YIELD RESPONSE OF TRANSPLANTED AMAN RICE (*Oryza sativa* L) TO PHOSPHORUS RATES IN COASTAL REGION OF SOUTHWESTERN BANGLADESH

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ABSTRACT

Cropping in the southwestern (SW) coastal region of Bangladesh is completely different from other parts of the country. Only one crop (T. *aman*) is cultivated here in a year thus the cropping pattern is fallow-fallow-transplanted (T) *aman*. Among the high yielding rice, BR23 is the popular T. *aman* rice in this area. However, farmers apply fertilizers including P to T. *aman* once in a year. This cropping and fertilizing trend have been practicing here for long time thus it is necessary to reinvestigate the rate of phosphorus (P) fertilizer whether it is optimum or low or overdose. The current field study was done in a typical coastal soil in Pankhali, Dacope (a saline part of Agro-ecological Zone, AEZ 13), Khulna, which is ~30 km away from Khulna city. The experiment had six rates: 0, 5, 7.5, 10, 12.5 and 15 kg P/ha with three replications. The results showed that no grain yield benefit was found due to addition of P from 5 kg P/ha to 15 kg P/ha where 10 kg P/ha is the current recommended rate. Ninety per cent grain yield that of the maximum was produced by zero added P indicated that (i) the field had sufficient residual P to support the growth and yield of T. *aman*, (ii) the current recommended P rate should be reduced to ~5 kg ha^{-1}, (iii) the residual P may support the growth and yield of a winter crop (if any) or the next year's T. *aman*.

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December 2019 The Author

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CHAPTER I

INTRODUCTION

Rice is grown in 80% arable land of Bangladesh during three cropping seasons: *aus* (the spring season, from March/April to June/July), *aman* (the monsoon season, from June/July to September/October) and *boro* (the winter season, from November/December to April/May) (Emran et al., 2019). In Bangladesh the area under rice cultivation is 11.8 million ha (Hossain, 2018). In *aus* season, the cultivation area is 0.95 million hectares, in *aman* season the area is 5.56 million hectares and in *boro* season the area is 4.47 million hectares during 2016-17, which produced 2.13 million tons, 13.6 million tons and 18 million tons respectively (BBS, 2018). Although *boro* production is high throughout Bangladesh, its production is very low in the southwestern (SW) part because it is cultivated in very few places and only *aman* is cultivated in most areas (Bell et al., 2019).

The coastal region of Bangladesh is totally different from other part of the country regarding salinity, cropping system, cultivation time, nutrient and organic matter status of the soil. Generally the nutrient content of the coastal soil is low to very low, especially nitrogen and phosphorus (FRG, 2018). In the SW Bangladesh cropping intensity is very low and crop production are very much dependent on the traditional methods and about 78% of the agricultural land is used for transplanted (T) *aman* rice cultivation (BBS, 2017). Among the three crop growing seasons in Bangladesh (*Rabi, Kharif* 1 *and Kharif* 2) single crop of T. *aman* rice (long duration, late transplanted and harvested) is generally the only crop planted in this region (Kabir et al, 2019) and 39.2% of farmers use T. *aman* variety BR23 (Rahman et al., 2019). As only one crop is grown per year and their livelihood is dependent on rice mainly, farmers usually apply sometimes over dose of fertilizers including P than that of

FRG (Md. Monaem Mia, unpublished data) to get more yields. Gap exists between farmer's application and current recommendation of fertilizer including P. Also recent study (Naher and Akter, 2018) in a typical coastal soil on omission of P showed that yield reduction due to excluding P application was negligible (10%). In other study combining nitrogen (N) with P on T. *aman* again showed that grain yield reduction due low amount of P rate was minimum, low N was the main cause to produce low grain yield (Aziz, 2018). In fertilizer recommendation guide (FRG, 2018) of Bangladesh, 10 kg P/ha is recommended for the T. *aman* in agroecological zone (AEZ) 13. A substantial number of farmers of this region cultivate local T. *aman* rice and mostly do not apply P fertilizer. In case of high yielding varieties (HYV) like BR23, farmers rarely follow the recommendation for P from FRG. Again recommendation of fertilizer in FRG is based on soil test basis (not based on plant response and soil test) and the soil samples collected from a large area of AEZ might not represent the whole AEZ. For example, AEZ 13 includes saline and non-saline soils, different types of topography with different nutrient status (Emran et al., 2019) but the fertilizer recommendation is approximately similar. This fertilizer recommendation may not match with the fertilizer requirement of crop in smaller zones (subzone) from where soil samples were not collected. Thus it is necessary to investigate the optimum rate of fertilizers including P for different areas in a AEZ and for different crops to optimize major fertilizers. In case of P fertilizer, it has residual effect that can support the growth and yield to next season crop [(Boeggaad et al., 1990), (Bolland et al., 1998) and (Selles et al., (2011)].

In SW coastal Bangladesh, no field crop is grown just after harvest of T. *aman* rice due to some constraints mentioned above. In this single T. *aman* cropping, residual P may support the next year T. *aman* crop. If a second crop is cultivated after T. *aman*, then the effect of residual P would be immediately realized. Recently some dry season crops after T. *aman* (e.g., sunflower, maize, wheat, potato) have been introduced in this area (Bell et al., 2019; Kabir et al., 2019). To these dry season crops, fertilizers are also being applying. The question has been arising whether the present recommendation of fertilizer for T. *aman* rice is optimum or the applied P fertilizer leaves some residue for the next dry season crops or by next year's T. *aman*. Although a recommended rates of P is available for the single T. *aman* for the SW area (where the current study was done) (FRG, 2018), this rate was also recommended in FRG (2005). Thus P rates investigation is necessary to reexamine the P rates for T. *aman,* and for the immediate next season-crop (dry season crop) to test whether the current P recommendation for T. *aman* is optimum or deficient or overdose and/or leave some residual P to help reduce the P rates of T. *aman* and/or dry season crops. In the T. *aman* season the P rates experiment was done and reported in this thesis. Thus the objectives of the study were:

- ✓ To examine the yield performance of T. *aman* to phosphorus variation.
- ✓ To find out the optimum rates of phosphorous for T. *aman* in the coastal soil of southwestern coastal Bangladesh.

CHAPTER II

REVIEW OF LITERATURE

2.1 Importance of rice

2.1.1. Global rice production

Rice is the only major crop food that can be grown under a wide range of climatic and geographical conditions on five continents and occupies 11% of the world's cultivated area (Khush, 1993). In majority of Asian countries it occupies one third or more of cultivated area (FAOSTAT, 2006).

The global annual production of rough rice is about 550-600 million tons (Maclean et al., 2002 quoted by Bouman et al., 2007), of which 90 percent is produced and consumed in Asia (Maclean et al., 2002; Buresh and Haefele, 2010). In sub-Saharan Africa (SSA), rice is ranked as the fourth most important crop in terms of production after sorghum, maize and millet (Dibba et al., 2012).With no surprise, rice serves as the staple food throughout much of the world. It is one of the most important crops representing the primary source of food for more than half of the world's population, with Asia and Africa the largest consuming regions (Khush et al., 2001; Maclean et al., 2002; Snyder and Slaton, 2002; FAO, 2004).

Between 1961 and 2005, the annual increase in rice consumption was 4.52% in SSA. However, despite the apparent importance of rice in SSA, the production levels are still far below the consumer demand (Dibba et al., 2012).

higher CO_2 pressure in the soil solution and (4) Desorption of phosphorus from clay and oxides of aluminum and iron.

2.3 Role of phosphorus and effects of P in rice production

Like all cereal grains, rice requires a considerable amount of phosphorus for vigorous growth and high yields (De Datta, 1981). Although in general response to phosphorus in irrigated rice is less marked than response to nitrogen, phosphorus is nontheless a very important nutrient (Dobermann and Fairhurst, 2000).

Phosphorus is mobile within the plant and promotes tillering by facilitating nitrogen absorption. An increase in tillering rate with P up to 0.2% was reported by Yoshida (1981), above which an increase in phosphorus has no effect on tillering. Phosphorus promotes root development, early flowering, and ripening. It is particularly important in early growth stages (Dobermann and Fairhurst, 2000). The critical level of P for tillering is affected by temperature (Yoshida, 1981).

Phosphorus is particularly important to the rice seedling during the time it is recovering from transplanting shock. Phosphorus greatly stimulates root development in the young plant, thus increasing its ability to absorb other nutrients from the soil (Dobermann and Fairhurst, 2000). During the reproductive phase, the phosphorus intake of rice decreases considerably. When absorbed during the ripening phase, phosphorus increases the protein content of the grains thus improving the food value of the crop. Phosphorus not only enhances the yields but also reduces spikelet sterility (Alam, 2009).

Phosphorus (P) deficiency is one of the major limiting factors of crop productivity in most soils throughout the world (Pierrou, 1976; Li et al., 2006). In addition to area of low absolute soil P content, P deficiency can arise in soils where P is strongly bound to soils particles

(Wissuwa et al., 2005). Plants suffering from phosphorus deficiencies exhibit retarded growth (Marschner, 1993, Mutters et al., 2006), with greatly reduced tillering (Mutters et al., 2006). Leaves are narrow, short, very erect, and dirt dark green. Stems are thin and spindly (Dobermann and Fairhurst, 2000). Other deficiency symptoms are decreased leaf blade length, reduced number of panicles per plant, and reduced number of seeds per panicle. The root architecture of plants can undergo several changes in response to P deficiency. For example Wissuwa et al. (2005) showed that P deficiency stimulated root elongation in rice.

Table 03: Optimal ranges and critical levels of P in rice plant tissue

Growth stage	Plant part	Optimum (%)	Critical level for deficiency (%)
Tillering to panicle initiation	Y leaf	0.20- 0.40	<0.10
Flowering	Flag leaf	0.20-0.30	<0.18
Maturity	Straw	0.10-0.15	<0.06

Source: Dobermann and Fairhurst, 2000

2.3 Phosphorus fertilizer application for rice production

Except on extremely acid or alkaline soils, the common P sources are about equally effective. The relative efficiencies are affected to some extent, however, by such factors as soil pH, soil P level and rate, time, and method of application (Sanyal and De Datta, 1991).

The water soluble P sources, such as superphosphate, are effective in all soil types except those that are extremely acid. In acid soil, soluble P readily reacts with Fe and Al, which apparently reduces its availability (De Datta, 1981).

The most commonly used P fertilizers for lowland rice are single and triple superphosphates, diammonium phosphate and ammonium phosphate (Sanyal and De Datta, 1991). Phosphate Rocks (PR) are also used as P fertilizers in many countries (De Datta, 1981).

The application of PR to lowland rice meets with two difficulties: (1) pH of an acidic soil will rise following submergence and this may adversely affect the solubility of PR in soil; (2) the ability of rice to derive P from PR is relatively low (Sanyal and De Datta, 1991). Several modifications of phosphate rocks have been suggested to increase its effectiveness (De Datta, 1981).

Generally, P fertilizers for rice should be applied at transplanting, but it may also be applied later, before the vigorous tillering stage (De Datta, 1981). Split-application of P has not been effective. In low temperature areas; more P is required during the early growth stage, and application at transplantation is more convenient than topdressing during later growth stage.

Judicious and proper use of fertilizers can markedly increase the yield and improve the quality of rice (Alam et al, 2009). Fertilizer is very important input for intensive rice production the profitability of rice production systems depends on yield and input quantities. So the appropriate fertilizer input that is not only for getting high grain yield but also for attaining maximum pro fertility. Nitrogen and phosphorus fertilizer is a major essential plant nutrient and key input for in increasing crop yield (Dastan et al., 2012)

Application of phosphorus fertilizer is one of the most important factors for higher crop yields (Bünemann et al., 2011). Phosphorus (P) availability in soil is closely related not only to soil P content but also to soil physico-chemical and biological properties, which are closely associated with P sorption and biochemical transformation (Guo et al., 2009). Paddy soils are characterized by a sequence of chemical and microbial transformations related to the changes in soil water content. These changes control the availability of phosphorus which is closely related to the degree of soil reduction (De Datta, 1981).

Large addition of P is required to reach a given level of solution P in fine textured compared to coarse textured soils. Consequently, high clay calcareous soils will often require more fertilizer P to optimize yields compared to loam soils. Soils containing large quantities of clay will fix more P than soils with low clay content. In other words, the more surface area exposed with a given type of clay, the greater is the tendency to absorb P (Tisdale et al., 2002).

Like all cereal grains, rice requires a considerable amount of phosphorus for vigorous growth and high yields (De Datta, 1981). Although in general response to phosphorus in irrigated rice is less marked than response to nitrogen, phosphorus is nonetheless a very important nutrient (Dobermann and Fairhurst, 2000). Phosphorus is an essential constituent of adenosine triphosphate (ATP), nucleotides, nucleic acids, and phospholipids. Its major functions are in energy storage and transfer within the plant (Dick, 2011). Phosphorus is a major component in ATP, the molecule that provides "energy" to the plant for such processes as photosynthesis, protein synthesis, nutrient translocation, nutrient uptake and respiration. Phosphorus is also a component of other compounds necessary for protein synthesis and transfer of genetic material (DNA, RNA) (Zhang and Raun, 2006)

Phosphorus is mobile within the plant and promotes tillering by facilitating nitrogen absorption. An increase in tillering rate with P up to 0.2% was reported by Yoshida (1981), above which an increase in phosphorus has no effect on tillering. Phosphorus promotes root development, early flowering, and ripening. It is particularly important in early growth stages (Dobermann and Fairhurst, 2000). The critical level of P for tillering is affected by temperature (Yoshida, 1981). Phosphorus is particularly important to the rice seedling during the time it is recovering from transplanting shock. Phosphorus greatly stimulates root development in the young plant, thus increasing its ability to absorb other nutrients from the soil (Dobermann and Fairhurst, 2000. During the reproductive phase, the phosphorus intake of rice decreases considerably. When absorbed during the ripening phase, phosphorus increases the protein content of the grains thus improving the food value of the crop. Phosphorus not only enhances the yields but also reduces spikelet sterility (Alam, 2009).

Phosphorus (P) deficiency is one of the major limiting factors of crop productivity in most soils throughout the world (Pierrou, 1976; Li et al., 2006). In addition to area of low absolute soil P content, P deficiency can arise in soils where P is strongly bound to soils particles (Wissuwa et al., 2005). Plants suffering from phosphorus deficiencies exhibit retarded growth (Marschner, 1993, Mutters et al., 2006), with greatly reduced tillering (Mutters et al., 2006). Leaves are narrow, short, very erect, and dirt dark green. Stems are thin and spindly (Dobermann and Fairhurst, 2000). Other deficiency symptoms are decreased leaf blade length, reduced number of panicles per plant, and reduced number of seeds per panicle. The root architecture of plants can undergo several changes in response to P deficiency. For example Wissuwa et al. (2005) showed that P deficiency stimulated root elongation in rice.

Phosphorus is often deficient in sandy soils with low organic matter content, calcareous /saline/alkaline soils, volcanic ash soils or acid upland soils with high P fixation capacity; peat soils and acid sulfate soils high in active iron and aluminum causing decrease in crop yields (Withers et al., 1994).

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P level and rate, time, and method of application (Sanyal and De Datta, 1991). The water soluble P sources, such as superphosphate, are effective in all soil types except those that are extremely acid. In acid soil, soluble P readily reacts with Fe and Al, which apparently reduces its availability (De Datta, 1981). The most commonly used P fertilizers for lowland rice are single and triple superphosphates, diammonium phosphate and ammonium phosphate (Sanyal and De Datta, 1991). Phosphate Rocks (PR) are also used as P fertilizers in many countries (De Datta, 1981). The application of PR to lowland rice meets with two difficulties: (1) pH of an acidic soil will rise following submergence and this may adversely affect the solubility of PR in soil; (2) the ability of rice to derive P from PR is relatively low (Sanyal and De Datta, 1991). Several modifications of phosphate rocks have been suggested to increase its effectiveness (De Datta, 1981).

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Mahbubul *et al.* (2016) find out in his that different doses of nitrogen and phosphorus varied significantly for growth and yield of BRRI dhan57.

A field experiment was conducted by Alam et al. (2009) at the Agronomic field of the Sher-e-Bangla Agricultural University to study the relative performance of inbreed and hybrid rice varieties at different levels of P. Three varieties of inbreed and hybrid (BRRI dhan48, Aloron and Hira 2) and five levels of P (0, 24, 48, 72 and 96 kg P ha^{-1}) were used as treatment. They reported that plant height and growth rate varied significantly due to variation of P and tallest plant was obtained with 96 kg P ha^{-1}.

A field experiment was conducted by Rao (2003) in India to determine the utilization pattern of phosphorus rates (30, 60 and 90 kg ha^{-1}) and sources (ammonium polyphosphate, urea nitric phosphate and diammonium phosphate) in rice crop in terms of apparent recovery factor, physiological and agronomic efficiency. He stated that 60 kg P ha^{-1} gave the highest agronomic efficiency when P was applied in the form of ammonium polyphosphate following by urea nitric phosphate and diammonium phosphate and the lowest term P rates.

Table 04. Recommended dose and actual dose of major fertilizer for rice (Basak, 2010)

Crop (HYV rice)	Recommended dose (kg/ha)			Actual dose (kg/ha)		
	Urea	TSP	MP	Urea	TSP	MoP
T. Aus[2]	141	101	69	135	28	17
T. Aman[3]	166	101	69	135	30	24
Boro[4]	269	131	121	192	47	37

2.4 Environmental and soil condition and cropping pattern of the research area

The climate in the coastal zone has shown a general warming trend in the last 40 years, equivalent to 0.04°C $year^{-1}$ (Yu *et al.*, 2019). Only the Canning Town station avoided the increase in temperatures which is attributed to a decrease in sunshine hours there. No general trend could be discerned in the rainfall records of the last 40 years for the coastal zone. However, since the 1960s, there has been an increase in the maximum rainfall over a 5-day period suggesting that rainfall is becoming more intense.

Rainfall in the dry season could be beneficial to crop production by alleviating drought stress. However, the dry season rainfall often occurs in a few heavy events. The likelihood of heavy rainfall events and their timing in the Rabi season is particularly important as a determinant of the riskiness of dry season cropping in the coastal zone. Events > 20 mm are not likely in December and January, but in November almost 50% of years may experience events of 20 mm and 25% of years' experience 50 mm events. These events can hamper timely early sowing or cause crop failure at establishment unless there is adequate drainage. Similarly, from February to April the likelihood of 20 mm rainfall events increases from 25 to 65%, while for 50 mm events the increase is from 5 to 30% of years. These heavy rainfall events tend to coincide with rising soil salinity and may create the combination of waterlogging and salinity conditions in the root zone which are particularly damaging to most crops (Barrett-Lennard, 2013).

The transplanted *aman* rice (T. *aman*) is the only crop in a year during the monsoon season and no crop is grown during the rest of year in the southwestern (SW) coastal region of Bangladesh. The fallow results from the prolonged post-monsoon (*Kharif* 2) soil saturation, soil and water salinity, as well as the low risk-bearing and investment capacity of resource-poor farmers. (Kabir et al., 2019)

2.5 Research Area and Phosphorus

Most of the land kept fallow in the summer or pre-monsoon hot season (March-early June) and autumn or post-monsoon season (October- February) because of soil salinity, lack of good quality irrigation water and late draining condition. In the recent past, with the changing degree of salinity of southwest coastal region of Bangladesh, rice production becomes very risky and crop yields, cropping intensity, production levels of rice and people's quality of livelihood are much lower than that in the other parts of the country (Kabir et al. 2012) .

Whereas P fertilizer is applied in excess in the Western world and some Asian countries (e.g. China, Japan and Korea; MacDonald et al., 2011), P deficiency is a major problem in many Asian and African countries, as well as in South America. Estimates suggest that ~50 % of agricultural soils are deficient in P (Lynch, 2011). The two main reasons for this are (i) insufficient application of P in the form of P fertilizer or manure and (ii) P-fixing soil properties which render P unavailable to plants even if it is present in sometimes large amounts. Phosphorus imbalances in the world, with too much P in some countries and too little or inaccessible P in others (MacDonald et al. 2011), will require different measures and breeding strategies.

Phosphorus is often deficient in sandy soils with low organic matter content, calcareous /saline/alkaline soils, volcanic ash soils or acid upland soils with high P fixation capacity; peat soils and acid sulfate soils high in active iron and aluminum causing decrease in crop yields (Withers et al., 1994).

Boeggaad et al., (1990). In acid soils with high Al and Fe contents, phosphoric acid and soluble P fertilizer transformed into insoluble forms of P so quickly that plants can derive very little from P fertilized treatments (Sinha,1999). Brady and Weil (2002) indicated that at pH lower than 5.5, the retention results largely from the reactions with Fe, Al and their hydrous oxides resulting into low forms of available P. Optimum P availability in mineral soils as generalized by these authors is believed to be near pH 6.5.

Flooded soils exhibit a greater capacity to supply plant available phosphorus than non-flooded soils (Dobermann and Fairhurst, 2000). Crops grown on flooded soils may not show a response to phosphorus applications, while the same crop grown on the same soil when dry may exhibit deficiencies (De Datta, 1981). Although the increase in availability of P is regarded as a benefit of flooding rice soils, the effect on rice growth may not be appreciable in acid clays high in active Fe (IRRI, 1985). The beneficial effect of flooding on P depends on the intensity of redox condition of submerged soil and Fe content (De Datta, 1981). Phosphorus behavior is not the same in soils that are continuously flooded compared to soil alternately dried and flooded. The duration and depth of flooding affects soil oxygen levels, soil pH, P availability, and levels and forms of some micronutrients. Extractable soil P levels, generally decrease after a flooded field is drained (Snyder, 2002).

CHAPTER III

MATERIALS AND METHODS

This portion represents a brief description of location, climate, soil, crop, experimental design, treatment, cultural operations and statistical analysis of collected data.

3.1 Description of the Experimental Site

3.1.1 Location

The experiment was conducted in Pankhali, Dacope, ~30 km away from Khulna. The field experiment was conducted in Agro-ecological Zone (AEZ) 13, i.e. Gangetic Tidal Floodplain and ($22^{0}38'00''$N latitude and $89^{0}30'12''$ E longitudes) at an elevation of ~3 meter from sea level.

3.1.2 Period of experiment

The experiment was conducted in *aman* season, during (14, August 2018 to 12, December 2018).

3.1.3 Soil

The experimental field was medium low land with clay dominated soil (soil texture: clay).

3.1.4 Climate

The experimental field was characterized by sub-tropical climate with moderately high temperature and heavy rainfall during the *kharif* season (April to October) and low rainfall with moderately low temperature during the *rabi* season (November to March) (Bell et al. 2019). Rainfall data (Figure 1), temperature and relative humidity data (Appendix 3).

3.2 Experimental Design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) with six treatments and three replications. Individual plot size was 5m X 8m = 40 m^2. Distance between plot to plot was 0.4 m and block to block was o.75 m. Six phosphorus (P) doses were the treatments as follows:-

Phosphorus rates (kg ha^{-1}):

P_0= No phosphorus added

P_1= 5 (50% of Recommended dose)

P_2= 7.5 (75% of Recommended dose)

P_3= 10 (100% of Recommended dose) (FRG, 2012)

P_4= 12.5 (125% of Recommended dose)

P_5= 15 (150% of Recommended dose).

Layout of the experimental field is presented in appendix 4.

3.3 Field preparation

Tillage system: wet tillage or puddling was done twice with a power tiller on 14 August 2018. All the stubbles were manually removed out of the field after tillage. The field was divided into unit plot size according to the design.

3.4 Fertilizer application

Other fertilizers were applied according the recommendation of the FRG (2012) for the t. *aman* rice of the AEZ 13. They were (kg ha^{-1}):

Urea-165 kg

MoP-36 kg

$ZnSO_4$-3 kg

Gypsum-19 kg

One-third of urea and total amount of all other fertilizers were applied during land preparation. The rest of urea was applied in three splits during 29.08.18 (15 DAT), 15.09.18 (30 DAT) and 01.10.18 (45 DAT).

3.5.1 Plant materials

BR23 a high yielding rice variety was used as plant material for the present study. Seed was collected from Bangladesh Agricultural Development Corporation (BADC) regional station, Fultola, Khulna.

3.5.2 Transplanting of seedlings

28 days old seedlings were uprooted and the seedlings were transplanted in the prepared land, on the same day (14.08.18).

3.5.3. Soil sample collection and analysis

Soil samples at depths (0-15 cm and 15-30 cm) were collected before transplanting to assess the nutrient status including P of the field. The soil samples were analyzed from the SRDI, Daulatpur, Khulna.

3.5.3 Care after transplanted of seedling

After establishment of seedlings, various intercultural operations were accomplished as weeding and urea split application. Plant protection measures were also taken. Irrigation was not required due to sufficient rainfall, thus the cropping was rain fed.

3.5.4 Weeding

Weeding was done firstly at field preparation and 15 days after transplanting (DAT).

3.5.5 Top dressing of nitrogen

After basal dose of nitrogen, the remaining doses of nitrogen were top-dressed in 3 installments, 1st split dose of urea was applied after two weeks of seedling transplanting. At 30 DAT, 2nd split dose was applied at 45 DAT, at booting stage, the 3rd split dose was applied.

3.5.6 Plant protection

The crop was attacked by different pest. The crop was sprayed with pesticide to control the pest. Detailed of the management system is given below:

Table 5. Pesticide application

Insecticide / Fungicide	Dose	Insect / Disease Name	Time of application
Furadan 5 g	15 kg / ha	Nematode	25 DAT
Nitro 505 EC (Chloropiriphos + Cyprermethrin)	1 ml/ L	Green leaf hopper	37 DAT

3.5.7 Harvesting and postharvest operations

The crop was harvested when 80–90% of the grains had turned golden yellow in color (on 12.12.18). One squire meter are from 3 places were harvested per plot for calculating grain yield. Threshing was carried out manually. The grains were cleaned and dried to a moisture content of 13%. The straw was oven dried. Finally, grain and straw yields of each treatment was determined and converted to t ha^{-1}.

3.6 Data collection, recording and calculation

Five hills were selected per plot to record the yield attribute of the crop

3.6.1 Plant height (cm)

The height of plant was recorded in centimeter (cm) at the time of 45, 60, 75, 90 DAT and at harvest. The height was measured from the ground level to the tip of the tiller.

3.6.2 Number of tillers $hill^{-1}$

The number of tillers $hill^{-1}$ was recorded at the time of 45, 60, 75, 90 DAT and at harvest. Data were recorded carefully by counting all tiller number from three hills of each plot.

3.6.3 Effective tiller $hill^{-1}$

Grain bearing panicle was considered as effective tiller. Total number of effective tiller $hill^{-1}$ was counted during harvesting time.

3.6.4 Panicle length (cm)

Panicle length was measured from five randomly selected panicle separately from each plot.

3.6.5 Number of grain $panicle^{-1}$

The total number of grains was collected from randomly selected 5 plants of a plot on the basis of grain in the spikelet and then average number of filled grains $panicle^{-1}$ was recorded.

3.6.6 Filled grain panicle^{-1}

The total number of filled grains was collected from randomly selected 5 plants of a plot on the basis of grain in the spikelet and then average number of filled grains panicle^{-1} was recorded.

3.6.7 Unfilled grains panicle^{-1}

The total number of unfilled grains was collected from randomly from selected 5 plants of a plot on the basis of unfilled grain in the spikelet and then average number of unfilled grains panicle^{-1} was recorded.

3.6.8 Weight of 1000 grain (g)

One thousand grain were counted randomly from the total cleaned grain of each individual treatment and then weighed in grams and recorded.

3.6.9 Grain yield (t ha^{-1})

Grains obtained from each treatment plot were sun-dried and weighed carefully. The weight of grains from average 1 m^2 area (from three places per plot, three m^2) was converted to t ha^{-1}.

3.6.10 Straw yield (t ha^{-1})

Straw yield was obtained in the same way of grain yield (from three m^2, three one-meter places per plot) sun-dried and weighed carefully and converted to t ha^{-1}.

3.6.11 Harvest index (%)

Harvest index was calculated from the grain and straw yield of rice for each plot and expressed in percentage. Harvest index was calculated by using formula:

$$\text{Harvest index (\%)} = \frac{\text{Economic yield}}{\text{Biological yield}} X\ 100$$

CHAPTER IV

RESULTS AND DISCUSSION

The result of the experiment was presented by evaluating the growth, yield attributes and yield of t. *aman* rice (BR23) response to phosphorus rates.

4.1 Soil nutrient analysis data

The soil analysis report of this field shows that soil contains 0.12% N, 34.6 micro g P per g soil, 0.41 meq. K per g soil, 103, 1.8 and 1.4 micro g per g soil sulphur, zinc and boron respectively (Table 6). The p^H is slightly alkaline. Among the tested nutrients only organic matter is low. Other nutrients were found high to highest level

Table 6. Soil nutrient analysis result

Depth (cm)	Analyzed result and fertility status								
	p^H	Salinity (EC) dSm^{-1}	OM	N	P	K	S	Zinc	Boron
			(%)		Micro g per g soil	meq. per 100g soil	Micro g per g soil		
0 - 15	7.3	8.4	2.10	0.122	34.56	0.41	102.91	1.84	1.41
	Neutral	Medium	Medium	Low	High	High	Highest	High	Highest
15 - 30	7.3	6.3	2.17	0.126	28.12	0.28	111.92	1.17	0.90
	Neutral	Low	Medium	Low	Optimum	Optimum	Highest	Medium	Highest

OM= Organic matter, N = Nitrogen, P = Phosphorus, K = Potassium, S = Sulphur

4.2 Rainfall during the experiment conducting

The measurement of rainfall during the experiment shows that there was sufficient rainfall during the experiment (Figure 1). Due to which there was no need for extra irrigation. The maximum rainfall was 49 cm to 1.1 cm minimum and there was considerable rainfall earlier the experiment.

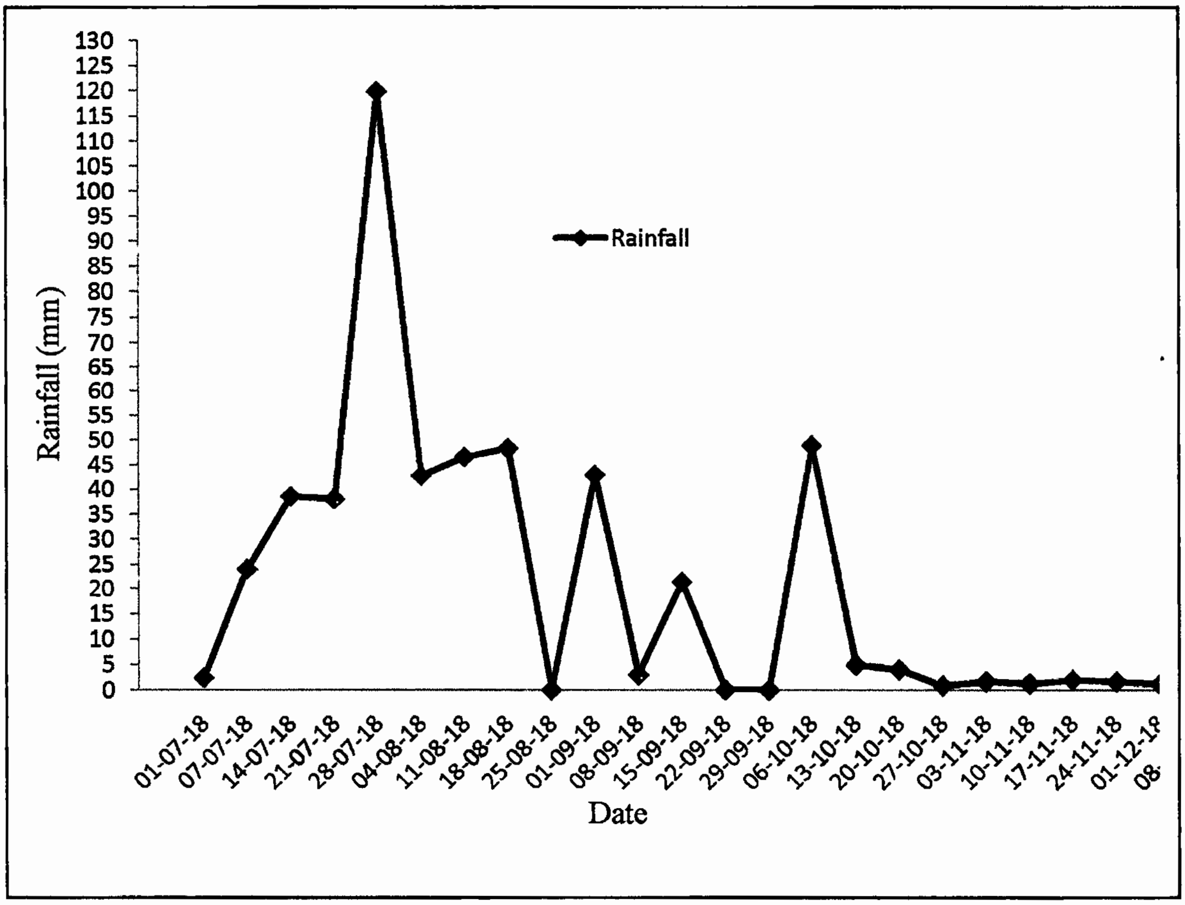

Figure 1. Weather condition during the experiment (rainfall).

4.3 Plant height (cm)

Plant height was statistically non-significant among the phosphorus rates at different DAT and at harvest (Figure 2). Phosphorus addition had no effect at a particular DAT on plant height but with the increase of plant age height increased and the tallest plant produced in all treatments at 90 DAT which remained approximately similar at harvest.

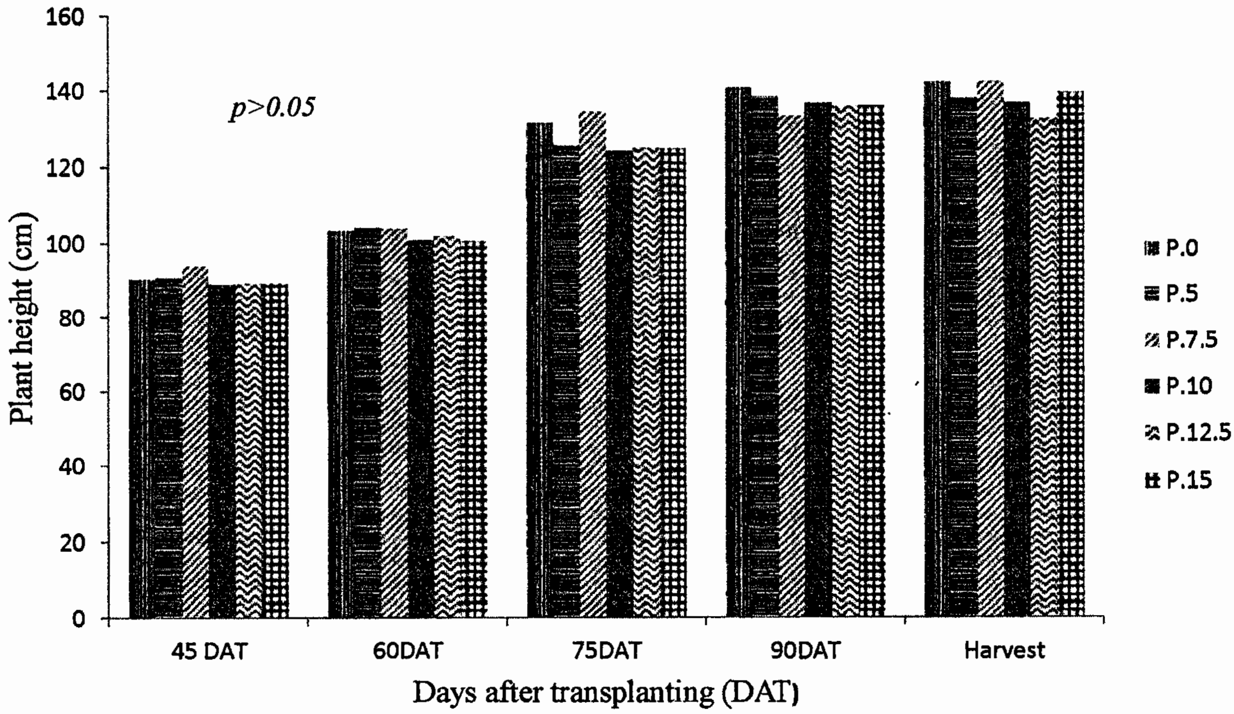

Figure 2. Effect of phosphorus rate on plant height of t. *aman* (BR23) in southwestern region of Bangladesh.

4.4 Number of tillers hill^{-1}

Number of tillers hill^{-1} in different treatments was recorded at the same time when the plant height was recorded i.e., at 45, 60, 75, 90 DAT and harvest. Different rates of phosphorus had no significant difference on tiller number hill^{-1} at different DAT (Figure 3). At 45 DAT numerically the highest tiller number (17.9) was obtained from 7.5 kg P ha^{-1} while the lowest (14.3) was recorded from 12.5 kg P ha^{-1}. At 60 DAT numerically the highest tiller number (18.3) was obtained from 7.5 kg P ha^{-1} while the lowest (15.3) was recorded from 5 kg P ha^{-1}. At 75 DAT numerically the highest tiller number (14.1) was obtained from 10 kg P ha^{-1} while the lowest (12.9) was recorded from 12.5 kg P ha^{-1}. At 90 DAT numerically the highest tiller number (12.4) was obtained from 10 kg P ha^{-1} while the lowest (11.1) was recorded from 15 kg P ha^{-1}. At harvest numerically the highest tiller number (16.1) was obtained from 0 kg P ha^{-1} while the lowest (12.6) was recorded from 12.5 kg P ha^{-1}.

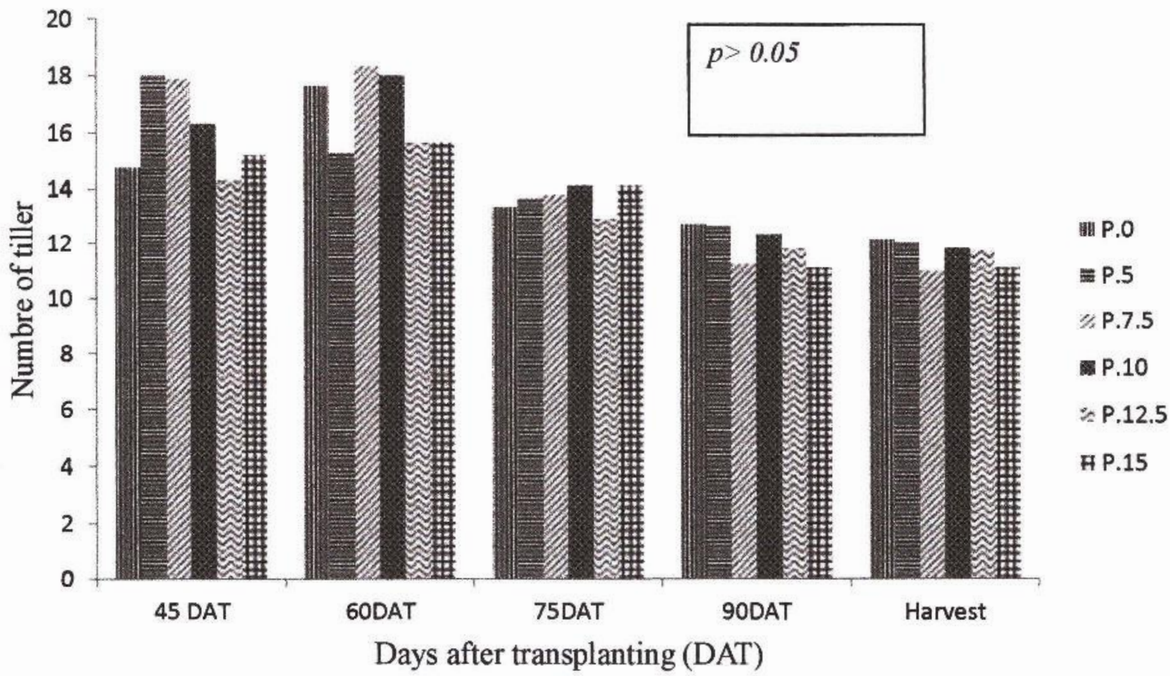

Figure 3. Effect of phosphorus on tiller number hill^{-1} of t. *aman* (BR23) in southwestern region of Bangladesh.

4.5 Number of effective tillers hill^{-1}

Statistically phosphorus rates had significant effect on effective tiller number hill^{-1} (Figure 4). The difference had no definite trend with the increase in P rates e.g., at no added P and highest rate of P, the number of tiller was similar, between these two lowest and highest rates the effective tiller number fluctuated.

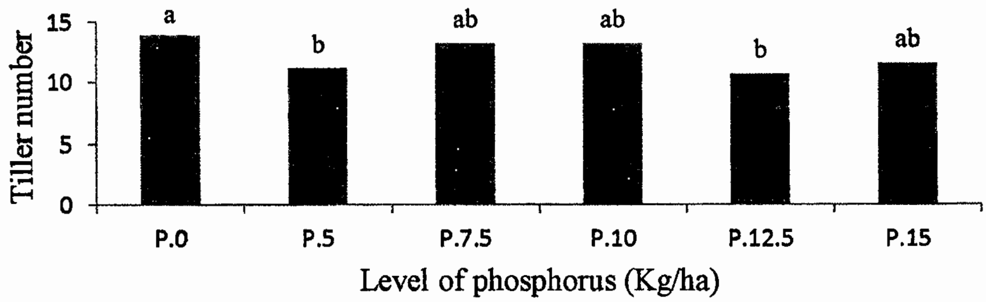

Figure 4. Effect of phosphorus doses on effective tiller number of BR23 rice in southwestern Bangladesh.

4.6 Length of panicle at harvest

The different rates of phosphorus had no significant difference on panicle length at harvest (Figure 5). Numerically the panicle length also showed very little difference (1.4.cm) between highest length (25.9 cm) at 12.5 $^{kg\ ha-1}$ and lowest length (24.5) at 0 P which is only 5.3% length difference between the rates.

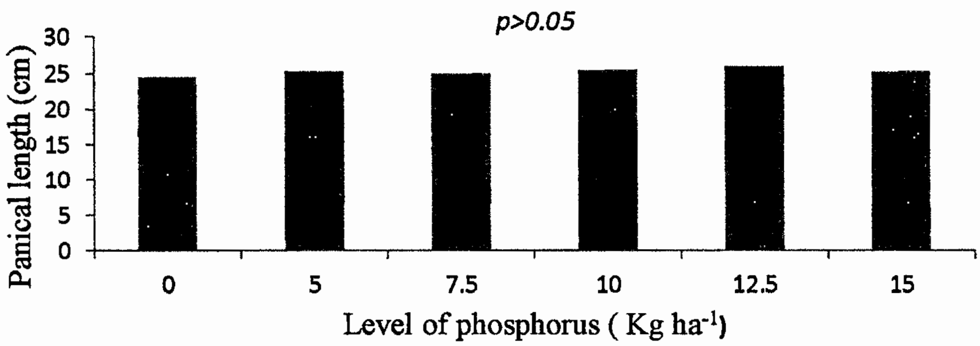

Figure 5. Effect of phosphorus doses on panicle length of BR23 rice in southwestern Bangladesh.

4.7 Number of grain panicle^{-1}

The different rates of phosphorus had no significant effect on grain panicle^{-1} (Table 7). Numerically the maximum number of grain panicle^{-1} (140.5) was recorded from 10 kg P ha^{-1} where the minimum (112.9) was found in 12.5 kg P ha^{-1}.

4.8 Number of filled grain panicle^{-1}

Phosphorus rates had no significant effect on the number of filled grain panicle^{-1} (Table 7). The maximum number of filled grain panicle^{-1} (123.9) was recorded from 7.5 kg P ha^{-1} where the minimum (101.4) was found in 0 kg P ha^{-1}.

4.9 Number of unfilled grain panicle^{-1}

The number of unfilled grain panicle^{-1} was statistically not significant among the different rates of phosphorus (Table 7). The maximum number of unfilled grain panicle^{-1} (27.9) was recorded from 5 kg P ha^{-1} where the minimum (11.5) was found in 10 kg P ha^{-1}.

Table 7. Effect of phosphorus on yield contributing character of T. *aman* (BR23) rice in southwestern Bangladesh.

Phosphorous rates (kg ha^{-1})	Effective.Tiller .Hill	No. of grain panicle^{-1}	No. of filled grain panicle^{-1}	No. of unfilled grain panicle^{-1}
0	13.9 a	118.3	101.4	16.9
5	11.1 b	134.1	125.4	27.9
7.5	13.2 ab	134.0	123.9	19.3
10	13.2 ab	140.5	121.0	11.5
12.5	10.7 b	112.9	109.1	24.4
15	11.6 ab	130.1	115.9	14.3
LS	*	NS	NS	NS
CV (%)	7.7	12.9	19.4	53.1

LS = Level of significance, NS = Non-significant, * = Significant at 5% level of significance, CV = Co-efficient of variation

4.10 1000 grain weight (g)

Effect of phosphorus on 1000 grain weight was not statistically significant (Table 8). Numerically the maximum weight (26.8 g) was found at 10 kg P ha^{-1} and the minimum (24.4 g) was obtained from 0 kg P ha^{-1}.

4.11 Grain yield (t ha^{-1})

In all P added treatments the grain yield was statistically similar i.e., the grain yield at 5 kg P/ha was similar to that of double rate (10 kg ha^{-1}) and triple rate (15 kg ha^{-1}) of P. Grain yield significantly differed only between no added P (0) and added P of any rate (Table 8).In zero P added plots the grain yield was 90% (4.3 t ha^{-1}) of the maximum grain yield (5.5 t ha^{-1}) found in 10 kg P ha^{-1} treatment.

4.12 Straw yield (t ha^{-1})

Phosphorus had no significant effect on straw yield (Table 8). It was found that, the straw yield showed an increasing trend with the increase in P rates. The maximum straw yield (7.6 t ha^{-1}) was recorded from 15 kg P ha^{-1} where the minimum (6.5 t ha^{-1}) was found in 0 kg P ha^{-1}.

4.13 Harvest index (%)

Phosphorus had no effect of harvest index (%) (Table 8).

Table 8. Effect of phosphorus rates on yield of T. *aman* (BR23) in the south-western coastal Bangladesh.

Phosphorous rates (kg ha^{-1})	1000 grain weight (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
0	24.4	4.3 b	6.4	40.5
5	25.1	4.9 ab	6.8	42.0
7.5	26.3	5.2 ab	6.8	43.5
10	26.8	5.5a	7.4	42.5
12.5	25.9	5.3 ab	7.6	41.4
15	26.1	5.3 ab	7.6	41.1
LS	NS	*	NS	NS
CV (%)	4.1	7.8	4.9	6.3

LS = Level of significance, NS = Non-significant, * = Significant at 5% level of significance,

CV = Co-efficient of variation

Discussion

Addition of P fertilizer from 0 to 15 kg ha^{-1} had almost no effect on most of the parameters including yield attributes (panicle length, number. of grain $panicle^{-1}$, number of filled grain $panicle^{-1}$ and number of unfilled grain $panicle^{-1}$) The grain yield was marginally significant (at 5% level) between 0 added P and the other P rates might be due to some yield attributes which were increased numerically (not statistically) that might had a combined effect on yield increase in added P treatments. Although the effective tiller $hill^{-1}$ was significantly different, it does not follow any definite trend: 0 and 10 kg P/ha was similar thus might not the cause of yield difference. Compared to the yield at recommended rate (10 kg ha^{-1}), 90% grain yield was obtained from the no P added treatment. The reason might be that there was no shortage of phosphorus in the experimental soil. The soil analysis report of this field showed that soil contained 34.6 µg P per g soil (1-15 cm soil depth) which is designated as high amount of P in soil for AEZ 13 (FRG, 2018). Since the residual phosphorus is present in soil, adding new phosphorus did not produce higher yield. As the fertilizer recommendation in FRG of Bangladesh is based on the soil test only, not based on the plant response, this experiment showed that the P recommendation is excess. The P rate in FRG (2018) is recommended at least 15 years before. P rates in FRG (2018) for T. *aman* in fallow-fallow-T. *aman* cropping pattern of saline soil of AEZ 13 is 10 kg P ha^{-1}. The same rate (10 kg P/ha) was also recommended for the same pattern and AEZ in FRG (2012) and FRG (2005). It is very likely that application of P fertilizer for last ~15 years to T. *aman* rice left residual P. The current study and studies by Naher and Akter (2018); and Aziz (2018) suggest that the P fertilizer recommendation should be much below the current 10 Kg ha^{-1}, Fifty per cent reduction (5 kg P ha^{-1}) of the current rate (10 kg P/ha) should produce the maximum yield of the most popular rice variety (BR23) for this region. Moreover, the rate might also support the growth of a winter crop if grown in the same land and for that research should be conducted in future.

P fertilizer has residual effect and this is proved by many research works and in many crops (Bolland et al., 1988, Bolland et al., 1995 and Bolland et al., 1998). P fertilizer usually utilized by crop only 8-15% in the current year (Bolland et al., 1995), the rest become available slowly in the subsequent years and/or seasons and majority remain as organic form (Bolland et al., 1995). The forms of slowly available residual P depends on the p^H of the soil. The pH of the soil of the current study is slightly alkaline thus calcium phosphate (Ca-P) might be the dominant form of residual P (Glaser and Lehr, 2019). P fractionation study will uncover the residual form of P in future.

In short, the study suggested that a reduced P rate (~5 kg ha^{-1}) from the current P recommendation (10 kg ha^{-1}) produced the maximum rice yield in this soil because all the P treatments produced the similar grain yield and the zero added P also produced 90% of the maximum yield.

Future study should be done on t. *aman* in other areas of SW region and on winter crop (after T. *aman* harvest) to test further the effect of residual P for realizing crop growth and yield. Also a P fractionation study should also be done to investigate which fraction(s) of P is/are remaining as residual P.

CHAPTER V

SUMMARY AND CONCLUSION

The experiment was conducted during August to December, 2018 with a view to investigate the optimum rate of phosphorus for realizing highest grain yield and yield components of a HYV T. *aman* rice BR23. There was 6 different level of phosphorus treatment as 0, 5, 7.5, 10, 12.5 and 15 kg phosphorus ha^{-1} with three replications.

Phosphorus rate had statistically non-significant effect on plant height, tiller number, panicle length, number of grain panicle^{-1}, number. of filled grain panicle^{-1}, number of unfilled grain panicle^{-1}, 1000 grain weight, grain yield, straw yield and harvest index except effective tiller hill^{-1} a non-definite trend. Despite the non-significant effects of yield attributes on grain yield, there was increasing trend (numerically) of most of the yield attributes, the probable reason of increased grain yield in added P treatments than that of zero added P. The zero P produced 90% yield that of the maximum indicated the sufficient presence of P in soil. The reason might be that there was no shortage of phosphorus in the experimental soil. Because the soil analysis of this field shows that soil contained 34.6 μg P/g soil (1-15 cm soil depth) which is designated as high amount of P in soil for AEZ 13 according to the fertilizer recommendation guide (FRF, 2018) of Bangladesh. The findings of the study suggests that the P fertilizer recommendation should be much below the current recommendation (10 Kg P/ha). Fifty per cent reduction (5 kg P ha^{-1}) of the current rate (10 kg P ha^{-1}) should produce the maximum yield of the most popular HYV T. *aman* rice for this region. Moreover, the rate might also support the growth of a winter crop if grown in the same land and for that research should be conducted in future. Moreover, the recent research showed that some winter crops have been successfully cultivating in this area, thus, although phosphorus application had poor response to increase yield of T. *aman* in that area, this residual P may support the growth and yield of new winter crops in the medium highland soil of southwestern coastal Bangladesh.

CHAPTER VI

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Appendix 3. Weather data of temperature and relative humidity