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Rice Yield Gap Minimization in Central Bangladesh: Using and Adapting Existing Technologies

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Abstract

Rice (*Oryza sativa* L.) in the dry season (Boro) followed by rice in the wet season (Aman) is the major cereal cropping system in Bangladesh. The average productivity (7 Mg·ha^{-1}) of this system is far below attainable yields (14 Mg·ha^{-1}) in farmers' fields, resulting in a large yield gap mainly due to farmers' traditional management practices. Narrowing yield gap is a vital complementary strategy in improving rice yield and consequently enhancing food security. We evaluated BRRI recommended management practices, BRRI recommended management practices along with two N management options (leaf color chart and Urea Super Granule) and farmers' crop management practices integrated with quality seed, leaf color chart (LCC) and Urea Super Granule (USG) in farmers' fields of Kapasia, Gazipur over 6 contiguous seasons during 2009-2012. Across years, all the management options increased grain yields compared with the farmers' practice (FP) by 1.12 Mg·ha^{-1} in Aman and 0.84 Mg·ha^{-1} in Boro season. The higher yield response (43%) occurred with BRRI recommended management practices followed by BRRI recommended management practices in combination with Urea Super Granule (42%) as N source (BRRI-USG). Yield advantage of 41% could be attained by BRRI recommended management practices with leaf color chart (LCC) aided N management (BRRI-LCC) while this was 22%, 13% and 13% higher than FP (farmer's practice) when only quality seeds, USG and LCC were used with farmers' management practice. BRRI Rec., BRRI-LCC and BRRI-USG·management options reduce the yield gap of FP by 41%, with an average of 2.87 Mg·ha^{-1}. When farmers adopted FP-QS, FP-USG and FP-LCC management options, they reduced the yield gap of FP by 21%, 13% and 12%, with an average of 1.49, 0.88 and 0.81 Mg·ha^{-1}, respectively. The average added net returns with BRRI Rec., BRRI-LCC and BRRI-USG·management options were US$175 to US$362 ha^{-1} in the wet season and US $158 to US $263 ha^{-1} in the dry season. BRRI management practices and BRRI management practices integrated with two N management options, either LCC or USG has the potential to boost rice yield and consequently total rice production in Bangladesh.

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Keywords

Rice-Rice Cropping System, Yield Gap, Productivity, Net Profit

Subject Area: Agricultural Science

1. Introduction

About half of the world's cereal production and 89% of the world's harvested rice are from Asia [1]. Economically disadvantaged people spend as much as 30% - 40% of their income just to buy rice [2]. Increasing the amount of rice production and keeping the rice price low and affordable to them are crucial for poverty reduction. Rice yield must continue to increase at an annual rate of 1.5% compared with the current rate of 0.8% to keep pace with the expected demand [3]. Like in many other Asian countries, rice is the staple food in Bangladesh and it contributes one-half of the agricultural GDP and 55% of the total labor employment [4]. During the last 20 years, Bangladesh has increased rice production 1.8 times with almost no increase in its land area of about 11.7 million ha [5]. However, because of the continuous increase in population growth, rice demand in 2050 is projected to be 56% higher than in 2001 [6]. This is going to be doubly challenging in light of the diversion of better quality land, water, and labor to other sectors of the national economy. Evidence is now appearing that the productivity of rice-rice and rice-wheat systems is plateauing because of a fatigued natural resource base [7] [8]. The productivity and sustainability of rice-based cropping systems are threatened because of i) the inefficient use of fertilizer, water, and labor; ii) increasing scarcity of water and labor; iii) changing climate; iv) emerging energy crisis and rising fuel prices; v) emerging socioeconomic changes such as urbanization, migration of labor, and preference for nonagricultural work [9]. In addition, recent increases in the prices of farm inputs in relation to outputs, fewer off-farm work opportunities for supplementing farm income, reduced remittances from relatives working outside villages, and declining income and purchasing power of poor consumers have threatened the existence of rice producers and consumers [9].

Bangladesh produced about 50.1 million tons of rough rice from 11.7 m ha of land in 2010 with a productivity of 4.3 $t \cdot ha^{-1}$ [5]. The present productivity is far below the attainable yield of 8 - 10 $t \cdot ha^{-1}$ in the dry season (Boro) and 5 - 6 $t \cdot ha^{-1}$ in the wet season (Transplanted Aman) in farmers' field experiments [10]-[13]. This difference in yield in farmers' fields between farmer-managed and researcher-managed trials exists because the best available production technologies are not adopted in farmers' fields. This could be, among others, due to farmers' characteristics (e.g., lack of knowledge and skills, and risk aversion), farm characteristics (e.g., poor soil, difficult terrain, and inaccessibility), and inappropriateness of the technology to farmers' circumstances (e.g., labor-intensive, high investment costs, and poor access to inputs). However, a large portion of this yield gap remains unexplained.

Minimizing the yield gap and increasing profit and product quality are becoming increasingly difficult to achieve by using a single-technology-centric approach. The use of a component technology in isolation also has limited widespread adoption. Combining and simultaneously applying a number of the best compatible individual or component technologies are crucial for maximizing overall benefits to farmers [9]. Depending on the need and profitability of new technologies, farmers generally integrate new technology with the cultural practices being practiced by them on their farms. The choice or selection of the best individual or component technologies in an integrated manner is crucial for achieving the full benefit. As narrowing yield gap of rice is attributed to many factors, it should be better quantified and understood. This paper aims to evaluate the contribution of different crop management factors in curtailing the rice yield gap over six seasons during three years.

2. Materials and Methods

2.1. Experimental Sites and Seasons

On-farm trials were conducted in a continuous rice–rice cropping system for six consecutive seasons during 2009-2012 at Moison village in Kapasia Upazila (24˚12'N and 90˚36'E) of Gazipur District. The farmers which represent common cropping systems, management practices, land types and soil types were selected (**Figure 1**). The climate of the area is subtropical, characterized by wide seasonal variations in rainfall, high temperatures and humidity. Weather data were collected from a nearby weather station of Bangladesh Meteorological Department. The weather pattern during the study period is given in **Figure 2** and **Figure 3**.

Moison village in Gazipur District belong to Agro-Ecological Zone (AEZ) 28 (Madhupur Tract). The soils are well drained friable clay loam to clay or heavy clay, strongly acidic, mainly phosphate fixing, low in P, K, S, and B in AEZ-28 [14]. Transplanted rice was grown on puddled soil under rainfed conditions in the wet season or Aman (June-July to November-December) and under irrigated conditions in the dry season or Boro (December-January to April-May). In both seasons, soils were well prepared through 4 - 5 passes with a power tiller followed by 2 - 3 ladderings. High-yielding semi-dwarf rice cultivars BRRI dhan49 (135 day seed to seed) and BRRI dhan28 (140 day seed to seed) were grown in the Aman and Boro seasons, respectively.

2.2. Experimental Design and Treatments

The trials were established in farmers' fields in a randomized complete block design with a set of seven treatments in each farmer's field. Farmers' fields were considered as replications. The number of replicate farmers was twenty. There were seven treatments, viz. farmers' management practices (FP), farmers' management prac-

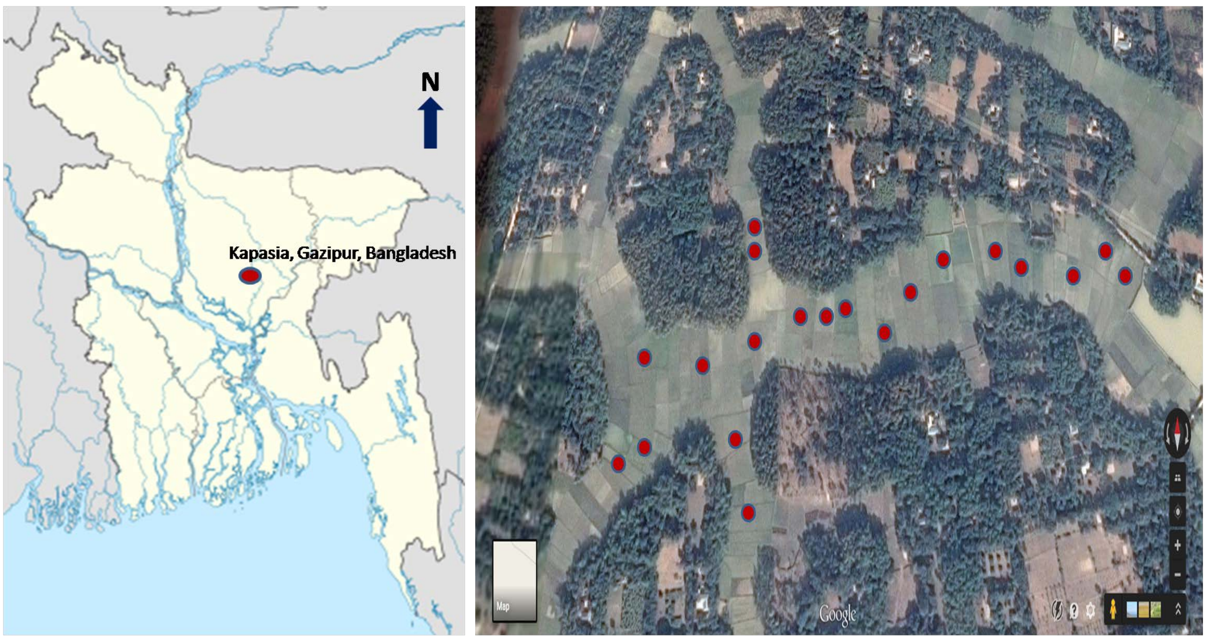

Figure 1. Position of the farmers' fields selected for this study.

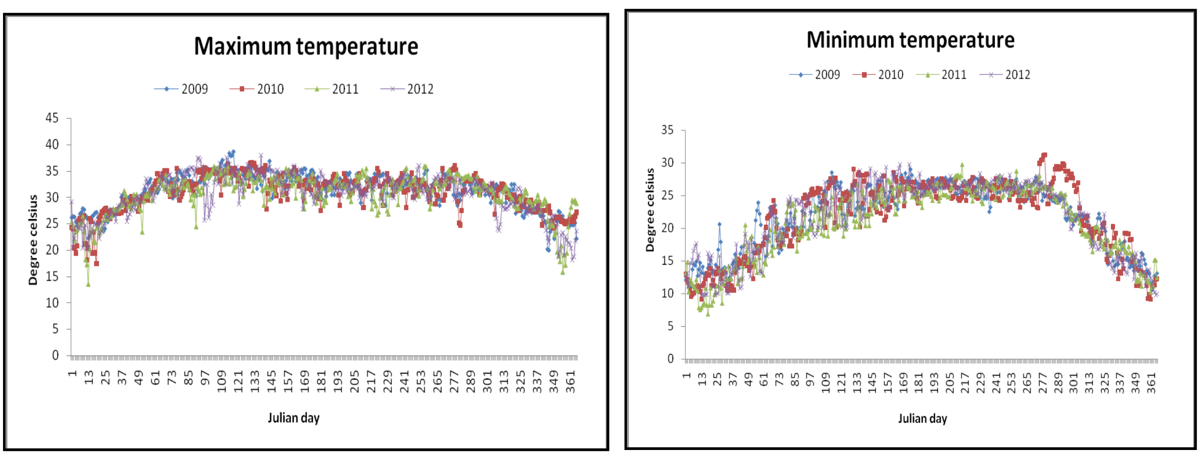

Figure 2. Daily maximum and minimum temperature at the experimental site during 2009-2012.

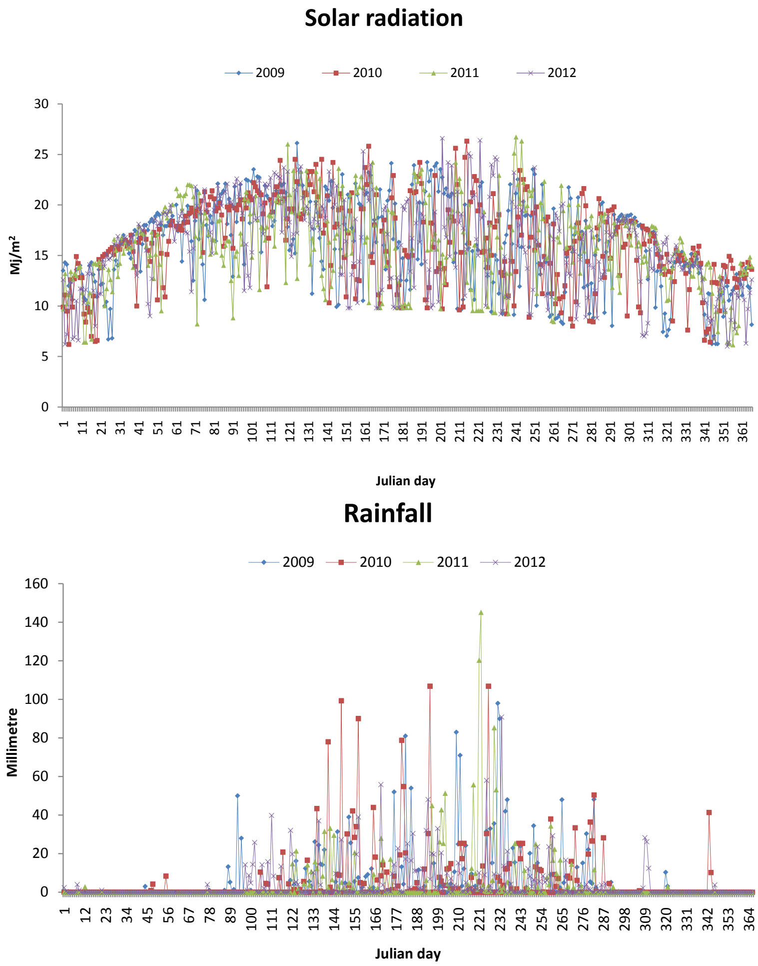

Figure 3. Daily solar radiation and rainfall at the experimental site during 2009-2012.

tices with quality seed (FP-QS), farmers' management practices with USG (FP-USG), farmers' management practices with LCC based N management (FP-LCC), Bangladesh Rice Research Institute (BRRI) recommended management practices coupled with leaf color chart (LCC)-aided fertilizer N management (BRRI-LCC), BRRI recommended management practices coupled with urea super granules (USG) as source of fertilizer N (BRRI-USG) and BRRI recommended management practices (BRRI Rec.).

2.3. Treatment Details

2.3.1. Farmers' Management Practices (FP)

The farmers' management practice of seed and seedling raising, planting·method, and fertilization varied considerably among farmers and seasons (**Table 1**). All farmers used seeds from their own source having 80% - 85% germination capacity without any seed treatment. They prepared a flat seedbed without any organic matter and used a very high seed rate (140 - 168 $g \cdot m^{-2}$) on the seedbed. Five to nine rice seedlings (35- - 44-day-old) per hill in Aman and five to eight rice seedlings (48- - 60-day-old) in the Boro season were transplanted at random spacing.

Across seasons and years, all farmers applied N fertilizer at early tillering, late tillering and panicle initiation stage. Farmers applied on an average 70% - 76% of N fertilizer between early tillering and late tillering (**Table 1**). In the Aman season, 100% farmers applied P and K fertilizer but no farmer applied S and Zn fertilizer. In the Boro season, 100% of the farmers applied P fertilizer, 100% applied K fertilizer, 80% - 100% applied S fertilizer, and 40% - 60% applied Zn fertilizer.

Table 1. Farmers' management practices for transplanted rice in central Bangladesh in Aman and Boro seasons during 2009-2012.

Parameter[a]	Aman 2009	Aman 2010	Aman 2011	Boro 2009-10	Boro 2010-11	Boro 2011-12
Seed rate on seed bed, range ($g\cdot m^{-2}$)	142 - 160	140 - 155	145 - 157	158 - 167	160 - 168	155-164
Seed rate to transplant 1 ha main field (kg)	55 ± 5	45 ± 7	50 ± 5	58 ± 4	49 ± 7	46 ± 6
Seedling age, range (days)	35 - 44	32 - 40	36 - 39	49 - 60	48 - 55	50 - 59
Hill spacing at transplanting (cm)	Random	Random	Random	Random	Random	Random
Seedling number ($hill^{-1}$)	5 - 8	5 - 9	5 - 8	5 - 7	5 - 8	5-8
Fertilizer management						
N applied at basal						
Farmer (%)	0	0	0	0	0	0
Amount ± S.D. ($kg\cdot ha^{-1}$)	0	0	0	0	0	0
N applied at early tillering						
Farmer (%)	100	100	100	100	100	100
Time ± S.D. (DAT)	15 ± 2	14 ± 2	18 ± 3	15 ± 4	16 ± 3	13 ± 4
Amount ± S.D. ($kg\cdot ha^{-1}$)	34 ± 9	33 ± 7	24 ± 6	39 ± 6	40 ± 4	43 ± 3
N applied at late tillering						
Farmer (%)	100	100	100	100	100	100
Time ± S.D. (DAT)	25 ± 3	30 ± 3	28 ± 4	30 ± 3	32 ± 5	37 ± 4
Amount ± S.D. ($kg\cdot ha^{-1}$)	37 ± 5	45 ± 5	39 ± 8	42 ± 4	36 ± 3	40 ± 4
N applied at panicle initiation						
Farmer (%)	100	100	100	100	100	100
Time ± S.D. (DAT)	40 ± 4	43 ± 2	39 ± 3	46 ± 3	41 ± 5	45 ± 4
Amount ± S.D. ($kg\cdot ha^{-1}$)	28 ± 6	24 ± 3	21 ± 3	34 ± 7	33 ± 4	33 ± 4
Fraction of total N applied						
At basal (%)	0	0	0	0	0	0
At early tillering (%)	34	32	29	34	37	37
At late tillering (%)	37	44	46	36	33	35
At panicle initiation (%)	28	24	25	30	30	28
P applied						
Farmer (%)	100	100	100	100	100	100
Amount ± S.D. ($kg\cdot ha^{-1}$)	7 ± 2	7 ± 2	7 ± 1	19 ± 4	14 ± 2	19 ± 4
K applied						
Farmer (%)	100	100	100	100	100	100
Amount ± S.D. ($kg\cdot ha^{-1}$)	14 ± 6	12 ± 3	16 ± 4	36 ± 3	40 ± 10	37 ± 5
S applied						
Farmer (%)	0	0	0	80	100	100
Amount ± S.D. ($kg\cdot ha^{-1}$)	0	0	0	5 ± 3	5 ± 3	6 ± 1
Zn applied						
Farmer (%)	0	0	0	40	60	40
Amount ± S.D. ($kg\cdot ha^{-1}$)	0	0	0	1 ± 1	1 ± 1	1 ± 1

[a]Mean ± standard deviation (S.D.). All reported means for timing and amount of fertilizers are based on farmers applying fertilizers.

2.3.2. Farmers' Practices with Quality Seed (FP-QS)

The management practices in FP-QS were same as FP except seed source. Certified seed from BRRI having 92-95% germination capacity was used.

2.3.3. Farmers' Practices with USG (FP-USG)

The management practices in FP-USG were same as FP except N fertilizer management. Nitrogen as USG was deep-placed within 7 - 10 DAT at 7 - 10 cm soil depth at the rate of one USG (1.8 g) in Aman and one USG (2.7 g) in Boro in the middle of 4 hills. The total N dose was 54 kg·ha^{-1} in Aman and 79 kg·ha^{-1} in Boro.

2.3.4. Farmers' Practices with LCC (FP-LCC)

The management practices in FP-LCC were same as FP except N fertilizer management. Nitrogen as urea was applied by using the LCC in a real-time N management approach [15]. The N rate varied among farmers' fields and seasons. The mean total N dose ranged from 77 to 103 kg·ha^{-1} in Aman and from 93 to 124 kg·ha^{-1} in Boro (**Table 2**).

2.3.5. BRRI Recommended Management Practices with LCC (BRRI-LCC)

A set of five BRRI recommended management practices integrated with existing farmers' practices were i) certified seeds, ii) healthy young seedlings, iii) hill spacing of 20 cm × 20 cm at transplanting with 3 - 4 seedlings per hill, iv) AEZ-based recommended P, K, S, and Zn fertilization, and v) N application by using the LCC in a real-time N management approach. The management practices recommended by BRRI were used for raising healthy seedlings (**Table 3**) [16]. Across the years, seedling age ranged from 28 to 34 days in Aman and from 40 to 48 days in Boro. The P, K, S, and Zn fertilizers were applied at the rates and time recommended by BRRI based on AEZ-based recommendations [16]. Nitrogen as urea was applied by using the LCC in a real-time N management approach [15]. The N rate varied among farmers' fields and seasons. The mean total N dose ranged from 77 to 103 kg·ha^{-1} in Aman and from 93 to 124 kg·ha^{-1} in Boro (**Table 3**).

2.3.6. BRRI Recommended Management Practices with USG (BRRI-USG)

The management practices in BRRI–USG were same as BRRI–LCC except N fertilizer management. Nitrogen as USG was deep-placed within 7 - 10 DAT at 7 - 10-cm soil depth at the rate of one USG (1.8 g) in Aman and one USG (2.7 g) in Boro in the middle of 4 hills. The total N dose was 54 kg·ha^{-1} in Aman and 79 kg·ha^{-1} in Boro.

2.3.7. BRRI Recommended Management Practices (BRRI Rec.)

The management practices in BRRI were same as BRRI–LCC except N fertilizer management. The total N dose was 54 kg·ha^{-1} in Aman and 79 kg·ha^{-1} in Boro. Nitrogen was applied as urea in three equal splits: 7 - 10, 25 - 30 and 35 - 40 days after transplanting (DAT) in Aman and at 15 - 20, 30 - 35 and 40 - 45 DAT in Boro.

2.4. Data Collection and Analysis

Grain yields (rough rice) were obtained from two central 6 m^2 harvest areas in each plot at·harvestable maturity and reported at 0.14 g H_2O g^{-1} fresh weight of grain. Human labor used for seedling raising, transplanting, and fertilizer application and wage rate were recorded. The time required to complete each field operation was expressed as person-days ha^{-1}, considering 8 h to be equivalent to 1 person-day. The farm-gate price of rough rice and prices of seed, fertilizers, and seed-treating chemicals were also recorded.

Table 2. N management integrated with famers' management practices in central Bangladesh in Aman and Boro seasons during 2009-2012.

Crop production factor[a]	FP-LCC
N fertilizer management, mean ± S.D.	The N rates (kg·ha^{-1}) for the LCC option given below: Aman 2009: 83 ± 12 in 3 - 4 splits; Aman 2010: 88 ± 14 in 3 - 4 splits; Aman 2011: 88 ± 14 in 3 - 4 splits; Boro 2009-10: 105 ± 17 in 3 - 4 splits; Boro 2010-11: 105 ± 17 in 3 - 4 splits; Boro 2011-12: 99 ± 14 in 3 - 4 splits

[a]S.D., standard deviation of the mean.

Table 3. BRRI recommended management practices for transplanted rice in central Bangladesh in Aman and Boro seasons during 2009-2012.

Crop production factors and parameter[a]	BRRI-LCC
	Seed and seedlings
Seed source	Certified seeds from BRRI
Seed germination (%)	92 - 95
Seed treatment	Seeds treated with bavistine at 3 g per kg seeds. Seeds were soaked in water mixed with bavistine for 24 h
Seed rate (kg·ha^{-1})	30 kg seeds used to transplant 1 ha main field
Land for seedbed preparation	Land having loamy or clay loam soils, sufficient sunlight, irrigation, and drainage facility was selected for seedbed preparation
Seedbed preparation	• Decomposed cowdung at 2.0 kg·m^{-2} was spread uniformly on the surface of the seedbed before or at land preparation • Land plowed 2 - 3 times by power tiller followed by laddering and allowed to decompose for 7 - 10 days to make the soil soft and muddy • When soils became sufficiently soft and muddy, 1.0-m-wide raised beds (length as long as the length of the land) were made surrounded by a 25-cm-wide and 10 - 15-cm deep canal. The soils from the canal were put on the bed. The number of beds made depended on the land size and requirement • Surface of the raised bed was leveled by a plane and flat wood • Soils at the surface of the raised bed were allowed to settle for 3 - 4 h before seed sowing
Seed rate sown on seedbed, range (g·m^{-2})	80 - 100
Water management	Canals surrounding the raised beds always kept full with water to prevent soil cracking at the surface of the raised bed. Soil surface of the raised bed was not allowed to crack
Seedling age, range (days)	28 - 34 in Aman and 40 - 48 in Boro
	Plant population at planting
Hill spacing at transplanting (cm)	20 × 20
Number of seedlings per hill (no.)	3 - 4
P, K, S, and Zn fertilizer management	Total amounts of P as triple superphosphate, S as gypsum, Zn as zinc sulfate, and K as KCl were applied basally immediately before transplanting rice in both Boro and Aman seasons. The fertilizer rates (kg·ha^{-1}) were: Boro season: 17 P, 62 K, 10 S, and 2 Zn; Aman season: 12 P, 42 K, 10 S, and 2 Zn
N fertilizer management, mean ± S.D.	The N rates (kg·ha^{-1}) for the LCC option given below: Aman 2009: 88 ± 14 in 3 - 4 splits; Aman 2010: 93 ± 11 in 3 - 4 splits; Aman 2011: 83 ± 12 in 3 - 4 splits; Boro 2009-10: 117 ± 14 in 3 - 4 splits; Boro 2010-11: 111 ± 17 in 3 - 4 splits; Boro 2011-12: 117 ± 14 in 3 - 4 splits

[a]S.D., standard deviation of the mean.

Analysis of variance (ANOVA) of the treatment means were compared using Least Significant Difference (LSD) at the 5% level of probability [17]. Descriptive statistics such as means, standard deviation, range, 25% quartile, and 75% quartile were used to determine the variability of parameters.

Treatments were evaluated based on added net return relative to the farmers' practice, which is the difference between added gross return and added cost for a treatment as compared with FP. Added gross return equaled additional yield as rough rice (yield of treatment−yield of FP) multiplied by the price of yield. Added cost equaled the sum of costs for differences in labor determined as [(labor for seedling raising, transplanting, and fertilizer application of the treatment-labor for seedling raising, transplanting, and fertilizer application of FP) × wage rate] and costs for differences in fertilizer and seed-treating chemicals determined as (fertilizer and seed-treating chemical costs of treatment-fertilizer and seed-treating chemical costs of FP). The prices of seeds, cowdung, fertilizer, seed-treating chemical, rough rice, and labor wage were as follows: seed = US $0.45 kg^{-1}, cowdung = US $12.86 to 19.29 Mg^{-1}, P fertilizer = US $0.28 to 0.51 kg^{-1} P, K fertilizer = US $0.19 to 0.45 kg^{-1} K, S fertilizer = US $0.06 to 0.08 kg^{-1} S, Zn fertilizer = US $1.29 to 1.54 kg^{-1} Zn, urea = US $0.15 to 0.26 kg^{-1}

N, USG = US $0.21 to 0.29 kg^{-1} N, seed-treating chemical = US $34.07 to 35.48 kg^{-1}, rough rice = US $0.22 to 0.26 kg^{-1}, and labor wage = US $1.93 to 2.57 person-day^{-1} (US $1 = Bangladesh Taka 77.78).

3. Results and Discussion

3.1. Grain Yield

BRRI management practices and BRRI management practices along with two N management options, either LCC or USG, had a significant response in rice grain yield in both Aman and Boro seasons in all three years (**Table 4** and **Table 5**). Famers' management practices when coupled with either quality seed, LCC or USG also showed significant increase in grain yields compared to farmers' practices. The yields of BRRI-LCC, BRRI-USG and BRRI recommended practices were always similar in the range 4.29 - 4.84 Mg·ha^{-1} in Aman and in 5.12 - 5.50 Mg·ha^{-1} Boro. BRRI recommended practices produced the highest yield in Aman 2009, 2011 and in Boro 2011-12. BRRI-USG produced the highest yield in Aman 2010 and in Boro 2010-11 and BRRI-LCC in Boro 2009-10.

BRRI-LCC, BRRI-USG and BRRI recommended practices turned out about 41% - 62% in wet and 27% - 38% higher grain yield in dry season, respectively. The results of the study also implies that yield advantage of 13% - 35% in wet season and 1% - 21% in dry season could be attained when only quality seeds, USG and LCC were used with farmers' management practice. On average, the yields in Boro were 18% higher than the yields in Aman, with the highest yield of 5.50 Mg·ha^{-1} in Boro and 4.84 Mg·ha^{-1} in Aman.

Figure in parenthesis indicates yield increase in percent over farmers practice

Irrespective of years, the average yield for the system (combined yield of Aman and Boro seasons within a cropping year) for FP was 7.04 Mg·ha^{-1}. The system productivity of FP-QS, FP-USG and FP-LCC, BRRI-LCC, BRRI-USG and BRRI Recommended management options was 8.53, 7.92, 7.85, 9.84, 9.91and 9.99 Mg·ha^{-1}. BRRI-reported that average attainable yield for this system is 14 Mg·ha^{-1} [10]-[13]. When farmers adopted BRRI Rec., BRRI-LCC and BRRI-USG·management options (9.91 Mg·ha^{-1}) resulting a yield gap of 4.09 Mg·ha^{-1}. On the other hand, system productivity of FP-QS, FP-USG and FP-LCC management options was 8.10 Mg·ha^{-1} resulted in a yield gap of 5.90 Mg·ha^{-1}. Thus, in this study, BRRI Rec., BRRI-LCC and BRRI-USG

Table 4. Rice grain yield with different management options during Aman seasons in farmers' fields of central Bangladesh, 2009-2011.

Treatments	Grain yield (Mg·ha^{-1})		
	2009	2010	2011
FP	3.09	2.99	3.05
FP-QS	4.16 (35)	3.76 (26)	3.77 (24)
FP-USG	3.83 (24)	3.74 (25)	3.44 (13)
FP-LCC	3.77 (22)	3.67 (23)	3.49 (14)
BRRI-LCC	4.69 (52)	4.67 (56)	4.29 (41)
BRRI-USG	4.55 (47)	4.84 (62)	4.39 (44)
BRRI Rec.	4.71 (52)	4.73 (58)	4.48 (47)
F values for treat		**	
F values for year		*	
F values for treat x year		NS	
$LSD_{0.05}$ for treat		0.34	
$LSD_{0.05}$ for year		0.22	
$LSD_{0.05}$ for treat x year		-	
CV (%)		11.6	

NS, *, ** for not significant, significant at 5 and 1% level, respectively.

Table 5. Rice grain yield with different management options during Boro seasons in farmers' fields of central Bangladesh, 2009-2011.

Treatments	Grain yield ($Mg \cdot ha^{-1}$)		
	2009-10	2010-11	2011-12
FP	3.96	3.99	4.04
FP-QS	4.54 (15)	4.47 (12)	4.88 (21)
FP-USG	4.45 (12)	4.04 (1)	4.26 (5)
FP-LCC	4.22 (7)	4.19 (5)	4.20 (4)
BRRI-LCC	5.31 (34)	5.45 (37)	5.12 (27)
BRRI-USG	5.21 (32)	5.50 (38)	5.23 (29)
BRRI Rec.	5.27 (33)	5.42 (36)	5.37 (33)
F values for treat		**	
F values for year		NS	
F values for treat x year		*	
$LSD_{0.05}$ for treat		0.14	
$LSD_{0.05}$ for year		-	
$LSD_{0.05}$ for treat x year		0.23	
CV (%)		5.9	

NS, *, ** for not significant, significant at 5 and 1% level, respectively.

management options reduced the yield gap of the farmers' practice by 2.87 $Mg \cdot ha^{-1}$. Results also revealed that famers can able to trim down the existing gap by 1.49, 0.88 and 0.81 $Mg \cdot ha^{-1}$ when only quality seeds, USG and LCC were used with farmers' management practice. The higher positive response of BRRI-LCC, BRRI-USG and BRRI recommended practices was due to the combined effects of certified seeds with seed treatment, healthy seedlings, optimum planting density, balanced fertilization, and better synchronization of N fertilization with plant needs. These findings suggest potential to increase farmers' rice yields through BRRI recommended practices in an integrated way. Other studies in India and Bangladesh rice fields also reported comparatively higher yields in the range 0.8 - 2.0 $Mg \cdot ha^{-1}$ with the use of improved methods of more than one crop production factor in an integrated way [18]-[20].

Box and whisker plots showed higher mean and median yield of wet and dry season rice on BRRI-LCC, BRRI-USG and BRRI Rec. treatments, with the lowest under farmers' practice (**Figure 4**). The inter-quartile range (IQR—a measure of variability, based on dividing a data set into quartiles) was higher in wet season rice and lower in dry season rice, indicating higher variability in the former than the latter.

In wet season, Box and whisker plots for grain yields under BRRI-LCC, BRRI-USG and BRRI Rec. treatments showed higher variability than the other treatments. High variation in rainfall and maximum temperature during the study period may have the contribution in higher grain yield variability (**Figure 2** and **Figure 3**). Whereas, BRRI-LCC, BRRI-USG and BRRI Rec. treatments showed lower variability in dry season rice. Lower variability of dry season rice yield may be the consequence of lower variation in minimum and maximum temperature in dry seasons (**Figure 3**). A similar observation was reported by [21] who examines the relationship between the yield of three major rice crops (e.g., Aus, Aman and Boro) and three main climate variables (e.g., maximum temperature, minimum temperature and rainfall) for Bangladesh.

3.2. Economic Analysis

Added costs and added net returns for different management options relative to the FP were used to assess profitability for the use of different management practices (**Table 6**). The average added costs for BRRI recommended management option and BRRI recommended management practices along with two N management options in Aman and Boro across years ranged from \$92 to 124 ha^{-1} and from \$75 to 114 ha^{-1}, respectively. The

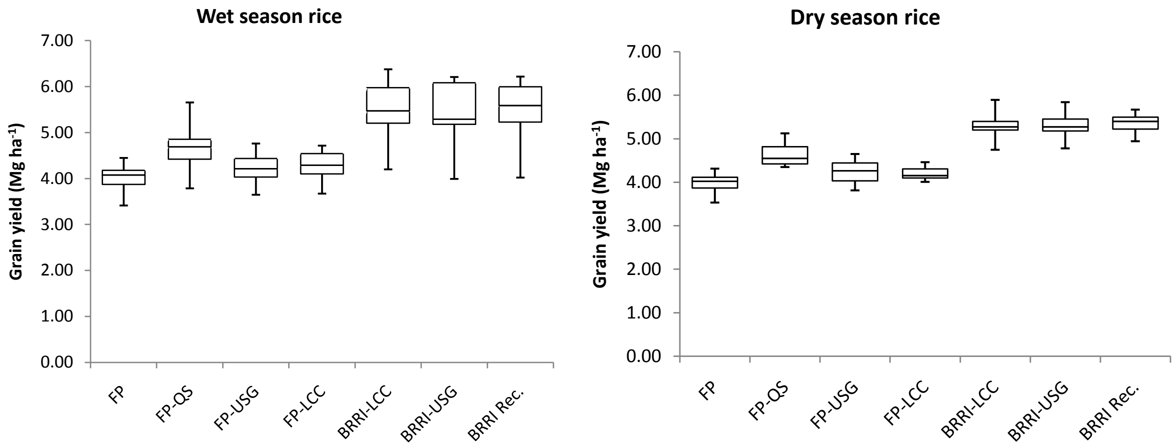

Figure 4. Box and whisker plots showing variability of grain yield of wet and dry season rice under different management options across 3 years of experimentation in central Bangladesh.

added costs associated with BRRI management practices involved treatments in at least 75% of the farmers' fields were ≥$94 - 123 ha^{-1} in Aman and ≥$77 - 114 ha^{-1} in Boro. These added costs for BRRI Rec., BRRI-LCC and BRRI-USG·management options were mainly because of the additional application of P, K, Zn and additional labor requirement with these management options. The large ranges in added costs suggest substantial variation in the amounts of additional P, K, Zn and labor use.

The average added costs for FP-QS in Aman and Boro across years was $13ha^{-1}. The average added costs for FP-USG in Aman and Boro across years ranged from $31 to 49 ha^{-1} and from $33 to 49 ha^{-1}, respectively. The added costs associated with FP-USG in at least 75% of the farmers' fields were ≥$33 - 46 ha^{-1} in Aman and ≥ $35 - 49 ha^{-1} in Boro. This cost for FP-USG was mainly because of the additional labor requirement with USG placement. FP-LCC management option did not impose any additional cost both in Boro and Aman across years except in Aman, 2011.

The average added net returns with BRRI recommended management option and BRRI recommended management practices along with two N management options were always positive, ranging from US $175 to 362 ha^{-1} in Aman and from US$159 to 265 ha^{-1} in Boro across years. The added net returns associated with BRRI-LCC, BRRI-USG and BRRI recommended practices in at least 75% of the farmers' fields were ≥$305 to 440 ha^{-1} in Aman and ≥$196 to 324 ha^{-1} in Boro (**Table 6**). The average added net return was highest with BRRI recommended management practice compared with other treatments in both seasons across three years. The average added net returns were higher with BRRI–LCC than with BRRI–USG in both seasons, suggesting LCC-aided N management as a more profitable option than USG. The average added net return with FP-QS was ranging from US $ 146 to 233 ha^{-1} in Aman and from US$101 to 177 ha^{-1} in Boro across years. The added net returns associated with FP-QS in at least 75% of the farmers' fields were ≥$187 to 267 ha^{-1} in Aman and ≥$121 to 324 ha^{-1} in Boro. The average added net return with FP-LCC was ranging from US$ 96 to 173 ha^{-1} in Aman and from US $37 to 60 ha^{-1} in Boro across years. The added net returns associated with FP-LCC in at least 75% of the farmers' fields were ≥$147 to 224 ha^{-1} in Aman and ≥$51 to 67 ha^{-1} in Boro. FP-USG resulted average added net return ranging from US $42 to 159 ha^{-1} in Aman and from US $24 to 76 ha^{-1} in Boro across years. The negative added net returns with FP-USG in at least 25% of the farmers' fields were mainly due to high added costs ($34 - 46 ha^{-1}) compared with added returns from increased yield (0.04 - 0.39 Mg·ha^{-1}) in Aman 2011, Boro 2010-11, and Boro 2011-12. The large ranges in added net returns ($115 to 662 ha^{-1}) indicate large farm-to-farm variability in the costs and gains associated with inputs and outputs for using BMP along with either LCC or USG across seasons and years (**Table 6**).

In Aman season, on an average per dollar net return (added net return divided by added cost) was highest in BRRI recommended management practices ($ 2.84) followed by BRRI-LCC ($ 2.70). But in Boro season, it was highest in BRRI-LCC ($ 2.54) followed by BRRI recommended management practices ($2.40). The results suggested that BRRI recommended management practices and BRRI-LCC were more profitable option compared to others.

Table 6. Added costs and added net returns with different management practices during Aman and Boro seasons in farmers' fields of central Bangladesh, 2009-2012.

Management practices	Added cost (US $ ha^{-1})				Added net return (US $ ha^{-1})			
	Mean	Range	25% quartile	75% quartile	Mean	Range	25% quartile	75% quartile
Aman 2009								
FP-QS	13	13	13	13	233	94 to 456	156	267
FP-USG	34	31 to 37	34	35	137	103 to 217	104	146
FP-LCC	0	0	0	0	154	65 to 243	111	198
BRRI-LCC	101	100 to 102	100	102	270	69 to 482	124	409
BRRI-USG	121	119 to 124	119	122	215	−32 to 425	82	365
BRRI Rec.	101	100 to 102	100	102	273	91 to 444	126	426
Aman 2010								
FP-QS	13	13	13	13	184	20 to 443	91	209
FP-USG	32	31 to 35	31	33	159	−38 to 412	5	262
FP-LCC	0	0	0	0	173	28 to 420	39	224
BRRI-LCC	93	92 to 94	92	94	338	155 to 662	173	386
BRRI-USG	112	107 to 115	109	113	362	142 to 630	268	440
BRRI Rec.	93	92 to 94	92	94	353	135 to 626	222	394
Aman 2011								
FP-QS	13	13	13	13	146	4 to 237	138	187
FP-USG	44	39 to 49	41	46	42	−12 to 126	−4	60
FP-LCC	2	2	2	2	96	19 to 223	36	147
BRRI-LCC	97	95 to 98	98	98	177	−37 to 328	92	305
BRRI-USG	120	118 to 123	118	123	175	−88 to 349	109	346
BRRI Rec.	101	100 to 102	100	102	213	−42 to 375	150	361
Boro 2009-10								
FP-QS	13	13	13	13	118	63 to 166	119	121
FP-USG	35	33 to 39	33	37	76	41 to 107	54	89
FP-LCC	0	0	0	0	60	29 to 79	58	67
BRRI-LCC	82	81 to 83	81	83	222	164 to 299	175	238
BRRI-USG	96	92 to 99	92	97	185	139 to 210	184	200
BRRI Rec.	77	75 to 79	75	77	218	163 to 274	190	238
Boro 2010-11								
FP-QS	13	13	13	13	101	−3 to 221	35	137
FP-USG	34	33 to 37	33	35	−24	−115 to 42	−69	35
FP-LCC	0	0	0	0	47	−13 to 132	31	51
BRRI-LCC	86	84 to 86	84	86	265	132 to 344	243	324
BRRI-USG	99	99 to 100	99	100	263	128 to 374	203	320
BRRI Rec.	103	100 to 107	101	105	241	80 to 414	221	245
Boro 2011-12								
FP-QS	13	13	13	13	177	65 to 276	132	231
FP-USG	46	44 to 49	44	49	3	−19 to 24	−4	8
FP-LCC	0	0	0	0	37	−12 to 98	17	62
BRRI-LCC	86	83 to 86	86	86	159	66 to 232	91	219
BRRI-USG	111	106 to 114	109	114	158	48 to 272	115	196
BRRI Rec.	96	94 to 97	94	97	204	102 to 279	185	234

The higher positive added net returns with the use of BRRI-LCC, BRRI-USG and BRRI recommended management practices in the majority of farmers' fields confirmed that they are ready for wide-scale evaluation and promotion in Bangladesh. Our results suggest that BRRI recommended management practices and BRRI recommended management practices along with either LCC or USG can be promoted through integration with the farmers' own portfolio of practices for increased profitability. The markedly increased yield and profit for rice in Bangladesh reported in another study [19] arise from the use of LCC-based N management combined with improved management of other nutrients and improved weed control.

4. Conclusion

Efficient and judicious integration of improved crop management practices along with the farmers' management practices has scope to increase rice production in Bangladesh. About 27% - 62% grain yield increases with BRRI-LCC, BRRI-USG and BRRI recommended management practices resulting in farmers' net profit increase of US $158 to 362 ha^{-1}. Adoption of BRRI-LCC, BRRI-USG and BRRI recommended management practices in an integrated way can be a measure to attain productivity through minimizing yield gap. A massive and effective program for wider demonstration, refinement, and dissemination of BRRI-LCC, BRRI-USG and BRRI recommended management practices in an integrated way throughout the country may be taken to improve the productivity and profit from rice farming.

5. Limitation of the Study

Although the selected fields were in same ecosystem, soil physical and chemical properties analysis might assist in better interpretation of the findings.

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