Original ResearchArticle

Rice yield potential of soils under unfavorable ecosystems inBangladesh

Abstract

Unfavorable ecosystems in Bangladesh are under intense pressure of crop production andclimate change impact; although the relationships of indigenous soil nutrients ratios with crop performanceareyettobefullyexplored.Experimentswereconductedundersubmergenceand 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.TheCa:PandN:Znratioswereplayingsignificantnegativerolewithriceyieldinwet 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. Dryseason irrigated rice grain yield was 13-27% lower in AEZ-26 than others AEZ because of variations in negative ratios of nutrients. Application of fertilizers improved dry season rice yieldsignificantly in all AEZ except AEZ-18 compared to indigenous soil fertility. Soil separates showed variable relationships with indigenous nutrient ratios in different AZE. It is concluded that indigenoussoil nutrient ratios play a vital role in improving rice yield under unfavorableecosystems.

Key word: Agricultural ecological zone, Native nutrient ratio, Riceyield

Comment [R1]: Clear up the levels of fertilizers

Introduction

Rice plays an important role in food security of Bangladesh and farmers grow this cropin 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 millionpeopleby2025(Bhuiyanetal.,2002).Theadditionalricerequirementneedstoobtain from favorable and unfavorable ecosystems in Bangladesh by adopting new improvedgenotypes together with improved fertilizer and watermanagement.

Fertilizer management requires proper understanding of indigenous soil nutrients and its behaviorinsoil-plantcontinuum.Eitherexcessordeficitplantnutrientconditionshavebeena topic of intensive research since the beginning of modern agriculture. In spite of the decades of researchinthisarea,manyproblemsstillexistedandincreaseduseoffertilizershasnotbeen alleviated the problems. Interactions of soil mineral elements with plants are either antagonistic orsynergisticdependingontheiravailabilityandratiosinrhizosphere.Theratiosarechanging becauseofcropcultureandsoilecologyandthuscausingeithernutrientdeficiencyortoxicity. For example, inadequate supplies of one or more nutrients in the growing medium shiftthe existingratiosofnutrients.Theinteractionsbetweenthesefactorscanbeextremelycomplex, interfering with the absorption and utilization of nutrient elements by the plants and thus leading tothesymptomsofabioticnutritionaldamage(Bergman,1992).Moreover,soilnutrientratios are influenced by parent materials, geological locations, intensity of cropping and use of fertilizersetc(Chadwicketal.,1999;ClevelandandLiptzin,2007).Excessesandshortagesof somenutrientsaffecttheuptakeofothernutrients.Forexample,plantMglevelsarereduced whensoilK:Mgratioisabove1.5:1orMg:Kratioislessthan0.67.Thiseffectisseverein

Comment [R2]: Very long paragraph

grasses, especially with corn (Anonymous, 2016). Research works are limited on indigenoussoil nutrientratiosforunfavorableecosystems,althoughtheyareutilizingforcropproductionin many countries including Bangladesh. Over the years, a significant amount of conversation and salesmanshiphasrevolvedaroundtheconceptoftheidealsoilCa:Mgratio.Mostoftheclaims fortheidealratiorangesbetween5:1and8:1(Anonymous,2016),althoughyieldorqualityof crop is not appreciably affected over a wide range of Ca:Mg ratios in the soil. Thoughstable 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 inrice 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 ofnativesoilnutrientconcentrationsandratiosonriceyieldunderunfavorableecosystemsin Bangladesh for sustainable use of thoseecosystems.

Materials andMethods

Comment [R3]: Write numbers to tables in the material

Sitedescription

Char and saline prone ecosystem(AEZ-18)

About1.0millionhectares(Mha)landofBangladeshisaffectedbyvaryingdegreesof salinity. Crop production in this area is dominated by traditional wet season rice (T. Amanrice) and farmers generally harvest 2 t ha^{-1} grain yield, which is very low than other parts ofthe countryduetosoilsalinityproblem,droughtindryseason,lackofadequatesalinitytolerant varieties as well as lack of appropriate fertilizer managementtechnologies.

Submergence and cold prone area(AEZ-3)

Itcoversabout2.6millionhectares.Thedevastatingfloodcausedconsiderablelossof ricecrop.Theaverageyieldofriceunderflood-proneecosystemisverylow(2.5tha^{-1})dueto lack of technologies on flood tolerance rice varieties and their appropriate fertilizer management packagesetc.

Drought and cold prone area(AEZ-26)

It is situated in north-west part of Bangladesh. Drought is very common in this part ofthe country having 1200-1400 mm mean annual rainfall from June to October. Drought affectedarea is nearly 2.5 Mha in Kharif and 1.2 Mha in dry season. Rice yield is poor due to lackof sufficient water and nutrition management. This low yield mightbe.

Non-saline tidal flood ecosystem(AEZ-13)

This ecosystem covers about 1.9 Mha and the average yield of rice under non-salinetidal floodecosystemisnotmorethan3.0tha^{-1} duetolackoftechnologiesonappropriatefertilizer management packagesetc.

Haor ecosystem(AEZ-21)

A haor is a wetland ecosystem in the north eastern part of Bangladesh. The total area in thisecosystemis80,000squarekilometers.Mostofthisarearemainsunderwaterforseven 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 forrice.

The characteristics of the study areas were asfollows:

Location/AEZ	Characteristics	
	CroppingPatternGongachara,Rangpur(AEZ-3)	
	Submergence and coldproneareas	Boro-Fallow-
T.AmanTanore,Rajshahi(AEZ-26)	Drought and coldproneareas	Boro-Fallow-T.Aman
Babugonj,Barisal(AEZ-13)	Non-saline tidalfloodecosystem	Boro-Fallow-T.Aman
Sonagazi,Feni(AEZ-18)	Char and salineproneecosystem	Boro-Fallow-
T.AmanBaniachang,Hobiganj(AEZ-21)		Haorecosystem
	Boro-Fallow-Fallow	

Cropping Pattern BasedExperiments

During project period (2011-13) field experiments in Boro and T. Amanseasons were conducted as cropping pattern based as detailedbelow:

Table .Cultural operation dates for different rice varieties in different locations ofBangladesh

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

The following treatments were tested: T_1 = NPKSZn (STB); T_2 = Absolute control. The experiment was laid out in a randomized complete block design (RCBD) with threereplications.

Comment [R4]: Write the ratio

Fertilizerapplication

One-third N and all other inorganic fertilizers were applied at final land preparation. The firsttopdress(One-thirdN)wasappliedat20DAT.Therest1/3Nwasappliedat5-7days before panicle initiation stage after drainage out of flood water. Necessary intercultural operations were done as and when ever required. At maturity, the crop was harvested from 5 m^2 area at the center of each plot and grain yield was adjusted to 14% moisture. The grain andstraw yields were recorded. Nutrient contents (N, P and K) from plant samples of the cropping pattern were determined by standard laboratoryprocedure.

Comment [R5]: Write the ratio

Soil sample collection andanalysis

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'fieldsateachlocation.Landtype,soilseriesandlandusewererecorded.Soilsamples were analyzed for texture, pH, EC, OC, total N, exchangeable cations (Ca, Mg and K), available P, S and Zn following standard methodology (Haqueet al., 2015; Saleque et al.,2004).

Statisticalanalysis

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 meancomparisons.

Results

Rice yield and nutrient ratios in wetseason

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 itshowed significantnegativerelationshipswithK:Ca,K:Mg,Ca:P,Ca:Zn.S:Zn,N:ZnandP:Znratios. Similarly,P:KandK:Caratiosweresynergisticallyrelatedwithgrainyieldbut 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 inAEZ-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:MgandN:Zn)showedsignificantlynegativerelationships with grain yield except K: Ca K: Mg, Ca:Zn, S:Zn and P:Zn ratios (Table3).

Rice yield and nutrient ratios under dryseason

In AEZ-18, K:Ca, K:Mg, Ca:P, Ca;Zn, S:Zn, N:Zn and P:Zn ratios showed significantly positiverelationshipswithgrainyieldbutsignificantlynegativewithC:K,N:P,N:K,P:Kand N:Mgratios.TheC:N,C:PandN:Pratioshadnosignificantrelationshipswithgrainyieldof rice.TheC:P,C:K,N:P,N:K,K:Mg,Ca:P,Ca:Zn,S:Zn,N:Mg,N:Zn,P:Znratiosfavored significantly rice grain yield in AEZ-3. Nonetheless, P:K and K:Ca ratios actednegatively againstriceyield.InAEZ-26,riceyieldswereinfluencedantagonisticallybyC:P,C:K,N:P, N:K,P:K,Ca:P,N:MgandN:Znratiosbutothersweresynergisticallycorrelated.InAEZ-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 wet season rice grain yield but other nutrient ratios had no significant relationships (Table 2). We found no significant correlation of C:N ratio with grain yields ofrice in any studiedlocation.

Nutrient ratios and soilseparates

In AEZ-18, sand fraction showed significant positive relationship with C:P, N:P andCa:P ratios.Therewassignificantpositiverelationofsiltwith P:Kbutnegativelywith Ca:Pratio (Table 3). Clay fraction had significant negative relationship with N:Mg, N:K and C:K ratiosbut onlyCa:Pratiowaspositivelycorrelated.InAEZ-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 4). Siltparticle had significant negative relations with N:Mg and S:Zn ratios. Clay particle hadsignificant negative relations with C:P, N:P,N:Zn ratios. The C:K, N:K, P:K, K:Ca andN: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 withsilt fraction (Table 5). No significant relationships of soil nutrient ratios were found with sandin AEZ-13 and AEZ-26 (Table 6, and 7). However, C:K, N:K and N:Mg ratios showed significant positiverelationswithsiltbutnegativewithclayfractioninAEZ-13.InAEZ-26,C:KandN:K hadsignificantpositiverelationswithsiltbutnegativewithclayfactionandK:Cahadnegative relationship with siltfraction.

Rice yield with addednutrients

Inwetseason,ricegrainyieldswerenotsignificantlyimprovedbecauseofNPKSZn fertilizer application under studied locations (Table 8). In dry season, grain yield significantly increased because of NPKSZn fertilizer application in all locations except AEZ-18 (Table9).

Site specific indigenous soil nutrientratios

Thenativesoilnutrientratiosvariedwidelydependingonnatureofsoilecologyand croppingintensityindifferentlocalitiesofBangladesh(Table10).InAEZ-21,theN:P,N:Mg, N:Zn, and Ca:Pratios were the widest compared to other studied locations (Table 10). 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 inAEZ-3.

Comment [R6]: No mention to the studied crop in this paragraph, the paragraph showed the soil ratio thus this paragraph and Table 10 moved to the material or mentioned that this soil ratios cleared after studied crop culture

Discussion

Indigenous soil nutrient availability and ratios influence crop production in unfavorable ecosystemdependingoncropvarietyandwatermanagement.Ourresultindicatedthatgrain yield was the lowest in AEZ-26 compared to other studied locations might be becauseof unfavorableC:NandS:Znratiosforcoarsetexturedsoil(Table10).Incoarsetexturedsoil,the C:Nneedstobearound25:1(Oyemetal.,2013),butitwaslowwithourfindings.Thelower S:ZnratioindicateshighersoilZnavailabilitymighthaveaffectedSuptakeandthusreduced riceyield(Singhetal.,2012).TheC:PratioclearlyindicatedthatsoilsweredeficientinPin studied areas in which rice grain yield improved in dry season because of added P inall locations.However,ourpreviousstudiesshowednobeneficialeffectofaddedPinAEZ-21 (BRRI, 2014) indicating that P analysis method used failed to determine available soil P.Climate imposesvitalroleinsoildevelopmentandthussoilbiotaanditsinteractionwithsoilnutrients

(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 andLiptzin, 2007; Redfield, 1958) because of lower soil P levels. Since the study locations arein high temperature and precipitation in tropical region, high P leaching and P occlusion mighthave 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 instudied 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 yieldin AEZ-3. Soil K/(Ca + Mg) or K/Mg ratios might have played vital role in this aspects (McLeanet al.,1983).WefoundK:Mg,Ca:Zn,S:ZnandP:Znratiosasvitalcomponentfordryseason irrigatedriceyieldimprovementinAEZ-18,flashfloodandcoldproneareas(AEZ-3)and droughtandcoldprone(AEZ-26)regionsofBangladesh(Table2).SoilKandMgshowedno effective linkages with sand, silt and clay fractions of studied locations in Bangladesh (Table 3, 4, 5, 6, 7). Kopittke and Menzies, 2007 also reported that K:Mg was not influenced bychemical, 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 saturationratio,whichevidentlydoesnotexist(McLeanetal.,1983).Itispossibletohavea deficiency of K and Mg even though the ratios might be in the ideal range. The cations ratiomay 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 ofBangladesh.

Conclusion

Nutrient management requires understanding of soil nutrients behaviorfor optimizing riceyieldthroughfertilizermanagement.Weobservedabout27%highergrainyieldinAEZ-3 thanAEZ-26becauseofvariationsinC:P,C:K,N:P,N:K,Ca:P,N:Mg,N:Zn,ratiosinwhich Ca,MgandZnwereplayingapivotalroleinriceproductioninunfavorableecosystemsof Bangladesh. Soil test for fertilizer application needs special attention for judicial use of ecologically fragile soils inBangladesh.

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Table 1 . Relationships of nutrient ratios with T. Aman riceyields

	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 ofprobability

Table 2 . Relationships of nutrient ratios with Bororiceyields

	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 ofprobability

Table 3. 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 ofprobability

Table 4 . 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 ofprobability

Table 5 . 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 ofprobability

Table 6 . 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 ofprobability

Table 7 . 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 ofprobability

Table 8 Rice grain yield in wet season under unfavorable ecosystems inBangladesh

Treatment	Grain yield (tha^{-1})		
	Rangpur (AEZ-3)	Rajshahi (AEZ-26)	Sonagazi (AEZ-18)
Nofertilizer	2.56	2.54	3.07
NPKSZnfertilizer	4.13	3.62	3.90
t-test	NS	NS	NS

Table 9 Rice grain yield in Boro season under unfavorable ecosystems inBangladesh

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.

Table 10 Native soil nutrient ratio with different AEZ under different unfavorable ecosystems in Bangladesh

Comment [R7]: Mentioned to the studied crop in the title

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 (AEZ13)																
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