Fertility Status and Possible Environmental Consequences of Tista Floodplain Soils in Bangladesh

M. M. Rahman and S. L. Ranamukhaarachchi
Asian Institute of Technology, Agricultural and Aquatic Systems and Engineering Program
PO Box 4, Klong Luang, Pathumthani 12120, Thailand.
Contact e-mail: rmizanur@ait.ac.th

Abstract

The fertility levels of soils in the Tista Floodplain in Bangladesh were assessed using one hundred and thirty seven soil samples from five major soil groups namely Dimla, Dumar, Manda, Pirgacha and Gangachora in order to explore possibilities to improve crop yield. The results showed that in Tista Floodplain soils organic matter and N contents were mainly low and very low respectively. Phosphorus was optimum to very high, K was medium, and Ca and Mg were very low. Sulfur ranged from very low to very high, while B and Zn were mainly low. Both Fe and Mn were in very high levels, thus there is a possibility for Fe and Mn toxicity. Farming has different effects on the environment depending upon deficiencies or surpluses of nutrients. Nutrient deficiency causes deterioration of soil quality. Nutrients in excess speed up nutrient leaching. The Tista Floodplain soils were rich in P, but application of P fertilizer is continued. The excess P may be transported from crop field to water bodies and may eventually pollute the environment. To ensure sustainable agriculture and friendly environment, a set of best management practices should be recognized and promoted to the farmers as a package. This package should include soil testing, location specific and cropping pattern based fertilizer recommendations, and maintenance of optimum OM level as priority.

Keywords: nutrients availability, soil fertility, soil test, Tista Floodplain

1. Introduction

Soil fertility is a complex but important quality indicator for sustainable agriculture. Sustainability is the main agenda in agricultural production systems all over the world, but is often threatened by environmental risks associated with the use of modern agricultural inputs, especially inorganic fertilizers. Soil fertility often changes in response to land use and management practices. Use of some cropping patterns and heavy use of inorganic fertilizers greatly affect the soil fertility. Soil reaction (pH), organic matter (OM) and different macro and micronutrients are the main determinants of soil fertility. OM is the key quality factor for retaining nutrients in soil and pH is the deciding factor for the availability of essential plant nutrients. OM is also a source of plant nutrients, especially nitrogen, and it also contains much P [1]. The amount and type of OM are indicative of soil productivity.

Thirty Agro Ecological Zones (AEZs) have been identified in Bangladesh and their crop species and fertility status vary considerably. The Tista Floodplain Zone is intensively cultivated with rice as the main crop. Wheat, potato, jute, mustard, sugarcane, cabbage, tomato, onion etc. are also grown to feed the ever-growing population. The major cropping patterns are rice-fallow-rice, wheat-jute-rice, potato-jute-rice, and mustard/rice-fallow-rice. The total food production in Bangladesh is about 25 million tons [2]. The total food production needs to be doubled in the next 20 years [3], while its natural resource base will shrink. To meet the food demand, crop yields have to be increased by 60-70 % within that period [4], which is a great challenge with the finite resource base. The increased yield results in increased nutrients removal from soils. Proper maintenance and management of soil fertility is therefore a must for sustainable food production.

Farmers apply only three major plant nutrients (N, P & K) to soils using inorganic fertilizers. But it is necessary to supply all deficit nutrients for better plant growth and higher yield. The importance of most of the other nutrients is mainly ignored except S, Zn and B are applied as fertilizers in some cases. The average rate of nutrients application in Bangladesh is 179 $kgha^{-1}y^{-1}$, while the estimated removal is 250-300 $kgha^{-1}y^{-1}$ [5]. For the cropping pattern mustard-fallow-rice, the recommended doses of N, P, K, S, Zn, Mg and B are 230, 37, 70, 23, 1.5, 10 and 0.5 $kgha^{-1}y^{-1}$ respectively [6], whereas the farmers' applications cover only 241, 69, 65, 4, 0, 0 and 0 $kgha^{-1}y^{-1}$ [4] respectively. This indicates that nutrients application in Tista Flood Plain soils is highly imbalanced, where P application is almost doubled the recommended rate.

The declining soil fertility followed by declining crop yields is the cause of imbalanced fertilizer application and nutrient mining. Moreover, excessive use of P can be a pollutant that restricts the potential uses of impacted water bodies [7]. Phosphorus transported from agricultural soils to surface water bodies (e.g. pond, lake, river etc.) can promote eutrophication. Therefore, optimum and balanced nutrient levels must be maintained for sustainable crop production and to avoid the transport of nutrients from cultivated soil to surface water in order to prevent environmental pollution. Amount of nutrients in the soils should be known in order to promote soil health, to predict potential crop productivity and to manage the soil environment for sustainable agriculture. The objectives of the study are i) to examine and document the current status of soil nutrients to recognize problems associated with the nutrient management practices and ii) to identify appropriate remedies and draw up guidelines for management and maintenance for sustainable agriculture and sound environment.

2. Materials and methods

Soil samples were collected from the Agro-ecological zone Tista Floodplain through a semi-detailed soil survey of Dimla subdistrict under Nilphamari district. Five major soil groups Dimla, Dumar, Manda, Pirgacha and Gangachora were taken into consideration for the study. These soils were categorized based on the land type of high (HL) and medium high level (MHL). The land in the Tista Flood Plain areas falls mainly under HL and MHL categories. HL can be defined as the land above normal flood level in the rainy season, while MHL is normally flooded up to 90cm depth in the rainy season continuously for more than two weeks. Composite soil samples were collected from the plow depth (0-15cm) at the rate of one sample from every 400 hectare of land of the series concerned. These samples were then placed separately on aluminum trays and dried in open air under a shed. After drying, samples were prepared for analysis by grinding and sieving using a 2 mm size sieve. These samples were kept in polyethylene bags with proper labeling. Thus 137 soil samples were collected and analyzed for different parameters in the Regional Laboratory, Soil Resource Development Institute (SRDI), Khulna, Bangladesh. Major attention was given to OM, P, S, B and Zn in this study, as various problems are experienced and associated with these parameters. Organic matter and total N were determined by Dry Combustion method (using LECO Carbon Analyzer 2000 instrument) [8] and Micro Kjeldhal systems [9] respectively. Calcium, Mg and K were analyzed by ammonium acetate extraction [10] method. The P Olsen's [11] (soil having pH 6.5 or above) and Bray & Kurtz [12] (soil having pH below 6.5) methods were followed. Sulfur and B were analyzed by Turbidimetric, and Azomethine-H [13] methods respectively. Iron, Mn and Zn were determined by DTPA extraction method [14]. The pH was determined with soil: water ratio 1:2.5 [15]. To interpret the soil test values, the critical levels of each elements were used as given in the Fertilizer Recommendation Guide [6].

3. Results and discussion

The means of each parameter using soil samples in each soil group are given in Table 1. The results are discussed based on the status class given in Table 2.

3.1 Soil pH

The soil pH in almost all major soil groups in the Tista Floodplain showed acidic nature. The possible exceptions were seen in Manda HL and Gangachora MHL, which showed the upper level of above 6.5. These soils, being non-calcareous, are limed very often to raise pH in order to facilitate nutrients availability to crops. Various factors over time are responsible for soil acidity, among which leaching loss of N fertilizers, crop removal of basic cations (Ca^{+2}, Mg^{+2}, and K^{+}), decomposition of organic residues and H^{+} ions released by Al^{+3} might be the causes of soil acidity in the Tista Floodplain soils. Soil pH controls solubility and availability of essential plant nutrients [16]. Therefore, a better understanding of the nature and management of soil pH is necessary.

3.2 Soil organic matter (OM)

Organic matter content in the soil is classified from very low to very high depending upon its content in soil (Table 1 & 3) [6]. The OM contents of HL of Dimla, Dumar, Manda, Gangachora soils were low, and ranged from 8.9 to 21.9gkg^{-1}, 9.3 to 23.8gkg^{-1}, 7.0 to 20.3gkg^{-1} and 8.3 to 25.9gkg^{-1} soils, respectively. It was also low for Manda MHL soils, which ranged from and 8.6 to 17.1gkg^{-1}soil. In Pirgacha HL and Gangachora MHL, soils were somewhat rich in OM content, which was ranked medium and the values ranged from 13.0 to 23.0gkg^{-1} soil and 9.0 to 28.7gkg^{-1} soils, respectively. In Kansas and Utah, the OM contents were 33.8gkg^{-1} and 26.9gkg^{-1} soils, respectively [9]. The OM content of a typical mineral soil varies from 20-60gkg^{-1} soil [17]. In Tista Floodplain soils, OM content was mainly low, which leads to low residual N in soils.

Considering the location specific test value, it was also observed that the OM content for most of the soils (63-76%) were low (Table 3). OM content was found to be medium in the 60% soils of Pirgacha HL and Gangachora MHL. Through mineralization, OM releases minerals in soils, thus nutrients become available to plants. It also helps in regulating soil pH [16], which greatly influence the nutrients availability.

It has been recognized that a productive soil should contain at least 40 g OMkg^{-1}soil [18]. But in Bangladesh, OM content of most soils is less than 15gkg^{-1}soil, and in some soils it even falls below 10gkg^{-1} [6]. The low OM content adversely affects on soil tilth, soil water retention, soil erosion, infiltration of air and water, and the fate of pesticides applied on soils [19], thus affecting environmental health and crop production. Low OM content results from the intensive cultivation and removal of crop stubble from the fields to use as a form of fuel in Bangladesh.

3.3 Soil phosphorus (P)

In general the p content of the Tista Floodplain soils falls from optimum to very high (Table 1 & 2). The P contents in soils of Dimla, Dumar and Pirgacha HL were very high, and Fe and Mn were also very high. The pH was strongly acidic to very strongly acidic in Dimla and strongly acidic to slightly acidic in Dumar and Pirgacha soils. Phosphorus was very high in soils of Manda HL and low in MHL, whereas soil pH ranges from very strongly acidic to neutral, and very strongly acidic to slightly acidic, respectively. Both Fe and Mn were found very high for Manda soils. The mean P content of Gangachora HL soils was high, whereas it was optimum in MHL soils. The pH was strongly acidic to slightly alkaline in Gangachora HL soils whereas it was strongly acidic to slightly acidic in MHL soils.

Phosphorus forms less soluble compounds in acidic soils with Fe (Fe^{3+}) and Al (Al^{3+}) [16], where pH declines below 5.5 [20]. As the soil of the study area is noncalcareous, the Ca content is very low; therefore, there is no possibility for P fixation and limitation due to Ca. In the Tista Floodplain soils the amount of available P was found to be much higher. This is attributed to inherently high P content in soils, and heavy doses of P fertilizer application by the farmers. The mean P concentration in soil solutions in Bangladesh is about 0.05 mgL^{-1} but varies widely among soils. The level of organically bound P varies between extremely negligible and 1000 mgL^{-1} [6]. In most soils, soil solution P ranges between <0.01 and 1 mgL^{-1}, and the minimum value needed for most agronomic crops is 0.2 mgL^{-1} P [21]. Therefore, a P fertilizer recommendation for crops in the Tista Floodplain soils varies, between 4 kgha^{-1} to 20 kgha^{-1} P [6]. This shows that the P availability in most of the soils of the Tista Floodplain region is higher than crops' requirement. However, the farmers apply P fertilizer in excess. This leads to imbalanced fertility status, which degrades the soil quality and land productivity. The excess P may be transported from the croplands by surface runoff, thus polluting the water environment. This is called eutrophication, which is the enrichment of surface water bodies with nutrients that leads to increased algal growth, decreased dissolved oxygen due to algal respiration demands, and increased turbidity, thus reducing water transparency [7].

Phosphorus availability declines during winter season due to low temperature, whereas it increases in summer season [22]. P application can be reduced in the second and third crop of the cropping pattern up to 30-60%, while a larger dose of P while a larger is applied for the winter crop [22].

3.4 Sulfur (S)

Sulfur status varies from very low to very high depending on the location in the Tista Floodplain soil (Table 1 & 2). The mean S content of Dimla HL was very low. It was low for Dumar and Pirgacha HL, and Gangachora MHL soils, optimum for Manda HL and MHL, and very high for Gangachora HL. Sulfur deficiency is usually observed in sandy soils having low OM content, and slightly to strongly acidic in soil reaction. Organic matter is a rich source of S, and in most soils organic sulfur accounts for about 90% of the total S in soils [6].

The soil in Tista Flood Plain is sandy to sandy loam/loam. OM content is usually low and the soil reaction in part of the area is strongly acidic. Therefore, S deficiency occurs in some areas [6]. Chlorosis in plants may occur due to S deficiency, but this is found usually in sandy soils, where sulfate may remain low throughout the season. This is because SO_4^{-2}-S is quite soluble and hence leaches down through sandy soils depending on the volume of water applied. The affect of sulfur deficiency was not much found on grain crops. Legumes, oil seeds, crucifers are common S loving crops and hence sensitive to S deficiency. Sulfur toxicity may arise in highly reduced soils, which causes necrosis of the leaves, reduction in growth etc. Therefore, to avoid toxicity, fertilizer containing S should not be recommended for soils with high and very high S contents, and also for crops following the winter crop [22].

3.5 Boron (B)

Boron status of the Tista Floodplain soil is low to medium (Table 1 & 2). The mean B content of HL of Dimla, Dumar, Pirgacha, Gangachora and Manda soils was low, and medium for MHL of Gangachora and Manda soils. B deficiency was observed in Tista Flood Plain soils [6].

The deficiency of B is common in areas with high-rainfall and high temperatures, coarse textured acidic soils, and in soils with a very low OM content [16]. Boron is highly soluble in soils and hence easily leaches out from root zones. This condition is also common in calcareous soils, where pH is higher than 7.5. Boron deficiency is also found in soils where excessive amounts of N and K fertilizers are applied. In many countries of the world, B deficiency is found in light sandy soils where leaching occurs and cropping is intensively practiced. These practices lead to diminished B reserves rapidly. The deficiency is also observed in soils where lime is applied to correct soil acidity [23]. Boron containing minerals are quite resistant to weathering, and most plant available forms come from the decomposition of soil OM and from B adsorbed and precipitated in the surface of the soil profile [16].

The soils in the Tista Floodplain are mainly sandy loam and acidic in nature, climate is high in both rainfall and temperatures, and the area is intensively cultivated. The OM contents in the Tista Floodplain soils are low, and liming is a common practice in the area to correct soil acidity. Therefore, B deficiency is common in the Tista Floodplain soils, which may adversely affect the formation of terminal growing points. There is a noticeable reduction in flowering in dicotyledons [24 and 25]. Thus, crop production is affected in this area.

3.6 Zinc (Zn)

Zinc contents of the Tista Floodplain soils range from very low to low (Table 1 & 2). It is low in HL of Dimla, Dumar, Pirgacha, Gangachora and Manda soils and MHL of Gangachora, and very low in MHL of Manda soils. It was observed that Zn deficiency is common in Tista Floodplain soil and is widespread in Bangladesh. This deficiency is often observed in wetlands, where high yielding rice (HYV) is grown [6]. In sandy soils, clay soils, and also soils naturally high in phosphates experience Zn deficiencies [16]. Heavy applications of phosphate fertilizers for several years can encourage a zinc deficiency. This may be due to competitive ion effects, which promote fixation of zinc with phosphate, thus making Zn unavailable for crops.

Characteristically, the Tista Flood Plain soils are predominantly sandy loam, HYV rice is the main crop, and heavy phosphate application is common, hence, P content is very high. These conditions usually lead to Zn deficiency.

Zinc deficiency can cause a reduction of net photosynthesis by 50% to 70% depending on plant species and degrees of deficiency, thus decreasing dry matter production and crop yield [26]. In many countries Zn deficiency threatens the world food production. There is a lot of information on P and Zn interactions, but the phenomenon is not well understood. In soils, phosphates can tie up zinc, thus causing both elements to become unavailable to plants. This is the reason why Zn and P fertilizers are not recommended to be applied together. Therefore, P fertilizers are applied 1-2 days prior to final land preparation, and Zn fertilizer is recommended to be applied during final land preparation [22]. Furthermore, Zn fertilizer is not applied every season and is recommended to be applied once for every fourth crop in a rotation. For calcareous and saline soils, Zn fertilizer is recommended annually [6].

3.7 Total nitrogen, calcium, magnesium, potassium, iron and manganese

Nitrogen status in all the soil groups was very low except Gangachora MHL (Table 1 & 2). This is due partly to low OM content and partly to N losses. Nitrogen losses commonly occur through leaching, surface runoff, denitrification, and ammonia volatilization. Therefore, a full dose of N fertilizer should be applied, but may be applied on a split basis to satisfy N requirement of each crop in the cropping pattern. For a crop following a green manure species or crop, N doses could be reduced.

Tista Flood Plain soils, being dominant with non-calcareous alluvial, Ca and Mg contents were found to be very low. Soils are mainly acidic, and hence these two elements usually go into cropland along with liming material. Moreover, Ca is also added to soil when triple super phosphate is applied.

Potassium content in these soils were mainly medium, but in some cases it was either optimum or very high depending upon soil type and location (Table 1 & 2). In general, soils of Bangladesh have a considerable amount of K and it is adsorbed on clay and humus particles in high land soils and hence is not subject to extensive leaching. About 25-35% of total K can be reduced in the subsequent crops after potato, tobacco, sugarcane, vegetables and spices where high doses of K fertilizers are generally used [22].

Iron and Mn in Tista Floodplain soils were very high. This may lead to Fe and Mn toxicity for paddies in acidic soils [16].

4. Conclusion

The results of the analysis of one hundred thirty seven soil samples from five major soil groups in the Tista Floodplain showed that the OM contents were mainly low, thus contributing to low N in soils; P contents of these soils were optimum to very high, and excess P may be transported from crop fields to water bodies, thus becoming a pollutant; S content varied from very low to very high; and both B and Zn contents were mainly low.

Fertilizer application in Bangladesh is highly imbalanced, which makes soil exhausted, degraded and polluted. N fertilizers have very little or no residual effect. But P, Zn and S fertilizers have considerable residual effects, which are available for subsequent crops. Through best management practices the land should be kept alive for maintaining or improving agricultural productivity and sound environment. These practices are the farming methods, which include soil testing, crop rotation and cropping pattern based fertilizer recommendations, and integrated pest management etc. to assure optimum crop growth and development and satisfactory yields, and in addition, to minimize adverse environmental effects. The importance of soil testing the is unquestioned and should be given priority as the best tool for management and decision making for sustainable agriculture. To make it popular among farmers, awareness and motivational programs should be conducted using mass media (newspaper, radio, television, and university extension). Based on the crops' needs of nutrients and the size of soil nutrient reserves as learned from the soil tests, balanced fertilizer requirement can be determined for various crops in the cropping pattern. The systems rely on the soil nutrient reserve and only the balanced needs should be applied. Fertilizers should be applied to supplement the nutrient elements that are in short supply in soils [6].

The main source of soil OM in the Tista Floodplain soils is the crop residues. The types of crops grown, the amounts of root and shoot biomass, and type of management of residues etc., affect soil OM content. Green manuring crops are suggested to be grown in the fallow period wherever possible. Selection of high residue crops in cropping rotation is also recommended. The overall benefits would be amplified when measures for increasing soil OM content and arresting the soil erosion are fulfilled. These two approaches will improve the efficiency of nutrients by enhancing both retention and uptake by crops.

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Table 1: Mean chemical properties of topsoil of five soil groups of Active Tista Floodplain

Soil groups (No. of soil samples & land type)	pH	Soil properties										
		OM	T-N	Ca	Mg	K	P	S	B	Fe	Mn	Zn
		(gkg^{-1}soil)		(cmolkg^{-1} soil)			(mgkg^{-1} soil)					
Dimla [6[(HL)	4.5-5.5 (SA)	15.0 (L)	0.79 (VL)	0.70 (VL)	0.16 (VL)	0.22 (M)	64.67 (VH)	6.42 (VL)	0.27 (L)	83.67 (VH)	5.72 (VH)	0.77 (L)
Dumar [17] (HL)	4.6-6.4 (SA-SIA)	15.2 (L)	0.70 (VL)	0.56 (VL)	0.20 (VL)	0.19 (M)	57.42 (VH)	12.04 (L)	0.28 (L)	81.60 (VH)	12.80 (VH)	0.70 (L)
Manda [35] (HL)	4.4-7.2 (VSA-N)	14.1 (L)	0.66 (VL)	1.07 (VL)	0.30 (VL)	0.28 (O)	28.76 (VH)	18.40 (O)	0.29 (L)	78.05 (VH)	11.22 (VH)	0.53 (L)
Manda [4] (MHL)	4.3-5.9 (VSA-SIA)	13.1 (L)	0.72 (VL)	0.61 (VL)	0.28 (VL)	0.20 (M)	8.54 (L)	16.01 (O)	0.36 (O)	51.65 (VH)	7.03 (VH)	0.18 (VL)
Pirgacha [15] (HL)	4.5-5.7 (SA-SIA)	17.4 (M)	0.84 (VL)	0.81 (VL)	0.29 (VL)	0.46 (VH)	65.60 (VH)	9.72 (L)	0.30 (L)	90.96 (VH)	13.16 (VH)	0.88 (L)
Gangachora [30] (HL)	4.6-7.9 (SA-SIAl)	15.3 (L)	0.78 (VL)	2.08 (L)	0.52 (L)	0.30 (O)	24.56 (H)	40.54 (VH)	0.25 (L)	83.19 (VH)	15.68 (VH)	0.80 (L)
Gangachora [30] (MHL)	4.5-6.0 (SA-SIA)	18.5 (M)	0.96 (L)	1.32 (VL)	0.37 (VL)	0.19 (M)	16.42 (O)	12.05 (L)	0.31 (O)	102.61 (VH)	13.12 (VH)	0.46 (L)

[HL = High land, MHL = Medium high land, VSA = Very strongly acidic, SA = Strongly acidic, SIA = Slightly acidic, SlAl = Slightly alkaline, N = Neutral, T-N = Total nitrogen, L = Low, VL = Very low, M = Medium, O = Optimum, H = High, VH = Very high]

Table 2: Standard ratings of nutrients available in soils [6]

Nutrient elements	Very low	Low	Medium	Optimum	High	Very high
Total-N (gkg^{-1})	≤0.90	0.91-1.80	1.81-2.70	2.71-3.60	3.61-4.50	>4.50
P (mgkg^{-1} soil)-						
Olsen	≤7.5	7.51-15.0	15.1-22.5	22.51-30.0	30.1-37.5	>37.5
Bray-Kurtz	≤5.25	5.26-10.5	10.51-15.75	15.76-21.0	21.1-26.25	>26.25
S (mgkg^{-1} soil)	≤7.5	7.51-15.0	15.1-22.5	22.51-30.0	30.1-37.5	>37.5
K (cmolkg^{-1}soil)	≤0.09	0.091-0.18	0.181-0.27	0.271-0.36	0.361-0.45	>0.45
Ca (cmolkg^{-1} soil)	≤1.5	1.51-3.0	3.1-4.5	4.51-6.0	6.1-7.5	>7.5
Mg (cmolkg^{-1} soil)	≤0.375	0.376-0.75	0.751-1.125	1.126-1.5	1.51-1.875	>1.875
Zn (mgkg^{-1}soil)	≤0.45	0.451-0.90	0.91-1.35	1.351-1.8	1.81-2.25	>2.25
Fe (mgkg^{-1} soil)	≤3.0	3.1-6.0	6.1-9.0	9.1-12.0	12.1-15.0	>15.0
Mn (mgkg^{-1}soil)	≤.0.75	0.76-1.5	1.51-2.25	2.26-3.0	3.1-3.75	>3.75
B (mgkg^{-1} soil)	≤0.15	0.151-0.30	0.31-0.45	0.451-0.60	0.61-0.75	>0.75

Table 3: Percentage distribution of soil samples occuring within each organic matter category

Soil groups	Land type	No. of soil samples	Organic matter category				
			Very low (<10 gkg^{-1} soil)	Low (10-17 gkg^{-1} soil)	Medium (17-34 gkg^{-1} soil)	High (34-55 gkg^{-1} soil)	Very high (>55 gkg^{-1} soil)
Dimla	HL	6	17	67	16	-	-
Dumar	HL	7	6	76	18	-	-
Manda	HL	35	14	66	20	-	-
Manda	MHL	4	25	75	-	-	-
Pirgacha	HL	15	-	40	60	-	-
Gangachora	HL	30	10	63	27	-	-
Gangachora	MHL	30	3	37	60	-	-