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Maximizing phosphorus use efficiency in summer rice (*Oryza sativa*) under *Terai* region of West Bengal

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Abstract
On farm trials for two years (2016-17 and 2017-18) during the *Rabi season,* following Randomized Block Design was undertaken to evaluate the phosphorus use efficiency (PUE) as well as yield in *boro* rice. (Cv. Gotra Bidhan-1) with three replications having eight treatment combinations. The conventional tillage practice was undertaken during the study. Treatment T_1 was control receiving recommended dose (RD) i.e. (N, K and without P application) and T_2 to T_8 has constant and RD of N and K with variables rates of P from different sources viz. inorganic and organic sources (FYM, Phosphocompost and Vermicompost).The maximum grain yield (6.25 ton ha^{-1} was obtained under T_3 (variables rate of P application with constant dose of N and K) over that of other treatment combinations or control. The harvest index (%) of the crop was higher (T_3) (35.26) over control or at par with T_6 (34.49%) and T_7 (34.87%) treatments. The Phosphorus Use Efficiency (PUE) of 34.43 was recorded under T_7 in grain (Balance method, %). This might be due to the judicious application of organic manures and chemical fertilizers, providing greater stability in crop production, maintain improvements in soil fertility and enhance the nutrient use efficiency for growth and yield of rice.

Keywords: Boro rice, nutrient expert software, uptake, yield, phosphorus use efficiency (PUE)

Introduction

Rice (*Oryza sativa*), the staple food of South Asia, is a major crop in Indian agriculture. It is the second most widely consumed cereal in the world after wheat. With a production of over 210 million metric tons China was the world's leading rice producer, followed by India being 166.5 million metric tons production in 2017-18(approx.) (Statistic portal; statista) [29]. India is the largest (12,500 thousand metric tons) and principle rice exporting country followed by Thailand and then Vietnam (Statistic portal; statista, 2018-19) [30]. In India, West Bengal is the largest(146.05 Lakh tons) consumer as well as the producer of rice providing 50% of its cultivated land for rice cultivation followed by Uttar Pradesh and Andhra Pradesh (Jegede *et al*., 2018) [10].

Rice crop responses well to P fertilization in both upland and wetland conditions; however, compared to nitrogen (N) it has received little attention. Phosphorus is the second most limiting nutrient after N for crop production. It is an essential plant nutrient for root development, tillering, early flowering, and ripening of the crop. It is relatively more mobile within the plant than in the soil. Phosphorus is an important nutrient for global food security, but its availability is limited and nonrenewable which makes its efficient use vitally important (Roberts *et al*., 2015) [20]. Due to extensive agriculture, majority of the world's Rock phosphate has already been mined and is still going on at rapid rate and used for the manufacturing of P fertilizers. The increased efficiency of P in the agriculture system may reduce the global demand of P resulting in the decreasing rate of depletion of fossil reserves. In a study (Smil *et al*., 2000) [22], it was projected that P reserves will be depleted to a greater extent in the next 50 to 100 years. Considering this non- renewable and non- substitutable nature of P, improving PUE is major area of concern.

Phosphorusis very inefficient in terms of plant utilization as P recovery by crops varies between 10-15% (Edwards *et al*., 2015) [5]. The crop Phosphorus efficiency either can be achieved by increasing yield by giving the recommended rate or by maintaining the yield stable with lower levels of P fertilizers application, mode of application, source, rate of fertilizer and their interactions. The residual fertilizer P is not recovered by the cropin most of the cases and is believed to be permanently fixed in the soil in forms not available to plants (Roberts *et al*., 2015) [20]. The combined use of organic manures and chemical fertilizers has the potential to provide greater stability in crop production, maintain improvements in soil fertility and enhance the Puse efficiency for growth and yield in hybrid rice (Kyi *et al*., 2017) [13]. In an another way, increase in PUE can be achieved by different fertiliszers formulations, rate of application, timing of application or by introducing such species of crops which can improve efficiency of P. PUE is nowadays gaining attention to evaluate the crop production systems. It is highly influenced by fertilizer as well as by soil-plant-water management with the aim to enhance the overall performance of cropping systems by providing minimum nutrient loss from the field and optimising economically nourishment to the crop (Paul *et al*., 2014) [18]. Improved PUE can enhance the life of the P reserves, increase the sustaninability of food production globally and reduce the environmental risk associated with excessive P fertilization.

Rice is one of the major crops grown in the Northern Districts of West Bengal (i.e. *Terairegion)* which are typically deficient in some plant nutrients like B, Zn and P. The soils are mostly acidic in reaction, sandy to sandy-loam in texture and contain high amount of Fe and Al oxides and hydroxides. Soil pH affects the chemistry of P in soils as it affects P adsorption and precipitation into solid forms in soil. Fixation of P by these oxides and hydroxides is an utterly important area of concern to the researchers as this problem affects the uptake of P by several crops grown this area. Additionally, the farmers are not applying proper doses of P fertilizer in intensively rice-cropped areas resulting in serious imbalance in soil fertility status and soil- physical properties.

Based on the above perspectives, the experiment was undertaken to improve the phosphorus use efficiency in summer rice in West Bengal.

Materials and methods

Materials

Experimental site

A field experiment was carried out at the agricultural farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal, India. The farm is located within the *Terai* Agro-climatic zone and its geographic location is 26º19'86" N latitude and 89º23'53" E longitude**.** The field experiment was carried out in the same field consecutively for two years. (*Boro season*, 2016-17 and 2017-18).

Experimental plots

The local topography of the study area is almost flat. The soil of the experimental site is sandy loam in texture having average composition of (sand- [51.47%], Silt- [25.16%] and Clay-[23.37%]). Before laying out the experimental plots, a set of surface soil samples were collected over the whole experimental area, composite together and tested in the laboratory following the standard methods. The measured physico-chemical properties (Table 1) were used as the baseline measurement for the experimental plots. The experimental design following RBD were laid out having 8 treatments combinations (Table 2) with 3 fold replications comprising a set of 24 plots (5m×4m). The treatment T_1 was control receiving recommended dose of N,K and without P application. The treatments from T_2 to T_8 received recommended doses of N and K, with different doses of P from different sources (i.e. organic and inorganic). The recommended doses of N:P:K: @ 120: 60:40 kg ha^{-1},FYM @ 20 ton ha^{-1}, Phosphocompost @5 ton $ha^{-1}$and Vermicompost @ 5 ton ha^{-1} were applied in soil. One of the treatments include Nutrient Expert®based recommendation (T_3), which is a decision support tool for fertilizer recommendation, works on the principles of SSNM (Site Specific Nutrient Management) (Pampolino *et al*., 2012) [16].

Table 1: Physico - Chemical properties of initial soil and Post harvest soil of two years

Particulars	Initial Soil	Postharvest Soil
pH	5.8	6.7
EC(dS/m)	0.19	0.15
Sand(%)	51.5	51.4
Silt(%)	25.2	25.1
Clay(%)	23.4	23.5
Oxidisable Organic carbon(%)	0.68	0.6
Nitrogen (kg ha^{-1})	170.5	164.3
Phosphorus(kg ha^{-1})	12.0	12.2
Potassium (kg ha^{-1})	76.9	72.3
CEC[cmol (p^+) kg^{-1}]	3.3	3.3

Table 2: Details on the experimental plots and treatment combinations

Crop	Summer Rice (*Oryza sativa*)
Cultivar (Cv.)	Gotra Bidhan-1
Experimental Design	Randomized Block Design
Plot Size	5×4 sqmt
Number of replication	3
Spacing	20cm ×15 cm
Treatment	**Combination**
T_1	Control – NK(RD)+ P_0
T_2	Farmer's practice (kg ha^{-1}) (N:P:K: =75:30:40)
T_3	Nutrient Expert® software recommendation (N:P:K: =118:37:40)
T_4	State Recommendation (RD) (N:P:K: =120:60:60)
T_5	NK+ 150% of the RD of SSP
T_6	NK+ 75% of the RD of SSP+25% Phosphocompost
T_7	NK+ 75% of the RD of SSP+25% RD FYM
T_8	NK+ 75% of the RD of SSP+25% Vermicompost

Recommended Dose (RD): 120:60:40 kg NPK ha^{-1} in the form of Urea, SSP and MOP. FYM (20 ton ha^{-1}), Phosphocompost (5 ton ha^{-1}) and Vermicompost (5 ton ha^{-1})

P_0: No phosphorus applications

Source of nutrients:

Organic nutrients	Farm Yard Manure (0.8 % P_2O_5) Phosphocompost (3% P_2O_5) and Vermicompost (0.75% P_2O_5)
Inorganic nutrients	Nitrogen : As Urea Phosphorus : As Single Super Phosphate (SSP) Potassium: As Murate of Potash (MOP).

Field operations

A single cropping sequence was maintained i.e. transplanted puddled summer rice followed by previous year transplanted puddled summer rice. During this field experiment, we have opted for conventional tillage method with Gotra Bidhan–1(Mid early duration) variety with the seed rate @ 50 kg ha^{-1}.One deep ploughing was given by tractor to break the clods. Seeds were soaked overnight in a Tricyclazol 75 WP@ 2g kg^{-1} of seed of water for easy germination in the seedbed. Seeds were sown by broadcasting, weeds were removed and cleaned. Each of the plot in accordance with the treatments was prepared. Recommended dose of P and K, well decomposed Farmyard Manure, Phosphocompost and Vermicompost were applied treatment wise (Table 2). The old seedlings of 25 days were transplanted with a spacing of20cm× 15cm. Treatmentwise top dressing of inorganic nitrogen in the form of urea was done in three equal splits, i.e., first one at 5, second one at 25 and third one at 46 days after transplanting, respectively. Plant samples were collected by leaving the border rows and keeping half of the area in each plot for recording biometrical observation including destructive plant sampling and other half for recording yield components and yield of rice. The height (cm) from ground level) of five randomly selected plants were recorded and averaged from each plot. The dry weight of shoots were also recorded. The number of tillers per m^2 was recorded from 10 randomly selected plants. The crop was harvested at ground level when 80% of the panicles with 80%grains in each panicle were matured. Test weight (1000 grain weight) of the grains per treatment was also recorded. Plants were harvested with the help of sickle and then sun dried and finally threshed properly. The final yield of rice grains andstraw were recorded and phosphorus use efficiency (PUE) was calculated using balance method (Syers*et al*., 2008) [24] as mentioned below.

PUE (%) = Uptake by the plant (kg ha^{-1})/ Fertilizer applied (kg ha^{-1})×100

Methods

Soil and Plant analysis

Collected plant and soil samples at four growth stages (i.e. tillering, panicle initiation, flowering, and harvesting) were analyzedin the laboratory. The pH and EC (electrical conductivity) of soil samples was analyzed in suspensions (soil: water 1:2.5) using a glass electrode pH meter and by a digital conductivity meter respectively (Jackson, 1967) [9]. Theoxidizable OC (Organic Carbon) content of soil samples were estimated by Walkley and Black's titration method (Nelson *et al*., 1982) [15]. Mechanical analysis of soil samples were carried out following the hydrometer method (Dewis *et al*., 1984) [4]. The textural class was determined from the particle size distribution of sand, silt, and clay particles. Available nitrogen (N) in soil and plant samples was determined by alkaline $KMnO_4$ method following Subbiah and Asija (Subbiah *et al*., 1956) [23]. Available phosphorus (P) in soil and plant sample was determined by the Bray and Kurtz method (Bray *et al*., 1945) [1], followed by colorimetric measurement at 780 nm using spectrophotometer. Available potassium (K) in soil was determined by extracting soil samples with neutral normal ammonium acetate solution using a flame photometer (Black, 1965) [2].

Statistical analysis

Statistical analysis for the collected data was performed in SPSS 2017 software. The correlation between the soil nutrient status at harvest and grain and plant uptake were also statistically calculated. The significant differences between the treatments was tested using ANOVA and LSD.

Results and Discussion

Yield of rice

The significant difference was observed among the treatment combinations on yield components of the rice (Table 3). The maximum mean grain yield (6.25 ton ha-^{1}) was observed in treatment T_3 (Nutrient Expert® software based recommendation), while minimum under control T_1 (4.16 ton ha-^{1}) (Figure 1). Significant yield improvement in rice with the use of the recommendation based on Nutrient Expert®for rice was reported and it was considered that the combination of balanced rate, time and method of application leaded this higher yield (Mandal *et al*., 2016 and Gupta *et al*., 2016) [14, 7]. Our results are in agreement with (Thapa *et al*., 2018) [25] who found that nutrient expert based fertilizer recommendations was successful in rice cultivation over the other fertilizer based recommendation. But after T_3, the higher mean grain yield was found under T_7over the rest of the treatments which supported the contention of the result found by (Parihar *et al*., 2015) [17], in which treatment receiving inorganic fertilizer along with FYM give maximum grain and straw yield.

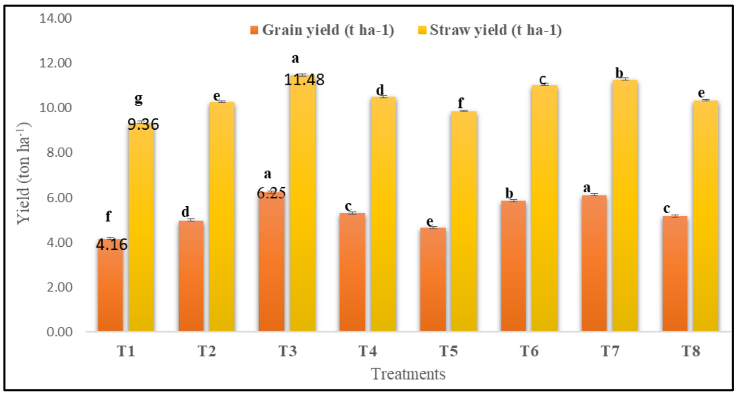

Fig 1: Effect of treatments on average Grain yield and Straw yield (ton ha^{-1}) of rice over two years. The Standard Error Mean (SEM) of measurement is shown as error bar (p≤0.05)

Table 3: Effect of treatments on the Yield Components of Rice with mean (average) over two years.

Treatments	Plant height (cm)			No of panicles per hill			Panicle length (cm)			No. of grains per Panicle			Test Weight (g) (1000 gram wt.)		
	1st year (2016-17)	2nd year (2017-18)	Mean	1st year (2016-17)	2nd year (2017-18)	Mean	1st year (2016-17)	2nd year (2017-18)	Mean	1st year (2016-17)	2nd year (2017-18)	Mean	1st year (2016-17)	2nd year (2017-18)	Mean
T_1	104.8^{c}	102.8^{c}	103.8	47.0^{de}	43.0^{de}	45.0	17.64^{bc}	15.64^{bc}	16.62	136.3^{d}	138.3^{d}	137.3	28.1^{c}	28.23^{c}	28.42
T_2	112.3^{abc}	114.5^{abc}	113.4	45.7^{ef}	44.7^{ef}	45.2	16.77^{c}	17.07^{c}	16.92	221.0^{abc}	225.0 ^{abc}	223	29.4^{ab}	29.56^{ab}	29.48
T_3	119.33^{a}	120.43^{a}	119.9	57.7^{a}	58.7^{a}	58.2	20.40^{a}	21.42^{a}	20.91	267.0^{a}	260.0^{a}	263.5	29.8^{b}	29.30^{b}	29.55
T_4	116^{abc}	108^{bc}	112.0	52.7^{bc}	51.7^{bc}	52.2	19.44^{ab}	20.04^{ab}	19.74	205.3^{bcd}	194.3^{bcd}	199.8	29.1^{ab}	29.32^{ab}	29.21
T_5	108^{bc}	106^{bc}	107.0	50.0^{cd}	49.0^{cd}	49.5	20.27^{a}	19.17^{a}	19.72	182.0^{bcd}	186.0^{bcd}	184	29.2^{ab}	29.42^{ab}	29.31
T_6	114.7^{ab}	112.6^{ab}	113.7	43.3^{f}	47.3^{f}	45.3	19.43^{ab}	18.43^{ab}	18.93	224.3^{abc}	214.3^{abc}	219	30.2^{ab}	30.10^{ab}	30.15
T_7	119.7^{a}	121.1^{a}	120.4	54.0^{b}	55.0^{b}	54.5	20.87^{a}	22.07^{a}	21.47	247.0^{ab}	257.0^{ab}	252	30.5^{a}	30.89^{a}	30.69
T_8	111.9^{abc}	109.2^{abc}	110.6	38.7^{g}	46.2^{g}	42.5	17.74^{bc}	18.24^{bc}	17.99	159.7^{cd}	152.7^{cd}	156.2	28.9^{ab}	29.10^{ab}	28.6
SEM (±)	2.85	2.02		1	1.05		0.64	0.64		20.14	19.94		0.62	0.65	
LSD	8.66	8.54		3.02	3.1		1.92	1.92		61.09	60.05		1.89	1.9	

Harvest Index

Harvest Index [average of two years (%)] was recorded maximum under T_3 (35.26) following T_7 (34.87) which was at par with T_6 (34.49) and minimum under control (Table 4). It was reported (Gaire *et al*., 2016) [6], that the highest biological yield was obtained in the Nutrient expert recommendation while lowest under farmer's practice. The high harvest index shows the efficiency of converting biological yield into economic yield (Kusalkar *et al*., 2003) [12].

Table 4: Harvest Index and Phosphorus use efficiency (PUE) [average] over two years

Treatments	Harvest index (%)	Phosphorus use efficiency (%)
	Mean	Mean
T_1	30.76^{e}	-
T_2	32.99^{c}	31.28^{b}
T_3	35.26^{a}	33.21^{a}
T_4	33.56^{c}	23.46^{d}
T_5	31.93^{d}	13.11^{e}
T_6	34.49^{b}	24.85^{c}
T_7	34.87^{ab}	34.43^{a}
T_8	33.30^{c}	33.38^{a}
SEM(±)	0.20	0.39
LSD	0.68	1.30

Uptake of nutrients by rice

Present study also highlights significant difference in the nutrient uptake across different treatments and at different stages of crops (Figure 2). The highest uptake (kg ha^{-1}) of N over the entire growth period was obtained in treatment T_7 and minimum N uptake was observed under control (T_1) (Figure 2). Similarly, the maximum uptake of P was recorded in T_7 while K uptake was highest in T_6.Similar to N uptake, a variable amount of P and K uptake was also recorded at different growth stages in different treatments. The total nutrient uptake (N-P-K) also varied across the treatments. As expected, T_1 (control) was recorded least amount of total nutrient uptake (N-P-K) while highest was in T_7.These results corroborates with (Rai *et al*., 2012) [19], who observed that inorganic fertilizers with enriched compost when applied alone was found effective in terms of supplementing readily available phosphate ion from the soil pool for rice crop. A significant difference was recorded in the uptake of different nutrients by grainand straw (Table 5). The highestuptake of N and P [for two years (kg ha^{-1})] was observed in treatment T_7, while in K (kg ha^{-1}) it was observed in T_6in grain of rice (Table 5). A different trend was observed for the uptake of nutrients by straw (Table 6). The N and K (kg ha^{-1}) uptake was recorded maximum in T_6 while in case of P it was recorded in T_7. A high correlation was also observed between the residual nutrient status in soil and the nutrient status in straw (Table 7) or between residual status in soil and the nutrient status in grain (Table 8). The enriched compost alone or in combination with inorganic fertilizers was found effective in terms of supplement in readily available phosphate ion in soil pool for rice crop (Rai *et al*., 2012) [19].

Table 5: Effect of treatments on the uptake of nutrients (kg ha^{-1}) by Grain [for two years]

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
T_1	49.41^{h}	51.9^{h}	50.66	6.70^{h}	7.2^{h}	6.95	19.9^{h}	17.2^{h}	18.55
T_2	80.36^{d}	82.9^{d}	81.63	9.21^{g}	9.56^{g}	9.39	33.2^{f}	37.5^{f}	35.35
T_3	65.20^{g}	68.3^{g}	66.75	12.23^{f}	12.45^{f}	12.34	64.9^{b}	68.22^{b}	66.56
T_4	85.40^{c}	87.2^{c}	86.30	13.05^{d}	15.10^{d}	14.08	49.7^{e}	51.10^{e}	50.40
T_5	76.21^{f}	72.9^{f}	74.56	12.30^{e}	11.30^{e}	11.80	32.4^{g}	33.30^{g}	32.85
T_6	98.38^{a}	96.5^{a}	97.44	20.05^{b}	20.96^{b}	20.51	66.4^{a}	69.89^{a}	68.15
T_7	96.04^{b}	92.1^{b}	94.07	29.10^{a}	29.45^{a}	29.28	55.3^{c}	56.96^{c}	56.13
T_8	78.53^{e}	73.2^{e}	75.87	18.23^{c}	18.10^{c}	18.67	50.2^{d}	52.10^{d}	51.15
SEM(±)	0.09	0.06		0.06	0.04		0.09	0.12	
LSD	0.27	0.25		0.18	0.16		0.28	0.29	

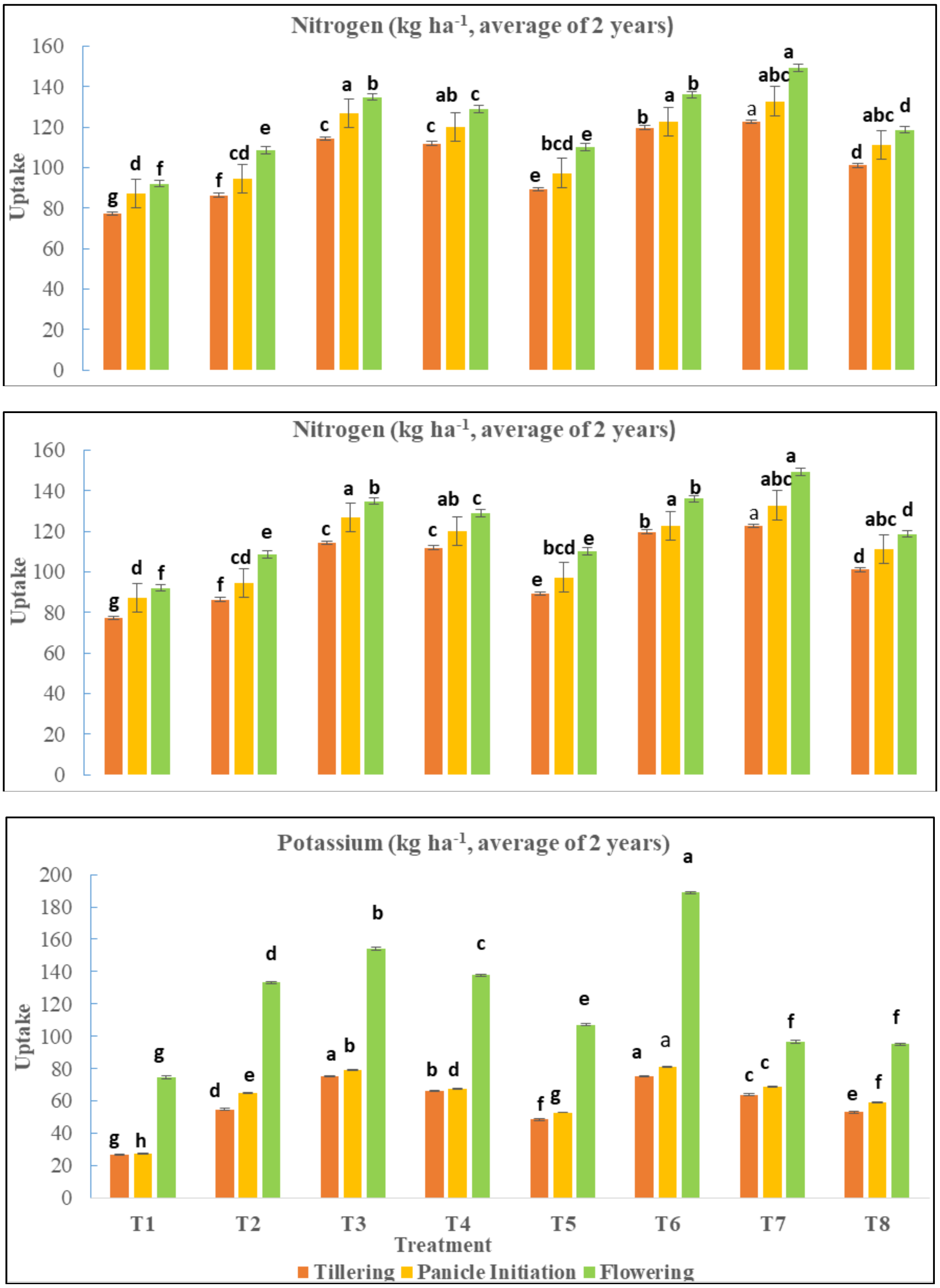

Fig 2: Effect of treatments on the uptake of nutrient [(N, P and K) kg ha^{-1}] status at different growth stages (Tillering, PanicleIntiation and Flowering) of rice. The Standard Error Mean (SEM) of measurement is

Table 6: Effect of treatments on the uptake of nutrients (kg ha^{-1}) by Straw [for two years]

Treatments	Nitrogen			Phosphorus			Potassium		
	1st year	2nd year	Mean	1st year	2nd year	Mean	1st year	2nd year	Mean
T_1	69.15^{h}	71.12^{h}	70.14	8.01^{h}	5.01^{h}	6.51	30.9^{h}	28.1^{h}	29.5
T_2	125.30^{f}	123.20^{f}	124.25	38.66^{f}	39.66^{e}	39.16	55.9^{d}	56.9^{d}	56.4
T_3	132.49^{c}	130.20^{c}	130.35	73.99^{b}	75.49^{b}	74.74	83.5^{b}	86.5^{b}	85.0
T_4	130.29^{d}	131.56^{d}	130.93	45.53^{e}	47.60^{f}	46.57	49.2^{f}	50.2^{f}	49.7
T_5	120.75^{g}	118.50^{g}	119.63	33.45^{g}	36.45^{g}	34.95	36.9^{g}	37.9^{g}	37.4
T_6	145.18^{b}	142.20^{b}	143.69	51.99^{c}	53.10^{c}	36.58	87.3^{a}	88.3^{a}	87.9
T_7	150.28^{a}	152.20^{a}	151.24	79.13^{a}	80.13^{a}	54.62	58.1^{c}	59.10^{c}	58.6
T_8	126.14^{e}	124.12^{e}	125.13	49.23^{d}	50.03^{d}	34.63	53.2^{e}	54.50^{e}	53.9
SEM(±)	0.17	0.15		0.22	0.24		0.18	0.16	
LSD	0.51	0.49		0.67	0.69		0.54	0.52	

Table 7: Correlation (r) between soil available nutrient status at harvest and nutrient content in straw averaged over two years

	Plant N	Plant P	Plant K
Soil N	0.49	0.20	0.44
Soil P	0.76*	0.36	0.71*
Soil K	0.89**	0.35	0.79*

*p<0.05, **p<0.01

Table 8: Correlation (r) between soil available nutrient status at harvest and nutrient content in grain averaged over two years

	Soil N	Soil P	Soil K
Grain N	0.46	0.75*	0.49
Grain P	0.93**	0.87**	0.75*
Grain K	0.84**	0.87**	0.76*

*p<0.05, **p<0.01

Residual status of nutrients

The treatment T_7 was recorded with the highest amount of residual N, P and K at the tillering stage (Figure 3) compared to panicle initiation, flowering and at maturity stage. There was no significant differences between the growth stages of rice, even the corresponding treatments were significant. There was significant difference in the residual N status of soil at different plots and at different growth stages. Initial application of N resulted a high amount of residual N at the tillering stage and gradually decreased towards maturity, which had the least amount of residual N (Figure 3). Unlike N,the maximum residual P was recorded in treatment T_3at different growth stages of rice, while in case of K, a different trend was observed showing maximum residual status under T_4 and T_6 respectively. A positive correlation was observed between the uptake of different nutrients and the grain- straw yield irrespective of different nutrients treatments (Figure 4).The correlation coefficient (r) was high as (0.94) between uptake of K and the grain yield (t ha^{-1}) while it was 0.67 and 0.64 between uptake of P and the Grain yield and Straw yield (Figure 4.) repectively. These results were in conformity with the findings of the (Waigwa *et al*., 2003) [28], who found that there was decrease in the soil available P in soil with increase in the P content in rice plant from active tillering to grain development stage.

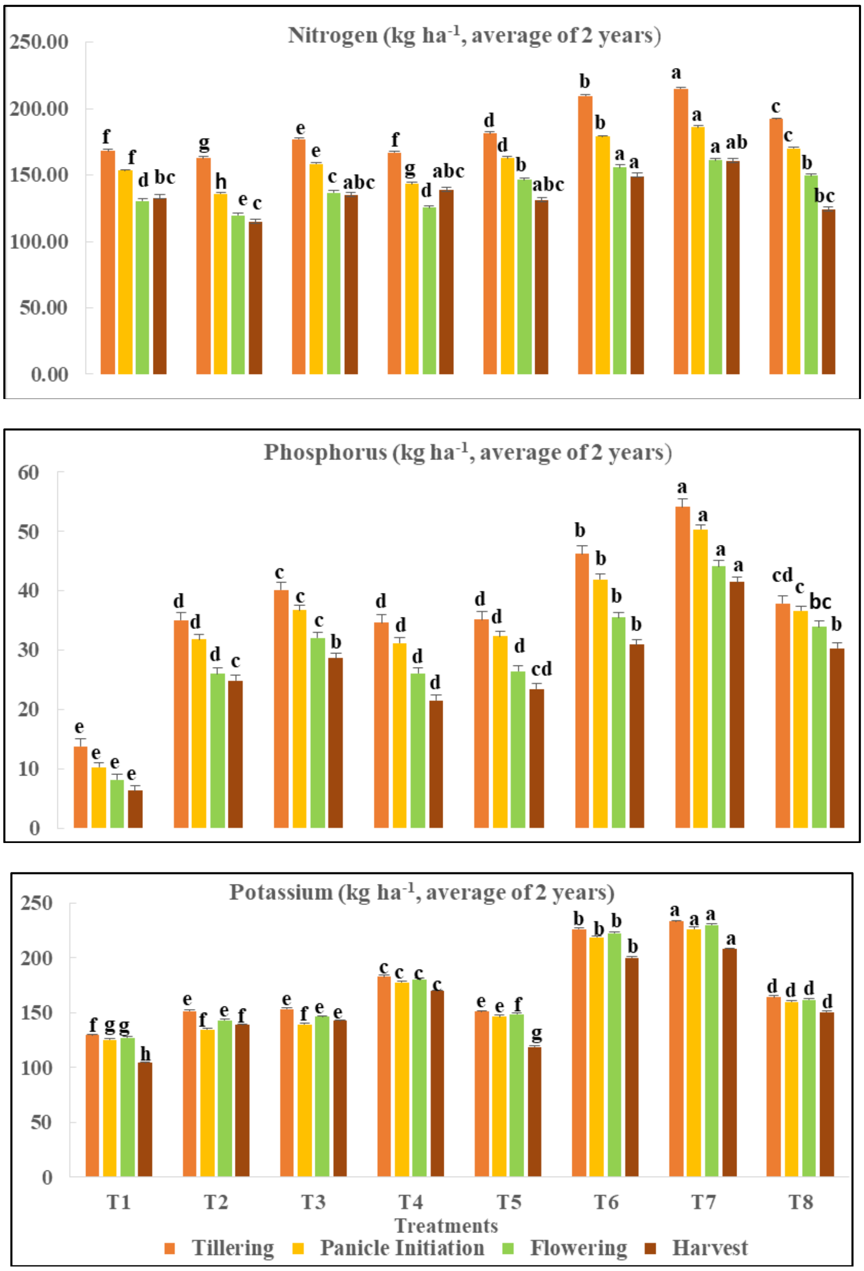

Fig 3: Effect of treatments on the residual nutrient [(N, P and K) kg ha^{-1}] status of soil at different growth stages (Tillering, Panicle Flowering and Harvest) of rice. The Standard Error Mean (SEM) of measurement is shown as error bar. ($p \leq 0.05$).

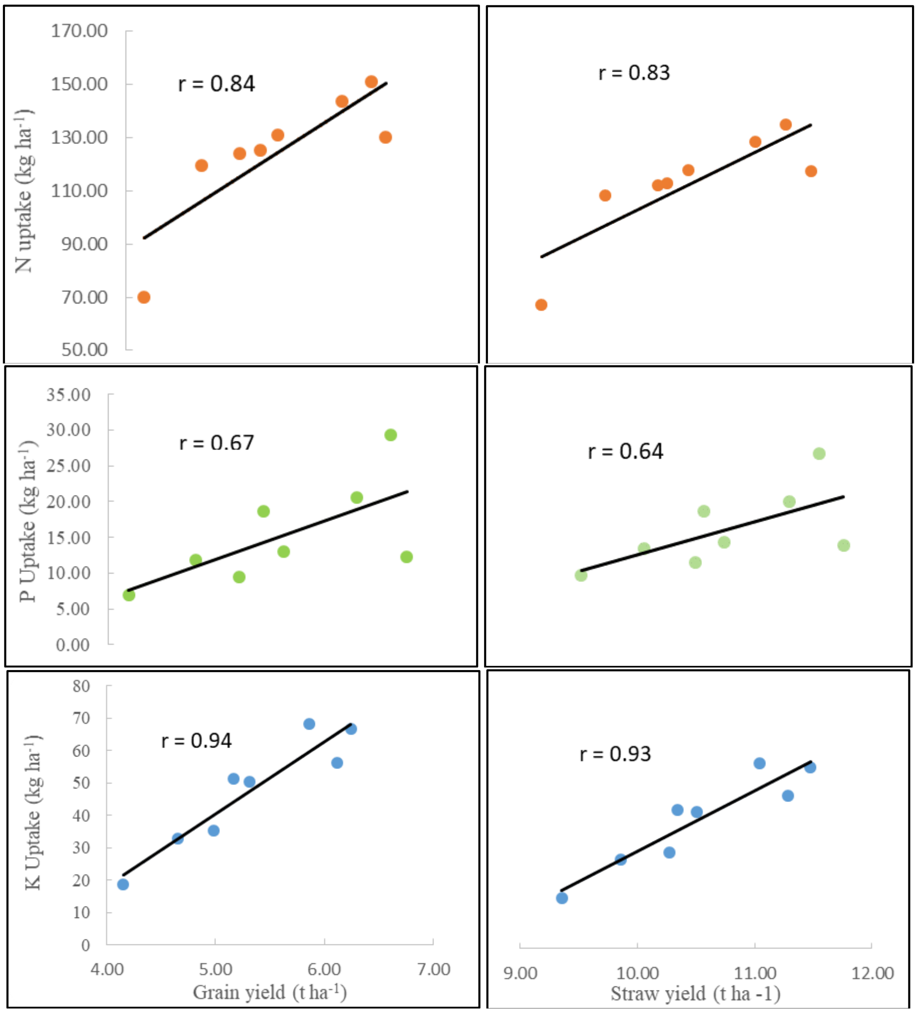

Fig 4: Correlation coefficient (r) between the nutrients (N, P and K) uptake (kg ha^{-1}) by plants with the grain and straw yield (ton ha^{-1}) of rice

Phosphorus use efficiency

The PUE (%) was calculated (Table 4) by using balance method and was found that highest PUE in T_7 (34.43) was at par with T_8 (33.38) and T_3 (33.21) respectively, while the lowest was under control (T_1).It was observed that efficiency calculated by balance method was more than that calculated by difference method, can exceed to 100% indicating the mining of the soil P reserves. (Chien *et al*., 2005) [3] reported that this might be due to the artefacts from not taking into account an experimental plot without adding P. Similarly, (Johnston, 2009) [11] reported that phosphorus use efficiency in soils when measured by balance method was exceeding 90%. In an another study (Hellal *et al*., 2013) [8] it was reported that the PUE in maize was more due to Phosphocompost application as compare to rock phosphate where more emphasis was given on the decomposition time and mineralization rate of Phosphocmpost fertilizers in the acidic soil. It was observed that PUE was improved by producing higher yield at T_7 (75 % of the RD of SSP) where lower rate has applied by inducing the remobilization of the taken up by P by the crop with in the system. Significant increase in fertilizer P use efficiency can be achieved by different fertilizer formulations, altering timing of application, altering placement in the soil or changing the rate of P applied and choosing crop species or varieties efficient at scavenging P from soils (Technical Bulletin *et al*., 2007) [26].

In a study (Rose *et al*., 2012) [21], it was observed that if a grain P concentration reduces and PUE increases it might be expected that there would be reduction in P fertilizers requirement. Thecombined use of FYM and inorganic enhanced rice productivity and the yield, nutrient uptake and utilization (Tilahun *et al*., 2013) [27].

Summary

This study examined the effect of different sources of phosphorus in combinations for determining the phosphorus use efficiency in Boro rice in *Terai* region of West Bengal. The yield components and grain yield of rice showed a significant differences among the treatment combinations. The maximum average grain yield (6.25 ton ha^{-1}) over two years was observed in treatment T_3.The minimum grain yield was observed in treatment T_1. A relatively higher yield was obtained from the treatments with any nutrient combination over that of the control. Along with the difference in grain yield, a significant difference in straw yield was also observed among the treatments. A positive correlation was observed between the uptake of nutrients and the yield of grain and straw in this region with acid soils. Highest harvest index (%) (average over two years) of 35.26 was observed in treatment T_3 while minimum was found under control (30.76). A different trend was found in case of PUE, where maximum PUE (34.43%) was recorded in treatment T_7 followed by T_8 and then T_3. The residual nutrients status showed a build-up of nutrients in soils. It might be due to the judicious use of organic manure and inorganic fertilizers in combination which influences the soil properties by enhancing PUE of rice. There is utterly need of awareness of the wide range of P management practices to increase the worldwide PUE for cereals.

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