Assessment of Influence and Inter-Relationships of Soil Properties in Irrigated Rice Fields of Bangladesh by GIS and Factor Analysis

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ABSTRACT

A research study was conducted assessing the influence and relationships of soil properties in irrigated rice fields of Bangladesh using 100 field plots from five land blocks and four land types of *Boro* (winter rice) – Fallow – *T. Aman* (summer rice) cropping system. Out of four land types medium highlands covered 53% of the study area whereas highland, lowland and medium lowland areas covered 26, 13 and 8% respectively; while soil groups, medium texture, moderately fine, and fine covered 68, 19 and 13% areas respectively. The clay content ranged between 9 to 47%, has significant influence on water holding capacity and nutrient leaching in irrigated rice fields. Soil pH was varied very acidic to moderately acidic with medium organic matter content of 1.8 – 2.4%. Overall soil nutrients status was poor; showing 75% area found low N, 97% area very low to low P, 90% area low to medium K, 43% area low to medium S and 50% area medium Zn status. Soil properties were grouped into four major factor components (eigenvalues >1) as: FC1-'*soil potential physical properties*' which included clay and porosity; FC2-'*soil highly potential nutrients*' which included SOM and N; FC3-'*soil moderately potential nutrients*' which included Zn and K; and FC4-'*soil additional properties*' which included S and silt. FC1 and FC2 showed highest influence on irrigated rice fields for holding water and nutrient components and causing influences on rice production.

Keywords: Soil quality, GIS, irrigated rice, soil properties, nutrients assessment, Thailand

1. INTRODUCTION

Soil is a dynamic, living, natural body and a key factor in the sustainability of terrestrial ecosystems. The components of soil include inorganic mineral matter (sand, silt and clay particles), organic matter, water, gases and living organisms such as earthworms, insects, bacteria, fungi, algae and nematodes (Fageria, 2002). Influential soil properties i.e. soil quality may have significant influence on the health and productivity of an ecosystem and the related environment (Larson and Pierce, 1991). Soil variability is not a problem, although it can be helpful in minimizing crop risk failure through design and implementation of site-specific management (Shukla *et al.*, 2004). A significant decline in soil productive capacity has occurred worldwide through adverse changes in its physical, physico-chemical, chemical and biological properties and contamination by inorganic and organic chemicals

(Arshad and Martin, 2002). The rate of growth of global grain production dropped from 3% in the 1970s to 1.3% in the 1983-93 periods, and one of the key reasons of this decline is inadequate soil and water management (Steer, 1998). Similar trend was also observed in irrigated rice production of Bangladesh (Saleque *et al.*, 2006).

Consultative Group of International Agricultural Research (CGIAR, 1996) along with 14 international research centers found good progress in reorienting their research towards soil and water management, but it was also found that inadequate attention paid to off-site interactions at the river basin, delta and regional levels (Steer, 1998). This was of particular concern since; off-site costs of unsustainable management practices are often greater than their impacts on on-site productivity. Three basic components of a soil productive capacity as well as quality (Rodale Institute, 1991) were: (1) the ability of soil to enhance crop production (Productivity component); (2) the ability of soil to function in attenuation of environmental contaminants, pathogens and off-site damage (environment component); and (3) the linkage between soil properties/quality and plant, animal and human health (health component). In a given agro-climatic region, the measurable soil properties that are primarily influenced on soil fertility are: soil depth, organic matter, texture, bulk density, infiltration, soil reaction, nutrient availability and retention capacity etc.

Soil fertility is an important quality indicator for sustainable agricultural production system, which has serious concern with deterioration of land quality as well as declining yields with increasing population. Optimum application of chemical/nutrient is important and has two major benefits; saving the cost of resources and environment (Jin and Jiang, 2002). Intensification of land use, together with irrigation, high-yielding varieties, chemical fertilizers and pesticides, could cause adverse effects on the land and may lead to degradation of soils while threatening the sustainable crop production systems in Bangladesh (Cook, *et al.*, 2003). Intensive cropping could lead to higher level of nutrient extraction from the soil without providing opportunities for natural regenerating processes. With fragmentations of land holdings (average farm size <0.7 ha) and predominance of small and marginal farmers, Bangladesh agricultural systems are basically constituted from disaggregated farm families (BBS, 2006). Unfortunately, the soil resources of Bangladesh has been exploited intensively without proper care and deleterious effects of continuous wet land rice systems have resulted in declining the availability of some nutrients particularly S and Zn, and reducing rice yields (Karim and Iqbal, 1997).

Soil fertility as well as integrated plant nutrition systems (IPNS) for restoring, maintaining and increasing soil productivity are major agricultural priorities for different agencies, particularly in the many parts of the developing world where soils are inherently poor in supplying nutrients and the demand for food and raw materials is increasing rapidly (FAO, 1998). Moreover, agricultural intensification requires increased flow of plant nutrients as well as higher material inputs to sustain soil quality and productivity for crops; and higher uptake of nutrients for most of the high yielding varieties (Ali, 2004). In this concern, GIS assisted spatial and temporal variability of soil and water is offer better management strategies for sustaining agricultural production and productivity for future world especially in the developing world where availability and access to resources are limited (Ping and Dobermann, 2005). This is a holistic approach of site-specific resources management for optimizing farm profits (Dobermann *et al.,* 2002; Plant, 2001; McKinion *et al.,* 2001). GIS associated many highly technical components suitable for developed countries; especially, its nutrient management techniques can be readily adoptable to developing country situation without a much expenses (Haque, *et al.,* 2005). However, evaluation of soil properties interaction, influences and their inter-relationships for irrigated rice production in the context of precision agriculture approach has never been observed in Bangladesh.

The objectives of this study were: (i) assessment of the level of soil properties by GIS technique and (ii) identify influences and inter-relationships of soil properties in irrigated rice field by factor analysis.

2. MATERIAL AND METHODS

2.1 Study Area Characteristics and Location

The study area was selected because it is an intensive cultivated area, having more than one rice crop in a year, cropping intensity (CI >200%) more than the national level and increases day by day, farmers depend on chemicals and fertilizers for crop production without caring the exact nutrients status of their lands. The study area (Figure 1) was in Trishal upazila (sub-district) under Mymensingh district of Bangladesh within agro ecological zone (AEZ9), Old Brahmaputra Floodplain, dominantly medium highland with low-permeability soil (BARC, 1997).

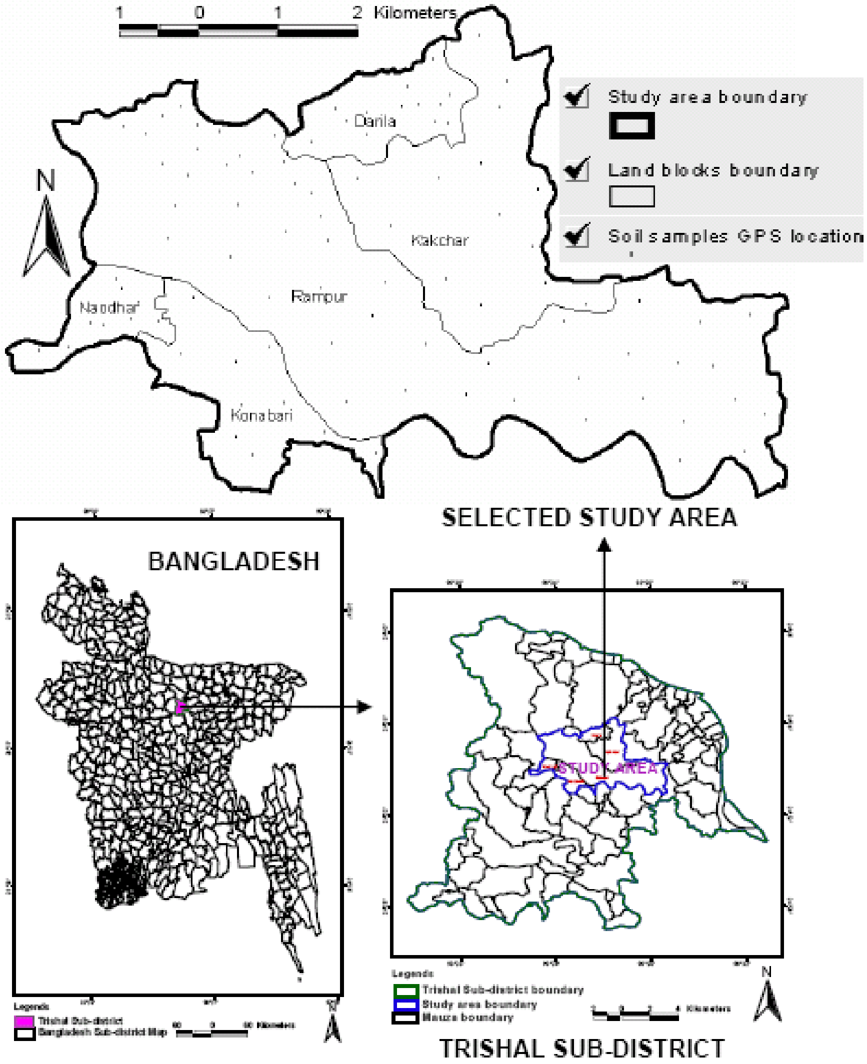

Figure 1. GIS based map showing geographical location of the study area.

Geographically the study area located between 24^{o}32'44" and 24^{o}36'41" North latitude and 90^{o}22'47" and 90^{o}28'45" East longitude (Figure 1). Soils in the area are predominantly fine texture (silty loam to silty clay loams on the ridges and clay in the basins. General soil types largely include dark grey floodplain soil. Organic matter content is low on the ridges and moderate in the basins, topsoils moderately acidic but sub-soils neutral in reaction.

2.2 Soil Analysis and Analytical Techniques

The investigation was carried out on 100 plots covering total 3216 ha land, divided into five land blocks and separated into four land types; cropping system with *Boro* (winter rice) – Fallow – *T. Aman* (summer rice) in 2006. Soil physical (texture, %sand, %silt, %clay, bulk density and porosity), physico-chemical (pH and SOM) and chemical (N, P, K, S and Zn) properties were determined. Primary data were collected by using GPS reading for soil samples physical, physico-chemical and chemical properties, and secondary data were collected from relevant institutions and organizations in Bangladesh. Statistical analysis was done to find out the influences and relationships among the data sets. GIS application maps were used for showing the overall effects of the study area and nearest farmer-fields situation from which soil samples were not collected for analyses. Geo-referenced composite soil samples were collected and prepared for analysis by using standard procedure given by BARC (1997) from a plough depth of 0-15 cm at the rate of 3.22 ha per sampling density along with a scale of 1:50,000 and 10m×10m pixel size. GIS maps were created for interpretation, analysis, assessment and modeling of the scenario (Haque *et al.,* 2005).

Soil particle size was measured by hydro-meter method with USDA soil particle size rating (Gee and Bauder. 1986). Bulk density was measured by core (7.5 cm diameter and 7.5 cm deep) method (Blake and Hartge, 1986); and total porosity was calculated from bulk density and assumed particle density of 2.65 g/cc. Soil pH was determined by glass electrode pH meter with soil water ratio of 1:2.5 (McLean, 1982). SOM and N were determined by dry combustion method (using LECO C-200 Analyzer instrument) (Petersen, 2002) and Kjeldahl method (Bremner and Mulvaney, 1982), respectively. The K was determined by ammonium acetate extraction method using flame photo meter (Baker and Surh, 1982), the P by Bray and Kurtz method and the S by purtidimetric method (Jones and Case, 1990). The Zn was determined by DTPA extraction method (Baker and Amacher, 1982); Analyses were rated by using USDA texture classification for soil physical properties and BARC (1997) for chemicals/nutrients (N, P, K, S and Zn) (Table 1). Landon (1991) classified soil pH range was <4.5 as strongly acidic; 4.5 – 5.2 as very acidic; 5.3 – 5.9 as moderately acidic; 6.0 – 6.5 as weakly acidic; 6.6 – 7.2 as neutral; 7.3 – 7.8 as moderately alkaline; 7.9–8.3 as alkaline and >8.3 as strongly alkaline.

Table 1. Soil nutrient rating for wetland rice crops on loamy and clayey soils in Bangladesh (BARC, 1997).

Nutrient element	*Very low*	*Low*	*Medium*	*Optimum*	*High*	*Very high*
Organic matter (OM) (%)	<1.0	1.0-1.7	1.7-3.4	-	3.4-5.5	>6.0
Nitrogen (N), %	<0.09	0.09-0.18	0.18-0.27	0.271-0.36	0.36-0.45	>0.45
Phosphorus (P), μg/g	<6.0	6.1-12.0	12.1-18.0	18.1-24.0	24.1-30.0	>30.0
Potassium (K), Cmol/kg	<0.075	0.0751-0.15	0.15-0.22	0.22-0.30	0.31-0.37	>0.375
Sulfur (S), μg/g	<9.0	9.1-18.0	18.1-27.0	27.0-36.0	36.1-45.0	>45.0
Zinc (Zn), μg/g	<0.45	0.451-1.09	1.1-1.35	1.351-1.8	1.81-2.25	>2.25

2.3 Statistical Analysis

Soil physical, physico-chemical and chemical properties were transferred to a spreadsheet. Square root transformation was done for all percentage data before analysis. All means were compared using 1-way ANOVA followed by Turkey's HSD post hoc for multiple comparisons. Influences and inter-relationships of soil properties in irrigated rice fields were assessed by using correlation and factor analysis. Factor analysis (FA) was carried out using covariance (raw data) and correlation (standardized/transformed data) matrix of the statistical software SPSS Windows version 10.0 with a level of significance of $p<0.05$. Using correlation matrix, factors with eigenvalues >1 were retained; and factors subjected to varimax rotation and 'Kaiser Normalization' to reduce influences soil properties to highly correlated major component groups. Correlation matrix was used for explaining measured soil properties inter-relationships and interactions. In the FA, standardized data with zero mean and unit variance were used. A measured soil property was assigned to a FA for which it had the highest value of communality estimate. Scoring coefficients were obtained for individual properties at each sample location by using score procedure (Garson, 2007; Shukla, *et al.*, 2006; Zhao *et al.*, 2007). All of the results and presentation were verified according to the mentioned objectives and to draw some valid conclusions.

3. RESULTS AND DISCUSSIONS

3.1 Study Area Scenario

Total land of the selected study area was 3216 ha. Area of Konabari, Naodhar, Darila, Kakchar and Rampur land blocks were 328, 133, 206, 689 and 1861 ha, respectively. There were four land types named highland (HL), medium highland (MHL), medium lowland (MLL) and lowland (LL) which covered 26%, 53%, 8% and 13% of the study area respectively (Figure 2).

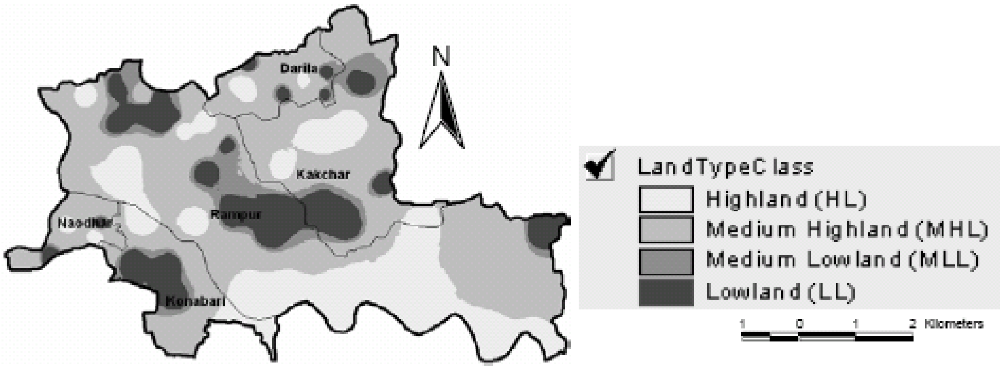

Figure 2. GIS application map showing different land types of the study area in 2006.

3.2 Soil Texture and Physical Properties

Entire study area was fallen under three texture groups, in which the medium texture group was found to cover 2180 ha (68%), moderately fine 609 ha (19%) and fine 427 ha (13%), respectively (Figure 3). For different land blocks and land types, soil physical properties (%sand, %silt, %clay, bulk density and porosity) statuses are presented in Table 2. The clay content covered 97% ranged between 9% and 47% (Figure 3). Except the sand content, significant difference was observed for other soil physical properties among land blocks and land types (Table 2).

Table 2. Soil physical properties of the study area in 2006 irrigated rice season.

Blocks / Types	*Soil physical properties*^{1}				
	Sand %	Silt %	Clay %	BD (gm/cm^{3})	Porosity %
Land blocks					
Konabari	17.67±1.54	61.33±1.08^{b}	21.00±1.14^{a}	1.36±0.012^{b}	48.90±0.42^{a}
Naodhar	18.83±1.65	57.33±1.83^{b}	23.83±1.85^{ab}	1.35±0.013^{b}	48.95±0.49^{a}
Darila	18.59±0.97	47.18±1.53^{a}	34.24±2.32^{c}	1.30±0.013^{a}	51.00±0.48^{b}
Kakchar	18.63±1.31	45.79±1.24^{a}	35.58±2.18^{c}	1.28±0.016^{a}	51.64±0.61^{b}
Rampur	20.60±0.96	50.00±0.98^{a}	29.37±1.04^{bc}	1.33±0.007^{ab}	50.00±0.26^{ab}
Land types					
HL	20.31±1.30	54.90±1.19^{b}	24.79±1.61^{a}	1.35±0.012^{b}	49.07±0.46^{a}
MHL	20.03±1.07	51.68±1.19^{b}	28.29±1.41^{a}	1.33±0.009^{b}	49.90±0.34^{a}
MLL	20.03±0.81	51.42±0.98^{b}	28.48±1.05^{a}	1.33±0.007^{b}	49.96±0.23^{a}
LL	17.69±1.46	45.10±1.71^{a}	37.21±1.77^{b}	1.27±0.012^{a}	51.85±0.42^{b}
Overall	19.53±0.59	50.80±0.68	29.65±0.79	1.32±0.005	50.20±0.19

[1] Mean±std.error, superscripts letters within column denoted significant differences (ANOVA, HSD; $p<0.05$) whereas same letter are not significantly differing.

BD - Bulk density ; HL – Highland, MHL – Medium Highland, MLL – Medium Lowland, LL – Lowland.

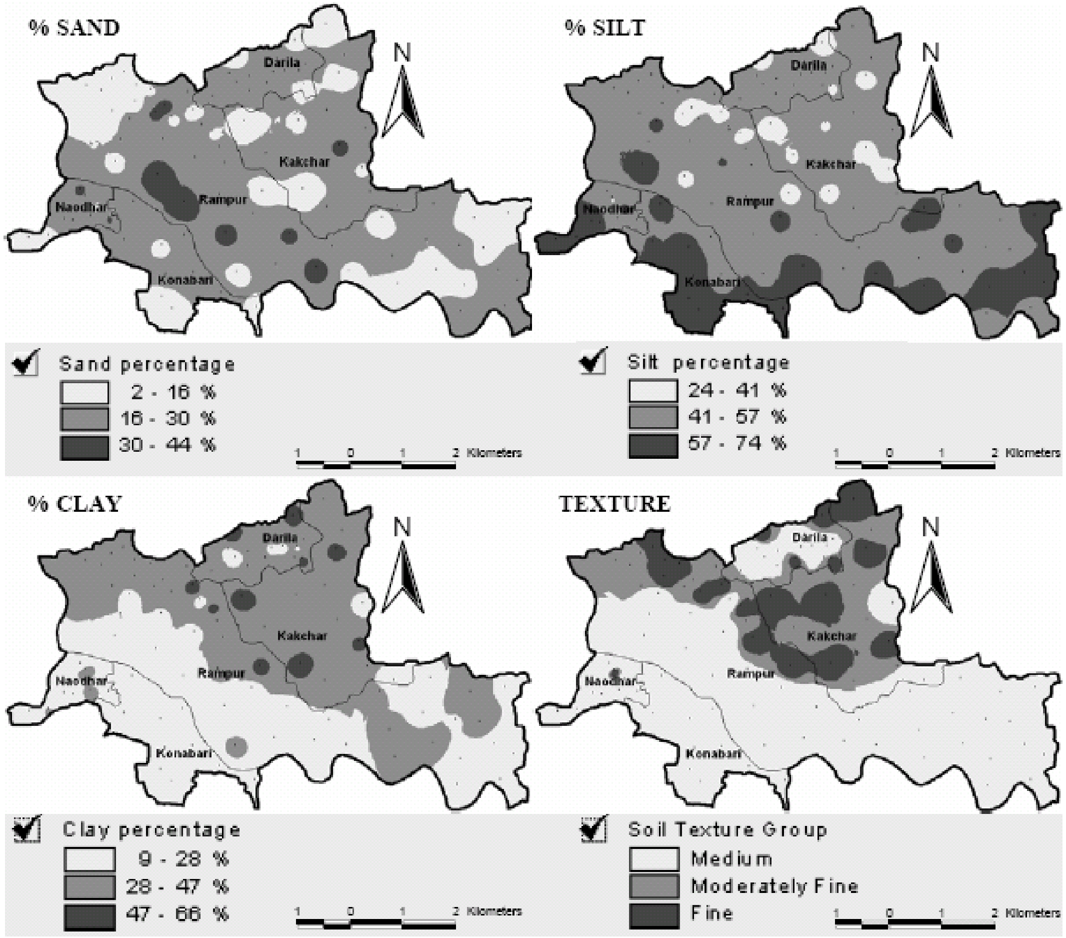

Figure 3. GIS maps of soil physical properties and texture groups in 2006 irrigated rice season in the study area.

Higher amount of clay content has significant influence on water holding capacity and it reduced nutrient leaching (Table 2 and Figure 3). Bulk density was highest in Konabari land blocks and lowest in Kakchar land blocks, whereas, highland possessed highest amount of bulk density than other land types (Table 2 and Figure 4). Lower bulk density indicted the higher degree of soil compactness and higher percentage of fine properties in the soil which was favorable for irrigated rice production (Figure 4).

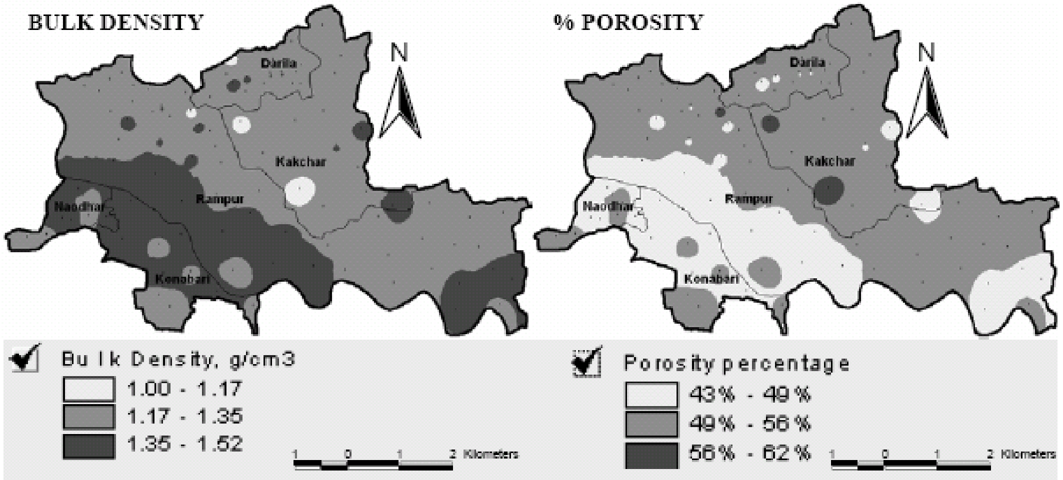

Figure 4. GIS maps of soil bulk density and porosity status in 2006 irrigated rice season.

3.3 Soil Physico-Chemical Properties

The pH value is one of the most important chemical properties of soil. The pH ranged from 4.5 to 6.8; very acidic to moderately acidic pH range (5.0–5.9) covered more than 90% of the study area (Figure 5). The pH range of the study area was favorable for wetland rice i.e. irrigated Boro rice cultivation. The pH values significantly differed ($p<0.05$) among the land blocks whereas no significant difference was observed with land types (Table 3). Soil pH and base saturation are important soil properties that influence nutrient availability and crop growth (Fageria *et al.*, 1998).

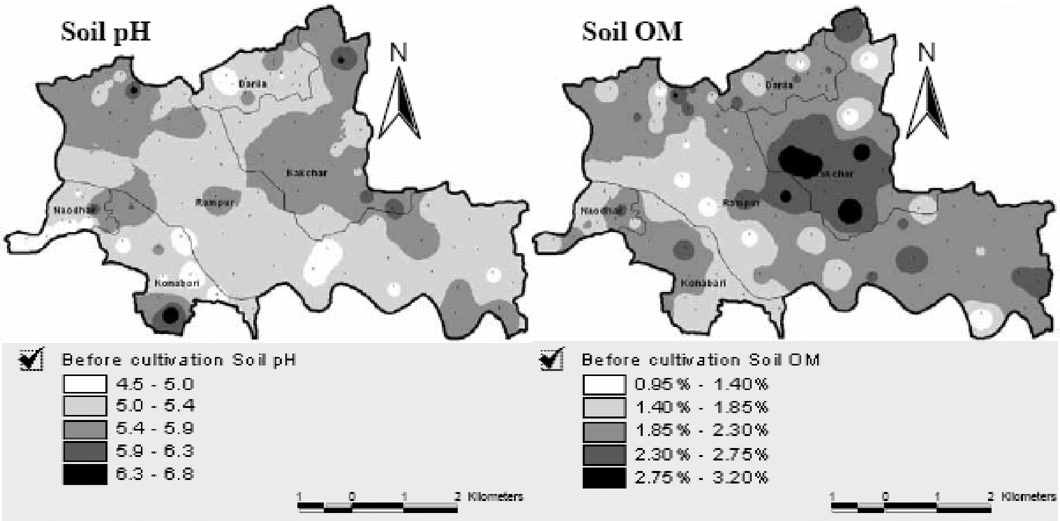

Figure 5. GIS maps of soil pH and organic matter status in 2006 irrigated rice season.

Organic matter in the soil exerts considerable influences on physical-chemical constituents and biological processes; and enhance on soil structure, water holding capacity, cation exchange capacity, and ability to form complexes with ions and as a nutrient sources and store in soil pool (Keulen, 2001). SOM ranged from 0.95% to 3.2%; however average organic matter content was around 2% which falls into medium level (Landon, 1991) and covered more than 80% study area (Table 3, Figure 5).Average SOM content of topsoil in HL and MHL situation in Bangladesh had decreased from about 2% to 1% due to intensive cultivation. More than 50% of the cultivated soils contain organic matter below the critical level of 1.5% (Hossain, 2001). A decline in SOM is considered to create negative effects on crop productivity; therefore improving its level was a prerequisite to ensuring soil quality; and future agricultural productivity and sustainability (Katyal *et al.,* 2001).

Table 3. Soil physicochemical and chemical/nutrient properties in 2006 irrigated rice season.

Blocks /Types	*Soil properties**						
	Physicochemical		Chemical / nutrients				
	pH	SOM (%)	N (%)^1	P (μg/g)^2	K (meq/100g)^3	S (μg/g)	Zn (μg/g)
<u>Land blocks</u>							
Konabari	5.33 ± 0.12^{ab}	1.84 ± 0.07^{a}	0.153 ± 0.004^{a}	6.80 ± 0.76^{b}	0.086 ± 0.005^{a}	27.0 ± 2.0	1.05 ± 0.08^{a}
Naodhar	5.12 ± 0.09^{a}	1.86 ± 0.06^{a}	0.154 ± 0.005^{a}	5.50 ± 0.44^{b}	0.109 ± 0.012^{ab}	28.1 ± 1.8	1.38 ± 0.09^{bc}
Darila	5.22 ± 0.06^{ab}	2.12 ± 0.07^{ab}	0.189 ± 0.007^{b}	5.30 ± 0.56^{ab}	0.109 ± 0.005^{ab}	24.2 ± 1.3	1.44 ± 0.06^{c}
Kakchar	5.58 ± 0.05^{c}	2.31 ± 0.11^{b}	0.181 ± 0.009^{ab}	6.21 ± 0.77^{b}	0.124 ± 0.005^{b}	24.2 ± 1.7	1.48 ± 0.05^{c}
Rampur	5.36 ± 0.04^{bc}	2.01 ± 0.04^{ab}	0.159 ± 0.003^{a}	3.43 ± 0.20^{a}	0.128 ± 0.004^{b}	21.4 ± 1.2	1.17 ± 0.03^{ab}
<u>Land types</u>							
HL	5.30 ± 0.05	1.80 ± 0.06^{a}	0.153 ± 0.005^{a}	5.28 ± 0.56	0.103 ± 0.005^{a}	22.3 ± 1.5^{ab}	1.22 ± 0.04
MHL	5.38 ± 0.06	1.93 ± 0.06^{ab}	0.157 ± 0.005^{a}	4.26 ± 0.35	0.124 ± 0.006^{b}	19.9 ± 1.5^{a}	1.25 ± 0.05
MLL	5.35 ± 0.04	2.05 ± 0.05^{b}	0.164 ± 0.006^{a}	4.84 ± 0.41	0.117 ± 0.005^{ab}	25.9 ± 1.5^{b}	1.33 ± 0.05
LL	5.38 ± 0.04	2.40 ± 0.05^{c}	0.189 ± 0.005^{b}	4.40 ± 0.35	0.130 ± 0.005^{b}	26.0 ± 1.3^{b}	1.30 ± 0.04
Overall	5.35 ± 0.02	2.04 ± 0.03	0.166 ± 0.003	4.70 ± 0.21	0.119 ± 0.003	23.5 ± 0.7	1.27 ± 0.02

[*] Mean±std.error, superscripts letters within column denoted significant differences (ANOVA, HSD; $p<0.05$); whereas same letter are not significantly differing.

[1] N (%) × 10^4 = N in ppm; [2] μg/g =Parts per million (ppm); [3] K meq/100 g × 391 = K in ppm;

HL – Highland, MHL – Medium Highland, MLL – Medium Lowland, LL – Lowland.

3.4 Soil Chemical / Nutrient Properties

Nitrogen is the most important nutrient element for crop and its deficiency is worldwide. It is the nutrient which normally produces the greatest yield response in crop plants (Timsina *et al.,* 2006). Understanding the behaviour of N in soil is essential for maximizing crop productivity and profitability (Hossain *et al.,* 2005). The average percentage of total N content was low (<0.18%), which covered more than 75% of the study area (Table 3; Figure 6). Nitrogen is easily lost from soil through various mechanisms such as ammonia volatilization, leaching and de-nitrification processes etc. (Prasad and Power, 1997). When N application was not synchronized with crop demand, N losses from the soil-plant system were large, which lead to reduce N use efficiency and consequently polluted environment (Ladha *et al.,* 2000). Significant differences ($p<0.05$) were observed of total N content for different blocks and land types (Table 3). Chang *et al.,* (2000) also found higher depletion of the N in HL, MHL, and MLL and LL. Due to the intensive cultivation (CI > 200%) of all land types in the study area seemed to cause the N deficiency (Table 3). Over the past three decades, intensive crop cultivation, removal of crop residues including roots, and use of N nutrient have considerably reduced both soil carbon (C) and soil N in Bangladesh (Ali, 2004).

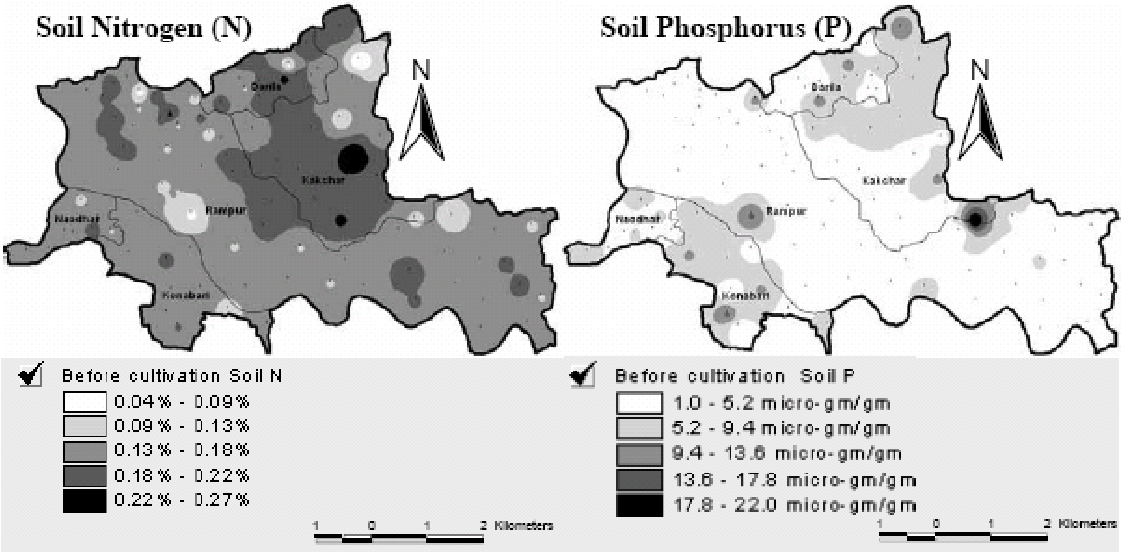

Figure 6. GIS maps of soil nitrogen and phosphorus status in 2006 irrigated season.

Next to N, phosphorus is essential for plant growth and grain development. P is an immobile nutrient and remains as abundantly in soils unlike N and K. P was frequently applied at transplanting time of irrigated rice cultivation in Bangladesh, which was emphasized with the hastening of rice grain maturity (Saleque *et al.,* 2006). Average P content was very low (<6.0 µg/g), whereas, it was ranged between 1.0 and 22.0 µg/g in soil (Table 3) and more than 97% study area possessed very low to low status of P content (Figure 6). Evidences have shown that PO_3 from recently added fertilizer provided only a fraction of P to the crop uptake and the portion not recovered by the first crop has definite residual value for following crops (Dobermann *et al.*, 2002). Although there were slight variations in soil P content in the different land blocks and land types of the study area and differences were significant ($p<0.05$) among land blocks. Study revealed that Rampur land block had very less (3.43±0.20 µg/g) amount of P content compared to the other land blocks (Table 3).

Potassium deficiency in paddy soils is becoming one of the limiting factors for increasing rice yield in low land areas of Asia. In Bangladesh the exchangeable K in soil varies from 40 to 600 ppm and the solution K from 1 to 10 ppm (Table 1). Soil K status was varied from low (0.07–1.5 meq/100g) to medium (0.151–0.22 meq/100g) status in different land blocks and the land types, it ranged between 0.04 and 0.23 meq/100g in soil of the study area (Table 3). Apparently average K status was low (0.119±0.003 meq/100g) although around 92% of the study area possessed very low to low status of K content (Figure 7). Significant differences were observed while slight variation was found which ranged from 0.09 to 0.13 meq/100g in different land blocks and land types (Table 3). Large quantity of K is extracted from Bangladesh soils due to intensive cultivation which frequently occurred K deficiency in multiple cropping system (Panaullah *et al.,* 2006). P and K lead to depletion of soil productive capacity due to intensive irrigated rice mono-cropping systems of Bangladesh as well as Asia which caused grain production losses significantly (Dobermann *et al.,* 2005). Although the initial yield response of lowland rice to P or K applications is often small whereas large cumulative yield increases accrue over time (Witt and Dobermann, 2004).

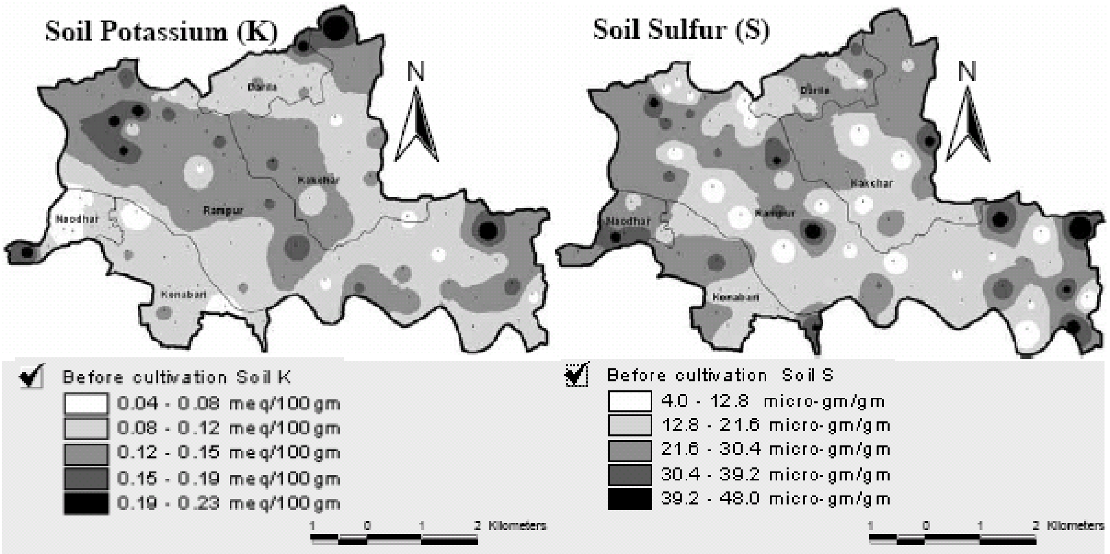

Figure 7. GIS application maps of (a) soil potassium (K) and (b) soil sulfur (S)

Sulfur is considered as the fourth major nutrient element for crop production. S is a critical nutrient for crop growth, while quantifications of S input into rice production systems are lacking (Blair and Lefroy, 1998). Although, S status was low (9.1–18.0 μg/g) to medium (18.1–27.0 μg/g) in different land blocks and land types; which was ranged from 4.0 to 48.0 μg/g in soil and possessed more than 87% of the study area (Figure 7). However, average overall S status was 23.5±0.7 μg/g in soil (Table 3) which shows a medium range (BARC ,1997). Variation of S status was observed in different land blocks and land types while differences were not significant with land blocks in the study area (Table 3). Although the contents of plant protein, chlorophyll and photosynthesis could be affected by S deficiency in rice based-cropping systems (Bhuiyan and Islam, 1989), therefore, transplanted rice should receive S on the priority basis along with N-P-K which increases the grain yield by 30-79% (Dobermann *et al.*, 1998).

Zinc is an essential micronutrient element for crop. Zinc deficiency in lowland is a common phenomenon all over Bangladesh, while low to medium status Zn was observed over the study area which was ranged from lowest 0.58 to highest 2.0 μg/g soil. However, overall average status was 1.27±0.02 μg/g in soil (Table 3), which fallen in medium rage (BARC, 1997). There were variation in soil Zn content among land blocks and land types, however, differences were not significant ($p<0.05$) (Table 3). It made fixation with P and S in long-time water logging condition,, therefore it become unavailable in the lowland and medium lowland condition for plant uptake in the long run (Sillanpaa, 1990).

3.5 Assessment of Influence and Inter-Relationships of Soil Properties

Correlation analysis was made for 12 soil properties representing soil physical, physico-chemical and chemical/nutrient which indicted intra and inter-relationships among the soil properties. Of 66 pairs in correlation matrix, 31 pairs showed significant relationships among them (Table 4). Significant positive and negative relationships were observed between clay and porosity ($r > 0.96$); and bulk density ($r > -0.96$), respectively (Table 4). Significant positive correlation was also found in SOM and soil N ($r = 0.79$). However, most of the soil properties were negatively correlated with sand and positively correlated with clay.

Table 4. Correlation matrix among soil properties (n=100) for assessing influences and inter-relationships.

	Sand	*Silt*	*Clay*	*Bulk density*	*Porosity*	*pH*	*SOM*	*N*	*P*	*K*	*S*
Sand	1.00										
Silt	-0.020^{ns}	1.00									
Clay	-0.636**	-0.727**	1.00								
Bulk density	0.763**	0.585**	-0.960**	1.00							
Porosity	-0.764**	-0.581**	0.962**	-1.00**	1.00						
pH	-0.177^{ns}	-0.031^{ns}	0.139^{ns}	-0.162^{ns}	0.160^{ns}	1.00					
SOM	-0.272**	-0.222*	0.372**	-0.367**	0.371**	-0.051^{ns}	1.00				
N	-0.244*	-0.264**	0.379**	-0.366**	0.370**	-0.107^{ns}	0.793**	1.00			
P	0.111^{ns}	0.027^{ns}	-0.111^{ns}	0.122^{ns}	-0.127^{ns}	0.088^{ns}	-0.195^{ns}	-0.217*	1.00		
K	-0.287**	-0.295**	0.417**	-0.367**	0.372**	0.042^{ns}	0.244*	0.226*	-0.091^{ns}	1.00	
S	-0.137^{ns}	0.149^{ns}	0.016^{ns}	0.026^{ns}	0.033^{ns}	-0.181^{ns}	0.134^{ns}	-0.082^{ns}	-0.052^{ns}	-0.005^{ns}	1.00
Zn	0.004^{ns}	-0.170^{ns}	0.132^{ns}	-0.103^{ns}	0.303^{ns}	-0.272**	0.060^{ns}	0.152^{ns}	0.279**	0.356**	0.174^{ns}

*,** Indicated relationships significance level at $p < 0.05$ and $p < 0.01$; ^{ns}- non-significant and '-' sign denoted negatively correlated.

Eigenvalues from the covariance analysis indicated that the first four factor components (FCs) accounted for 99% of the variance of soil properties raw data (Table 5). The first factor component (FC1) explained 48% of total variance followed by the second factor component (FC2), the third factor component (FC3) and the fourth factor component (FC4) explained 30%, 18% and 4% of the total variance respectively (Table 5). Covariance analysis proved inadequate data distribution due to the differences in units of soil properties and apart from first and second factor components. Therefore, FA was repeated using a correlation matrix on standardized values of the measured soil properties with each variables having a zero mean and unit variance with total variance = number of variables (Garson, 2007). First four FCs, eigenvalues >1, accounted for >75% of the variability in measured soil properties (Table 6). The FCs with eigenvalues >1 were retained, since eigenvalues <1 indicated the factor could explain less variance than an individual soil properties. FC1, FC2, FC3 and FC4 explained 37%, 15%, 12%, and 11% of the total variance respectively (Table 6).

Table 5. Eigenvalue, proportion and cumulative variance explained by factor analysis using covariance matrix (raw data) of 12 soil properties.

Factor	*Eigenvalue*	*Difference*	*Proportion*	*Cumulative*
1	239.179	88.827	0.48	0.48
2	150.352	57.174	0.30	0.78
3	93.178	82.591	0.18	0.96
4	10.587	10.13	0.02	0.99

Table 6. Eigenvalue, proportion and cumulative variance explained by factor analysis using correlation matrix (standardized data) of 12 soil properties.

Factor	*Eigenvalue*	*Difference*	*Proportion*	*Cumulative*
1	4.47	2.723	0.37	0.37
2	1.747	0.357	0.15	0.52
3	1.39	0.016	0.12	0.63
4	1.374	0.474	0.11	0.75

The FC1 explained 37% of total variance (Table 6) which included clay, porosity, sand and bulk density (communality estimate > 0.90 for each variable) as the major contributing variables (Table 7). The FC2 accounted further 15% of the total variance (Table 6) which included soil N, SOM and soil P (communality estimate varied between 0.52 and 0.79 for different variables) as the major contributing variables (Table 7). Similarly the FC3 explained 12% of the total variance which included soil Zn, soil K and soil pH (communality estimate varied between 0.45 and 0.81 for different variables) as the major contributing variables whereas FC4 explained 11% of total variance which included soil silt and soil sulfur (communality estimate for silt = 0.58 and for Sulfur = 0.79) as the major contributing variables (Tables 6 and 7).

A high communality estimates suggests that high portion of the variance was explained by the factor components, therefore, it would get higher preference over a low communality estimates (Garson, 2007; Dunteman, 1989).The magnitude of the eigenvalues were used as a criterion for interpreting the relationship between measured soil properties and factor components (Table 6 and 7).

Table 7. Proportion of variance using varimax rotation and Kaiser Normalized, and communality estimates for 12 soil properties (Principal component method).

Soil properties	*FC1*	*FC2*	*FC3*	*FC4*	*Communalities estimates*
Sand	**-0.312**	0.101	0.088	-0.359	0.91
Porosity	**0.267**	-0.028	-0.006	0.002	0.97
Bulk density	**-0.265**	0.029	0.001	0.004	0.97
Clay	**0.222**	-0.014	0.039	-0.116	0.94
Soil organic matter	-0.059	**0.454**	-0.045	0.052	0.77
Nitrogen (N)	-0.08	**0.447**	0.03	0.023	0.79
Phosphorus (P)	0.037	**-0.344**	0.368	-0.061	0.52
Zinc (Zn)	-0.022	-0.053	**0.569**	0.084	0.81
Potassium (K)	0.06	0.008	**0.301**	-0.048	0.46
Soil pH	0.136	-0.172	**-0.236**	-0.233	0.45
Sulfur (S)	0.053	0.066	0.092	**0.518**	0.58
Silt	0.013	-0.07	-0.124	**0.448**	0.79
% total Variance explained	37	15	12	11	

The rotation convergent in 6 iterations. Factor scores of variables in bold letters indicated the major contributors in the group.
FC- Factor component

Soil properties were assigned to a factor for which their eigenvalues was the highest. Factor analysis reduced 12 measured soil properties into four FCs groups that explained >75% of the total variability. FC1 was directly related to *'soil potential physical properties'* which explained 37% of the total variance (Tables 6 and 7) with a positive loading from clay and porosity and negative loading from sand and bulk density (Table 7). The soil potential physical properties (FC1 in Table 7) included clay which explained the major variation of water holding capacity of irrigated rice system. The FC2, named as *'soil highly potential nutrients'* explained 15% of variance with positive loading from SOM and soil N; and negative loading from P (Table 7). The soil highly potential nutrients (FC2 in Table 7) included SOM and soil N which played crucial role for nutrient holding in soil pool and responsible for plant vegetative growth as well respectively. While soil P showed negative loading due to its very low to low status in soil (Table 3 and Figure 6). FC3, called as *'soil moderately potential nutrients'* explained 12% of the variance had positive loading from Zn and K; and negative loading from pH (Table 7). FC4 named as *'soil additional properties'* explained only 11% of variance had positive loading from S and silt (Table 7). Soil 90% S comes from SOM sources, therefore it had the associate influenced with *'soil highly potential nutrients'*. Although, S deficiency in the plant environment limits the efficiency of N uptake, and therefore, availability of S was necessary to achieve the maximum utilization of applied N (Saleque *et al.,* 2006).

4. CONCLUSIONS

Soil properties have significant influence on the soil health and productivity of an ecosystem and the related environment. Soil productivity depends on soil potential properties with specified system of managements. The study area largely fallen in moderately fine texture with higher amount of clay content which indicated favorable condition for irrigated rice production system. The clay content has significant influence on water holding capacity and reduces nutrient leaching. Very to moderately acidic soil pH condition is also favorable for irrigated rice production. Medium range (1.4%–2.3%) of SOM was observed which collaborates well with a number of important soils physical, chemical and microbiological properties. As SOM increases considerably then availability of soil nutrients i.e. N, P, K, S also increases. In addition, SOM and clay binds soil particles as stable aggregates that resist nutrients leaching, water infiltration, reduce soil bulk density and help to maintain a stable soil pH which is essential for irrigated rice production system. Overall soil nutrients status was poor, possessing low status (<0.18%) of N, very low to low status (<9.4 µg/g) of P, low to medium status (<0.15 meq/100g) of K, low to medium status (<21.6 µg/g) of S and medium status (<1.35 µg/g) of Zn.

Correlation and factor analysis assessed the influences and inter-relationships among 12 measured soil properties and explained into four FCs groups (eigenvalues>1). FC1-*'soil potential physical properties'* which included clay and porosity; FC2-*'soil highly potential nutrients'* which included SOM and N; FC3-*'soil moderately potential nutrients'* which included Zn and K; and FC4-*'soil additional properties'* which included S and silt as positive loading. Significant highest positive and negative inter-relationships were observed between soil clay and porosity and bulk density. SOM and clay influenced water holding and nutrients in soil system which was essential for irrigated rice production. Soil N influenced early growth of rice whereas inherently poor N and P status significantly reduced rice production in irrigated rice domain of Bangladesh. Moreover, inappropriate cropping systems and imbalance conditions of soil chemicals/nutrients seem to have restricted the activities of additional organic and inorganic nutrients, which were used as fertilizers. Finally these situations could adversely affect on crop production and productivity; and degrade rice ecosystem. Caring and efficient maintenance of the influential soil properties are major concern in intensive crop cultivation situation like in Bangladesh for improving soil productive capacity, food safety and or environmental quality.

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