Original Research Article

SOIL FERTILITY DELINEATION TECHNIQUES AND RICE PRODUCTION

ABSTRACT

Determination of soil fertility with minimum data set for crop zoning and devising fertilizer recommendations. Soil fertility evaluation method based on pH, cation exchange capacity (CEC), soil organic carbon (SOC), available phosphorus (P), sulphur (S), zinc (Zn), boron (B) and exchangeable potassium (K). The data were collected from existing literatures and scoring was done on 0–100 scale. The lowest score was assigned for the minimum value of tested attributes and then gradually higher scoring values. Arithmetic, weighted, geometric and most minimum of mean scores were calculated and their performances were compared with grain yield of dry season irrigated (Boro) rice. Soil fertility in 10-12 and 39-52 percent areas of the country are very low and low, respectively. Medium fertile and fertile soils are distributed in 17-41% and in about 8% areas of the country. About 55% soils scored 70–95 (medium to high SOC) and the rest belongs to inferior quality. In some areas P build up has taken place (25% areas), but widespread K mining. Sulphur and Zn status in about 40 areas are low to very low (scored <35 and <40). Soils of the major areas of the country are with low pH (5.0-6.0) and CEC in the range of 15-25 $cmol_c\ kg^{-1}$. Weighted mean score and most minimum of eight attributes score showed good relationships with dry season irrigated rice yields than other tested methods indicating that this technique can be used for soil fertility rating in tropical countries.

Key words: Soil attributes, Score, Weighted mean, Most minimum mean, Maps

1. NTRODUCTION

Global population is increasing and so does the demand for food production, which has already created tremendous pressure on soil, a finite resource for mankind. It is our obligation to keep soil healthy and productive through appropriate amendments and crop management practices [1]. Indigenous nutrient supplying capacity and fertilizer management may make a soil fertile for one type of crop but could be deficient for the others. So, determination of soil fertility range would be important not only for producing healthy crops economically but also for maintaining its productivity for future generations. Soils in Bangladesh are exposed to high temperatures mostly; plenty of rainfall and greater pressure from growing two or more crops in a year with or without balanced fertilizations [2] and thus nutrients mining are widespread. New nutrient deficiencies are emerging [3], and there might be potential hidden hunger for many others that need to be identified for efficient crop production.

Soil fertility varies among regions indicating that variable amounts of fertilizers need to be applied for different types of crop production. Inadequate dose will impair crop yield, while overdose can cause not only economic losses but also could be responsible for environmental pollutions [4]. So, a broad knowledge on soil fertility can provide a better perception on current nutrient status, distribution patterns and trends [5] that can be obtained through geo-statistical and geospatial analyses [6,7]. Such analyses help in decision making processes for precision agriculture and thus for improvement of crop productivity [8,9].

Soil fertility can be determined in different ways [10,11] by using soil pH, SOC, P, K, exchangeable calcium (Ca), magnesium (Mg) and aluminium (Al), S, etc [12,13]. Mbogoni et al [14] evaluated soil fertility by using average weighted data on SOC, soil pH, total N, electrical conductivity, C/N ration, available P, exchangeable Ca, Mg and texture for rice based system productivity improvement. Khaki et al [15] utilized square-root method as parametric approach and Joint Fuzzy Membership functions to compute soil fertility index

(SFI). They found both the system suitable for soil fertility mapping and showed good relations with rice yield. Desavathu et al [7] used soil pH, EC, N, P and for soil fertility evaluation through inverse distance weightage interpolation. Thus it is found that researchers had taken initiative for making soil fertility maps for specific locations or regions but a simple method for a country is still lacking. Therefore, the objective of this study was to use geo-referenced data on selected soil attributes for preparation of soil fertility maps using average, weighted mean, geometric mean and most minimum value techniques for Bangladesh and to establish their relationships with rice yields.

2. MATERIALS AND METHODS

Data on soil organic carbon (SOC), available phosphorus (P), sulphur (S), zinc (Zn), and boron (B), cation exchange capacity (CEC), soil pH and exchangeable K were collected from Bangladesh Agricultural Research Council website, Soil Resource Development Institute and existing available literatures. Average Boro clean rice (dry season irrigated crop, hereafter as Boro rice) yields from 2007 to 2013 were collected from different volumes of Bangladesh Bureau of Statistics and its relationships were established with soil fertility scores. Although crop yields vary depending on inherent soil fertility, some other factors like electrical conductivity, water quality (such as salinity) and its availability, agronomic management practices, other biotic and abiotic factors also greatly influences crop productivity. Nonetheless, inclusion of all those factors that influence soil fertility is beyond the scope of the present investigation.

2.1.Scoring criteria and map preparation

Soil nutrient status in Bangladesh has been classified as very low, low medium, optimum and high based on different ranges (Table 1). This classification system was considered for assigning scoring values (Table 2) against each selected soil attribute. The scoring scale, as considered in the present investigation, was 0–100. Attribute-wise soil fertility ratings over different locations of Bangladesh were made by using MS-Excel Macros and IDRISI3.2.

Soil fertility scores, as determined by arithmetic mean (AM), geometric mean (GM), weighted mean and (WM) and most minimum attribute ($MAtrib_{score}$) techniques, were used to find out their relationships with Boro rice yields (64 districts of Bangladesh from 2007 to 2013) through regression analyses. Considering higher R^2 values, final soil fertility rating maps were prepared based on weighted mean scores (Equa. I) and scores of the most minimum of eight parameters for each district (Equa. II). Among soil attributes the most limiting factors dictate crop yield, so we have provided weight to such factors in determining WM as follows:

$$WM = ([SOC_{score}]*[P_{score}]*[K_{score}]*[CEC_{score}]*[pH_{score}])\text{^}(1/5)*0.5 + [S_{score}]*0.25 + ([Zn_{score}]*[B_{sore}])\text{^}(1/2)*0.25 \quad \ldots\ldots \quad (I)$$

where, SOC_{score} is the soil organic carbon, P_{score}, K_{score}, CEC_{score}, pH_{score}, S_{score}, Zn_{score} and B_{score} stand for phosphorus, potassium, cation exchange capacity, soil pH, sulphur, zinc and boron scores, respectively.

$MAtrib_{score}$ for selected eight soil parameters were determined as follows:

$$MAtrib_{score} = \text{Geomean}(\text{Small}(Atrib1:Atrib8,1),\text{Small}(Atrib1:Atrib8,2),\ldots\ldots, \text{Small}(Atrib1:Atrib8,8)) \quad \ldots\ldots \quad (II)$$

where, Atrib1, 2, 3, ..., 8 are the soil parameters considered first, second, etc.

GM score was calculated as follows:

$$GM = ([B_{score}]*[K_{score}]*[P_{score}]*[CE_{Cscore}]*[pH_{score}]*[SOC_{score}]*[S_{score}]*[Zn_{score}])\text{^}(1/8) \ \ldots \ (III)$$

AM score was computed as follows:

$$AM = ([B_{csore}]+[K_{score}]+[P_{score}]+[CEC_{score}]+[pH_{score}]+[SOC_{score}]+[S_{score}]+[Zn_{score}])/8 \text{ ...... (IV)}$$

Scores for most minimum of 1, 2, 3, 4, 5, 6 and 7 soil attributes were also found out in similar fashion of Equa. II. The maps of tested attributes were prepared by using IDRISI3.2. Soil fertility rating maps on the basis of WM and most minimum of eight attributes were used for soil fertility delineation in Bangladesh. The other maps prepared based on different techniques were used as supplementary figures.

3. RESULTS

Soil organic carbon, a vital component of fertility index showed >95 score for about 25% areas in Bangladesh (Fig. 1a). About 55% soils had 70–95 score (medium to high SOC) and the rest belongs to inferior quality. The scores for soil P varied from <10 to >75 in which very low (<7 ppm), low (7-15 ppm), optimum (15-30 ppm) and high (>30 ppm) P levels covered about 22.64, 47.74, 12.98 and 16.64 percent areas in the country (Fig. 1b). About 25% soils are with optimum/high (>80 score) K fertility. Majority areas (~43%) bear low K (0.091-0.18 meq 100 g^{-1} soil) and the rest belong to very low (<10 score) and medium (40-80 score) K categories y (Fig. 2a). The least score (<10) for S indicated that about 15.62% soils are very poor (<7.5 ppm); 26.04% low and 14.54% medium and 43.79% areas are with optimum/high S fertility status (Fig. 2b). In about 37.61% areas (score >75), soil Zn contents are optimum to high (>1.351 ppm), 20.77% areas (40-75 score) are with medium Zn containing soils and 41.61% soils scored <10 to 40 indicating (Fig. 3a) that Zn application is a must practice for Bangladesh. Boron fertility is very low to low in about 50% soils (score <10 to 40) and rest of the soils had medium B content (Fig. 3b).

Soil pH score varied from <25 to >85 depending on locations and soil types in the country. Maximum area coverage was 44.59% followed by 32.25% in the pH range of 5.0-6.0 and 6.5-7.5, respectively (Fig. 4a). Soil pH below 5.0 and above 7.5 covers about 7.29% areas of the country. The rest of the soils (15.22% areas) are with pH range of 6.0-6.5. The CEC scores ranged from <25 to >85 depending on location in the country (Fig. 4b). The CEC of major soils (47.46%) are 15-25 $cmol_c\ kg^{-1}$ followed by less than 15 $cmol_c\ kg^{-1}$ in 37.72% areas of the country. Higher CEC (>25 $cmol_c\ kg^{-1}$) was found in 14.81% areas only.

3.1. Soil fertility relationships with rice yield

Soil fertility score based on different techniques and their relationships with clean rice yields are shown in Fig. 5. About 49% yield variabilities are explained by the WM and most minimum of eight tested soil attributes score (MAttrib-8). The performances of AM and GM techniques in explaining yield variabilities were the least compared to others. Most minimum 1-7 soil attributes score explained Boro rice yield variabilities by about 23-42 percent.

3.2. Soil fertility status

Soil fertility scores varied from <35 to >60 with WM score technique and it was <35 to >55 with the MAttrib-8 (Fig. 6). In the lowest soil fertility score (<35), area coverages are 10-12% of the country based on above stated two techniques. The largest areas (28-30%) fall within the score of 40-45 under both the techniques. Areas covered by higher scores (>55) were only about 16% of the country. Soil fertility scores of 35-40 represented 9.41% and 24.08% areas under WM and MAttrib-8 techniques, respectively. Similarly, 45-50 and 50-55 scores under WM and MAttrib-8 represented about 20% and 11-16% areas, respectively of the country. Based on GM, AM and MAttrib-1 to MAttrib-7 soil fertility score varied greatly and represented different areas of the country, but major areas showed low fertility score (data not shown). There were variations in the highest and the lowest scores because of method employed (Table 3). The standard deviations were ± 8.52, ± 7.19, 7.73 and ± 8.52 for GM, AM, WM and MAttrib-8 means score, respectively having corresponding co-efficient of variations of 19.62%, 14.22%, 16.58% and 19.62%.

4. DISCUSSION

In about 29% areas of the country, the SOC was at medium category; although there are high and very high SOC in certain areas, especially with peat soils. In general, SOC was higher in low lying areas, the single cropped zones, which remain 5–6 months under water in a year. This level of SOC specifically in about 18% areas of the country is still inadequate for satisfactory crop production [16]. As population pressure is increasing, farmers are using such lands to increase total production through cropping intensification resulting in depletion of SOC along with other essential plant nutrients. The decrease rate of SOC is comparatively faster with arable cropping over time [17] with or without addition of organic manures. So, we have found lower SOC rating in intensely cropping zones of Bangladesh. Partial productivity of applied fertilizers is also decreasing indicating that nutrients from organic matter (OM) need to be added that has been observed in our experiments at BRRI. Most soils showed good response when OM was incorporated either from poultry litter, cow dung, vermicompost [18,19] or green manuring because SOC influences soil pH, buffering capacity, nutrient supplies and soil biological activity [20].

Although available P in the category of very low and low cover a larger area (about 70%), in some areas its build up has taken place (Fig. 1b) because of cropping patterns followed, soil acidity, fertilizer management options and inherent characteristics of parent materials [16,21]. As a greater area suffers from available P, corrective measures have to be taken for profitable production [22]. This scenario is also true for global perspective in which P is depleting by 5.1 kg ha^{-1} yr^{-1} [23]. However, majority of the farmers in Bangladesh prefer to add N fertilizer because of its immediate visible effects [2] and thus nutrient imbalance impose negative impact on soil properties and crop production as a whole.

Potassium levels in major areas were very low to low (Fig. 2a) indicating that K mining was taking place because of its substandard dose used by the farmers. Since farmers generally use more N fertilizer and minimum K rate, the later is depleting rapidly in many areas of Bangladesh [21, 22, 24]. In the global perspective, K is also depleting by 38.8 kg ha^{-1} yr^{-1} [23]; although its build up is not either uncommon in some areas because of excessive use with certain crops [16]. Though S and Zn deficiencies are widespread in the country, its wet and dry depositions are also taking place because of industrial development [25]; but S fertilizer application still improves rice yields in many areas of the country. The scenario of B fertility is not healthy because in some areas it has depleted severely over time [16]. Yields of wheat, mustard and papaya reduce greatly in many parts of the country without B application. The depletion of soil fertility in areas with high cropping intensities [26] indicated that replenishment of removed nutrients were not taking place or it is beyond the capacity of the soils to supply major nutrients for growing high yielding crop varieties. There are evidences that Zn and B contents have been depleted severely from 1991 to 2012 in some selected areas of Bangladesh and thus crop productivity is declining [16].

Lower soil pH covers quite larger areas in the north and north-east part and higher pH in the southern part of the country where essential plant nutrients availability is a limiting factor for satisfactory crop production without proper amendment. In some cases soil pH is increasing, especially in northern part of the country and thus playing a negative role on nutrient availability. It was reported that nutrient availability from applied fertilizers may be unavailable by more than 33-75% if soil pH ranges from 4.5 to 5.5 [27]. Generally, major nutrients are available for plants when soil pH varies from 6.5 to 7.5 [28]. Among others, soil P and many micronutrients become unavailable when pH exceeds 7.5, but molybdenum availability increases in alkaline pH. Moreover, CEC also depends on soil pH in a neutral soil will have higher CEC than acidic soils [29]. Low CEC indicates light textured soils having tendency of K and Mg deficiencies and faster decrease in soil pH [29, 30]. In such situations frequent liming is needed for sandy type soils than clay category for profitable crop cultivation.

We have seen good relationships (R^2 = 0.49) of WM and MAttrib-8 scores with rice yields, which is similar to the findings of Vasu et al. [31]. In Bangladesh, no groping of soils has been made based on combine scores or combine effects of different soil attributes; but component-wise soil fertility delineations are available [22,26, 32]. So, our efforts are to group soil fertility status combining all tested attributes as score <35 (very low fertility), 35-45 (low fertility), 45-55 (medium fertile) and >55 (fertile). Accordingly, 10-12 and 39-52 percent areas of the country represented very low and low soil fertility, respectively (Fig. 6). Medium fertile and fertile soils are distributed in 17-41% and in about 8% areas of the country. These findings clearly indicate that special cares are needed for efficient and economic crop production in major areas of Bangladesh. However, crop yields not only depend on soil fertility, but also on other factors like water availability, temperature, and so on. Moreover, soil fertility scores alone cannot explain yield variability of a crop rather it can provide an indication for fertilizer rate determination and crop zoning for profitable farming.

Population pressure is increasing in Bangladesh, while soil fertility is decreasing indicating that we are manipulating our soils beyond its bearing capacity. In general, nutrient mining is taking place in Bangladesh at about 100 kg ha^{-1} yr^{-1} [22, 33] also reported low to very low soil fertility for most of the studied soils in Bangladesh. This scenario is also true in terms of global scale where soil fertility problems are associated with human-induced nutrient depletion [23]. Besides, soil nutrient availability is limiting in cultivated lands of tropical countries because of low inherent soil fertility [34]. Calcium deficiencies are emerging in some agro-ecological zones (AEZ-3 and 21) of Bangladesh [3] and there might be hidden hunger for micronutrients and thus reducing soil fertility and ultimately crop yield, but not considered in the present investigation because of unavailability of data for the whole country. In time series analyses for nutrient depletion, it was found that the contents of exchangeable K, Ca and Mg have declined in all physiographic units except Old Himalayan Piedmont and Madhupur Tract after 27 years of crop cultivation [35]. In one of our study, it was also found that soil nutrient ratios have been changed in many places of Bangladesh because of over exploitation of inherent soil fertility and thus Ca:P and N:Zn were playing significant negative role with wet season rice yields under unfavourable ecosystems of Bangladesh [36]. Similarly P: K ratio was acting antagonistically in agricultural ecological zone 3, 18 and 26 of Bangladesh. All these factors indicate that we have to know our soils before its use for crop production. Determination of soil fertility status by combining important but minimum attributes can help in this regard for profitable farming and to recuperate soil fertility through crop and fertilizer management.

5. CONCLUSION

A simple method of soil fertility evaluation for a country with minimum data sets is very much desirable for proper crop zoning and delineating agronomic management options for satisfactory crop production. We have determined soil fertility scores using pH, CEC, SOC, available P, S, Zn, B and exchangeable K and following geometric, arithmetic, weighted and mean approaches along with most minimum of tested attributes score. Weighted mean and most minimum of soil attribute scoring methods showed better relationships with dry season irrigated rice yields in Bangladesh indicating that this technique can be employed for soil fertility assessment and its subsequent use for crop zoning and for determination of fertilizer rates in similar environments around the globe.

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Figure titles

Fig. 1. Status of (a) soil organic carbon and (b) phosphorus in Bangladesh

Fig. 2. Status of (a) soil potassium and (b) sulphur in Bangladesh

Fig. 3. Status of (a) soil zinc and (b) boron in Bangladesh

Fig. 4. Distribution patterns of (a) soil pH (b) CEC in different parts of Bangladesh

Fig. 5. Relationships of clean Boro rice yields with scores of different soil attributes, Bangladesh

Fig. 6. Soil fertility variations in Bangladesh as per (a) weighted mean and (b) most minimum of eight soil-attributes scores

Supple. Fig. 1. Soil fertility for Bangladesh according to (a) arithmetic mean, (b) geometric mean, (c) one most minimum, (d) two most minimum, (e) three most minimum, (f) four most minimum and (g) five most minimum, (h) six most minimum and (i) seven most minimum attributes

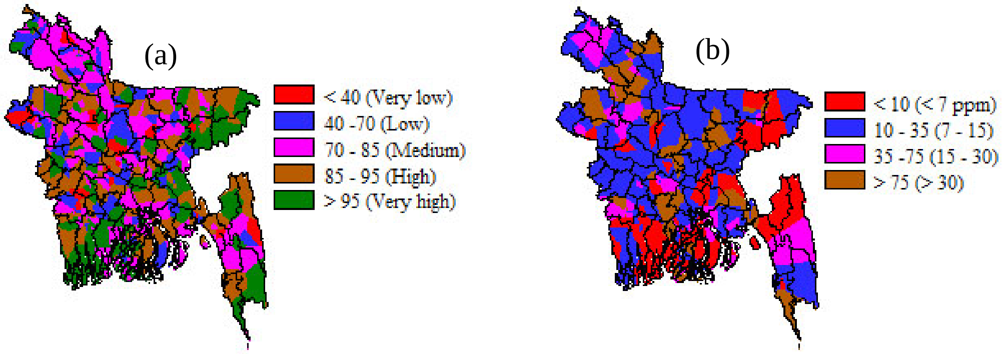


Fig. 1 a & b

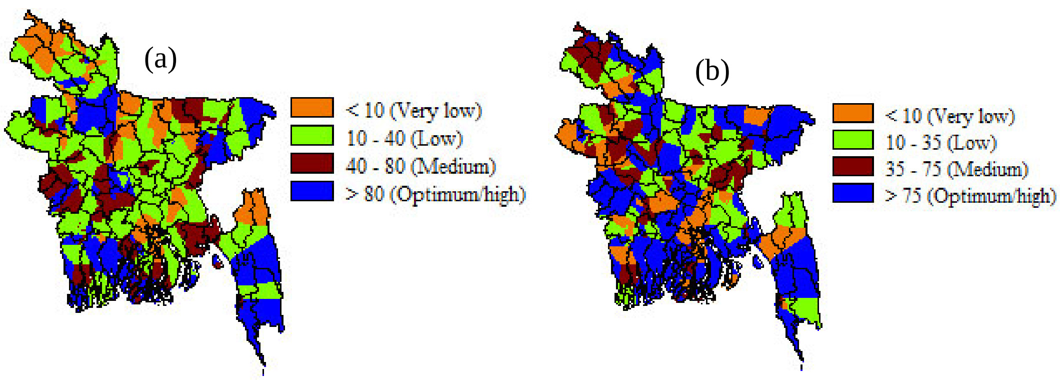


Fig. 2 a & b

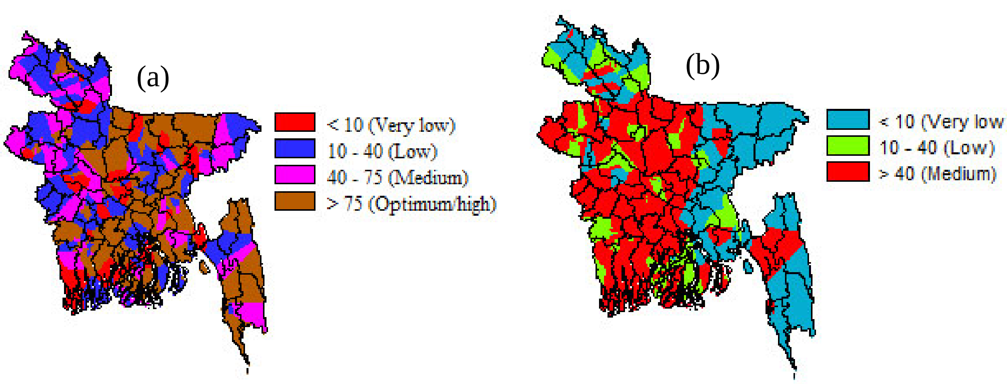


Fig. 3 a & b

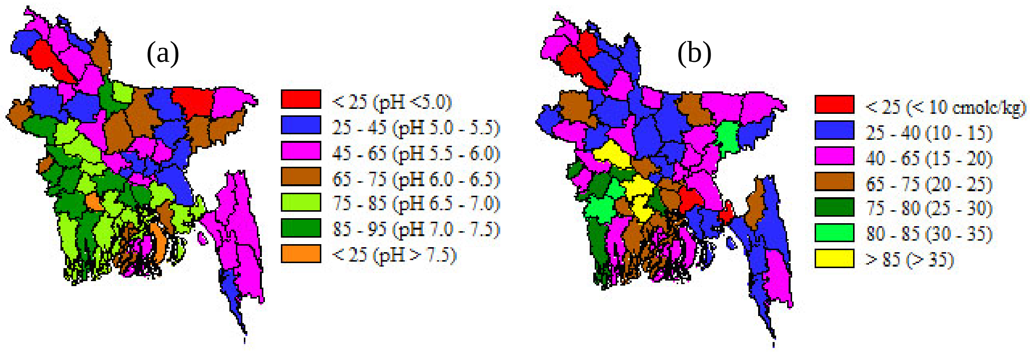
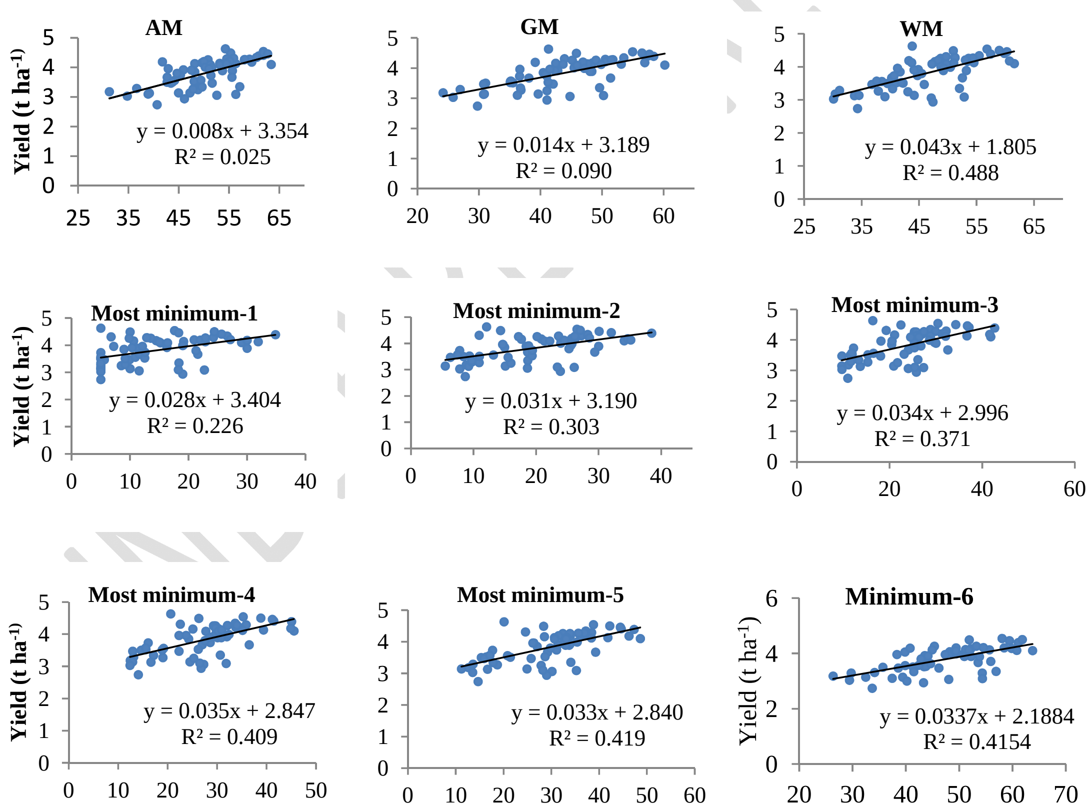

(a)
(b)
< 25 (pH <5.0)
25 - 45 (pH 5.0 - 5.5)
45 - 65 (pH 5.5 - 6.0)
65 - 75 (pH 6.0 - 6.5)
75 - 85 (pH 6.5 - 7.0)
85 - 95 (pH 7.0 - 7.5)
< 25 (pH > 7.5)
< 25 (< 10 cmolc/kg)
25 - 40 (10 - 15)
40 - 65 (15 - 20)
65 - 75 (20 - 25)
75 - 80 (25 - 30)
80 - 85 (30 - 35)
> 85 (> 35)

Fig. 4 a & b


AM
y = 0.008x + 3.354
R² = 0.025
GM
y = 0.014x + 3.189
R² = 0.090
WM
y = 0.043x + 1.805
R² = 0.488
Most minimum-1
y = 0.028x + 3.404
R² = 0.226
Most minimum-2
y = 0.031x + 3.190
R² = 0.303
Most minimum-3
y = 0.034x + 2.996
R² = 0.371
Most minimum-4
y = 0.035x + 2.847
R² = 0.409
Most minimum-5
y = 0.033x + 2.840
R² = 0.419
Minimum-6
y = 0.0337x + 2.1884
R² = 0.4154
Yield (t ha-1)

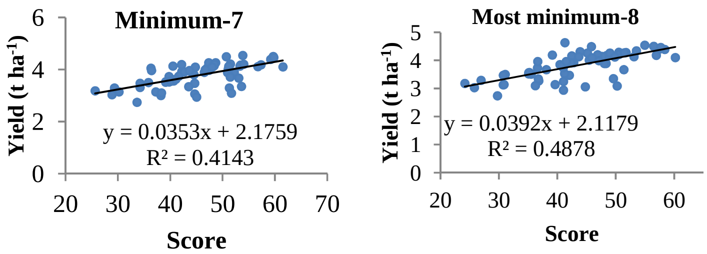


Fig. 5

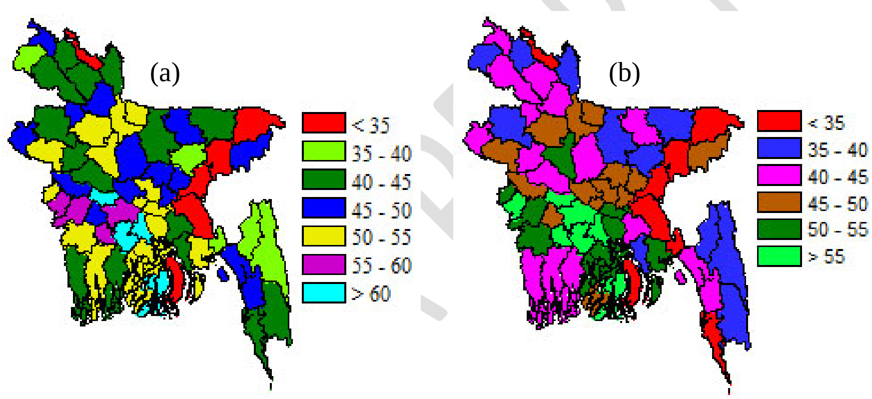


Fig. 6 a & b

Table 1. Soil nutrient status and its classifications in Bangladesh

	Critical limit	Very low	Low	Medium	Optimum	High
SOC (%)	-	<0.336	0.337-0.574	0.575-1.148	1.489-2.308*	>2.308**
Olsen P (ppm)	10	<7.50	7.51-15.00	15.1-22.5	22.51-30.00	30.1-37.50

Bray P (ppm)	7	<5.25	5.25-10.50	10.51-15.75	15.76-21.00	21.10-26.25
S (ppm)	10	<7.50	7.51-15.00	15.1-22.5	22.51-30.00	30.1-37.50
K (meq 100 g^{-1} soil)	0.12	<0.09	0.091-0.18	0.181-0.27	0.271-0.36	0.361-0.45
Ca (meq 100 g^{-1} soil)	2	<1.50	1.51-3.00	3.1-4.50	4.51-6.00	6.1-7.50
Mg (meq100 g^{-1} soil)	0.5	<0.0375	0.376-0.75	0.751-1.25	1.16-1.50	1.51-1.875
Cu (ppm)	0.6	<0.15	0.151-0.30	0.31-0.45	0.451-0.60	0.61-0.75
Zn (ppm)	0.2	<0.45	0.451-0.90	0.91-1.35	1.351-1.81	1.81-2.25
Fe (ppm)	4	<3.00	3.10-6.00	6.1-9.00	9.1-12.00	12.1-15.00
Mn (ppm)	1	<0.75	0.756-1.50	1.51-2.25	2.56-3.00	3.1-3.75
B (ppm)	0.2	<0.15	0.151-0.30	0.31-0.45	0.451-0.60	0.61-0.75
Mo (ppm)	0.1	<0.075	0.076-0.15	0.151-0.225	0.226-0.30	0.31-0.375

FRG, 2012; *High and **Very high

Table 2. Scoring criteria for different nutrient levels

Soil nutrients		Soil pH		SOC		CEC	
Status	Score	Range	Score	Range	Score	Range	Score
Very low	5	<5.0	25	<0.336	40	<5	25
Low	30	5.0-5.5	45	0.337-0.574	70	5-10	40
Medium	70	5.5-6.0	65	0.575-1.148	85	10-20	65
Optimum	100	6.0-6.5	75	1.489-2.308	95	20-30	75
High	100	6.5-7.0	85	>2.308	100	30-40	80
		7.0-7.5	95			40-50	85
		>7.5	25			>50	100

Table 3. Soil fertility scoring variations due to methods

	Geometric mean	Arithmetic mean	Weighted mean	MAttrib-8
Maximum	60.19	63.38	61.55	60.19
Minimum	24.20	31.20	30.10	24.20
Mean	43.42	50.57	46.60	43.42
Sd (±)	8.52	7.19	7.73	8.52
CV(%)	19.62	14.22	16.58	19.62