Rice yield potential under unfavorable soil ecosystems in Bangladesh

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Abstract

Unfavorable ecosystems in Bangladesh are under intense pressure of crop production and climate change impact; although the relationships of indigenous soil nutrients ratios with crop performance are yet to be fully explored. Experiments were conducted under submergence and cold prone areas (agricultural ecological zone, AEZ-3), drought and cold prone areas (AEZ-26), non-saline tidal flood ecosystem (AEZ-13), char and saline prone ecosystem (AEZ-18) and haor ecosystem (AEZ-21) for evaluating rice grain yield with native nutrients ratios. Synergistic and antagonistic relationships were observed in different AEZ depending on indigenous nutrient ratios. The Ca:P and N:Zn ratios were playing significant negative role with rice yield in wet season. In dry season, P:K ratio was acting antagonistically in AEZ-18, AEZ-3 and AEZ-26 but K:Mg, Ca:Zn S:Zn P:Zn were playing synergistic role in the same localities. The C:K ratio was playing antagonistic role with dry season irrigated rice yield in AEZ-13 and AEZ-21. Dry season irrigated rice grain yield was 13-27% lower in AEZ-26 than others AEZ because of variations in negative ratios of nutrients. Application of 187-13-75-15-1.1, 174-27-19-840, 162-11-58-11-0, 180-24-14-15-4 and 144-36-5-3-0 kg/ha of N-P-K-S-Zn, respectively for Rangpur, Rajshahi, Barisal, Sonagazi and Habiganj improved dry season rice yield significantly in all AEZ except AEZ-18 compared to indigenous soil fertility. Soil separates showed variable relationships with indigenous nutrient ratios in different AEZ. It is concluded that indigenous soil nutrient ratios play a vital role in improving rice yield under unfavorable ecosystems.

Key word: Agricultural ecological zone, Native nutrient ratio, Rice yield

Introduction

Rice plays an important role in food security of Bangladesh and farmers grow this crop in most of their land throughout the year. It covers about 77% of total cropped area (13.88 million hectares) in Bangladesh (Quayum and Salam, 2012). Net cultivable area is decreasing, but food demand is increasing. It will require about 41 million metric tons of rice to feed about 169 million people by 2025 (Bhuiyan et al., 2002). The additional rice requirement needs to obtain from favorable and unfavorable ecosystems in Bangladesh by adopting new improved genotypes together with improved fertilizer and water management.

Fertilizer management requires proper understanding of indigenous soil nutrients and its behavior in soil-plant continuum. Either excess or deficit plant nutrient conditions have been a topic of intensive research since the beginning of modern agriculture. In spite of the decades of research in this area, many problems still existed and increased use of fertilizers has not been alleviated the problems. Interactions of soil mineral elements with plants are either antagonistic or synergistic depending on their availability and ratios in rhizosphere. The ratios are changing because of crop culture and soil ecology and thus causing either nutrient deficiency or toxicity. For example, inadequate supplies of one or more nutrients in the growing medium shift the existing ratios of nutrients. The interactions between these factors can be extremely complex, interfering with the absorption and utilization of nutrient elements by the plants and thus leading to the symptoms of abiotic nutritional damage (Bergman, 1992). Moreover, soil nutrient ratios are influenced by parent materials, geological locations, intensity of cropping and use of fertilizers etc (Chadwick et al., 1999; Cleveland and Liptzin, 2007). Excesses and shortages of some nutrients affect the uptake of other nutrients. For example, plant Mg levels are reduced when soil K:Mg ratio is above 1.5:1 or Mg:K ratio is less than 0.67. This effect is severe in grasses, especially with corn (Anonymous, 2016). Research works are limited on indigenous soil nutrient ratios for unfavorable ecosystems, although they are utilizing for crop production in many countries including Bangladesh. Over the years, a significant amount of conversation and salesmanship has revolved around the concept of the ideal soil Ca:Mg ratio. Most of the claims for the ideal ratio ranges between 5:1 and 8:1 (Anonymous, 2016), although yield or quality of crop is not appreciably affected over a wide range of Ca:Mg ratios in the soil. Though stable organic matter plays an important role in maintaining C:N:OP:S (carbon, nitrogen, organic phosphorus and sulfur) ratios for determining the availability of N, P and S for humus-C sequestration (Kirkby et al., 2011), high (Ca+Mg)/K ratios may contribute to K deficiency in rice soils (Dobermann et al., 1996). All these factors have been adequately studied for crop production in unfavorable ecosystems. So, the purpose of this study was to determine the effect of native soil nutrient concentrations and ratios on rice yield under unfavorable ecosystems in Bangladesh for sustainable use of those ecosystems.

Materials and Methods

Site description

Salient features of different regions are shown in Table 1

Char and saline prone ecosystem (AEZ-18)

About 1.0 million hectares (M ha) land of Bangladesh is affected by varying degrees of salinity. Crop production in this area is dominated by traditional wet season rice (T. Aman rice) and farmers generally harvest 2 t ha^{-1} grain yield, which is very low than other parts of the country due to soil salinity problem, drought in dry season, lack of adequate salinity tolerant varieties as well as lack of appropriate fertilizer management technologies.

Submergence and cold prone area (AEZ-3)

It covers about 2.6 million hectares. The devastating flood caused considerable loss of rice crop. The average yield of rice under flood-prone ecosystem is very low (2.5 t ha^{-1}) due to lack of technologies on flood tolerance rice varieties and their appropriate fertilizer management packages etc.

Drought and cold prone area (AEZ-26)

It is situated in north-west part of Bangladesh. Drought is very common in this part of the country having 1200-1400 mm mean annual rainfall from June to October. Drought affected area is nearly 2.5 million hectares (Mha) in Kharif and 1.2 Mha in dry season. Rice yield is poor due to lack of sufficient water and nutrition management.

Non-saline tidal flood ecosystem (AEZ-13)

This ecosystem covers about 1.9 Mha and the average yield of rice under non-saline tidal flood ecosystem is not more than 3.0 t ha^{-1} due to lack of technologies on appropriate fertilizer management packages etc.

Haor ecosystem (AEZ-21)

A haor is a wetland ecosystem in the north eastern part of Bangladesh. The total area in this ecosystem is 8 Mha square kilometers. Most of this area remains under water for seven months of the year. During dry season most of the water drains out, leaving small shallow lakes or may completely dry out by the end of dry season. This exposes rich alluvial soil, extensively cultivated for rice.

Cropping Pattern Based Experiments

During project period (2011-13), field experiments were conducted in Boro and T. Aman seasons considering different cropping patterns (Table 2).

The treatments tested were: T1 = N-P-K-S-Zn @ 187-13-75-15-1.1, 174-27-19-840, 162-11-58-11-0, 180-24-14-15-4 and 144-36-5-3-0 kg/ha respectively for Rangpur, Rajshahi, Barisal, Sonagazi and Habiganj regions in Boro season. Similarly N-P-K-S-Zn added for wet season were 100-7-39-10-1, 62-11-28-9-0 and 97-12-7-10-3 in Rangpur, Rajshahi and Sonagazi, respectively T2 = Absolute control. The experiment was laid out in a randomized complete block design (RCBD) with three replications.

Fertilizer application

One-third N and all other inorganic fertilizers were applied at final land preparation. The first top dress (One-third N) was applied at 20 DAT. The rest 1/3rd N was applied at 5-7 days before panicle initiation stage after drainage out of flood water. Necessary intercultural operations were done as and when ever required.

Data collection and analysis

At maturity, the crop was harvested from 5 m^2 area at the center of each plot. Grain and straw yields were recorded. Grain yield was adjusted to 14% moisture. Nutrient contents (N, P and K) from plant samples of the cropping pattern were determined by standard laboratory procedure.

Soil sample collection and analysis

A total of 125 composite soil samples (10 samples/spot) were collected from the surface layer (0-20 cm depth) from five AEZs (3, 13, 18, 21 & 26). Soil samples were collected from 25 farmers' fields at each location. Land type, soil series and land use were recorded. Soil samples were analyzed for texture, pH, EC, OC, total N, exchangeable cations (Ca, Mg and K), available P, S and Zn following standard methodology (Haque et al., 2015; Saleque et al., 2004).

Site specific indigenous soil nutrient ratios

The native soil nutrient ratios before crop culture varied widely depending on nature of soil ecology and cropping intensity in different localities of Bangladesh (Table 3). In AEZ-21, the N:P, N:Mg, N:Zn, and Ca:P ratios were the widest compared to other studied locations (Table 3). The C:N ratios ranged from 9.90:1 to 10.95:1. The P:Zn ratio was the lowest in AEZ-21 and N:P and Ca:P ratios were the lowest in AEZ-3.

Statistical analysis

Means for rice yield and soil properties were compared by using Tukey's HSD method. Fisher's protected least significant difference (LSD) was calculated at the 0.05 probability level for making treatment mean comparisons.

Results

Rice yield and nutrient ratios in wet season

In saline prone areas (Sonagazi, AEZ-18), indigenous soil nutrient ratios C:K, N:K, P:K and N:Mg showed significant positive correlations with wet season rice yield, although it showed significant negative relationships with K:Ca, K:Mg, Ca:P, Ca:Zn. S:Zn, N:Zn and P:Zn ratios (Table 4). Similarly, P:K and K:Ca ratios were synergistically related with grain yield but C:N, C:P, C:K, N:P, N:K, K:Mg, Ca:P, Ca:Zn, S:Zn, N:Mg, N:Zn and P:Zn ratios acted antagonistically in AEZ-3 (flash flood and cold prone areas). In drought prone areas (AEZ-26), all studied nutrient ratios (C:P, C: K ,N:P, N: K, P:K, Ca:P, N:Mg and N:Zn) showed significantly negative relationships with grain yield except K: Ca K: Mg, Ca:Zn, S:Zn and P:Zn ratios (Table 4).

Rice yield and nutrient ratios under dry season

In AEZ-18, K:Ca, K:Mg, Ca:P, Ca;Zn, S:Zn, N:Zn and P:Zn ratios showed significantly positive relationships with grain yield but significantly negative with C:K, N:P, N:K, P:K and N:Mg ratios (Table 5). The C:N, C:P and N:P ratios had no significant relationships with grain yield of rice. The C:P, C:K, N:P, N:K, K:Mg, Ca:P, Ca:Zn, S:Zn, N:Mg, N:Zn, P:Zn ratios favored significantly rice grain yield in AEZ-3. Nonetheless, P:K and K:Ca ratios acted negatively against rice yield. In AEZ-26, rice yields were influenced antagonistically by C:P, C:K, N:P, N:K, P: K, Ca:P, N:Mg and N:Zn ratios but others were synergistically correlated. In AEZ-13 (Tidal ecosystem), rice yield showed significant negative relationships with C:P, C:K, N:P, N:K, K:Ca, K:Mg, N:Mg and N:Zn ratios, but no significant relationships with P:K, Ca;P, Ca:Zn, S:Zn and P:Zn ratios. In AEZ 21 (haor ecosystem), only C:K showed significant antagonistic relationship with Boro rice grain yield but other nutrient ratios had no significant relationships (Table 5). We found no significant correlation of C:N ratio with grain yields of rice in any studied location.

Nutrient ratios and soil separates

In AEZ-18, sand fraction showed significant positive relationship with C:P, N:P and Ca:P ratios. There was significant positive relation of silt with P:K but negatively with Ca:P ratio (Table 6). Clay fraction had significant negative relationship with N:Mg, N:K and C:K ratios but only Ca:P ratio was positively correlated. In AEZ-21, C: P, C:K, N:P, N:K, N:Mg, N:Zn, P:Zn, Ca:Zn, S:Zn ratios showed significant positive relations with sand fraction (Table 7). Silt particle had significant negative relations with N:Mg and S:Zn ratios. Clay particle had significant negative relations with C:P, N:P,N:Zn ratios. The C:K, N:K, P:K, K:Ca and N:Mg showed significant positive relations with sand and clay fractions in AEZ-3. However, Ca:P, Ca:Zn, S:Zn ratios were negatively related with sand and clay separates and positively related with silt fraction (Table 8). No significant relationships of soil nutrient ratios were found with sand in AEZ-13 and AEZ-26 (Table 9, 10). However, C:K, N:K and N:Mg ratios showed significant positive relations with silt but negative with clay fraction in AEZ-13. In AEZ-26, C:K and N:K had significant positive relations with silt but negative with clay faction and K:Ca had negative relationship with silt fraction.

Rice yield with added nutrients

In wet season, rice grain yields were not significantly improved because of NPKSZn fertilizer application under studied locations (Table 11). In dry season, grain yield significantly increased because of NPKSZn fertilizer application in all locations except AEZ-18 (Table 12).

Discussion

Indigenous soil nutrient availability and ratios influence crop production in unfavorable ecosystem depending on crop variety and water management. Our result indicated that grain yield was the lowest in AEZ-26 compared to other studied locations might be because of unfavorable C:N and S:Zn ratios for coarse textured soil (Table 3). In coarse textured soil, the C:N needs to be around 25:1 (Oyem et al., 2013), but it was low with our findings. The lower S:Zn ratio indicates higher soil Zn availability might have affected S uptake and thus reduced rice yield (Singh et al., 2012). The C:P ratio clearly indicated that soils were deficient in P in studied areas in which rice grain yield improved in dry season because of added P in all locations. However, our previous studies showed no beneficial effect of added P in AEZ-21 (BRRI, 2014) indicating that P analysis method used failed to determine available soil P. Climate imposes vital role in soil development and thus soil biota and its interaction with soil nutrients (Chadwick et al., 1999; Vitousek, 2004). We have found C:N:P ratios of 10.8:385.4:1, 10.0:55.67:1, 9.9:551.3:1, 10.95:320.6:1 and 10.18:319.11:1 for AEZ-13, AEZ-21, AEZ-26, AEZ-3 and AEZ-18, respectively. These ratios are far higher than available literature (Cleveland and Liptzin, 2007; Redfield, 1958) because of lower soil P levels. Since the study locations are in high temperature and precipitation in tropical region, high P leaching and P occlusion might have taken place (Vitousek and Walker, 1987; Neufeldt et al., 2000; Zhang et al., 2005). At the same time, higher cropping intensity and imbalanced fertilizers used by the farmers (Biswas et al., 2004, 2008) could be the reason of skewed soil C:P N:P, N:Mg, N:Zn, and Ca:P ratios in studied locations.

The findings of present investigation shows that indigenous soil nutrient ratios like C:P, N:P, N:K, K:Mg, Ca:P, Ca:Zn and S:Zn significantly influenced dry season irrigated rice yield in AEZ-3. Soil K/(Ca + Mg) or K/Mg ratios might have played vital role in this aspects (McLean et al., 1983). We found K:Mg, Ca:Zn, S:Zn and P:Zn ratios as vital component for dry season irrigated rice yield improvement in AEZ-18, flash flood and cold prone areas (AEZ-3) and drought and cold prone (AEZ-26) regions of Bangladesh (Table 5). Soil K and Mg showed no effective linkages with sand, silt and clay fractions of studied locations in Bangladesh (Table 6, 7, 8, 9, 10). Kopittke and Menzies, 2007 also reported that K:Mg was not influenced by chemical, physical, and biological fertility of soil. Emphasis should be placed on providing sufficient, but not excessive levels of each basic cation rather than attempting to attain a favorable basic cation saturation ratio, which evidently does not exist (McLean et al., 1983). It is possible to have a deficiency of K and Mg even though the ratios might be in the ideal range. The cations ratio may be less than ideal for some fine-textured soils, but may have adequate amounts for crop production and additional applications are not necessary (McLean, 1976). Result indicated that indigenous Ca, Mg and Zn were playing a vital role for rice production in unfavorable ecosystems of Bangladesh. Besides, variations in rainfall and temperature patterns and salinity influence crop production in different ecosystems of Bangladesh.

Conclusion

Nutrient management requires understanding of soil nutrients behavior for optimizing rice yield through fertilizer management. We observed about 27% higher grain yield in AEZ-3 than AEZ-26 because of variations in C:P, C:K, N:P, N:K, Ca:P, N:Mg, N:Zn, ratios in which Ca, Mg and Zn were playing a pivotal role in rice production in unfavorable ecosystems of Bangladesh. Soil test for fertilizer application needs special attention for judicial use of ecologically fragile soils in Bangladesh.

Acknowledgments

We greatly acknowledge TATP Phase-I, BARC for funding the project activity (SPGR Sub-project ID No. 344.)

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Table 1. The characteristics of the study areas

Location/AEZ	Characteristics	Cropping Pattern
Gongachara, Rangpur (AEZ-3)	Submergence and cold prone areas	Boro-Fallow-T. Aman
Tanore, Rajshahi (AEZ-26)	Drought and cold prone areas	Boro-Fallow-T. Aman
Babugonj, Barisal (AEZ-13)	Non-saline tidal flood ecosystem	Boro-Fallow-T. Aman
Sonagazi, Feni (AEZ-18)	Char and saline prone ecosystem	Boro-Fallow-T. Aman
Baniachang, Hobiganj (AEZ-21)	Haor ecosystem	Boro-Fallow-Fallow

Table 2. Cultural operation dates for different rice varieties in different locations of Bangladesh

Location/AEZ	Variety	Date of Soaking	Date of Transplanting	Date of Harvesting
Boro season, 2011-12				
Sonagazi, Feni (AEZ-18)	BRRI dhan47	20-11-11	17-01-12	27-04-12
Tanore, Rajshahi (AEZ-26)	BRRI dhan29	06-12-11	20-01-12	20-05-12
Gangachara, Rangpur (AEZ-3)	BRRI dhan29	30-11-11	16-01-12	24-05-12
Babugonj, Barisal (AEZ-13)	BRRI dhan29	05-12-11	23-01-12	07-05-12
Baniachang, Hobigonj (AEZ-21)	BRRI dhan29	20-11-11	10-01-12	11-05-12
T. Aman season, 2012				
Sonagazi, Feni (AEZ-18)	BRRI dhan46	24-07-12	03-09-12	05-12-12
Tanore, Rajshahi (AEZ-26)	BRRI dhan56	25-06-12	27-07-12	05-11-12
Gangachara, Rangpur (AEZ-3)	BRRI dhan52	23-06-12	03-08-12	21-11-12
Babugonj, Barisal (AEZ-13)	LIV	08-05-12	13-06-12	12-12-12
Boro season, 2012-13				
Sonagazi, Feni (AEZ-18)	BRRI dhan28	05-12-12	09-02-13	09-05-13
Tanore, Rajshahi (AEZ-26)	BRRI dhan29	26-11-12	25-01-13	21-05-13
Gangachara, Rangpur (AEZ-3)	BRRI dhan29	25-11-12	18-01-13	29-05-13
Babugonj, Barisal (AEZ-13)	BRRI dhan29	27-11-12	19-01-13	11-05-13
Baniachang, Hobigonj (AEZ-21)	BRRI dhan29	12-12-12	01-02-13	16-05-13
T. Aman season, 2013				
Sonagazi, Feni (AEZ-18)	BRRI dhan46	11-07-13	17-08-13	05-12-13
Tanore, Rajshahi (AEZ-26)	BRRI dhan56	04-07-13	27-07-13	28-10-13
Gangachara, Rangpur (AEZ-3)	BRRI dhan52	29-06-13	29-07-13	08-12-13
Babugonj, Barisal (AEZ-13)	LIV	16-06-13	16-08-13	Damaged

Table 3. Native soil nutrient ratio with different AEZ under different unfavorable ecosystems in Bangladesh

Sand (%)	Silt (%)	Clay (%)	C:N	C:P	C:K	N:P	N:K	N:Mg	N:Zn	P:K	P:Zn	K:Ca	K:Mg	Ca:P	Ca:Zn	S:Zn
Barisal (AEZ 13)																
12.52	52.40	35.08	10.81	385.47	136.69	56.47	12.73	2.01	564.11	0.24	10.88	0.04	0.16	123.97	983.43	16.09
Habiganj (AEZ 21)																
20.00	20.64	59.36	10.07	5567.14	126.46	687.04	12.54	10.56	1050.66	0.02	1.51	0.19	0.87	352.49	452.60	18.49
Rajshahi (AEZ 26)																
33.76	50.65	15.59	9.90	551.37	159.36	75.95	16.09	6.23	436.20	0.22	6.78	0.07	0.40	63.24	321.50	8.66
Rangpur (AEZ 3)																
24.32	64.60	11.08	10.95	302.61	124.27	38.82	14.39	4.22	336.25	0.35	10.76	0.14	0.30	29.92	259.07	8.92
Sonagazi (AEZ 18)																
13.80	55.64	30.56	10.18	319.11	67.93	48.10	6.61	1.43	987.24	0.15	34.96	0.09	0.22	90.92	1179.05	57.15

Table 4. Relationships of nutrient ratios with T. Aman rice yields

	Sonagazi (AEZ-18)	Rangpur (AEZ-3)	Rajshahi (AEZ-26)
C:N	-0.28039NS	-1.35154**	0.32920NS
C:P	0.27049NS	-0.66653*	-0.81137**
C:K	0.82750**	-0.67253*	-0.79981**
N:P	0.48109NS	-0.70784*	-0.80105**
N:K	0.82067**	-0.67662*	-0.79644*
P:K	0.82095**	0.67373*	-0.80794**
K:Ca	-0.81655**	0.674319*	0.79914**
K:Mg	-0.80278**	-0.56359NS	0.82170**
Ca:P	-0.81679**	-0.66761*	-0.80119**
Ca:Zn	-0.83085**	-0.67224*	0.80121**
S:Zn	-0.88622**	-0.67197*	0.80119**
N:Mg	0.77828*	-0.65103*	-0.81750**
N:Zn	-0.81474**	-0.66697*	-0.80308**
P:Zn	-0.83218**	-0.67201*	0.80118**

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 5. Relationships of nutrient ratios with Boro rice yields

	Sonagazi (AEZ-18)	Rangpur (AEZ-3)	Rajshahi (AEZ-26)	Barisal (AEZ-13)	Habiganj (AEZ-21)
C:N	0.29247NS	0.05079	-0.06786	0.58939NS	-0.20384NS
C:P	-0.28071NS	0.90350**	-0.85980**	-0.66043*	0.44432NS
C:K	-0.87984**	0.89921**	-0.85635**	-0.75850*	-0.67812*
N:P	-0.49775NS	0.90441**	-0.85670**	-0.67133*	0.53709NS
N:K	-0.87398**	0.89881**	-0.85765**	-0.75710*	-0.59344NS
P:K	-0.87707**	-0.89811**	-0.84797**	0.19370NS	-0.48828NS
K:Ca	0.87408*	-0.89793**	0.85533**	-0.88700**	0.61392NS
K:Mg	0.87550**	0.87424**	0.85023**	-0.70563*	0.54072NS
Ca:P	0.89447**	0.89967**	-0.85612**	0.40561NS	0.23405NS
Ca:Zn	0.88315**	0.89878**	0.85601**	0.47548NS	0.06181NS
S:Zn	0.88368**	0.89894**	0.85611**	-0.21137NS	0.29181NS
N:Mg	-0.80469**	0.89573**	-0.86679**	-0.84712**	0.09366NS
N:Zn	0.86545**	0.89833**	-0.85685**	-0.89038**	0.48385NS
P:Zn	0.88147**	0.89868**	0.85610**	0.00570NS	0.06518NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 6. Nutrient ratios as influenced by soil separates, Sonagazi (AEZ-18)

	Sand	Silt	Clay
C:N	-0.11523NS	0.08390NS	0.13250NS
C:P	0.43015*	-0.35858NS	-0.22078NS
C:K	0.20770NS	-0.07508NS	-0.45713*
N:P	0.45842*	-0.37910NS	-0.24978NS
N:K	0.22453NS	-0.08243NS	-0.49595*
P:K	-0.32930NS	0.41385*	-0.31302NS
K:Ca	-0.12504NS	0.13626NS	-0.11501NS
K:Mg	0.00033NS	0.08383NS	-0.31027NS
Ca:P	0.50976**	-0.61572**	0.46506*
Ca:Zn	0.21613NS	-0.26396NS	0.20521NS
S:Zn	-0.08008NS	0.04833NS	0.08146NS
N:Mg	0.24371NS	-0.09160NS	-0.53658*
N:Zn	0.17604NS	-0.21294NS	0.15641NS
P:Zn	0.10111NS	-0.14268NS	0.15648NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 7. Nutrient ratios as influenced by soil separates, Habiganj (AEZ-21)

	Sand	Silt	Clay
C:N	0.25724NS	-0.08004NS	-0.25854NS
C:P	0.54720**	-0.31605NS	-0.44798*
C:K	0.44669*	-0.38395NS	-0.29086NS
N:P	0.54058**	-0.33084NS	-0.43263*
N:K	0.43423*	-0.39228NS	-0.2717NS
N:Mg	0.52929**	-0.46121*	-0.33888NS
N:Zn	0.53988**	-0.36913NS	-0.39071*
P:K	-0.11396NS	0.01818NS	0.12769 NS
P:Zn	0.40201*	-0.27168NS	-0.28834NS
K:Ca	-0.01681NS	-0.20668NS	0.12707NS
K:Mg	-0.09444NS	0.03676NS	0.08247NS
Ca:P	0.09008NS	0.25929NS	-0.24921NS
Ca:Zn	0.45705*	-0.22924NS	-0.37347NS
S:Zn	0.52011**	-0.45848*	-0.31758NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 8. Nutrient ratios as influenced by soil separates, Rangpur (AEZ-3)

	Sand	Silt	Clay
C:N	-0.25254NS	0.26440NS	-0.28638NS
C:P	0.04395NS	-0.05308NS	0.08765NS
C:K	0.61698**	-0.63920**	0.54027**
N:P	0.07549NS	-0.08669 NS	0.12523NS
N:K	0.62624**	-0.64966**	0.55717**
P:K	0.52216**	-0.53482**	0.40785*
K:Ca	0.40491*	-0.45006*	0.54915**
K:Mg	0.17215NS	-0.16354NS	0.07337NS
Ca:P	-0.49858*	0.50816**	-0.41216*
Ca:Zn	-0.56713**	0.59414**	-0.59428**
S:Zn	-0.42094*	0.45311*	-0.48367*
N:Mg	0.70868**	-0.72870**	0.59532**
N:Zn	0.15874NS	-0.16617NS	0.15239NS
P:Zn	-0.04760NS	0.06567NS	-0.16471NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 9. Nutrient ratios as influenced by soil separates, Barisal (AEZ-13)

	Sand	Silt	Clay
C:N	0.09828NS	-0.24010NS	0.23033NS
C:P	-0.32632NS	0.33186NS	-0.16779NS
C:K	-0.28809NS	0.56204**	-0.51366**
N:P	-0.33030NS	0.35216NS	-0.19074NS
N:K	-0.28022NS	0.56588**	-0.52585**
P:K	0.10760NS	0.23041NS	-0.37442NS
K:Ca	-0.22735NS	0.14206NS	0.02911NS
K:Mg	0.17177NS	-0.23086NS	0.12099NS
Ca:P	-0.02861NS	-0.18354NS	0.23972NS
Ca:Zn	0.20291NS	-0.28018NS	0.17966NS
S:Zn	-0.13536NS	0.03165 NS	0.02667NS
N:Mg	-0.18597NS	0.45879*	-0.48588*
N:Zn	-0.26113NS	0.391678NS	-0.30865NS
P:Zn	0.16866NS	-0.02902NS	-0.09475NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 10. Nutrient ratios as influenced by soil separates, Rajshahi (AEZ-26)

	Sand	Silt	Clay
C:N	-0.07562NS	0.19797NS	-0.29734NS
C:P	-0.10179NS	0.18273NS	-0.20563NS
C:K	-0.25048NS	0.43507*	-0.51893**
N:P	-0.09790NS	0.15394NS	-0.14698NS
N:K	-0.24787NS	0.41615*	-0.48346*
N:Mg	-0.23424NS	0.32796NS	-0.30115NS
N:Zn	0.11079NS	-0.19723NS	0.16286NS
P:K	-0.19971NS	0.30267NS	-0.32778NS
P:Zn	0.10410NS	-0.23053NS	0.26160NS
K:Ca	0.39349NS	-0.45240*	0.25756NS
K:Mg	0.05929NS	-0.13604NS	0.19855NS
Ca:P	-0.08519NS	0.00664NS	0.18150NS
Ca:Zn	0.18744NS	-0.34518NS	0.35627NS
S:Zn	0.28081NS	-0.39007NS	0.25017NS

NS = Non significant; * = Significant at 5% level;
** = Significant at 1% level of probability

Table 11. Rice grain yield in wet season under unfavorable ecosystems in Bangladesh

Treatment	Grain yield (t ha^{-1})		
	Rangpur (AEZ-3)	Rajshahi (AEZ-26)	Sonagazi (AEZ-18)
No fertilizer	2.56	2.54	3.07
NPKSZn fertilizer	4.13	3.62	3.90
t-test	NS	NS	NS

Table 12. Rice grain yield in Boro season under unfavorable ecosystems in Bangladesh

Treatment	Grain yield (t/ha)				
	Barisal (AEZ-13)	Habiganj (AEZ-21)	Rangpur (AEZ-3)	Rajshahi (AEZ-26)	Sonagazi (AEZ-18)
No fertilizer	3.78	3.20	3.83	2.79	3.70
NPKSZn fertilizer	7.52	6.92	7.50	6.54	5.28
t-test	*	*	*	*	NS

Note: NS means not significant * denote significant at 5% levels.