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EFFECT OF ORGANIC AND INORGANIC PHOSPHORUS ON THE YIELD AND NUTRIENT USE EFFICIENCY OF T. AMAN RICE

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ABSTRACT

A field study was conducted to evaluate the effect of combined use of organic and inorganic phosphorus (P) sources on yield contributing characters, yield and nutrient use efficiency of T. Aman rice. Eight treatments including a control, a recommended doses of inorganic fertilizers and six other treatments which were combinations of inorganic and organic fertilizers where 50 % and 75 % of recommended doses of P were provided by using triple super phosphate (TSP) and the remaining 50 % and 25 % of P were amended by using either cowdung (CD), poultry manure (PM) or household waste (HW). The nutrient P as per treatments and nitrogen (N), potassium (K) and zinc (Zn) as per recommended dose were applied. Combined application of inorganic and organic sources of P significantly increased the yield and yield contributing characters of T. Aman. The effect of PM was prominent than that of CD and HW. The treatment T_4 receiving 50 % P through TSP and 50 % P through PM produced the highest grain yield of T. Aman rice (4.34 t/ha) and also showed the highest % recovery efficiencies (RE), agronomic efficiencies (AE) kg/kg, physiological efficiencies(PE) kg/kg and internal efficiencies (IE) kg/kg of nitrogen(N) but failed to increase the physiological efficiencies(PE) kg/kg and internal efficiencies (IE) kg/kg of phosphorus(P).Thus, the present study indicated that the use of both organic and inorganic source of P is an effective way to enhance the yield and increase the nutrient use efficiency (NUE) for T. Aman rice.

Keywords: phosphorus, organic amendment, inorganic fertilizers, nutrient use efficiency

INTRODUCTION

Phosphorus (P) is an important plant nutrient for all crops and component of nucleic acid, phytin and phospholipids. It is a key constituent of Adenosine Di-phosphate (ADP) and Adenosine Tri Phosphate (ATP) and plays significant role in the energy transformation in plants (Sanker *et al.*, 1984). It plays vital role in cell division, flowering, and fruiting including seed formation, crop maturation, root development and quality improvement. Many soils of the Indo-Gangetic plain, including Bangladesh have become P deficient (BRRI, 1992; Ali *et al.*, 1997). Rice yield in P deficient soil was less than 50% of that obtained from soils containing even moderate levels of P (Saleque *et al.*, 1998). Much of the P applied to soils as fertilizer become fixed into unavailable forms to plant (Choudhury *et al.*, 2007), leading to agronomic and economic inefficiency. Phosphorus fertilizer management is complex as it requires knowledge of the supply of other nutrients to crop, the overall P balance in soil, the effective P supply from indigenous soil resources, fertilizer application, crop P export and recycling, and the processes that govern the availability of P in a particular soil (Doberman *et al.*, 1996). The amount of soil P removed by crops needs to be replenished through the application of fertilizer to maintain soil P balance. The crucial fact about P application to agricultural soils is that an under dose will impede crop growth, while an overdose will be wasteful and also pose an environmental threat of eutrophication (Sharpley *et al.*, 2001). The continuous use of chemical fertilizers are decreasing crop productivity day by day (Srivastava *et al.*, 1988; Stinner and House, 1989) and international community addresses increasing concern for sustainable agriculture through integrated and holistic approach to soil nutrient management (IRRI, 1991). The integrated nutrient management comprises the integrated use of fertilizers from organic and inorganic sources and their management for efficient and economic use and maintenance of soil fertility and productivity (Prasad and Rovima, 1991). To get maximum yield combination of organic and inorganic fertilizer is the best option

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(Babhulker *et al.,* 2000). The major possible sources of organic manures are cowdung (CD), poultry manure (PM) and household wastes (HW) which can be used as an alternative for the inorganic fertilizer. Nutrients contained in organic manures are released slowly and are stored for longer time in soil, thereby ensuring a long residual effect, supporting better root development, leading to higher crop yields. The soil fertility status is improved by activating the soil microbial biomass. Supply of nutrients from the organic materials can be complemented by enriching them with inorganic nutrients that will be released fast and utilized by crops to compensate for their late start in nutrient release.

In Bangladesh, most of the cropping patterns are rice-based and the soils are deficient in P and other macro and micro nutrients. To achieve sustainability and increase nutrient use efficiency of rice based cropping pattern it is the demand of time to develop an integrated inorganic with organic soil fertilization program for higher crop yield and improve soil health. Hence an experiment regarding integrated nutrient management in rice-based cropping patterns was undertaken to determine the influence of P applied through triple super phosphate and different organic manures on the growth and yield as well as on nitrogen and phosphorus use efficiency of T. Aman rice.

MATERIALS AND METHODS

The study was conducted at Bangabandhu Sheikh Mujibur Rahman Agricultural University Research Farm, Gazipur, Bangladesh. We used the soil whose properties are shown in Table 1.

Table 1. Physiochemical properties of experimental plots

Physio-chemical properties	Value
Bulk density (g/cc)	1.37
Particle density (g/cc)	2.68
Soil pH	5.95
Organic Carbon (%)	0.93
Total N (%)	0.079
Available P (ppm)	5.8
Exchangeable K (meq/100 g soil)	0.14
Available S (ppm)	7.12
Exchangeable Ca (meq/100 g soil)	6.55
Exchangeable Mg (meq/100 g soil)	1.88
Exchangeable Na (meq/100 g soil)	0.32
Cation exchange capacity (CEC meq/100 g soil)	10.65

Treatments consisted of different levels of phosphorus (P) derived from both inorganic and organic sources are shown in Table 2. As an organic sources of P well decomposed poultry manure (PM), cowdung (CD) and household wastes (HW) were applied as per treatments one week before final land preparation and inorganic P as triple super phosphate (TSP), potassium as muriate of potash (MOP), sulphur from gypsum, and zinc as zinc oxide were applied two days before final land preparation.

Table 2. Treatments of phosphorus on the yield and nutrient use efficiency of T. Aman rice

Treatments	Description
T_0 = Control	No fertilizers
T_1 = RD	Recommended fertilizer dose
T_2 = TSP_{50}+CD_{50}	50% P through TSP and 50% P through cowdung
T_3 = TSP_{75}+CD_{25}	75% P through TSP and 25% P through cowdung
T_4 = TSP_{50}+ PM_{50}	50% P through TSP and 50% P through poultry manure
T_5 = TSP_{75}+ PM_{25}	75% P through TSP and 25% P through poultry manure
T_6 = TSP_{50}+ HW_{50}	50% P through TSP and 50% P through household wastes
T_7 = TSP_{75}+ HW_{25}	75% P through TSP and 25% P through household wastes

Figures shown as subscript represent percent phosphorus either from TSP, CD, PM or HW

Nitrogen as urea was applied in three equal splits. Urea was top dressed in three equal installments (splits) at the time of final land preparation, maximum tillering stage and at booting i.e. panicle initiation stage of crop growth. A common procedure was followed in raising of seedling in seed bed. The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments were randomly assigned to the plots. Twenty five days old seedlings were transplanted in experimental plots with distances of 20 cm from row to row and 15 cm from plant to plant. Irrigation was done as required and other intercultural operations were performed regularly. The crop was harvested separately on different dates at full maturity when 90 % of the grains become golden yellow color. Ten samples hills were collected from each plot for collection of data on plant characters and yield components. The grain and straw weights of each plot were recorded as measured t/ha after proper sun drying. The grain yield was adjusted at 12 % moisture level. The nutrient use efficiency such as recovery efficiency (%), agronomic efficiency (kg/kg), physiological efficiency (kg/kg) and internal efficiency (kg/kg) were measured according to the following formulae-

Recovery efficiency (RE): Recovery efficiency was calculated by using the following formula:

$RE (\%) = [(Nup_f - Nup_o)/Nap] \times 100$

Where,

Nup_f = Nutrient uptake from fertilizer applied plot or treatment (Kg/ha)

Nup_o = nutrient uptake from control plot (Kg/ha)

Nap = Amount of nutrient applied (Kg/ha)

Agronomic efficiency (AE): It is the ratio of economic yield to the amount of nutrient applied. It was calculated by using. The following formula:

$AE\ (kg\ kg^{-1}) = (Y_f - Y_O)/N_{ap}$

Where,

Y_f = Yield of fertilizer applied plot (kg ha^{-1})

Y_O = Yield of control plot (kg ha^{-1})

N_{ap} = Amount of nutrient applied (kg ha^{-1}).

Physiological efficiency (PE): It represents the ability of a plant to transform a given amount of acquired nutrient into economic yield. It was calculate by using the following formula:

$PE\ (kg\ kg^{-1}) = (Y_f - Y_O)/ (N_{upf} - N_{upo})$

Internal Efficiency (IE): It was calculated by using the following formula:

$IE\ (kg\ kg^{-1})$ = Yield/Total uptake of nutrient (kg ha^{-1}).

All data were subjected to analysis of variance (ANOVA) and tested for significance by Duncan's Multiple Range Test (DMRT) using the PC-SAS software (SAS Institute).

RESULTS AND DISCUSSION

The results of yield and yield contributing characters and nitrogen and phosphorus use efficiency of T. Aman rice as influenced by the application of phosphorus through triple super phosphate (TSP) along with cowdung, poultry manure and household wastes are presented and discussed. Investigated yield and yield contributing characters as well as nutrient use efficiency in this experiment were: plant height, number of tillers per hill, panicle length, number of filled grains/panicle, number of total grains/panicle, 1000-grain weight, grain yield, straw yield, percent recovery efficiency, agronomic efficiency, physiological efficiency and internal efficiency of nitrogen and phosphorus.

Yield and yield contributing characters of T. Aman rice

Effects of different treatments were found significant (Table 3) in term of plant height of T. Aman rice. Treatment T_4 receiving 50% P through TSP and 50% P through poultry manure was found to produce the tallest plant with the height of 107.00 cm which was closely followed by T_2 receiving 50% P through TSP and 50% P through cowdung and T_6 receives 50% P through TSP and 50% P through household wastes respectively. The lowest plant height was recorded in control treatment T_0 with the value of 93.33 cm. Plant height is one of the most important vegetative parts of plant giving bearing support for panicle of rice. All fertilizers treatments gave higher plant height over control where treatment T_4 produced the tallest plant. Mineral composition of the organic materials clearly indicated the superiority of poultry manure over other sources which were reflected in plant height. Fertilizers encouraged plant height by providing balanced nutrients to rice plant. These observations were in agreement with previous research experiences (Begum *et al.*, 2002; Rahman *et al.*, 2007; Parvez *et al.*, 2008). Mollah *et al.* (2007) reported higher plant height (104.6 cm) in T. Aman rice through integrated nutrient management. Vanaja and Raju (2002) found the tallest plant in combinations of recommended doses of chemical fertilizers along with poultry manure at the rate of 2 t/ha.

Number of tiller per hill of T. Aman rice was significantly influenced by the application of phosphorus through TSP along with cowdung, poultry manures and household wastes (Table 3). All the fertilizer treatments were able to increase the number of tiller per hill over control. The significantly highest tiller number (7.38/hill) was found in T_4 treatment receiving 50% P through TSP and 50% P through poultry manure. The second highest number of tillers (6.49/hill) was recorded in T_2 treatment receiving 50% P through TSP and 50% P through cowdung closely followed by T_6 (6.42/hill) receiving 50% P through TSP and 50% P through household wastes. Number of tiller per hill was found to be influenced by the application of different P treatments. Such variations perhaps due to the pooled effect of triple super phosphate along with cowdung, poultry manure and household wastes causing variable number of tillers per hill. This observation was supported by previous studies (Eneji *et al.*, 2001; Satyanarayana *et al.*, 2002; Helen, 2007) that poultry litter and farmyard manure in combination with inorganic fertilizer significantly increased number of tiller in rice.

Table 3. Effects of phosphorus applied through triple super phosphate (TSP), cowdung, poultry manure and household wastes on plant height, number of tillers and number of panicles of T. Aman rice

Treatment	Plant height (cm)	No. of tillers/hill	Number of panicles/hill
T_0 = Control	93.33c	5.43c	4.73c
T_1 = Recommended dose	100.67b	6.15bc	5.65ab
$T_2 = TSP_{50}+CD_{50}$	103.67ab	6.49b	5.90ab
$T_3 = TSP_{75}+CD_{25}$	102.13b	6.26bc	5.63ab
$T_4 = TSP_{50}+ PM_{50}$	107.00a	7.38a	6.25a
$T_5 = TSP_{75}+ PM_{25}$	101.34b	6.32bc	5.55b
$T_6 = TSP_{50}+ HW_{50}$	103.33ab	6.42b	5.75ab
$T_7 = TSP_{75}+ HW_{25}$	100.67b	6.13bc	5.54b
CV (%)	6.75	7.85	7.83
LSD (0.05)	5.107	0.87	0.62

Means in a column followed by same letter (s) are not significantly different at 5% level of significance by DMRT.

Number of panicles per hill of T. Aman rice is presented in Table 3. Results show that there was a significant effect of applied TSP along with cowdung, poultry manure and household wastes on number of panicles per hill. All the treatments produced higher number of panicles/hill over control. Maximum number of panicles (6.25/hill) was recorded in treatment T_4 receiving 50% P through TSP and 50% P through poultry manure. The effect of this treatment was statistically similar to all the treatments except T_5 receiving 75% P through TSP and 25% P through cowdung, T_7 receiving 75% P through TSP and 25% P through household wastes and T_0 (control). An increase in number of panicles per hill of rice plant is important as it contributes to the number of grains and hence yields of rice. All fertilizer treatments produced higher number of panicles per hill over control. The reason for increased number of panicles per hill might be due to the mutual effect of cowdung, poultry manure and household wastes applied in combination with TSP-phosphorus. Islam (1997) observed that phosphorus fertilization significantly increased the number of fertile tiller/m^2. Ofori *et al.* (2005) also found an increase in number of effective tillers in rice with organic manure application.

All the phosphorus sources increased panicle length in T. Aman rice over control treatment (Table 4). The maximum panicle length (26.20 cm) was recorded in treatment T_6 receiving 50% P through TSP and 50% P through household wastes which was closely followed by treatments T_2 receiving 50% P through TSP and 50% P through cowdung and T_4 receiving 50% P through TSP and 50% P through poultry manure with the values of 26.00 cm and 25.60 cm, respectively. The lowest panicle length (21.00 cm) was recorded in control treatment followed by T_1 receiving recommended dose (23.23 cm). Treatments amended with organic fertilizers showed significant influence on panicle length of T. Aman rice. This could be due to the effect of triple super phosphate and organic amendments which releasing different available nutrients to rice plant for absorption resulting higher length of panicle. These results were in line with previous research reports (Rahman *et al.*, 2007; Parvez *et al.*, 2008). Recommended NPK fertilizer along with ash and cowdung increased the panicle length of rice (Begum *et al.*, 2002). Poultry manure (3t/ha) in combination with inorganic nitrogen (80 kg/ha) significantly increased the panicle length of rice (Rahman *et al.*, 2009). Number of filled grains per panicle of T. Aman rice was significantly influenced by the application of triple super phosphate in combination with cowdung, poultry manure and household wastes (Table 4). Maximum number of filled grains (106.0 grains/panicle) was recorded in treatment T_4 receiving 50% P through TSP and 50% P through poultry manure. The effect of this treatment was statistically similar to all the treatments except T_1, T_3 and control. Control (T_0) treatment was recorded with the lowest filled grains (84.0 grains/panicle). Higher number of filled grains per panicle was recorded in treatment T_4 receiving 50% P through TSP and 50% P through poultry manure. This could be due to the available nutrients for rice plants resulting higher number of filled grains per panicle. These were in agreement with the findings of Chettri *et al.* (2002) and Channabasavanna (2003). Islam (1997) also observed that phosphorus fertilization significantly increased the number of grains/panicle which resulted in significant increase in grain yield. Umanah *et al.* (2003) reported that application of poultry manure increased the grain number per panicle.

Table 4. Effects of phosphorus applied through triple super phosphate (TSP), cowdung, poultry manure and household wastes on panicle length number of filled grains and total grains per panicle of T. Aman rice

Treatment	Panicle length (cm)	No. of filled grains/panicle	No. of total grains/panicle
T_0 = Control	21.00c	84.00c	107.67c
T_1 = Recommended dose	23.23b	99.33b	122.83bc
T_2 = TSP_{50}+CD_{50}	26.00a	102.33ab	145.33a
T_3 = TSP_{75}+CD_{25}	24.57ab	100.33b	140.50ab
T_4 = TSP_{50}+ PM_{50}	25.87a	106.00a	138.50ab
T_5 = TSP_{75}+ PM_{25}	25.60a	102.00ab	130.00ab
T_6 = TSP_{50}+ HW_{50}	26.20a	103.17ab	135.67ab
T_7 = TSP_{75}+ HW_{25}	25.40a	101.00ab	121.50bc
CV (%)	4.26	6.88	9.45
LSD (0.05)	1.85	4.65	20.00

Means in a column followed by same letter (s) are not significantly different at 5% level of significance by DMRT.

Effects of different levels of P through TSP along with cowdung, poultry manure and household wastes on number of total grains per panicle of T. Aman rice were significant (Table 4). Among the treatments, T_2 receiving 50% P through TSP and 50% P through cowdung recorded the maximum number of grains (145.33 grains/panicle) whose effect was statistically similar to treatments T_3, T_4, T_5, and T_6 but superior to the rest of the treatments. The effects of T_4 and T_6 treatments were followed by T_2 and T_3 treatments in number of grains per panicle. The lowest number of grains (107.67 grains/panicle) was recorded in T_0 (control) treatment. Increased total number of grains per panicle was found in this study was in agreement with the reports of Mondal *et al.*, (1990) and Ranjha *et al.*, (2001). Chettri *et al.*, (2002) found the highest number of grains per panicle in rice with the application of 60, 3 and 10 kg N, P_2O_5, K_2O along with FYM.

Thousand grain weights of T. Aman rice were significantly influenced due to application of different levels of P through TSP in combination with cowdung, poultry manure and household wastes (Table 5). The maximum 1000-grain weight (23.95 g) was recorded in treatment T_4 receiving 50% P through TSP and 50% P through poultry manure which was statistically similar to all the treatments except control. Thousand grain weight obtained from different treatments may be ranked in the order of $T_4>T_6>T_2>T_5>T_7>T_1>T_3>T_0$. The minimum 1000-grain weight (21.94 g) was recorded in T_0 (control). Different phosphorus treatments increased the 1000-grain weight of T. Aman rice which was in agreement with the results of Ranjha *et al.*, (2001) and Chettri *et al.*, (2002). 1000-grain weights of rice were found to increase with increasing NPK rates along with FYM application (Mondal *et al.*, 1990). Satyanarayana *et al.*, (2002) also obtained increased 1000- grain weight by the application of FYM at the rate of 10 t/ha and inorganic fertilizer at the rate of 120, 60 and 45 kg N, P_2O_5 and K_2O/ha.

Effects of P through triple super phosphate along with cowdung, poultry manure and household wastes were found significant (Table 5) in grain yield of T. Aman rice. Plant treated with 50% P through TSP and 50% P through poultry manure combination, T_4 recorded the highest grain yield (4.34 t/ha). The effect of this treatment was statistically similar to T_2 and T_6 but superior to the rest of the treatments. The lowest grain yield (2.37 t/ha) was recorded in T_0 (control). The grain yields obtained from different treatments can be ranked in the order of $T_4>T_2>T_6>T_5>T_3>T_7>T_1>T_0$. Higher rice yield was obtained with phosphorus treatments amended with organic manures. The higher grain yield obtained with the use of organic manures especially poultry manure might have the consequence of balanced supply of nutrients to rice plant to support growth and reproduction. These results were in agreement with the findings of Reddy *et al.*, (2005) and Sreelatha *et al.*, (2006). Similar result of poultry manure was reported by Rahman *et al.*, (2009). The poultry manure increased the yield of rice grain 2.6 times higher than that of cattle manure (Maskina *et al.*, 1988). Poultry manure has been reported to produce higher grain yield compared to other organic materials. Poultry manure is a good source of organic matter and nutrients for rice production (Saleque *et al.*, 2004).

Table 5. Effects of phosphorus applied through triple super phosphate (TSP), cowdung, poultry manure and household wastes on 1000-grain weight, grain and straw yields of T. Aman rice

Treatment	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)
T_0 = Control	21.94b	2.37c	3.45c
T_1 = Recommended dose	23.32a	3.58b	4.75ab
T_2 = $TSP_{50}+CD_{50}$	23.70a	3.90ab	5.03a
T_3 = $TSP_{75}+CD_{25}$	23.30a	3.60b	4.68b
T_4 = $TSP_{50}+PM_{50}$	23.95a	4.34a	4.80ab
T_5 = $TSP_{75}+PM_{25}$	23.62a	3.65b	4.83ab
T_6 = $TSP_{50}+HW_{50}$	23.73a	3.84ab	4.80ab
T_7 = $TSP_{75}+HW_{25}$	23.47a	3.59b	4.88ab
CV (%)	2.57	8.82	10.49
LSD (0.05)	1.05	0.56	0.29

Means in a column followed by same letter (s) are not significantly different at 5% level of significance by DMRT.

Straw yield was influenced by the application of TSP in combination with cowdung, poultry manure and household wastes and is presented in Table 5. Results show that there was a significant difference in straw yield due to the different levels and sources of organic manures. Straw yield ranged from 3.45 to 5.03 ton per hectare. The maximum straw yield (5.03) was found in T_2 treatment receiving 50% P from triple super phosphate and 50% P from cowdung. The effect of this treatment was statistically identical to all the treatments except T_0 and T_3. The results of the present study showed that there was a significant difference in straw yield due to the different treatment of phosphorous fertilizers. These results were consistent with previous researches (Ranjha *et al.*, 2001; Roul and Sarawgi, 2005; Vanaja and Raju, (2002) reported that different combination of chemical fertilizer along with organic manure gave the highest grain and straw yields of rice.

Nutrient use efficiency

Nitrogen and phosphorus use efficiency of T. Aman rice varied significantly with different treatments receiving phosphorus through TSP along with cowdung, poultry manure and household wastes. The recovery efficiency (RE), agronomic efficiency (AE), physiological efficiency (PE) and internal efficiency (IE) of N and P were calculated and discussed accordingly.

Nitrogen use efficiency by T. Aman

Recovery efficiency (%)

As shown in Figure 1A recovery efficiency of N in T. Aman varied from 30.23 to 47.59%. The highest N recovery was recorded in treatment T_4 receiving 50% P through TSP and 50% P from poultry manure. Results also showed that N recovery efficiency of T. Aman rice with 100% NPKS (RD) fertilizer was 30.23%. This efficiency increased to 47.59% in T_4, 41.85% in T_6 and 40.27% in T_2. Thus increase in N recovery efficiency over recommended dose was 17.36, 11.62 and 10.04 percent in T_4, T_6, and T_2 treatments, respectively.

Agronomic efficiency (kg kg^{-1})

The agronomic efficiency of N in T. Aman rice ranged from 15.15 to 24.66 kg kg^{-1} (Figure 1B). The highest efficiency was observed in T_4 treatment receiving 50% P through TSP and 50% P through from poultry manure followed by T_2 receiving 50% P through TSP and 50% P through cowdung and T_6 receiving 50% P through TSP and 50% P through household wastes, respectively. The efficiency of N with recommended fertilizer was (15.15 kg kg^{-1}) lower than that of other treatments. This efficiency increased to 9.51, 4.0 and 3.26 kg kg^{-1} in treatments T_4, T_2 and T_6, respectively compared to recommended dose.

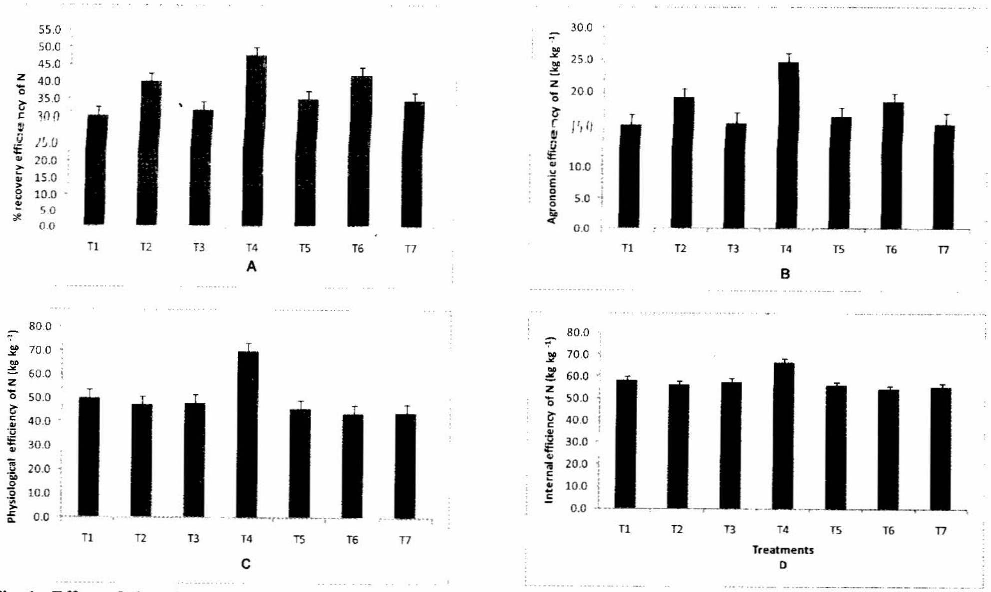

Fig. 1. Effect of phosphorus on (A) percent recovery efficiency, (B) agronomic efficiency, (C) physiological efficiency and (D) internal efficiency of N on T. Aman rice applied through TSP along with CD, PM and HW.

Physiological efficiency (kg kg^{-1})

In this study, the physiological efficiency of N in T. Aman rice differed significantly due to different treatments. The highest physiological efficiency of N was recorded in T_4 treatment receiving 50% P from TSP and 50% P from poultry manure and the lowest in T_6 treatment receiving 50% P from TSP and 50% P from household wastes. The physiological efficiency of N in T. Aman rice was recorded as 50.02 kg kg^{-1} with 100% NPKS (T_1). It enhanced to 70.16 kg kg^{-1} in T_4 treatment but rest of the treatments showed lower physiological efficiency than that of recommended fertilizer (Figure 1C).

Internal efficiency (kg kg^{-1})

The internal efficiency of nitrogen by T. Aman varied from 54.35 to 66.52 kg kg^{-1}. The highest internal efficiency of N was recorded in T_4 treatment (50% P through TSP and 50% P through poultry manure) and the lowest in T_6 treatment (50% P through TSP and 50% P through from household wastes) while recommended fertilizer showed 58.35 kg kg^{-1} (Figure 1D).

Phosphorus (P) use efficiency by T. Aman

Recovery efficiency (%)

Results presented in Figure 2A indicated that the maximum recovery efficiency of P was recorded with treatment T_4 (50% P through TSP and 50% P through poultry manure) and was followed by the treatments T_2 (50% P from TSP and 50% P from cowdung) and T_6 (50% P from TSP and 50% P from household wastes). The lowest recovery efficiency (21.44%) of P was found with recommended fertilizers.

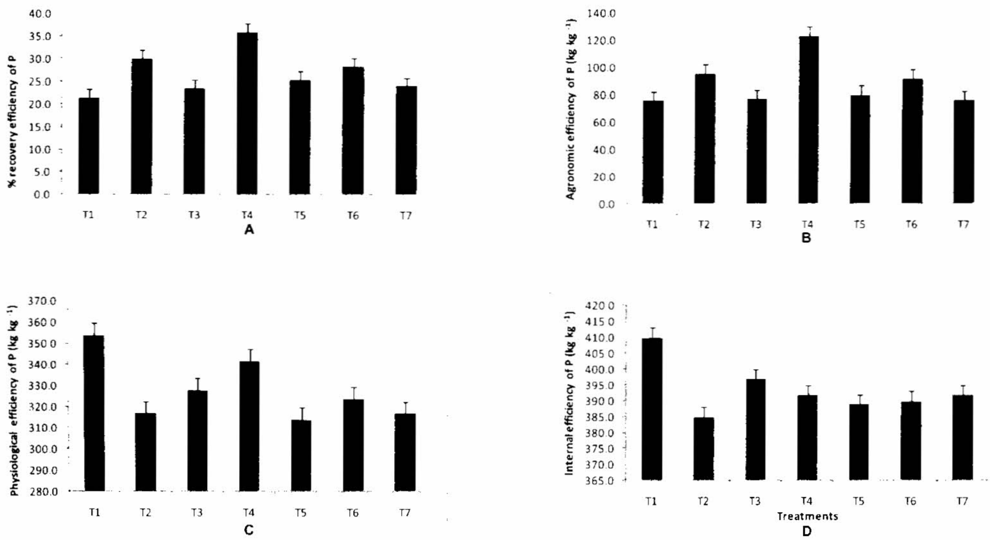

Fig. 2. Effect of phosphorus on (A) percent recovery efficiency, (B) agronomic efficiency, (C) physiological efficiency and (D) internal efficiency of P on T. Aman rice applied through TSP along with CD, PM and HW.

Agronomic efficiency (kg kg^{-1})

The agronomic efficiency of P was the highest in treatment T_4 (50% P through TSP and 50% P through poultry manure) and followed by the treatments T_2 (50% P through TSP and 50% P through cowdung) and T_6 (50% P through TSP and 50% P through household waste), respectively. The recommended fertilizer showed the lowest efficiency of P (75.77 kg kg^{-1}) (Figure 2B).

Physiological efficiency (kg kg^{-1})

As shown in Figure 2C physiological efficiency of phosphorus in T. Aman varied from 313.73 to 353.8 kg kg^{-1}. The highest physiological efficiency (353.80 kg kg^{-1}) of P was recorded in recommended fertilizer (T_1)

and the lowest (313.73 kg kg^{-1}) was recorded in T_5 (75% P through TSP and 25% P through poultry manure) treatment. All the organic manure containing treatments recorded the lower physiological efficiency of P compared to recommended fertilizer treatment, suggesting that rapid absorption of P from inorganic P than organic source.

Internal efficiency of phosphorus (kg kg^{-1})

The results showed that the highest internal efficiency (410 kg kg^{-1}) of P was observed by recommended fertilizer followed by the treatment T_3 receiving 75% P through TSP and 25% P through cowdung. The lowest (385 kg kg^{-1}) was recorded in T_2 (50% P through TSP and 50% P through cowdung) treatment (Figure 2D).

The recovery efficiency (RE), agronomic efficiency (AE), physiological efficiency (PE) and internal efficiency (IE) of nitrogen were found to be higher in treatment T_4 receiving 50% P through TSP and 50% P through poultry manure than that of other treatments. The percent recovery efficiency and agronomic efficiency of phosphorus were also found to be higher with treatment T_4. However, all the organic manure containing treatments showed the lower physiological and internal efficiency of P compared to recommended fertilizer treatment, suggesting rapid release of P from inorganic fertilizers than organic source.

The effect of P applied through organic and inorganic fertilizers was evaluated on the growth, yield and nutrient use efficiency of T. Aman rice. Significant variations among different treatments were found suggesting that selection of different phosphorus treatments in combination of organic and inorganic fertilizers was logical.The combined use of organic and inorganic fertilizers was promising than sole use of inorganic fertilizers. Treatment T_4 appeared as the best combination of organic and inorganic fertilizers as P source which provided the highest growth, yield and nutrient use efficiency of T. Aman rice. T_4 receiving 50% of P from TSP and remaining 50% P from PM recorded higher grain yield and nutrient use efficiencies in terms of agronomic, recovery and internal efficiency of T. Aman rice. The overall results indicated that fertilization of P by using TSP and PM sources could be the best practice for sustainable production of T. Aman rice.

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