

MORPHOGENESIS OF THREE SURFACE-WATER GLEY SOILS FROM THE MEGHNA FLOODPLAIN OF BANGLADESH

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Key words: Meghna floodplain, Morphogenesis, Soil chemico-physical properties

Abstract

Surface-water gley soils comprise extensive area on the seasonally wet landscape of Meghna floodplain in Bangladesh. Three typical surface-water gley soils from the above floodplain were studied in the field and laboratory for their pedogenesis. Morphological properties indicate that there is formation of gleyed/pseudogleyed horizons in the soil profiles. Extensive development of mottles, ploughpans and flood coatings or gleyans is the most notable morphogenetic features in these soils. Physically, these soils are medium to fine textured where textural class ranged between silt loam and silty clay. Chemically, the soils are moderately acidic to neutral in reaction with seasonally fluctuating pH in the surface horizon. The ΔpH values are all negative and range from -0.90 to -2.01 . The organic matter content in the surface soil is relatively low that decreases steadily with depth. The cation exchange capacity (CEC) of the soils ranged from 3.53 to 14.08 cmol p+/kg with an average of 10.10 cmol p+/kg and base saturation per cent (BSP) varied from 59 to 86. The $\text{Ca}^{++}/\text{Mg}^{++}$ ratio is less than unity indicating loss of Ca^{++} due to gleization in these soils.

Introduction

The surface-water gley soils are agriculturally very important soil group in Bangladesh. They are hydromorphic soils containing less clay and with a seasonally fluctuating pH in the surface horizon and occur extensively on the seasonally flooded landscapes⁽¹⁾. As per Ramsar Convention they are categorized as Wetland soils⁽²⁾. In the United States the surface-water gleys are categorized as Gray hydromorphic soils,⁽³⁾ in the southeast Asia as Paddy soils⁽⁴⁾ and Aquorizems⁽⁵⁾. These soils have aquic moisture regimes and paddy is the dominant crop. Both local and HYVs- are the rice crops grown that support the burgeoning population in the area⁽⁶⁾. The present paper deals only with the surface- water gley soils occurring on the Lower Meghna floodplain situated in the Chandpur district of Bangladesh. The Meghna sediments are noncalcareous and are mostly silty. Soils developed on this floodplain differ in their physical and chemical properties mainly due to its mineralogy, age of sedimentation, local relief, drainage and anthropic activity.

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Mineralogical properties of these soils were studied ⁽⁷⁾. The present communication reports a study of the morphology and some chemico-physical characteristics of the soils to ascertain their pedogenesis.

Materials and Methods

This study was conducted on the Meghna floodplain soils in Bangladesh. The study area represents smooth, nearly level landscape of floodplain ridges and basins consisting of unconsolidated alluvium. The area under study experiences seasonal flooding of various depths and durations during the monsoon months. Ridges remain mainly above normal flood level while parts remain seasonally shallowly flooded for a period ranging from 1 - 2 months. The basins or basin depressions are flooded more deeply and for a longer period. The climate of the area is humid tropical monsoon with a mean annual temperature of 25.5°C and an annual rainfall of around 2250 mm⁽⁸⁾. The temperature regime is hyperthermic and most of the agricultural fields have aquic moisture regime. The area under study had been used for large scale paddy and jute cultivations for centuries. Broadcast aus/jute - transplanted aman followed by Rabi crops and boro - fallow or transplanted aman is the cropping pattern of this area.

The sampling sites were selected to represent major typical surface-water gley soils in the Meghna floodplain. Three profiles from three extensive soil series viz., Tippera, Debidwar and Burichang were selected in three selected sites for soil sample collection. The exact locations of the selected soil profiles and a sketch of the catena as well as the horizons of soil profiles are presented in Fig. 1. Major physical environment of the studied soils is shown in Table 1. Pits were dug in the selected sites and soil profiles were described in the field according to the procedures outlined in the Soil Survey Manual⁽⁹⁾. A total of 18 soil samples were collected from the three selected profiles on genetic horizon basis. The samples were processed properly and analysed in the laboratory for determining their physical and chemical properties.

The pH was determined using glass electrode in soil suspensions in H₂O and 1 M KCl. The ΔpH was calculated by subtracting pH in H₂O values from pH in KCl values. Particle-size distribution was carried out by sieving and using hydrometer method as per Gee and Bauder⁽¹⁰⁾. Organic carbon was measured by Walkley and Black⁽¹¹⁾ wet oxidation method and total nitrogen was estimated by digestion of the soil in the sulfuric acid followed by a Kjeldahl distillation⁽¹²⁾. Cation exchange capacity (CEC) was measured with 1 N ammonium acetate solution at pH 7.0. and exchangeable bases were determined from the same 1 N ammonium acetate leachate using atomic absorption spectrophotometer⁽¹³⁾. Exchangeable K⁺ and Na⁺ were determined with a flame photometer.

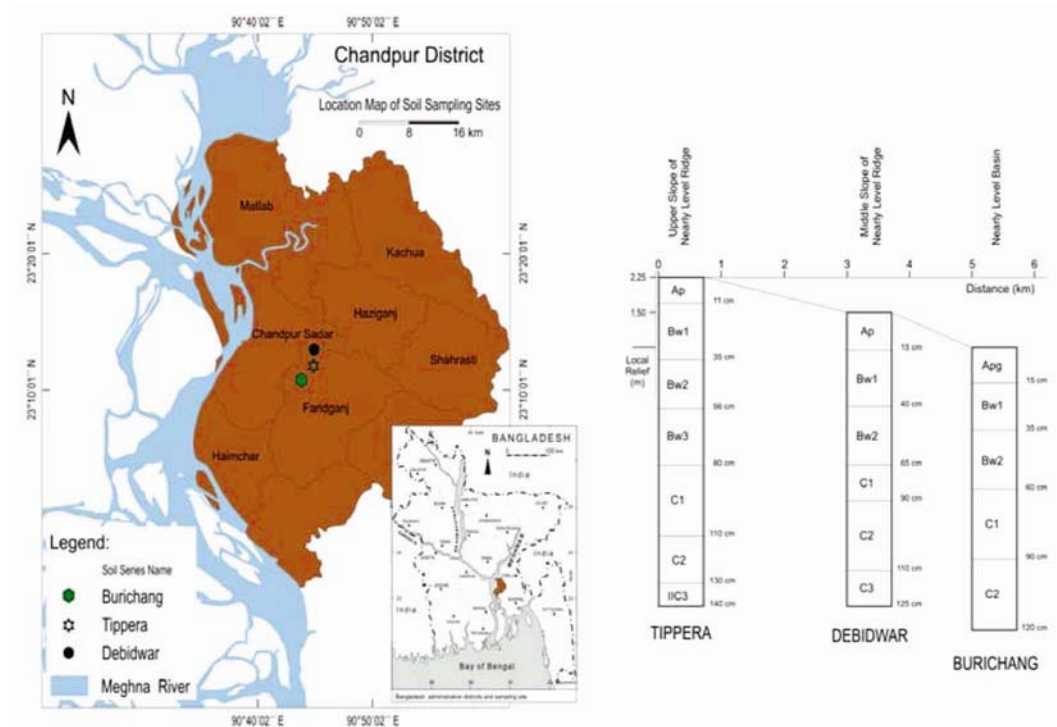


Fig. 1. Location and a sketch of the catena as well as horizons of the soil profiles in the Meghna floodplain in Bangladesh.

Results and Discussion

Some salient morphogenetic features of the three surface-water gley soils from the Meghna floodplain of Bangladesh have been presented in Table 2. Oxidation during the dry season and reduction during the wet season are the two usual conditions in these soils. The soils exhibit gray matrix colour with value 3 to 5 and chroma 1 to 3 possibly due to prolonged submergence and subsequent development of reducing conditions during the flooding season. Moreover, all the soils have dark brown to dark yellowish brown mottles, prominent in the middle zone of the profiles, where oxidation-reduction conditions alternate. The alternate wetting and drying conditions in the soils resulted in release of Fe from iron-bearing minerals which in turn was precipitated and fixed in the form of mottles in the subsurface horizons⁽¹⁴⁾. Surface gleying (pseudogleys) and subsurface grayization (gleys) are the most notable morphometric features in these soils. A low chroma of the matrix is generally associated with the gleying phenomena of the soils. Stoops and Eswaran⁽¹⁵⁾ noted that with increasing hydromorphism Fe hydroxide segregations appear in the groundmass and low chromas in the peds. The presence of gleyed/pseudogleyed layers and mottlings near the surface horizons of the studied soils indicates that these soils have hydromorphic properties⁽¹⁾. Joffe⁽¹⁶⁾ noted that the presence

Table 1. Location, environmental conditions and classification of the soils in study area.

Soil series	Location	Area (ha)*	Inundation land type	Drainage/flooding scenario	Cropping pattern	**Soil family
Tippera	23°12'203" N 90°45'363" E	92,194	Medium high land	Poorly drained (only shallowly flooded for 1 - 2 months)	Aus/jute - T. aman	Loamy, mixed, nonacid, hyperthermic, aeric Endoaquepts
Debidwar	23°13'538" N 90°45'407" E	77,562	Medium high land	Poorly drained (flooded up to 90 cm for 2 - 3 months)	Boro -fallow/ T. aman	Loamy over clayey, mixed, nonacid, hyperthermic, typic Endoaquepts
Burichang	23°11'958" N 90°44'186" E	67,014	Medium low land	Poorly drained (flooded up to 140 cm for 3 - 4 months)	Boro - fallow	Loamy over clayey, mixed, nonacid, hyperthermic, typic Endoaquepts

*Area in the country, **Hussain⁽²³⁾.

Table 2. Morphogenetic properties of three studied soils from the Meghna floodplain*.

Soil series	Horizon	Depth (cm)	Munsell colour notations		Texture	Structure	Consistency	Boundary	Special features
			Matrix (moist)	Mottles					
Tippera (ridge)	Apg	0-11	5Y 5/3	fid lyb	sil	m	mfr, wss, wps	as	-
	Bw1	11-35	5Y 5/2	cid yb	sil	2c pr/2c-m abk	mfr, wss, wps	as	-
	Bw2	35-56	5Y 5/1	cid lyb; fid yb	sil	1c pr/abk	mfr, wss, wps	cs	-
	Bw3	56-80	5Y 5/2	cid yb	sil	1vc pr	mfr, wss, wps	cs	-
	C1	80-110	5Y 5/3	cid dyb	sil	1vc pr	mfr, wss, wps	cs	-
	Cg1	110-130	5Y 5/3	fid db	sil	m	mfr, wss, wps	cs	-
	2Cg2	130-140+	5Y 3/1	-	si	m	mfr, wso, wpo	-	-
Debidwar (lower slope of ridge)	Apg	0-15	5Y 5/1	fid stb	sicl	m	mfr, wss, wps	as	Fe-staining along root channel
	Bw1	15-40	5Y 5/1	cif dyb	sicl	2vc pr	mfr, wss, wps	as	-
	Bw2	40-65	5Y 4/1	cif db	sic	2cpr/2c-m abk	mfr, wss, wps	cs	-
	C1	65-90	5Y 5/3	cid dyb	sic	1c pr	mfr, wss, wps	as	-
	Cg1	90-110	5Y 5/3	fid dyb	sil	1vc pr	mfr, wss, wps	cs	-
	2Cg2	110-125+	2.5Y 5/4	fif dg	sic	m	mvfr, wso, wpo	-	-
	Apg	0-15	5Y 4/1	cip stb & yb	sicl	m	mfi, ws, wp	as	Fe-staining along root channel;
Burichang (basin)	Bw1	15-35	2.5Y 4/2	cid yb	sicl	2vc-c pr/c-m abk	mfi, ws, wp	as	dark grey coatings on ped faces
	Bw2	35-60	5Y 5/1	mud yb	sic	2vc pr/c-m abk	mfi, ws, wp	cs	-
	Cg1	60-90	2.5Y 5/4	cif g	sil	1vc pr	mfi, ws, wp	cs	-
	Cg2	90-120+	2.5Y 5/4	cid stb & fif g	sil	m	mfr, wss, wps	-	-

*The abbreviations used are those of USDA system (Soil Survey Staff 1993).

of mottles indicate fluctuation of ground water table while the presence of gleys in the lower zone is an unfailing indication of perennial hydromorphism.

Moreover, all the soils have continuous, thick, grey to dark grey flood coatings on structural ped faces due to mechanical down washings of unoriented clay, fine silt and humus when the soils get flooded and ploughed⁽⁶⁾. This coatings form quite rapidly and generally have the same colour and mineralogy as the top soils. The name gleyans has been proposed for these flood coating since the coating material is always gleyed (reduced)⁽⁶⁾.

Ploughpan is a special morphogenetic (anthropogenic) features in these soils. Plough pan - a compact slowly permeable layer - below the Ap horizon has been formed due to puddling by using traditional ploughs to which the soils were subjected to for transplanted paddy cultivation. The plough pan being less permeable and compact is favourable for transplanted paddy cultivation but this compact layer restricts penetration of crop root below to harness moisture and nutrients present in the lower layers. On all landscape puddling for rice cultivation apparently accelerates the processes giving rise to the albic horizon and concentrate them in the ploughed layer and ploughpan⁽¹⁾.

Albic horizons are known to be developed in many mature surface- water gley soils of Bangladesh⁽¹⁾. The seasonal alternate wetting and drying cycles create a condition for transformation of Fe^{++} to Fe^{+++} that finally causes decomposition of clay. This process has been designated as ferrolysis by Brinkman⁽¹⁾. The net result of ferrolysis is the lowering of clay fraction with a subsequent lowering of cation exchange capacity of soils thus affected.

The soils are medium to fine textured, where textural class ranged between silt loam and silty clay. The structure is massive in the surface horizons because of ploughing for many years with puddling. A moderate medium to coarse prismatic and blocky structure has developed in the B horizons. Alternate wet and dry periods favour the formation of structural peds in these soils⁽⁶⁾. Pedogenetically these soils have developed properties of cambic horizon under the ochric epipedon.

Consistencies of soils occurring in the floodplain ridges (e.g. Tippera and Debidwar series) are friable, slightly sticky and slightly plastic while the consistencies of soils occurring on basin bottoms (e.g. Burichang series) are firm, sticky and plastic, depending on the clay content. All the soil profiles showed abrupt to clear and smooth horizon boundaries, reflecting young soil development or rejuvenation processes.

The soils contained large quantities of silt, ranging from 47 to 86%, with an average of 63% (Table 3). Based on silt content the studied soils show the following gradation along the catena: Burichang > Debidwar > Tippera. These high silt content is a characteristic property of the floodplain soils of Bangladesh⁽¹⁷⁾. The clay content ranged from 8 to 48%, with an average of 28%. High values of clay are found in the Burichang soils occurring on basin bottoms while

Table 3. Some physical and chemical properties of soils.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Sand/silt ratio	Silt/clay ratio	pH H ₂ O KCl	ΔpH	Org.C (%)	Total N (%)
Tippera series									
0 - 11	12	62	26	0.19	2.37	6.65	4.83	0.55	0.07
11 - 35	11	63	26	0.17	2.42	7.27	5.26	0.27	0.04
35 - 56	10	62	28	0.16	2.27	7.27	5.39	0.24	0.04
56 - 80	6	72	22	0.08	3.18	7.27	5.29	0.26	0.03
80 - 110	6	77	18	0.07	4.27	7.32	5.38	0.21	0.02
110 - 130	5	86	9	0.05	9.81	7.20	5.32	0.20	0.03
130 - 140+	6	86	8	0.07	10.35	5.07	4.06	0.25	0.04
Debidwar series									
0 - 15	5	62	33	0.08	1.86	5.24	4.22	1.65	0.13
15 - 40	6	56	38	0.09	1.42	6.14	4.57	1.10	0.11
40 - 65	4	51	45	0.08	1.11	6.14	4.67	1.12	0.12
65 - 90	3	55	42	0.05	1.31	6.12	4.75	1.01	0.11
90 - 110	9	69	22	0.12	3.14	5.20	4.05	0.53	0.06
110 - 125+	3	54	43	0.04	1.22	5.82	4.70	0.21	0.04
Burichang series									
0 - 15	14	55	31	0.25	1.82	6.10	5.20	1.83	0.18
15 - 35	8	58	34	0.13	1.68	6.71	5.78	1.20	0.15
35 - 60	5	47	48	0.10	1.00	6.55	5.58	1.02	0.14
60 - 90	14	60	26	0.23	2.25	5.88	4.55	0.43	0.06
90 - 120+	23	56	21	0.41	2.61	5.68	4.46	0.22	0.04
Mean	9	63	28	0.13	2.98	6.31	4.89	0.70	0.07

low values are found in the Tippera and Debidwar series occurring on floodplain ridges. Based on clay content the soils showed the following gradation: Tippera > Debidwar > Burichang. In general the ridge soils have silt loam to silty clay loam texture while the basin soils are clayey⁽¹⁸⁾. The rather erratic vertical distribution of particle size components indicate the heterogeneity and lithological discontinuity of the sediments and the turbulent condition under which they were deposited. The silt/clay ratio in many horizons varied erratically (1.00 to 10.35) and indicated that the observed variation of silt/clay ratio is lithological rather than weathering of silt into clay *in situ*. The sand/silt ratio of the soils is less than 1.0 with a mean value of 0.13.

Surface impoverishment of clay is quite a noticeable feature in these soils. But it is difficult to predict if this impoverishment has been caused by the ferrolisis/gleization processes. Impoverishment of clay in the surface horizons of the soil profiles is a common feature in the mature surface-water gley soils where ferrolisis is a common soil forming process⁽¹⁾.

The studied soils were moderately acidic to neutral with pH values ranging from 5.07 to 7.32 (Table 3). In all profiles, there was a trend of increasing pH up to a certain depth. This increase in pH with depth is a common feature in most of the surface-water gley soils of Bangladesh where ferrolisis is a common soil forming process⁽¹⁾. Ponnampuruma⁽¹⁹⁾ noted that acidification of topsoil is caused by continual displacement of bases by ferrous iron during the anaerobic or reduction phase associated with annual flooding. An observed decline of pH (1N KCl) in all the soils and the Δ pH values are presumed to be due to the difference in reserve acidity.

The organic carbon contents in the soils is low and range from 0.21 to 1.83% (Table 3). These results are in agreement with those reported for soils from the floodplains of Bangladesh⁽¹⁷⁾. Most mineral wetland soils of tropical Asia have only up to 3% organic matter content, but this amount influences productivity to nearly the same degree as the inorganic constituents⁽²⁰⁾. The seasonally flooded soils of Bangladesh are presently puddled using the mechanical or traditional ploughs to cultivate transplanted paddy⁽⁶⁾. Consequently, paddy straws are smeared in the topsoil in large quantity. Due to addition of paddy straw having wide C/N ratio the microbial activities in topsoil are augmented as the microbes can derive adequate energy from the added paddy straw. The phenomenon depletes the soil nitrogen content as the microbes derive the needed nitrogen for cell formation from the soil humus.

Highest amount of organic carbon is found in the surface horizon of basin soils (e.g. Burichang profile) whereas the lowest content is found in the ridge soils (e.g. Tippera profile). Low organic carbon content is a problem in Bangladesh soils, which is possibly due to rapid decomposition of organic matter under hyperthermic temperature regime. The total nitrogen content in the soils ranged from 0.02 to 0.18% with an average of 0.07% (Table 3). As expected the vertical distribution patterns of total nitrogen follows closely the sequence of organic carbon.

The CEC of the soils ranged from 3.53 to 14.08 cmol p+/kg, with an average of 10.10 cmol p+/kg (Table 4). Higher values of CEC occurred in the sub-surface horizons of Burichang profile

while lower values are found in the sub-surface horizons of Tippera profile. The CEC in these soils bears a significant positive correlation with the clay contents ($r=0.87^{**}$). The Mg^{2+} in some horizons of the profiles was the dominant cation in the exchange phase of these soils followed by Ca^{2+} and K^+ . It has been reported that, under the gleization process of soil formation, exchangeable Mg^{2+} becomes the dominant cation in the exchange complex⁽²¹⁾. In the studied surface-water gley soils the mean Ca^{2+}/Mg^{2+} ratio is 0.85 (Table 4). The Ca^{2+}/Mg^{2+} ratio is less than unity indicating loss of Ca^{++} due to gleization in these soils. Buol *et al.*⁽²²⁾ reported that the Ca^{2+}/Mg^{2+} ratio in the soil decreases with increasing maturity. The soils have very high percentage of base saturation.

Table 4. Charge characteristics of the surface-water gley soils from Meghna floodplain.

Soil series	Depth (cm)	CEC	Ca^{++}	Mg^{++}	Na^+	K^+	Ca^{++}/Mg^{++} ratio	BSP*
Tippera	0 - 11	9.12	3.58	3.33	0.09	0.14	1.07	78
	11 - 35	11.30	3.80	5.24	0.10	0.15	0.73	82
	35 - 56	10.84	4.04	4.65	0.09	0.18	0.87	83
	56 - 80	8.53	3.76	2.61	0.07	0.11	1.44	77
	80 - 110	7.80	2.97	2.66	0.07	0.13	1.12	76
	110 - 130	6.67	3.13	1.57	0.06	0.13	1.99	73
	130 - 140+	3.53	1.20	0.69	0.05	0.15	1.74	59
Debidwar	0 - 15	10.13	3.94	3.73	0.28	0.18	1.06	80
	15 - 40	13.93	4.45	6.80	0.37	0.21	0.65	85
	40 - 65	14.50	4.66	7.13	0.41	0.22	0.65	86
	65 - 90	15.30	4.66	7.81	0.46	0.19	0.60	86
	90 - 110	7.53	1.81	2.95	0.32	0.33	0.61	72
	110 - 125+	14.63	4.25	7.16	0.49	0.13	0.59	82
Burichang	0 - 15	14.08	6.52	4.55	0.87	0.14	1.43	86
	15 - 35	12.99	4.03	5.30	1.16	0.39	0.76	84
	35 - 60	14.95	4.48	6.60	1.67	0.28	0.68	87
	60 - 90	6.58	1.83	2.64	0.98	0.23	0.69	86
	90 - 120+	5.70	1.44	1.44	0.87	0.14	1.00	68
	Mean	10.45	3.59	4.27	0.47	0.19	0.85	79

*Base saturation per cent.

Parent material and the conditions like poor drainage and aquic moisture regime due to regular inundation during the rainy season are probably the factors moulding the morphogenesis of the soils. Parent materials were of mixed origin and were at an incipient stage. The seasonal submergence and drying set the conditions of alternate oxidation and reduction which are the most striking feature of the pedochemical environment in these soils. The presence of gleys, mottles and flood coatings or gleyans indicates that there is

hydromorphism in these soils. The process of hydromorphism in the soils is mainly attained due to the reduction and/or loss of iron and manganese and the development of grey colours.

Alternate wet and dry conditions produce vertical cracks leading to big prisms in the soil profiles. With the passage of time, the horizontal cracks and combined effect of flocculation, root penetration, organic matter addition and the biotic activity produced angular and sub-angular blocky structures in the studied soils. These structural B horizons have been considered as cambic B horizons. Formation of structure in these soils is relatively faster than in other soils.⁽⁶⁾ The structure is massive in the surface horizons because of ploughing for many years with puddling. Structurelessness in the lower most horizons was also observed in these soils.

The reaction of the soils closely follows the course of oxidation-reduction conditions because the soils contain considerable amounts of Fe and Mn which are subject to change. Alternate wetting and drying conditions in the soils resulted in release of Fe from iron-bearing minerals which in turn was precipitated and fixed in the form of mottles in the subsurface horizons of soils. This kind of mobilization and fixation of iron indicates that gley horizons occur in the deeper zone of the soils in the permanent ground water zone. Gleization can possibly be designated as the major pedogenic process in these soils. The low exchangeable $\text{Ca}^{++}/\text{Mg}^{++}$ ratio, massive structure in the topsoil and structurelessness in the lowermost horizon of these soils also support this fact⁽²¹⁾.

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(Manuscript received on 28 May, 2011; revised on 24 August, 2011)