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CHARACTERIZATION AND CLASSIFICATION OF SOME INTENSIVELY CULTIVATED SOILS FROM THE GANGES RIVER FLOODPLAIN OF BANGLADESH

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Abstract

Most of the soil samples from four pedons representing some extensive soil series from the Ganges river floodplain of Bangladesh found to be heavy textured with clay content averaging from 43 to 55 per cent up to a depth of one meter. The soils had neutral to alkaline reaction with high percentage of base saturation. Because of seasonal flooding ranging from two - three months the soils have developed redoximorphic features including redox concentration in the middle zone and a redox depletion in the lower zone of the profiles. The seasonal submergence and drying are the most active factors in developing the morphogenetic features in these soils. Smectite was the dominant clay mineral followed by mica and kaolinite with small quantities of vermiculites and interstratified minerals. The minerals in the clay fraction of the soils appear to be inherited from alluvial parent materials with very little *in situ* mineral transformation. The soils were characterized at the family categoric level of USDA soil taxonomy.

Introduction

The Ganges floodplain in Bangladesh represents a typical riverine landscape which covers about one-fifth of its total land area covering parts of greater Rajshahi, Pubna, Dhaka, Barisal, Khulna and whole of Kushtia, Jessor and Faridpur districts. It comprises the active floodplain of the Ganges river and the adjoining meander floodplain landscape of ridges, basins and old channels. Three physiographic units, such as the Ganges river floodplain, Ganges tidal floodplain and Gopalganj-Khulna beels have been identified in this vast floodplain. The soils developed on this floodplain differ in their morphological, physical and chemical properties mainly due to its mineralogy, age of sedimentation, relief and drainage.(1) Clay soils predominate in basin and on many places of the floodplain but silt and occasionally sand occupy higher ridge crests. The sediments of the Ganges delta are calcareous and fine textured. The calcareous sediments of the Ganges floodplain in many places have been decalcified and the mechanism of this decalcification process has been illustrated by Brammer.(2) Being fabulously fertile and densely populated, the soils of the Ganges delta have been the subject of extensive use for rice paddy cultivation for a long time.

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Few sporadic studies dealing with the morphological and mineralogical properties of the soils and sediments of the Gangetic alluvium in Bangladesh and India have been reported.[3,4,5] Properties of soils having agricultural significance are considered at the family level, the fifth category of USDA soil taxonomy. Soils of Bangladesh could not be characterized in the family categoric level due to lack of mineralogical data. Hence more mineralogical study is needed to characterize the soils to understand the mineralogical impacts on soil productivity and also to understand the mineral transformations and degree of soil development. Moreover, kknowledge about soil characterization is essential for good land evaluation, which is prerequisite for sound land management. Since these floodplain soils are intensively used for growing paddy rice, their mineralogy, morphology and taxonomic classification should be meticulously studied for better understanding of maintaining sustainability in soil health as well as crop production.

The present paper reports some salient morphological, physical, chemical and clay minerlogical properties for charaterization and classification of four extensively occurring soil pedons from the Ganges river floodplain of Bangladesh.

Materials and Methods

The Ganges river floodplain soils in Bangladesh represents nearly level to gently undulating landscape of floodplain ridges, inter-ridge depressions, infilled channels and basins consisting of unconsolidated river borne alluvium lying between 10 and 15 meters above the mean sea level. The soils here were traditionally used for the cultivation of rice and jute. The climate of the area is humid tropical monsoon (moist subhumid megathermal), with a mean annual temperature of 25.5°C and an annual rainfall of around 2250 mm.[1] The temperature regime is hyperthermic and most of the agricultural fields have udic/aquic moisture regimes.

Four extensive soil series *viz.,* Amjhupi, Gangni, Garuri, and Sara in the Ganges river floodplain of Bangladesh have been selected for this study. All these soils are flooded annually for varying periods during the rainy season and used mainly for cultivation of rice and jute. The information on soil sampling sites and their environmental conditions are presented 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.[6] A total of 27 soil samples were collected from the four selected profiles on genetic horizon basis. The soil samples were duly processed and analysed in the laboratory for determining their physical, chemical and clay mineralogical properties.

The soil pH was determined following the method of Jackson[7] and particle size analysis was carried out following the method reported by Black.[8] Organic carbon was measured by Walkley and Black's wet oxidation method.[7] Cation exchange capacity (CEC) was measured with ammonium acetate method at pH 7.0.[7]

For clay mineralogical analysis the soil samples were treated with hydrogen peroxide to decompose organic matter. The samples were finally treated with sodium dithionite-citrate-bicarbonate to remove free oxides of iron and manganese.[9] Thereafter, the samples were dispersed and clay (< 2 μm) fraction was separated from soil suspension by centrifugation and decantation method. The exchange complex of each clay sample (< 2 μm) was Mg- and K-saturated by repeated washings with normal solutions of $MgCl_2.6H_2O$ and KCl, respectively. Four slides of each pre-treated soil clays were prepared from samples of (1) Mg-saturated and air-dried, (2) K saturated and air-dried, (3) Mg-saturated and glycerol solvated and (4) K-saturated and heated at 550°C for at least 2 hours. These slides were scanned with GEOL X-ray diffractometer with Ni filtered Cu Kα radiation (at 30 kV, 40 mA) at a scanning speed of 2° 2θ per minute from 2° to 30° 2θ. The clay minerals in the clay fractions were identified following the method of Jackson.[10] A semi-quantitative estimation of minerals in the clay fraction of the soils were carried out following the method of Johnson *et al.*[11]

Table 1. Location and environmental conditions of the soils.

Characteristic features	Soil series			
	Amjhupi	Gangni	Garuri	Sara
Location (Latitude and longitude)	Jhikargacha upazila (23°10´N and 89°06´E)	Jhikargacha upazila (23°09´N and 89°08´E)	Jessore sadar upazila (23°07´N and 89°11´E)	Jessore sadar upazila (23°12´N and 89°15´E)
Area (ha)	1,09,737	1,01,255	1,82,732	1,89,236
Parent material	Ganges river alluvium	Ganges river alluvium	Ganges river alluvium	Ganges river alluvium
Relief	Nearly level ridge	Nearly level ridge	Nearly level basin	Nearly level ridge
Land type	Medium high land	Medium low land	Medium low land	Medium high land
Vegetation/ land use	Aus/Jute-Rabi	Aus/Jute-T. aman	T. aman-Fallow/ T.aman-Boro	Aus/Jute-Rabi
Taxonomic classification*	Aeric Endoaquept	Aeric Endoaquept	Aeric Endoaquept	Aquic Eutrochrept

*Subgroups of US Soil Taxonomy.[13]

Results and Discussion

The soil matrix had a mixture of olive brown (2.5Y 4/4), light olive brown (2.5Y 5/4; 2.5Y 5/6), greyish brown (2.5Y 5/2) and dark grey (5Y 4/1) colours with abundant quantities of variously coloured mottles prominant in the middle zone of the profiles (Table 2). The alternate wetting and drying conditions in these soils resulted in the reduction and subsequent release of iron oxides, which were accumulated in the form of brown, light olive brown, dark brown and dark yellowish brown mottles in the middle zone of the profiles. Redoximorphic features associated with wetness resulted from alternating periods of reduction and oxidation of iron and manganese compounds in the soils.[12] The redox depletion at the surface contributed to the development of dark grey colour to the surface soils. Redox concentrations in the subsoil zone were responsible for the formation of mottles.

Table 2. **Some morphogenetic features of soils from the Ganges river floodplain.***

Soil series	Horizon	Depth (cm)	Munsell colour		Field textural class	Structure	Effervescence (dilute HCl treatment)
			Matrix (moist)	Mottles			
Amjhupi	Apg	0-12	2.5Y5/4	f_1d g	sicl	m	eo
	Bwg1	12-32	2.5Y4/4	c_1d og	sic	3c-m abk	eo
	Bwg2	32-57	2.5Y4/4	f_1d db	c	3c-m abk	eo
	2Cg	57-75	2.5Y 5/4	f_1d gb	cl	m	ev
	3Ab	75-90	2.5Y 5/4	f_1d gb	sic	m	ev
	3Bwgb	90-113	2.5Y 5/6	c_1d g	sic	2c pr/2c-m abk	ev
	3Cb	113-129	2.5Y 5/6	c_1d db	sicl	m	ev
Gangni	Apg1	0-10	2.5Y 5/2	-	sic	m	eo
	Apg2	10-17	2.5Y 5/2	f_1d dyb	c	m	eo
	Bwg1	17-48	2.5Y 4/4	c_1d g	c	3c pr/3c-m abk	eo
	Bwg2	48-62	2.5Y 4/4	c_1d g	c	3c pr/3c-m abk	eo
	Bwg3	62-88	2.5Y 4/4	f_1d g	sic	2c pr	es
	Cg1	88-97	2.5Y 5/4	f_1d g	sicl	m	ev
	C2	97-192	2.5Y 5/4	-	sil	m	ev
Garuri	Apg1	0-10	5Y 4/1	f_1d db	sic	m	eo
	Apg2	10-16	5Y 4/1	f_1d db	c	m	eo
	Bw1	16-26	2.5Y 4/4	c_1d db	c	3c pr/3c-m abk	eo
	Bw2	26-35	2.5Y 4/4	f_1d db	c	3c pr/3c-m abk	es
	Bw3	35-43	2.5Y 4/4	c_1d db	sic	2c pr/2c-m abk	ev
	C1	43-79	2.5Y 4/4	-	sicl	-	ev
	Cg2	79-146	2.5Y 4/4	f_1d g	sic	-	ev
Sara	Apg	0-15	2.5Y 5/2	c_1d dyb	sil	m	es
	Bwg1	15-35	2.5Y 4/4	c_1d gb	sil	m	ev
	Bw2	35-65	2.5Y 4/4	f_1d dyb	sil	1c pr	ev
	C1	65-98	2.5Y 4/4	c_1d dyb	sicl	1c pr	ev
	C2	98-120	2.5Y 5/4	f_1d dyb	sil	m	ev
	C3	120-135	2.5Y 5/4	f_1d db	sic	m	ev

*The abbreviations used are those of USDA system [6]

In Sara soil profile there was a weak, very coarse prismatic structure in the B horizon. This horizon has been considered as an incipient cambic horizon.[13] Other three soil profiles had moderate to strong, medium to coarse prismatic and blocky structures in their control section. These structural B horizon have been considered as a cambic horizon.[13] Alternate wet and dry periods favoured the formation of these structural B horizon.[2] All the soils have continuous, thick, grey to very dark grey cutans on ped faces. The coatings on ped faces may possibly be due to mechanical downward washing of materials from the soil surface through cracks when the soils get flooded and ploughed.[2] The textures of the soils vary from silt loam to clay. The consistency was firm, sticky and plastic, which was indicative of moderate water retention of these soils.

Effervescence with HCl was noticeable in all the soil profiles which indicates calcareousness of the soils. Strong effervescence was observed below 50 cm in some soils which indicates the symptom of decalcification.

Silt contents in the soil of Amjhupi and Gangni avarage in the forties, in Garuri it is in the 50s while in Sara it is over 60 per cent (Table 3). The clay content was high in Amjhupi, Gangni and Garuri soils while it was low in Sara soil. These high clay content is a characteristic property of the lower Ganges river floodplain soils of Bangladesh.[2] The vertical and horizontal variation in texture is mainly due to sedimentation rather than weathering.

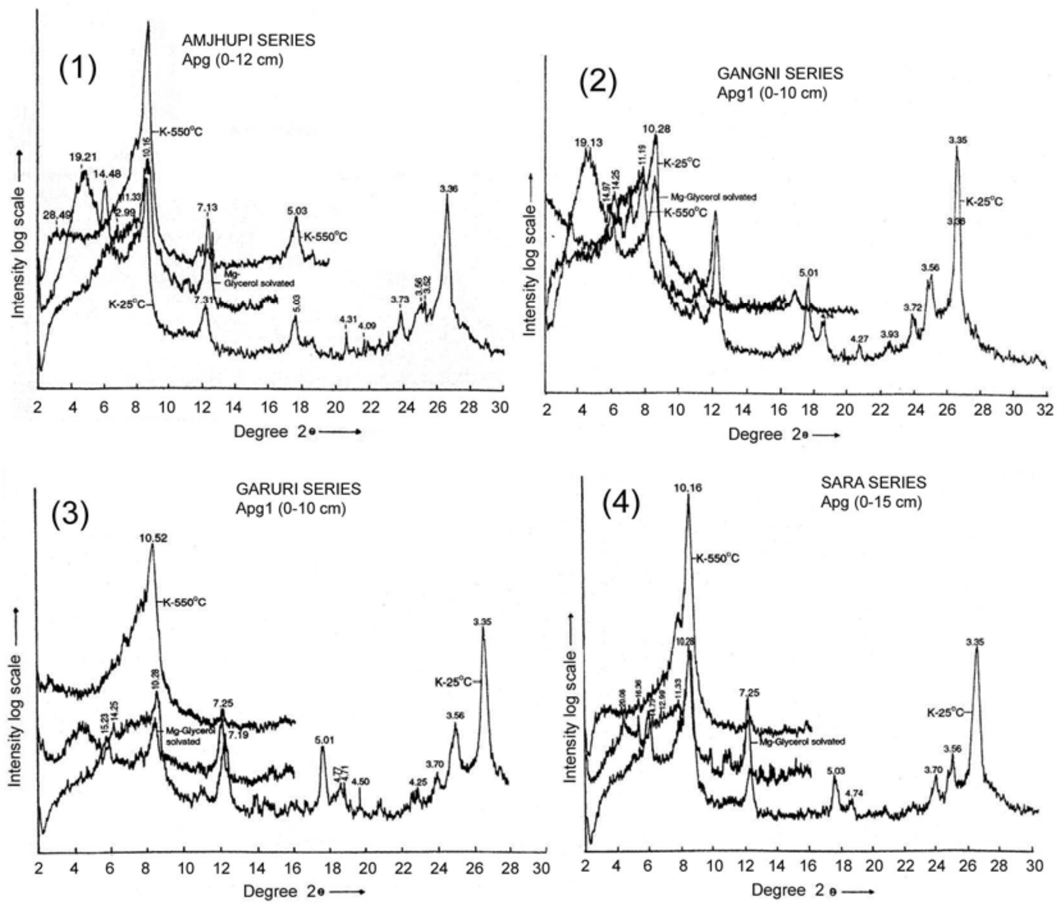
Table 3. Some physical and chemical properties of the soil.

Soil series	Sand content (%)	Silt content (%)	Clay content (%)	Organic carbon (%)	CEC [cmol(p+) kg^{-1}]	pH (H_2O)	BSP*	Free lime (%)
Amjhupi:								
Range	2 - 25	33 - 57	18 - 65	0.21 - 0.76	8.1 - 29.4	7.3 - 7.7	88 - 100	2.0 - 6.0
Mean	14	43	43	30.9	19.8	7.5	95	4.0
Gangni:								
Range	6 - 21	18 - 71	15 - 71	0.18 - 0.95	7.7 - 34.3	6.9 - 7.9	93-100	2.0 - 7.5
Mean	12	41	47	0.43	23.0	7.4	97	5.0
Garuri :								
Range	2 - 10	30 - 57	33 - 68	0.24 - 1.57	12.8 - 34.5	7.5 - 7.6	92-100	3.0 - 8.0
Mean	4	51	55	0.63	27.9	7.5	96	5.0
Sara:								
Range	5 - 22	42 - 69	13 - 53	0.18 - 0.60	8.5 - 24.5	7.5 - 7.7	89-99	3.5 - 7.5
Mean	16	62	22	0.28	12.3	7.6	94	6.0

*BSP - Per cent base saturation.

The soils were neutral to alkaline with pH values ranging from 6.9 to 7.9 (Table 3). The alkaline pH of the soils might be due to the calcareous nature of parent materials. The organic carbon contents in the soils is low. Low organic carbon content is a common problem in Bangladesh soils, which is possibly due to rapid decomposition of organic matter, caused by cultivation under tropical conditions. The cation exchange capacities and the base saturation percent are high. Free lime content in the soils ranged from 2 to 8 per cent.

X-ray diffractograms (Figs 1- 4) of the clay fraction showed the occurrence of both swelling and non-swelling types of clay minerals. The semi-quantitative estimation of clay minerals showed the dominance of smectite which occupied more than 50% of the clay fraction of the soils followed by mica which occupied about one-third of the clay fraction (Table 4). The presence of mica in the studied soils indicates that the transformation of mica to expanding lattice minerals has been slow. Mica in most soils originated mainly from soil parent materials and tend to weather to other minerals with time. [14] This mineral is generally more prevalent in clay fraction of younger and less weathered soils (Entisols), Inceptisols and Alfisols.[14]



Figs 1-4: 1. X-ray diffractograms of clay samples from Apg horizon of Amjhupi soil series. 2. X-ray diffractograms of clay samples from Apg horizon of Gangni soil series. 3. X-ray diffractiograms of clay samples from Apg horizon of Garuri soil series. 4. X-ray diffractograms of clay samples from Apg horizon of Sara soil series.

Table 4. Semi-quantitative estimates of clay minerals in the clay fraction of surface soils.

Soil series	Horizon	Depth (cm)	Clay content (%)	Clay mineral composition (out of 10)*				
				K	M	V	S	I
Amjhupi	Apg	0-12	36	1.0	3.0	0.5	5.5	tr
Gangni	Apg1	0-10	65	1.0	2.5	0.5	6.0	tr
Gerua	Apg1	0-10	57	2.0	3.0	tr	4.5	0.5
Sara	Apg	0-15	15	1.5	3.5	1.0	4.0	tr

*K - kaolinite, M - mica, V - vermiculite, S - smectite, I - interstratified (11-12 Å) minerals, tr - trace (< 0.5).

The third dominant mineral in the clay fraction was kaolinite. Kaolinite in the present soils is of allogenic origin. Kaolinite is one of the most widespread clay minerals in the humid tropical soils which is the product of acidic weathering.[15]

A small quantity of vermiculites and interstratified minerals were present in the clay fraction of all the soils. Occurrence of small quantities of vermiculites in the soils indicates that transformation of mica to expanding lattice minerals has not progressed considerably. White,[16] however noted that vermiculite in Bangladesh soils was formed by transformation of mica. The presence of small quantities of interstratified minerals in the clay fraction of the Ganges floodplain soil is also interesting and needs further study.

Smectites have been reported to be quite abundant in the soils of Gangetic alluvium.[17,18] Moslehuddin and Egashira [19] reported high quantity of smectite (62 - 88 %) in the fine clay fractions of the Ganges floodplain soils. They noted that the smectite mineral was mainly of iron-rich beidellite type with an estimated chemical formula of $(Si_{6.9}Al_{1.10})(Al_{2.46}Fe_{0.99}Mg_{0.76})$ $O_{20}(OH)_{4.0}X_{1.25}$. According to Brammer[2] the clay minerals in the soils formed on the floodplains of Bangladesh were mostly inherited from their parent materials. According to him, neosynthesis of smectites was possible in the calcareous Gangetic alluvium as the chemical environment (e.g. high pH, high BSP and calcareousness) existing in these soils appeared to be congenial for their formation and persistence. Singh and Misra[20] from their study on a number of soils from the Indo-Gangetic plains noted that the fairly high amount of Mg in the existing pedochemical environment including high pH and high base saturation might suggest the persistence of smectite and even vermiculite as an intermediate weathering product.

The studied soils have developed on recent alluvial parent materials where seasonal flooding of various duration and consequent siltation are a common feature during the monsoon months. From the particle size distribution of soils it might be inferred that the parent materials are to some extent heterogeneous in nature and of mixed origin. Morphological features of these soils indicate that their profile development did not proceed far. All the soils under the present investigation appear to be only weakly developed. This may be due to environmental conditions and time factors. The soils may, therefore, be reasonably considered to be in their incipient age of development. Moreover, the nature of parent material, local relief and the seaonal submergence and drying conditions are probably the factors affecting the profile characteristics of the soils. Apart from that the soils have been under rice cultivation for a long time, which disturbed the normal pedogenic processes and helped in the mechanical translocation of finer fractions downward forming a ploughplan at a depth of 5 - 15 cm, and flood coatings in the subsoil zone. These coatings are not clay skins but are flood coatings or gleyans as called by Brammer.[2] Moreover, annual siltation due to seasonal flooding is a common phenomenon in these soils which hampers pedogenesis.

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. These alternate wetting and drying situations hasten the process of soil profile development. 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. [2]

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. The enrichment of free iron (mottlings) in the middle zone of the soil profile is possibly due to these alternate oxidation reduction conditions. This kind of mobilization and fixation of iron in the soil indicates that gleization is probably the pedogenic process. The soils of the Ganges river floodplain are calcareous. The processes of decalcification and calcification are involved in these soils. The soil reaction closely follows the course of oxidation-reduction conditions but as the soils contain lime in considerable amounts the soil pH is always alkaline.

On the basis of morphological, physical, chemical and clay mieralogical properties the studied soils were characterized according to USDA soil classification system.[13] Based on morphogenetic features and other relevant properties it can be inferred that all the soils show some marks of profile development that have resulted in the formation of a cambic horizon along with an ochric epipedon. Hence, these soils were characterized under Inceptisol order. On the basis of properties associated with wetness and the presence of an ochric epipedon the studied soils were placed into two suborders: Aquepts and Ochrepts.

Table 5. Characterization of soils from the Ganges river floodplain in Bangladesh.

Soil taxonomy*					Soil series
Order	Suborder	Great group	Subgroup	Family	
Inceptisols	Aquepts	Endoaquepts	Aeric Endoaquepts	Clayey, Smectitic, Nonacid, Hyperthermic, Aeric Endoaquepts	Amjhupi
			Aeric Endoaquepts	Clayey, Smectitic,Nonacid, Hyperthermic, Aeric Endoaquepts	Gangni
			Aeric Endoaquepts	Clayey, Mixed, Nonacid, Hyperthermic, Aeric Endoaquepts	Garuri
	Ochrepts	Eutrochrepts	Aquic Eutrochrepts	Loamy, Mixed, Nonacid, Hyperthermic, Aquic Eutrochrepts	Sara

*According to USDA Soil Taxonomy.[13]

Considering the mechanism by which the aquic moisture regime originated as the basis and the soils got wet, the soils belonging to the Aquept suborder (Amjhupi, Gangni and Garuri series) were placed into Endoaquepts great group. The Sara series belonging to Ochrept suborder can be placed into Eutrochepts great group because of calcareousness of the profile throughout and a base saturation (NH_4OAc) of 60% or more in some horizon between 25 and 75 cm depths.

At the subgroup level Amjhupi, Gangni and Garuri soil pedons are further characterized as Aeric Endoaquepts subgroup as these soils have 50% or more matrix colour chroma $\geq$ 2 within 75 cm depth. While the Sara series fit into Aquic Eutrochrepts subgroup because of the presence of grey mottles within 60 cm from the surface. Finally, on the basis of textural class, clay mineralogical composition, soil reaction class and temperature regime the soils have been classified at the family level of the U.S. Soil Taxonomy (Table 5). This family level classification may serve as useful vehicle for crop production and agrotechnology transfer.

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