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RESEARCH ARTICLE

Optimum and Economic Doses of Inorganic Fertilizers for Rice in Cold and Submergence Ecosystem of Bangladesh

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Abstract

Appropriate fertilizer application is an important management practice to improve soil fertility and increase rice yield. An experiment was conducted for four consecutive seasons: Boro (dry season) 2011-12 to T. Aman (wet season) 2013 at the farmer's field in Gongachara, Rangpur (25.86° N and 89.24° E) to find out optimum fertilizer dose for rice-based cropping systems in cold and submergence ecosystem in Bangladesh. In the present study, we examined the effects of eight fertilizer treatments and laid out in randomized complete block design with three replications. The treatment combinations were: T_1=100% NPKSZn (Soil test basis), T_2=T_1+25% N, T_3=T_1+25% NP, T_4=T_1+25% NK, T_5=T_1+25% PK, T_6=T_1+25% NPK, T_7=75% of T_1 and T_8=Absolute control. Results showed that application of different fertilizers significantly affected the rice yield at both of the seasons. In dry season 2011-12, the highest grain yield was found in treatment T_3 while T_6 gave the highest grain yield in dry season 2012-13. On the other hand, in wet season 2012 and 2013, the highest grain yield was found in T_6 treatments. However, on the basis of yield performance, economic analysis and nutrient absorption, it is observed that 25% additional NP (T_3) is more profitable than that of other fertilizers combinations.

Keywords: AEZ 3, Cropping pattern, Crop-cycle, Nutrient uptake, Marginal benefit cost ratio.

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1. INTRODUCTION

Bangladesh is one of the densely populated countries of the world. The total area of Bangladesh is 147, 570 km^2. Most of the people depend on rice as main food all the year especially. Rice production increases must be achieved at a faster rate than in most other countries, while the land planted to rice is not expanding. In addition, Bangladesh is faced with production constraints such as drought, cold, lack of irrigation facilities, flooding, submergence and salinity of soils, coupled with appropriate fertilizer management technologies. To maintain self-sufficiency in rice, Bangladesh will have to continue to expand rice production by raising yields at a rate that is at least equal to population growth until the demand for rice has stabilized.

Increased pressure of growing population demand more food. Thus it has become increasingly important to explore the possibilities of increasing the potential of these (cold and submergence ecosystem) lands for increased production of crops. To meet the food grain requirement for a growing population with limited land resources, an increasing pressure on the land is taking place without adequate compensation of the plant nutrient taken up from the soil. Nutrient mining is one of the major causes for stagnation or decline in yield of major crops of Bangladesh. If this problem of nutrient depletion is not corrected it will cause a serious damage of the soil and to the welfare of mankind. Relatively higher amount of fertilizers need to be used in HYV of different crop cultivation. Fageria *et al*. [1] stated that supplying of mineral nutrients to crops in adequate amounts is one of the most important factors in achieving higher productivity. Recently, it has been observed that more fertilizer application than soil test basis (STB) recommended fertilizer dose gives extra benefit in unfavorable ecosystems of Bangladesh [2 & 3]. There might be a reason: STB dose is determined on the basis of critical limit of nutrient for crop and critical limit was identified on the basis of average data of whole country. As a result, critical limit is not equally effective for unfavorable ecosystems (saline, drought, cold, submergence, tidal, etc.). It is, therefore, urgently needed to research on fertilizer requirement for rice based cropping system in unfavorable ecosystems.

Therefore, we attempted to find out the optimum and economic dose of fertilizer for rice-fallow-rice and rice-based cropping systems in cold and submergence ecosystem under agro-ecological zone (AEZ) 3.

2. Materials and Methods

2.1 Experimental sites and seasons

Field experiment was carried out for four consecutive seasons: Boro (dry season) 2011-12 to T. Aman (wet season) 2013 at the farmer's field in Gongachara, Rangpur (25.86° N and 89.24° E). Two rice crops were grown annually in two seasons known as T. Aman and Boro. T. Aman was the wet season (June–July to November–December) in which transplanted rice was grown under partially irrigated conditions in the study area. Boro was the dry season (December–January to April–May) in which transplanted rice was grown under fully irrigated conditions. Semi-dwarf, high-yielding rice varieties were grown in the study area; BRRI dhan29 with 165 days' duration was grown in dry season (2011-12 and 2012-13) and BRRI dhan52 with 140 days' duration was grown in wet season (2012 and 2013). The field belongs to AEZ number 3 known as Tista Meander Floodplain. The silt loam soil having pH 6.43, organic carbon 0.70%, total N 0.06%, available P 16.0 mg kg^{-1}, available K 0.13 cmol kg^{-1}, available S 14.4 mg kg^{-1} and available Zn 0.98 mg kg^{-1} was used in the experiment.

2.2 Experimental design and treatments

The experiment was established in farmer's fields in a randomized complete block design with eight treatments and three replications. The treatments were: T_1 = 100 % NPKSZn (Soil Test Basis, STB, according to the BARC, 2005 [4]); $T_2 = T_1$ + 25 % N; $T_3 = T_1$ + 25 % NP; $T_4 = T_1$ + 25 % NK; $T_5 = T_1$ + 25 % PK; $T_6 = T_1$ + 25 % NPK; T_7 = 75 % of T_1 and T_8 = Absolute control (no fertilizer). In dry season, NPKSZn were applied @ 187-13-75-15-1.1, 234-13-75-15-1.1, 234-16-75-15-1.1, 234-13-94-15-1.1, 187-16-94-15-1.1, 234-16-94-15-1.1, 140-10-56-11-0.8 and 0-0-0-0-0 kg ha^{-1} in T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 treatments, respectively. In wet season, NPKSZn were applied @ 100-7-39-10-1, 125-7-39-10-1, 125-9-39-10-1, 125-7-49-10-1, 100-9-49-10-1, 125-9-49-10-1, 75-5-29-7.5-0.75 and 0-0-0-0-0 kg ha^{-1} in T_1, T_2, T_3, T_4, T_5, T_6, T_7 and T_8 treatments, respectively. The total amounts of P as triple superphosphate, K as KCl and S as gypsum, were applied as basal-immediately before transplanting of rice in both dry and wet seasons. In the recommended practice for rice, N was applied as urea in three equal splits at basal, 25-30 days after transplanting (DAT) and 5-7 days before PI stage in dry season. In wet season, N fertilizer was applied as urea in three equal splits at basal, 20 DAT and 5-7 days before panicle initiation stage. Unit plot size was 20 m^2 (4 m × 5 m). All plots were surrounded by permanent bunds to prevent transfer of soil and nutrients between plots. In all cases, rice was transplanted and grown on submerged soil with irrigation. Weeds and insects were controlled to avoid yield losses.

2.3 Soil and plant sampling and analysis

Initial soils were collected before land preparation with an auger with 5 cm internal diameter in the plough layer (0–15 cm) at nine randomly selected locations and then mixed as one sample. All fresh soil samples were air-dried, ground and passed through a 2-mm sieve and prepared for routine analyses of texture, pH, OC, total N, available K, P, S and Zn using the methods described by Islam [5]; Saha *et al*. [6]; Islam *et al*. [7, 8, 9 & 10].

Grain yield was recorded from the central 5 m^2 harvest area in each plot at maturity and reported on 14% moisture basis. At maturity, 16 hills (four hills from each of the four sides of the grain harvest area) were collected at ground level and fresh straw weight was determined after separating the grains. Grain and straw were dried at 70°C to constant weight and dry weights were recorded. The ratio of fresh and oven-dry weights of straw for 16-hill samples was then used to determine straw yields on an oven-dry basis from fresh straw weights [11, 12 & 13]. Dry grain and straw from the 16-hill samples were ground to pass through a 0.5-mm sieve and analyzed for total N, P and K following standard procedure. The N, P and K contents in grain plus straw were taken as the measure of total N, P and K uptake.

Total N was determined following Micro Kjeldahl method [14]. Plant samples were digested using the HNO_3-$HClO_4$ (5:2) di-acid mixture. Phosphorous was determined colorimetrically by spectrophotometer (Model-V-630, Jasco) and potassium was determined by flame photometer (model-410, Sherwood) according to the procedure described by Yoshida *et al.* [15].

2.4 Data analysis

Analysis of variance (ANOVA) was performed on yield and N, P and K uptake to determine the effects different treatments using the IRRISTAT software version 4.1 [16]. Least significant difference (LSD) at the 0.05 level of probability was used to evaluate the differences among treatment means.

3. RESULTS AND DISCUSSION

3.1 Rice yield

Applied fertilizer significantly influenced the grain and straw yield in dry seasons of 2011-12 (Table 1) and 2012-13 (Table 2). In dry season (2011-12), the highest grain yield of 8.68 t ha^{-1} was obtained with the treatment T_3, while the lowest grain yield (4.39 t ha^{-1}) was found in the treatment T_8 (Table 1). Straw yield (9.01 t ha^{-1}) was higher in treatment T_3, which was statistically similar to the treatments T_2, T_4 & T_6 (Table 1). The lowest straw yield (6.06 t ha^{-1}) was found in the treatment T_8. In dry season (2012-13), the grain yield was higher in the treated plots than that of the control plot (T_8). The highest grain yield of 9.10 t ha^{-1} was obtained with the treatment T_6, which was statistically similar to T_1, T_2, T_3, T_4 and T_5 (Table 2). The lowest grain yield (3.30 t ha^{-1}) was found in the control plot (T_8). In case of straw yield similar trend was noted (Table 2).

Table 1. Effect of different fertilizer packages on the yield of rice (t ha^{-1}) in a Boro-Fallow-T. Aman cropping pattern, 2011-12.

Treatments	Dry season 2011-12 (BRRI dhan29)		Wet season 2012 (BRRI dhan52)		Annual yield (t ha^{-1} crop-cycle^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1 = NPKSZn (STB)¶	7.00	6.76	5.55	6.55	12.55	13.31
$T_2 = T_1$+ 25% N	7.12	8.66	5.35	8.24	12.47	16.9
$T_3 = T_1$+ 25% NP	8.68	9.01	5.73	8.60	14.41	17.61
$T_4 = T_1$+ 25% NK	7.25	8.89	5.36	7.99	12.61	16.88
$T_5 = T_1$+ 25% PK	7.41	6.74	5.57	8.87	12.98	15.61
$T_6 = T_1$+ 25% NPK	6.67	8.53	6.02	8.03	12.69	16.56
T_7 = 75% of T_1	7.44	7.67	5.34	6.53	12.78	14.2
T_8 = Control	4.39	6.06	4.01	6.19	8.4	12.25
$LSD_{0.05}$	1.00	0.80	0.54	1.03	-	-
Significant level	**	**	**	**	-	-
CV (%)	8.1	5.8	5.8	7.7	-	-

¶Nutrient rates for $T_1 = N_{187} P_{13} K_{75} S_{15} Zn_{1.1}$ (Boro) and $T_1 = N_{100} P_7 K_{39} S_{10} Zn_1$ (T. Aman), ** = Significant at 1% level

Like dry season, applied fertilizer significantly influenced the grain and straw yield in wet season of 2012 (Table 1) and 2013 also (Table 2). The grain yield was higher in the treated plots than that of the control plot (T_8). In wet season 2012, the highest grain yield of 6.02 t ha^{-1} was obtained with the treatment T_6, which was statistically similar to T_1, T_2, T_3, T_4, T_5 and T_7 (Table 1). The lowest grain yield (4.01 t ha^{-1}) was found in the control plot (Table 1). Treatments T_2, T_3, T_4, T_5, and T_6 produced higher equal level of straw yield (7.99-8.03 t ha^{-1}) than that of T_1, T_7 and T_8 (6.19-6.55 t ha^{-1}) (Table 1). In wet season 2013, like first year (wet season 2012).

Table 2. Effect of different fertilizer packages on the yield of rice (t ha^{-1}) in a Boro-Fallow-T. Aman cropping pattern, 2012-13.

Treatment	Dry season 2012-13 (BRRI dhan 29)		Wet season 2013 (BRRI dhan52)		Annual yield (t ha^{-1} crop-cycle^{-1})	
	Grain	Straw	Grain	Straw	Grain	Straw
T_1 = NPKSZn (STB)¶	8.00	7.26	3.90	4.53	11.90	11.79
$T_2 = T_1$+ 25% N	8.16	7.27	3.31	5.07	11.47	12.34
$T_3 = T_1$+ 25% NP	8.57	7.49	4.14	4.94	12.71	12.43
$T_4 = T_1$+ 25% NK	9.06	6.85	4.10	4.95	13.16	11.80
$T_5 = T_1$+ 25% PK	8.53	6.68	2.98	3.79	11.51	10.47
$T_6 = T_1$+ 25% NPK	9.10	6.62	4.30	3.83	13.40	10.45
T_7 = 75% of T_1	6.94	5.26	2.94	3.33	9.88	8.59
T_8 = Control	3.30	3.82	1.64	1.90	4.94	5.72
$LSD_{0.05}$	0.67	1.14	0.40	0.91	-	-
Significant level	**	**	**	**	-	-
CV (%)	5.0	10.1	6.7	12.8	-	-

¶Nutrient rates for $T_1 = N_{187} P_{13} K_{75} S_{15} Zn_{1.1}$ (Boro) and $T_1 = N_{100} P_7 K_{39} S_{10} Zn_1$ (T. Aman), ** = Significant at 1% level

the highest grain yield of 4.30 t ha^{-1} was also obtained with the same treatment T_6 (Table 2). It was statistically similar to the treatments T_1, T_3 & T_4. The lowest grain yield (1.64 t ha^{-1}) was found in the control plot (Table 2). Straw yield (5.07 t ha^{-1}) was highest in treatment T_2, which was statistically similar to the treatments T_1, T_3 & T_4 (Table 2). The lowest straw yield (1.90 t ha^{-1}) was found in the treatment T_8 (Table 2). Additional fertilizer might be beneficial for maximizing rice yield in submergence area [2]. Availability of the nutrients is the resultant of a complex of soil factors [17]. So, nutrient availability is not same in all ecosystems. More fertilizer P is required at low soil temperatures to ensure sufficient P uptake [18]. This is an especially important phenomenon in cold and submergence ecosystem of Bangladesh where soils are often cold in dry season. The use efficiency of fertilizer N by the crop is typically low, due at least in part to losses of the applied fertilizer N arising from unique features of submerged soils as compared with aerated soils [19].

In 1st year crop-cycle, the highest annual grain yield 14.41 t ha^{-1} crop-$cycle^{-1}$ was obtained with the treatment T_3 (Table 1). The highest annual straw yield 17.61 t ha^{-1} crop-$cycle^{-1}$ was obtained with the same treatment T_3 (Table 1). But in 2nd year crop-cycle, the highest annual grain yield of 13.40 t ha^{-1} crop-$cycle^{-1}$ was obtained with the treatment T_6 (Table 2). On the other hand, the highest annual straw yield of 12.43 t ha^{-1} crop-$cycle^{-1}$ was obtained with the treatment T_3 like 1st year crop-cycle (Table 2).

3.2 Economic analysis

The estimated total variable cost (TVC), gross return, total value of extra production (added return) and marginal benefit cost ratio (MBCR) are presented in Table 3. Economic analysis was done considering the following: fertilizer cost, fertilizer application cost and labor cost for the additional product including by products due to fertilizer application. The application of fertilizer increased the gross and added return in all the treatments (Table 3). The gross return from the control plot per crop-cycle ha^{-1} was only about BDT 1,68,530/- and the application of fertilizer increase the gross return, which ranged from BDT 2,66,605/- ha^{-1} crop-$cycle^{-1}$ in T_7 to BDT 3,26,145/- ha^{-1} crop-$cycle^{-1}$ in T_3. The highest added-return of BDT 1,57,615/- ha^{-1} crop-$cycle^{-1}$ was obtained with T_3 followed by T_4 (BDT 1,41,635/- ha^{-1} crop-$cycle^{-1}$). The MBCR of all treated plots ranged from 4.28 (T_2) to 5.00 (T_3), which were higher than the permissible limit (2.00).

Table 3. Average yield (t ha^{-1}) and fertilizer use economy as affected by nutrient combinations, 2011-13.

Treatment	Average yield (2011-12 & 2012-13)				Gross return** (BDT ha^{-1} crop-$cycle^{-1}$)	Total value of extra production (BDT ha^{-1} crop-$cycle^{-1}$)	TVC* (BDT ha^{-1} crop-$cycle^{-1}$)	MBCR
	Dry season (BRRI dhan29)		Wet season (BRRI dhan52)					
	Grain	Straw	Grain	Straw				
T_1 = NPKSZn (STB)	7.50	7.01	4.73	5.54	289005	120475	26592	4.53
$T_2 = T_1$ + 25% N	7.64	7.97	4.33	6.66	294595	126065	29478	4.28
$T_3 = T_1$ + 25% NP	8.63	8.25	4.94	6.77	326145	157615	31500	5.00
$T_4 = T_1$ + 25% NK	8.16	7.87	4.73	6.47	310165	141635	31252	4.53
$T_5 = T_1$ + 25% PK	7.97	6.71	4.28	6.33	291825	123295	28088	4.39
$T_6 = T_1$ + 25% NPK	7.89	7.58	5.16	5.93	308975	140445	31949	4.40
T_7 = 75% of T_1	7.19	6.47	4.14	4.93	266605	98075	20510	4.78
T_8 = Control	3.85	4.94	2.83	4.05	168530	0	0	0

*Total variable cost (TVC) included fertilizer cost (chemical fertilizer), fertilizer application cost and labor cost for additional product. Price (BDT/kg): Urea = 20.00; TSP = 22.00; MP = 16.00; Gypsum = 12.00; $ZnSo_4$ = 180.00. Labor wage rate = BDT 230/day, **Price (BDT/kg): Paddy = 18.50; straw = 5.00.
Two additional man-days/ha are required for applying fertilizer and four man-days/ha for per ton additional products including byproducts.

Two additional man-days/ha are required for applying fertilizer and four man-days/ha for per ton additional products including byproducts.

3.3 Nutrient uptake

Applied fertilizer significantly influenced the nutrient uptake by Boro and T. Aman rice of the cropping pattern (Table 4). The highest total NPK nutrient uptake (kg ha^{-1} crop-$cycle^{-1}$) was observed in the treatment T_3 followed by T_4. The lowest total NPK nutrient uptake (kg ha^{-1} crop-$cycle^{-1}$) was observed in the treatment T_8 (Table 4).

Table 4. Effect of different fertilizer packages on the nutrient uptake (kg ha^{-1}) by rice in a Boro–Fallow–T. Aman cropping pattern, 2011-12

Treatments	Dry season 2011-12			Wet season 2012			Total nutrient uptake (kg ha^{-1}crop-$cycle^{-1}$)		
	Nutrient uptake (kg ha^{-1})			Nutrient uptake (kg ha^{-1})					
	N	P	K	N	P	K	N	P	K
T_1 = NPKSZn(STB)¶	91	18	157	101	9	143	192	28	301
$T_2 = T_1$+25% N	104	20	201	88	10	202	191	30	403
$T_3 = T_1$+25% NP	130	22	207	112	11	207	242	33	414
$T_4 = T_1$+25% NK	137	20	213	99	10	189	235	30	402
$T_5 = T_1$+25%PK	96	20	159	107	11	224	203	32	383
$T_6 = T_1$+25% NPK	114	19	194	119	11	183	233	30	377
T_7 = 75% of T_1	94	19	170	98	9	162	191	27	332
T_8 = Control	56	12	139	67	8	145	123	20	284
$LSD_{0.05}$	24	3	31	29	1	27	-	-	-
Significant level	**	**	**	*	**	**	-	-	-
CV (%)	13.4	10.0	10.0	16.6	7.1	8.4	-	-	-

¶Nutrient rates for $T_1 = N_{187} P_{13} K_{75} S_{15} Zn_{1.1}$ (Boro) and $T_1 = N_{100} P_7 K_{39} S_{10} Zn_1$ (T. Aman), ** = Significant at 1% level, *= Significant at5% level,

Conclusion

On the basis of yield performance, economic analysis and nutrient absorption the treatment $T_3 = T_1$+25% NP ($N_{234} P_{16} K_{75} S_{15} Zn_{1.1}$ for dry season and $N_{125} P_9 K_{39} S_{10} Zn_1$ for wet season) performed the best among the treatments in cold and submergence ecosystem. From the result it is observed that present recommended dose of fertilizer is not sufficient to obtain optimum yield. So, 25% more NP fertilizer is required to obtain better yield in this ecosystem.

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