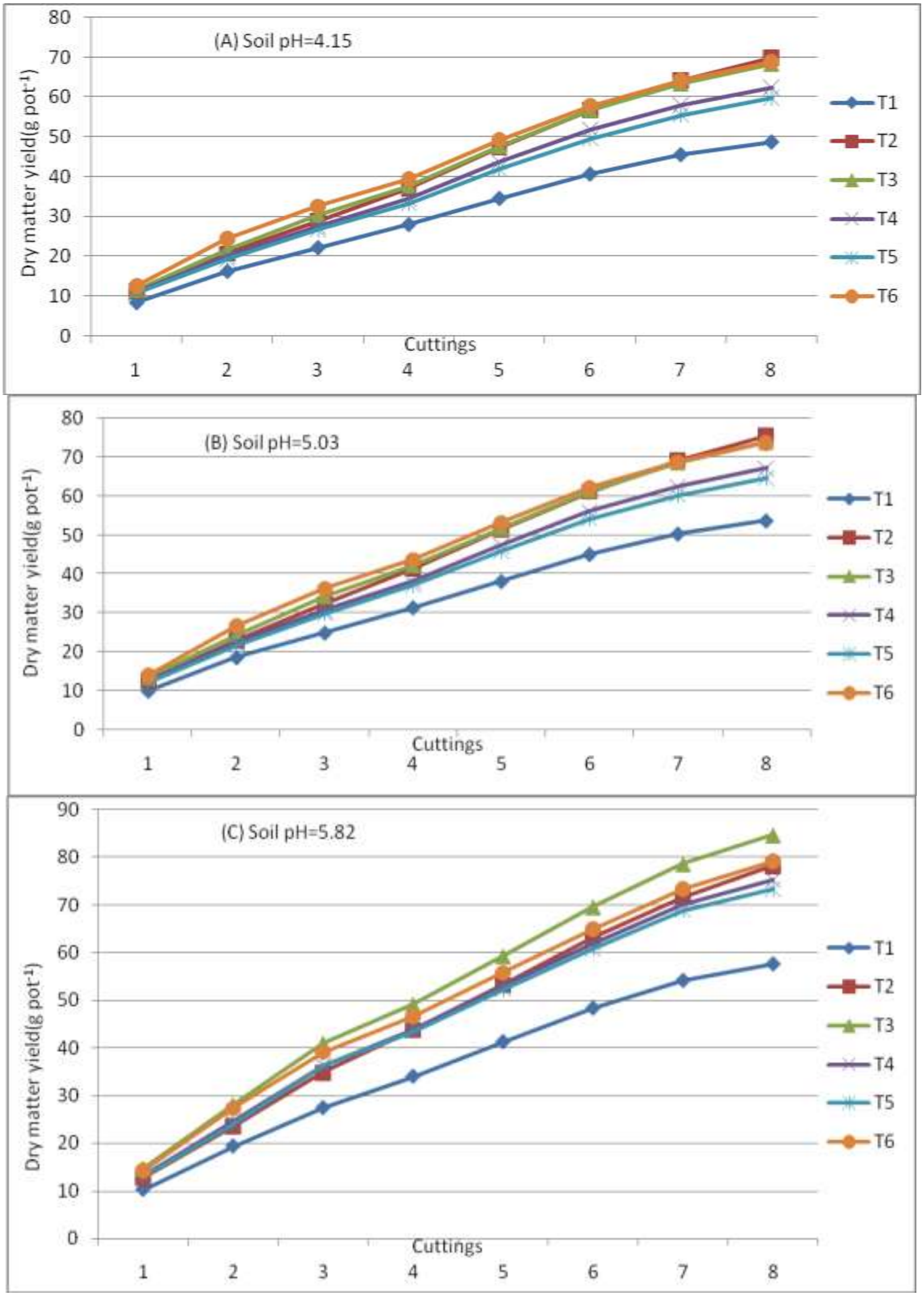


Fig.5 Total biomass yield of hybrid napier grass (g pot^{-1}) as influenced by soil pH

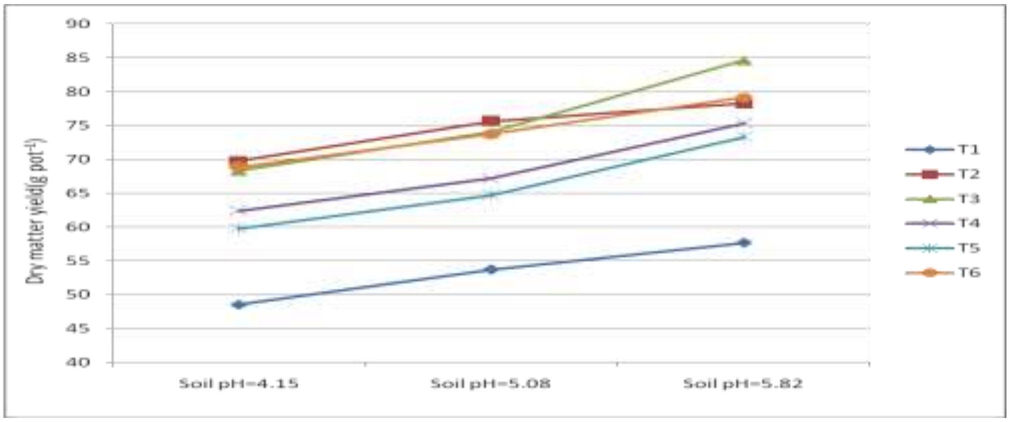


Fig.6 Correlations between mean soil available P and total dry matter yield of hybrid napier grass

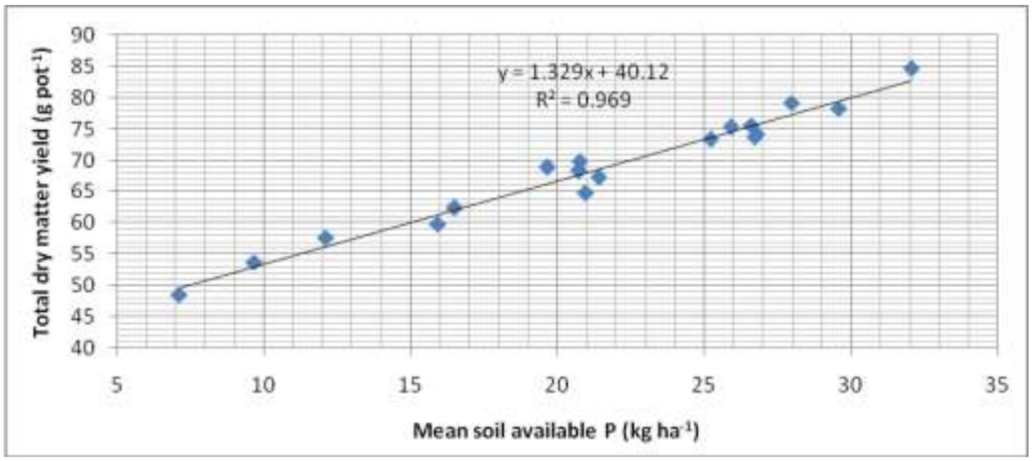
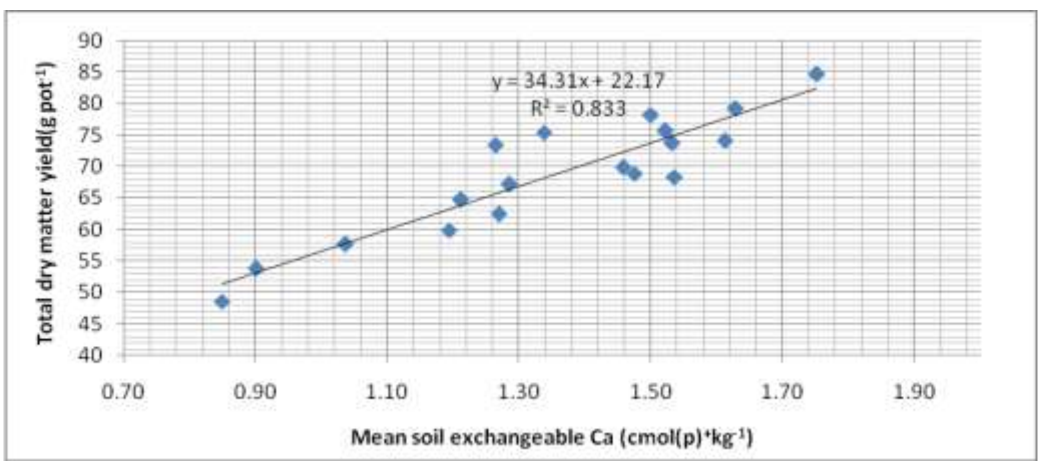


Fig.7 Correlations between mean soil exchangeable Ca and total dry matter yield of hybrid napier grass



At the end of 8^{th} cutting, exchangeable calcium content in control decreased by 52-58 % over the initial value might be due to crop removal from the native soil source. Sole application of higher dose of URP (T_2) increased calcium content significantly over all other treatments but was at par with T_3 (URP+ SSP) treatment at the end of 8^{th} cutting. Addition of lime with URP recorded higher calcium content in soil than URP+ FYM or URP+PSB but was at par with URP+ SSP treatment (Table 6 and Fig. 3).

Biomass yield of hybrid napier grass at different stages of cutting

The cumulative biomass yield of hybrid Napier grass increased significantly in URP treatments compared to that in the control. The magnitude of increase varied from 23-44 % in S_1, 20-41 % in S_2, and 27-47 % in S_3 (Table 7 and Fig. 4).

Sole application of higher dose of URP (200%P-T_2) recorded higher biomass yield than other treatments in S_1 (pH-4.15) and S_2 (pH-5.03) whereas, URP+SSP (T_3) recorded maximum yield in S_3 (pH-5.82) might be due to dissolution of URP got slower with increased soil pH (Fig. 5).

Addition of URP+SSP or URP+ lime showed similar trend in S_1 and S_2 but lower than URP alone (T_2). However, URP+SSP combination recorded higher yield in S_3 over all treatments. Combined application of URP+FYM or URP+ PSB recorded lower yield as compared to other treatments except control.

The relative agronomic efficiency (RAE) of treatments was calculated taking URP+SSP (T_3) treatment as standard.

It was observed that sole application of higher dose of URP (T_2) recorded higher RAE than standard treatment in S_1 (107%) and S_2 (108%), but the efficiency decreased in S_3 (76%) with increasing pH. The efficiency of URP greatly influenced by soil pH.

Correlations between soil available phosphorus, exchangeable calcium and hybrid napier grass yield

There were significant correlations between soil available phosphorus and biomass yield (R^2=0.964**) and soil exchangeable calcium and biomass yield (R^2=0.833**) (Fig. 6 and 7). The significant correlations indicate that the amounts of soil available P and exchangeable Ca derived during dissolution of rock phosphate could explain the yield variations. Phosphorus and calcium supplied to napier grass by amendments is consequently an important condition to achieve higher biomass yield in acid soils.

Properties of soil and organic manure used

Dissolution of phosphate rock is favoured by low pH, Ca and P because such a situation provides protons and Ca and P sinks (Ranjan *et al.,* 1996, Szilas 2002).The P component of PR dissolves in moist soil as per this following reaction -$Ca_{10}(PO_4)_6F_2 + 12H^+ \rightleftharpoons 10Ca^{2+} + 6\ H_2PO_4^- + 2F^-$

The dissolution rate therefore depends on the supply of H^+ ion (Kanabo and Gilkes, 1987a) and lowering of Ca^{2+} and $H_2PO_4^-$ ion activities through diffusion or adsorption reactions (Bolan and Hedley, 1989).The pH of the three soils used in our study was S_1-4.15, S_2-5.03 and S_3-5.83, which provides a conducive environment to denote H^+ ion for dissolution of RP. Bolan *et al.,* (1986) and Tambunan (1988) reported that the pH of top 10cm soils with pH 5 to 6 were sufficient to dissolve 2.3 to 7.8 t North Carolina PR per hectare under adequate moisture condition.

Lower available P (8.92-15.74 kg/ha) and exchangeable calcium (1.32-1.50 c mol (P^+) kg^{-1}) content of these soils provide a sink for dissolution of RP. Diffusion and adsorption of P on soil surface or by crop removal decrease the P concentration around PR particles and favour dissolution of PR (Kirk and Nye, 1986b, White 1988b, Kanabo and Gilkes 1987a). According to mass action law, PR dissolution releases Ca ion and soil with high Ca content would slow down PR dissolution (Hammand *et al.*, 1986b). For many tropical acid soils, exchangeable Ca is relatively low, thus providing favourable condition for PR application. The nutrient composition of FYM (N, P, K, and Ca) makes it a fairly good amendment on acidic laterite soils.

Effects of treatments on soil properties

The increase in soil pH in all treatments except control can be attributed to the release of Ca due to dissolution of PR. Increase in pH and Ca has a positive impact on reduction of P sorption capacity and exchangeable Al in acid soils. Reduction of exchangeable Al was caused by formation of complex with Ca. Combined addition of lime or SSP with URP maintained high pH during initial stage of growing period resulted in instant release of Ca from these sources over the period. On the otherhand, higher dose of URP released more Ca in latter stage of growth resulting higher pH than all other treatments. Hammond *et al.*, (1986b) reported the high pH and increased calcium resulting from liming decrease PR dissolution. Therefore it is necessary to fix lime rates carefully to alleviate Al-toxicity problem, at the same time to avoid adverse effect of PR dissolution (Chien and Friesen, 1992). Mishra and Pattanaik (1997) working with acidic laterite soil observed the dissolution of different phosphate rocks reached equilibrium at 45days of incubation due to build up of Ca and P ions released from PR due to inadequate size of sinks (in absence of a crop). However, under present study the dissolution of PR continued in long run since the nutrient removal by grass acted as a strong sink for calcium and phosphorus.

The decrease in exchangeable Al accompanied by increase in soil pH and exchangeable Ca has a positive effect on reducing P sorption capacity of soil (Sanyal and De Datta, 1991). This was revealed by an increase in available P in all treatments except control upto 2nd - 5th week and there after declined with decrease in soil pH. The decline in soil available P with progress of time can partly be attributed to crop uptake which is continuous throughout all cuttings. Phosphorus adsorption, precipitation and lack of application of acidity ameliorating amendments could have been led to declining available P levels in the control treatments. Mokwunye *et al.*, (1996) reported that P deficiency observed in acid soils is often associated with high P fixation between pH 5.0-6.0 where $H_2PO_4^-$ dominates (Furihata *et al.*, 1992). Holford (1997) observed that more than 80% of applied P in acid soils undergoes adsorption, precipitation or conversion to the organic form. The higher levels of available P in URP+SSP treatment could be possible due to addition of water soluble P (through SSP) as well as consumption of H^+ from soil for dissolution of URP resulting decline in P fixation capacity of soil. Combined application of lime with URP increased soil pH and exchangeable Ca that reduces P fixation and increased available P. Dissolution of URP is not affected since crop uptake acted as a strong sink for Ca and P. This was reflected in declining soil pH after 3rd cutting. Higher level of available P in T_2 (200%P) after 5th cutting was associated with decline in soil pH that favour dissolution of 'P' in latter stage of growth.

FYM combined with URP also increases available P in soil through chelation and decomposition. The decomposition products of organic materials have significant chelation capacity that lowers the activity of Fe and Al which form insoluble salts with P and so liberate phosphorus. Several authors have reported competition between organic acids and P for sorption sites that usually favours adsorption of organic acids and delays P adsorption (Volante and Gianfreda 1993, Geelhoed *et al.,* 1999).

Inclusion of PSB with URP also recorded similar effect on soil pH and available P. PSB application enhances dissolution of phosphate rock through production of organic acid and chelating substances (Adhya *et al.,* 2015) as well as production of growth promoting hormones.

Biomass yield and Phosphorus use efficiencies of hybrid napier grass

The lower biomass yield of hybrid napier in control may be attributed to the low availability of P due to fixation in acid soil. Conversely, the supply of P and Ca by P sources (URP, SSP) and amendments (lime, FYM, PSB) in combination contributed significantly higher biomass yield. Mishra and Pattanaik (1997) reported similar result with hybrid napier grass in an acidic sandy loam soil (pH 5.6, low available P). Subehia and Minas (1993) studied the effect of URP with FYM and poultry manure in clay loam soil with pH 5.7.

The organic manure enhanced the dissolution of PR or chelation of Ca^{2+} ions and subsequently lowering of Ca^{2+} ion activity in soil solution providing a sink for Ca^{2+}.

Under certain field conditions such as high pH, short term crop or low reactive PR, the agronomic efficiency of PR may not be feasible as that of water soluble SSP. Mixing of PR with SSP can be effective under such situation. In this study URP and SSP mixture in 1:1 ratio recorded higher biomass yield in S_3 (soil pH 5.82) than URP +lime or lone URP treatment but it was inferior to these two treatment in S_1 (soil pH 4.15) and S_2 (soil pH 5.08) (Fig. 4).

Similar observation was made by Prochnow *et al.,* (2004) in Brazil for wheat and rye grass with PR: SSP compaction at 1:1 ratio because the water soluble SSP provides P to plants initially (Starter effect) resulting in better plant root development, which in turn allowed the plants to utilize the PR more effectively in later stage. Such a mixtures further reduces the P fixation by depressing the activity of free Fe and Al in soil solution and enhance the solubility of PR by action of initial soil acidity created in root rhizosphere (Mc Lean and Wheeler, 1964).

Higher dose of URP (200% P) application in S_1 (soil pH - 4.15) and S_2 (soil pH -5.08) recorded higher biomass yield than URP+SSP and URP+ lime treatments because of higher dissolution of URP due to low pH, low available P and low exchangeable Ca content in soil during entire crop period. However, this treatment in S_3 with high pH and high Ca content was inferior to URP + SSP or URP + lime due to slow down of PR dissolution, according to mass action law. (Hammond *et al.,* 1986 b).

In conclusion, phosphate rock is a viable alternative to the expensive water soluble P fertilizers (SSP) in increasing crop productivity in acid soils of India. Application of URP alone or with amendments increased soil pH, available P, Ca, biomass yield of hybrid napier grass. The effect was higher when applied with lime or mixed with SSP in 1:1 ratio. Higher dose of URP alone was as effective as URP: SSP mixture in 1:1 ratio for long duration crops as reflected by biomass yield and RAE and can therefore be used as an affordable alternative to the more expensive water soluble SSP fertilizer. Effect of FYM or PSB on URP dissolution rate as reflected by soil available P, soil pH, exchangeable Ca and biomass yield of hybrid napier was low as compared to combined application of URP+ SSP mixture or URP+ lime.

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