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Nutrient Elements in Some Benchmark Soil Pedons from the Ganges River Floodplain of Bangladesh

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Abstract

This paper presents the results of chemical analysis of seven selected nutrient elements in soil samples collected from four pedons representing four extensive benchmark soil series from the Ganges river floodplain of Bangladesh. The results of total and available N, P and K contents as well as DTPA (diethelene-triamine pentaacetic acid) -extractable and total Fe, Mn, Cu and Zn contents in the soils were reported. With respect to nutrient status, the soils were rated as fertile with reasonably high production potential under balanced fertilization. The nutrient contents are presumed to be renewed every year by fresh siltation during the monsoon floods. High contents of total iron and potassium in these soils are noteworthy features. Iron in these paddy soils forms redoximorphic features. The release mechanism of K^+ from the potash bearing minerals needs further study to determine the need for K fertilization in these soils. The total quantities of the seven studied nutrients in these soils vary widely. In the same way the quantities of extractable (available) nutrients in the soils vary widely. For elements like P, K and Fe less than one percent of the total remain in the available forms. Soil characteristics like organic matter, clay content, cation exchange capacity, pH and lime content have important roles in the availability of nutrients in soils.

Keywords: Ganges floodplain, Benchmark soil, DTPA-extractable micronutrients, Soil characteristics

Introduction

The Ganges floodplain in Bangladesh represents a typical riverine landscape which covers about one-fifth of its total land area. The soils in the floodplain were known to be productive under the centuries-old agricultural practices. But in recent years food grain production in this floodplain has witnessed an unprecedented increase due to modernization of agriculture. With the intensification of agriculture, these soils have witnessed depletion of nutrients that includes both macro- and micro-nutrients. Nutrient deficiency in Bangladesh soils first appeared in 1960s following the introduction of high yielding rice varities coupled with the use of high analysis fertilizers (Islam, 1992). Very few systematic studies have been carried out so far with respect to the total and available contents of various nutrient elements, particularly the micronutrient cations, in the soil of the Ganges floodplain in Bangladesh.

Through reconnaissance soil survey around 476 soil series have been identified and mapped in Bangladesh (SRDI Staff, 1965-1986). Of these, 25 soil series were selected as benchmark soil in Bangladesh (Hussain *et al.* 2005). The bench mark soils are considered as the representative reference soils in which agronomic research results can be generated and subsequently transferred and extrapolated to other soil sites having similar or varying properties. These benchmark soils were established in terms of physiographic location, agroclimatic conditions, their morphological and physico-chemical characteristics, and taxonomic classification (Hussain *et al*. 2005).

The inorganic minerals that make up about one half of the volume of most soils are the reservoirs of most nutrient elements for plants. Weathering of primary minerals releases the nutrient elements from their crystal core and subsequently retained by secondary minerals through adsorption, cation exchange and precipitation. In studying the nutrient elements in soils a thorough understanding of all the above facets of the various minerals is needed.

Some nutrient elements in soils are important pedogenetically. Nutrient element like iron that occurs in paddy soils in abundant quantity often shows the presence of redoximorphic features. With repeated cycles of reduction and oxida-

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tion, patterns of iron oxide depletion and accumulation develop. Soil mottles are examples of this kind of accumulation in the rice soils (Hossain, 1996). The redoximorphic accumulations commonly include minerals like lepidocrocite, goethite and ferrihydrite (Bigham *et al*. 2002).

The present paper reports the results of chemical analysis of some macro- and micro- nutrient elements in four benchmark soil pedons from the Ganges river floodplain of Bangladesh, and further explore the relationships of these nutrient elements with the soil minerals as well as certain soil characteristics.

Materials and Method

Four benchmark soil series in the Ganges river floodplain of Bangladesh have been selected for this study. The names of these soil series and their respective environmental conditions are presented in Table I. All these soils are flooded annually for varying periods during the rainy season and used mainly for cultivation of rice and jute. Pits were dug at the selected sites and soil samples were collected on genetic horizon basis. The collected soil samples were processed and analysed in the laboratory for the total and available quantities of N, P and K using standard procedures. Total amounts of iron, manganese, copper and zinc in soil were determined in their Na_2CO_3 fusion extract. The available quantities of iron, manganese, copper and zinc in these soils were extracted with DTPA-$CaCl_2$ reagent (Lindsay and Norvell, 1978). The elements in the extract were determined with the help of atomic absorption spectrophotometer. Results of physical and chemical properties of the soil are presented in Table II.

Results and Discussion

Nitrogen (N)

Total nitrogen contents in the studied soils ranges from 0.22 to 1.70 g kg^{-1} (Table III). Among the studied soil profiles Garuri series has the highest contents of total nitrogen while Sara series has the lowest content. In all the pedons there is a regular decrease of total nitrogen content from the surface downward. Similar results and distribution patterns of total N were repored by Mazumder *et al.* (2003) for some floodplain soils of Bangladesh. A highly significant positive correlation (r =+0.95**) between organic carbon and total nitrogen suggests that addition of organic matter will lead to higher nitrogen content in these soils.

The available nitrogen in the studied soils ranges from 60 to 140 mg kg^{-1} (Table III). The available nitrogen in all the soils was higher (106-140 mg kg^{-1}) in the surface horizons, probably due to addition of organic matter content. The highly significant positive correlation (r=+0.97**) between available nitrogen and total nitrogen in the soils implies that the quantity of the available nitrogen contents is closely related to the quantity of total nitrogen.

Phosphorus (P)

Total phosphorus content in the soils ranged from 0.88 to 1.50 g kg^{-1} (Table III). These values are slightly higher than those reported in some other floodplain soils of Bangladesh (Islam and Mandal, 1977). The high content of total phosphorus in these soils may be due to the presence of phosphorus containing minerals in the soil materials (Harris, 2002).

Table I. Environmental conditions and classification of the soil

Soil Series	Location (Latitude and Longitude)	Parent material	Land type	Vegetation/ land use	Soil classification*
Amjhupi	Jhikargacha upazila (23^{O}10´N and 89^{O}06´E)	Ganges river alluvium	Medium high land	Aus/Jute-Rabi	Aeric Endoaquept
Gangni	Jhikargacha upazila (23^{O}09´N and 89^{O}08´E)	Ganges river alluvium	Medium low land	Aus/Jute-T. aman	Aeric Endoaquept
Garuri	Jessore sadar upazila (23^{O}07´N and 89^{O}11´E)	Ganges river alluvium	Medium low land	T. aman-Fellow	Aeric Endoaquept
Sara	Jessore sadar upazila (23^{O}12´N and 89^{O}15´E)	Ganges river alluvium	Medium high land	Aus/Jute-Rabi	Aquic Eutrochrept

*Subgroups of US Soil Taxonomy (Soil Survey Staff, 1999)

Table II. Physical and chemical properties of the soil

Soil series	Clay content (%)	Organic C (%)	CEC [cmol(p+) kg^{-1}]	pH (H_2O)	$CaCO_3$(%)
Amjhupi					
Range	18-65	0.21-0.76	8.1-29.4	7.3-7.7	1.0-5.0
Mean	43	0.39	19.8	7.5	3.5
Gangni					
Range	15-71	0.18-0.95	7.7-34.3	6.8-7.9	1.0-7.5
Mean	47	0.43	23.0	7.4	5.0
Garuri					
Range	33-68	0.24-1.57	12.8-34.5	7.5-7.6	3.0-8.0
Mean	55	0.63	27.9	7.5	40
Sara					
Range	13-53	0.18-0.60	8.5-24.5	7.5-7.7	2.5-7.5
Mean	22	0.28	12.3	7.6	5.0

Source: Hossain (1996).

The total phosphorus contents in soils have been found to be significantly correlated with the clay (r=+0.79**) and organic matter contents (r=+0.67*). Islam and Mandal (1978) reported that the contents of total phosphorus in soils of Bangladesh varied with the variation of organic matter, pH and clay contents. The vertical distribution of total phosphorus contents in the soil profiles shows irregular pattern indicating an alluvial character of the soil materials.

The available phosphorus contents in the soils varied widely ranging from 2 to 15 mg kg^{-1} (Table III). The average values are 4 mg kg^{-1} in Amjhupi, 8 mg kg^{-1} in Gangni, 4 mg kg^{-1} in Garuri and 6 mg kg^{-1} in Sara series, which fell in the low range (BARC, 2005). Only 0.5 percent of the total P in the soils occur as available P (Table III). As the soils are alkaline in reaction and contain calcareous materials, the contents of available phosphorus are expected to be low because of its fixation. However, the total/available phosphorus ratio in the soils indicated a poor releasing capacity of available phosphorus in soils. The available phosphorus in the surface soils of Amjhupi and Garuri were 7 and 4 mg kg^{-1} soil and according to Murthy and Hirekerur (1980) and BARC (2005) these soils could be categorized as P deficient. Application of phosphatic fertilizers is thus recommended for maintaining nutrient balance in order to obtain sustainable productivity.

Potassium (K)

The contents of total potassium in the studied soils ranged from 21.22 to 40.53 g kg^{-1} (Table III). These high values of total potassium in the soils bear testimony to the fact that these soils are rich in K-bearing minerals like mica and feldspar (White, 1985). The vertical distribution of total potassium in the soil profiles is irregular in nature. This is due to alluvial character of these soils where the potassium content depends on the type of parent material.

The available potassium contents in the soils ranged from 100 to 260 mg kg^{-1} (Table III). These results corroborated well with the values reported by Saleque *et al.* (1990). Only 0.5 percent of the total K in the soils occurs as available K (Table III). This indicates that the release of potassium from the crystal lattice of K-bearing minerals is slow (Thompson and Ukrainczyk, 2002). Higher concentration of available potassium was found in the upper horizon of the profiles. Black (1968) noted that the higher concentration of potassium in the surface in comparison to subsurface layer might be due to the action of plant roots in transporting potassium to the surface and also to addition of crop residues.

Mineralogical studies indicated that these soils contained high amount of micaceous and expanding lattice minerals (Huizing, 1971). Consequently, both the availability and fixation of potassium by mica and the expanding lattice minerals in the soils during weathering stages remain as vexing problems on which study is necessary. These facts bring to the fore a basic problem whether these soils having high K-bearing minerals need potash fertilization or the potassium releasing capacity of soil is good enough to meet the needs of the growing plants. The quantity-intensity relationship

Table III. Distribution of total and available macronutrients (N, P and K) in the soil profiles

Horizon	Depth (cm)	Total nutrients (g kg^{-1})			Available nutrients (mg kg^{-1})			Avail. N Total N ratio×100	Avail. P Total P ratio×100	Avail. K Total K ratio×100
		N	P	K	N	P	K			
Amjhupi series										
Apg	0-12	0.82	1.09	33.19	140	7	160	17	0.6	0.5
Bwg1	12-32	0.55	1.07	37.57	80	5	140	14	0.4	0.4
Bwg2	32-57	0.50	-	-	60	3	140	12	-	-
2Cg	57-75	0.44	1.50	39.19	53	3	100	12	0.2	0.2
3Ab	75-90	0.44	-	-	86	3	120	19	-	-
3Bwgb	90-113	0.40	-	-	73	4	120	18	-	-
3Cb	113-129	0.30	-	-	93	4	160	31	-	-
Mean	-	0.50	1.22	36.65	89	4	134	18	0.4	0.4
Gangni series										
Apg1	0-10	1.15	1.20	37.93	106	14	200	09	1.1	0.5
Apg2	10-17	0.93	-	-	80	13	120	08	-	-
Bwg1	17-48	0.52	1.32	40.53	86	7	200	15	0.5	0.5
Bwg2	48-62	0.50	-	-	93	8	180	18	-	-
Bwg3	62-88	0.33	-	-	86	4	120	25	-	-
Cg1	88-97	0.22	1.14	26.71	99	4	120	45	0.3	0.4
C2	97-192	0.40	-	-	93	4	100	23	-	-
Mean	-	0.58	1.22	35.06	92	8	149	16	0.6	0.4
Garuri series										
Apg1	0-10	1.70	1.18	38.24	114	4	240	07	0.3	0.6
Apg2	10-16	1.24	-	-	114	3	180	09	-	-
Bw1	16-26	0.70	1.14	39.75	94	3	240	13	0.2	0.6
Bw2	26-35	0.52	-	-	80	2	260	15	-	-
Bw3	35-43	0.52	-	-	107	3	220	22	-	-
C1	43-79	0.30	0.96	28.44	101	5	180	33	0.5	0.6
Cg2	79-146	0.41	-	-	94	6	220	23	-	-
Mean	-	0.77	1.09	35.48	101	4	220	13	0.3	0.6
Sara series										
Apg	0-15	0.65	1.26	21.22	136	15	160	21	1.2	0.7
Bwg1	15-35	0.40	1.09	29.24	78	4	100	19	0.3	0.3
Bw2	35-65	0.31	-	-	78	3	100	25	-	-
C1	65-98	0.33	-	-	123	6	140	37	-	-
C2	98-120	0.22	1.16	22.73	104	6	100	47	0.5	0.4
C3	120-135	0.30	-	-	97	3	200	32	-	-
Mean	-	0.37	1.17	24.40	103	6	133	27	0.5	0.5
Grand mean		0.54	1.12	30.73	100	5	155	21	0.5	0.5

(Q-I curve) remains an important feature for K-release in soils. No reliable scientific study on this issue has been done as yet by any competent soil chemist. This is an important matter that can save millions of dollars of foreign exchange for purching muriate of potash from foreign countries.

Iron (Fe)

Total Fe contents in the studied soils range from 3.06 to 9.09 percent (Table IV). The average Fe content in the profiles in decreasing order is Garuri (7.44%), Gangni (7.28%), Amjhupi (6.98%) and Sara (3.97%). No definite sequence in the distribution of Fe with depth was noticeable probably due to young nature of these alluvial soils. Khan *et al*. (1997) reported 5.3 to 6.6 percent total Fe in some alluvial soils of Bangladesh. Total Fe showed significant correlation with clay content (r=+ 0.828**) (Table V), which is in agreement with the results reported by Follet and Lindsay (1970), Katyal and Sharma (1991) and Khan *et al*. (1997).

DTPA-extractable (available) Fe contents in the studied soils ranged from 8 to 255 mg kg^{-1} (Table IV). It is only a very minute fraction (0.07 percent) of total Fe in the studied soils (Table IV). Alkaline pH and calcareousness of the soils may be responsible for this low extractability of the total Fe. Singh and Sekhon (1991) reported 7 to 200 mg kg^{-1} DTPA-extractable Fe in twenty soils from the Indo-Gengetic plains of India. The minimum content of available Fe was observed in the Sara series and maximun in the Gangni series. Prolonged submergence coupled with reducing conditions are reported to be the reasons for higher available Fe contents. Considering 4.5 mg kg^{-1} soil as the thresold value of DTPA-extractable Fe (Lindsay and Norvell, 1978), all the studied soils had sufficient available Fe content.

Manganese (Mn)

Total Mn contents in the studied soils vary widely (572 to 1125 mg kg^{-1}). However, these results were within the range reported by Prasad and Sahi (1989) and Mazumder *et al.* (2003) in some soils of India and Bangladesh. The minimum content of total Mn was found in Sara soil and maximum in Amjhupi soil. The occurrence of Mn-bearing minerals in the parent materials might be the reason for higher content of total Mn in the soils. In general, distribution of Mn with depth did not show any specific trend. Lime ($CaCO_3$) and clay contents were the major factors determining Mn distribution in soils as suggested by significant positive coefficient of correlation between total Mn and these parameters (Table V).

Table IV. Distribution of total and available (DTPA-extractable) micronutrients in the soil profiles

Horizon	Depth (cm)	Total Fe (%)	Total (mg k^{g-1})			DTPA-extractable (mg k^{g-1})				DTPA-Fe Total-Fe ratio×100	DTPA-Mn Total-Mn ratio×100	DTPA-Cu Total-Cu ratio×100	DTPA-Zn Total-Zn ratio×100
			Mn	Cu	Zn	Fe	Mn	Cu	Zn				
Amjhupi series													
Apg	0-12	5.90	945	145	393	40	52	2.0	6.0	0.07	5.5	1.3	1.5
Bwg1	12-32	8.00	965	74	252	32	32	3.0	3.5	0.04	3.3	4.0	1.3
2Cg	57-75	7.03	1031	75	187	12	15	1.2	0.2	0.01	1.4	1.6	0.1
Mean	-	6.98	980	98	277	28	33	2.1	3.2	0.04	3.3	2.1	1.0
Gangni series													
Apg1	0-10	8.08	637	112	206	255	57	5.0	2.0	0.30	8.9	4.4	0.9
Bwg1	17-48	9.09	1125	116	271	40	37	3.0	tr	0.04	3.2	2.5	0.0
Cg1	88-97	4.68	785	71	196	12	9	0.2	tr	0.02	1.1	2.8	0.0
Mean	-	7.28	849	100	224	102	34	2.7	2.0	0.10	4.0	2.7	0.9
Garuri series													
Apg1	0-10	7.65	599	116	263	65	18	13.0	0.6	0.08	3.0	11.2	0.2
Bw1	16-26	8.91	761	114	228	12	11	4.0	1.2	0.01	1.4	3.5	0.5
C1	43-79	5.77	757	74	148	10	13	tr	3.0	0.01	1.7	0.0	2.0
Mean	-	7.44	706	101	213	29	14	8.5	1.6	0.03	1.9	8.4	0.7
Sara series													
Apg	0-15	3.06	572	35	105	35	29	2.0	2.5	0.10	3.0	5.7	2.3
Bwg1	15-35	4.55	692	36	109	17	16	tr	1.2	0.03	2.3	0.0	1.1
C2	98-120	4.30	591	36	138	8	8	tr	1.2	0.01	1.3	0.0	0.8
Mean	-	3.97	618	36	117	20	18	2.0	1.6	0.05	2.2	5.7	1.4
Grand mean		6.42	788	84	207	45	25	3.8	1.8	0.07	3.0	2.2	1.0

The DTPA-extractable Mn contents in the studied soils vary widely ranging from 8 to 73 mg kg^{-1}. The average values for the profiles vary as well (33 mg kg^{-1} in Amjhupi, 34 mg kg^{-1} in Gangni, 14 mg kg^{-1} in Garuri and 18 mg kg^{-1} in Sara) (Table IV). Almost similar values for DTPA-extractable Mn were reported for alluvial soils elsewhere (Kumar *et al.* 1996; Mazumder *et al*. 2003). Essential features of DTPA-Mn distribution were a negative correlation with pH and lime content; and a positive correlation with orgnic matter (Table V). Among the various factors associated with DTPA-Mn- judged from the coefficients of correlation- pH is likely to dominate the Mn availability in soils. Lindsay and Cox (1985) identified pH as the key factor influencing the Mn availability in soils. Taking 3.0 mg kg^{-1} DTPA-Mn in soils as the critical limit (Anonymous, 1976), it can be safely concluded that the studied soils have adequate quantities of available Mn.

with total Zn and Fe in the soils implies that perhaps some similar soil factors govern their distribution.

The DTPA-extractable Cu in the studied soils varied from 2 to 13 mg kg^{-1} (Table IV). Katyal and Sharma (1991) reported that the soils with an aquic moisture regimes were richer in available Cu. Khan *et al*. (1997) noted that the floodplain soils in Bangladesh as a whole contained somewhat higher quantities of DTPA-extractable Cu. Considering the 0.2 mg kg^{-1} of DTPA-extractable Cu as the critical limit as reported by Lindsay and Norvell (1978) the quantities of available Cu in the studied soils was fairly higher. The DTPA-extractable Cu was significantly correlated with the organic matter contents in the soils (Table V). This fact is in agreement with the results reported by Sakal *et al.* (1988) and Tripathi *et al.* (1994) who noted that the DTPA-extractable Cu in some alluvial soils of India was positively correlated with their organic matter contents, irrespective of pH, clay and carbonate contents.

Table V. Correlation coefficients between the total and available micronutrient and some soil properties

Soil properties	DTPA-extractable				Total			
	Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Clay content	+	+	0.439	0.406	0.414	0.607*	0.620*	0.828**
Organic carbon	+	0.961**	0.826**	0.230	0.313	0.419	+	0.230
pH (water)	+	0.276	-0.821**	-0.338	0.334	+	-0.744**	+
CEC	+	0.406	+	+	0.667**	0.733**	+	0.831**
CaCO3	+	+	-0.776**	0.411	+	0.771**	0.665**	0.321
Total micronutrients								
Zn	+	+	+	+	1.00			
Cu	0.290	0.239	+	+	0.886**	1.00		
Mn	+	-0.463	0.628*	+	+	+	1.00	
Fe	+	0.254	+	+	0.575*	0.744**	0.230	1.00

Note: + stands for correlation coefficient (r) falling below 0.210

Copper (Cu)

Total Cu content in the soils ranged from 35 to 145 mg kg^{-1}. The highest average value of total Cu was found in Garuri soil followed by Gangni, Amjhupi and Sara soil (Table IV). These values for total Cu seem to be higher than those reported on a number of soils elsewhere (Follet and Lindsay, 1970; Karim *et el.* 1976; Katyal and Sharma, 1991). The former authors observed that some residual soils formed on basalt contained higher quantity of total Cu than the transported soils in coastal plain. Total Cu in the studied soils was correlated positively with lime, clay content, total Zn and total Fe (Table V). A high degree of correlation of total Cu

Zinc (Zn)

Total Zn content in the soils ranged from 105 to 393 mg kg^{-1} with an average content of 277 mg kg^{-1} in Amjhupi, 224 mg kg^{-1} in Gangni, 213 mg kg^{-1} in Garuri and 117 mg kg^{-1} in Sara soil profiles (Table IV). These results are comparable to that reported by Hassan (1991), Khan *et al.* (1997) and Mazumder *et al.* (2003) in the floodplain soils of Bangladesh. The vertical distribution pattern of total Zn in the profiles is irregular and is thought to be influenced by several factors like drainage, clay and organic matter contents of the soils.

The DTPA-extractable Zn in the soils varied between 0.6 and 6.0 mg kg^{-1} (Table IV). It was only a small fraction of total Zn in these soils. The present results are in agreement with those reported by Hassan (1991) and Khan *et al.* (1997). Taking 0.8 mg kg^{-1} as the critical limit of DTPA-extractable Zn (Lindsay and Norvell, 1978), all the soils contained available Zn above the threshold value.

Conclusion

The results of the study indicate that organic matter is the dominant factor that controls the availability of several nutrient elements in the soils of the Ganges river floodplain. Low availability and poor releasing capacity of available phosphorus in the soil remain problem for sustainable crop production. Therefore, application of moderate doses of phosphatic fertilizers along with organic manures is recommended for a high productivity of these soils.

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