

A PEDOGENIC STUDY OF SOME SOILS FROM THE BRAHMAPUTRA FLOODPLAIN OF BANGLADESH

DIGITIZED

A DISSERTATION SUBMITTED IN FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN

SOIL SCIENCE

UNDER

THE UNIVERSITY OF DHAKA

GIFT

382458

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1996

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ABSTRACT

Seven extensive soil series from the vast Brahmaputra floodplain of Bangladesh were studied in the field as well as in the laboratory. The salient morphological features such as colour, colour patterns, texture, structure, mottles, consistency and floodcoatings of the soils were studied in the field. In all the pedons prismatic to angular blocky structure developed in the subsurface horizons.

Silt was by far the dominant mechanical fraction of the soils followed by sand and clay fraction. The distribution pattern of the sand /silt ratio and the clay content in the profiles were irregular which indicated the heterogeneous nature of the parent materials. All the soils were found to have higher bulk density in the Ap₂ horizons (plough pan) due to compaction resulting from intensive rice cultivation.

The important chemical properties of the soils such as pH, organic carbon, total nitrogen, cation exchange capacity, exchangeable bases, free oxides of Fe, Al, and Mn and fusion analysis of soils and clays were determined. Organic matter contents of the soils were low in general and all the dpH values were negative. The percentage base saturation was high and showed a tendency to increase with depth in all the profiles.

The clay fraction had mixed mineralogical composition consisting of mica, kaolinite and vermiculite. The higher content of mica in the clay fraction suggested that the soils were well-supplied with potassium..

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The total content of N, P, K, Ca and Mg in soils were almost comparable with those in the most other agricultural soils of Bangladesh. Total and DTPA-extractable Fe, Mn, Cu and Zn were determined. Zn deficiency was found to be widespread in all the soils.

Gleization seemed to be the major pedogenic process. The soils were classed at the family level according to the US soil taxonomy which may facilitate the process of agrotechnology transfer among these soils.



CERTIFICATE

Certified that the thesis entitled **"A Pedogenic study of some soils from the Brahmaputra Floodplain of Bangladesh"** by Md. Aminur Rahman Mazumder in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Soil Science under the Faculty of Biological Sciences, University of Dhaka, Dhaka, is an original research work carried out under our supervision. No part of the thesis has been submitted anywhere for any other degree or diploma.



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ACKNOWLEDGEMENT

The author has the great pleasure to express sincere appreciation and indebtedness to his reverend teacher Professor Mohammad Sultan Hussain, M. Sc. (Dhaka), Ph. D. (Hawaii, U.S.A), Department of Soil Science, and Dean of the Faculty of Biological Science, University of Dhaka, for his effective guidance, constant encouragement and affectionate feelings which he extended at all times during the tenure of this research work and also in the preparation of this manuscript.

The author expresses his heart-felt gratitude and gratefulness to Professor S.M.A. Faiz, M.Sc. (Dhaka), Ph. D (Aberdeen, UK), Department of Soil Science, former Dean, Faculty of Biological Science, University of Dhaka and at present Chairman, Bangladesh Public Service Commission (on deputation from the University of Dhaka) for his valuable guidance, and useful suggestions throughout the period of this work.

The author wishes to express his gratefulness to Professor S. A. Ahad, Professor T. H. Khan and Professor S. F. Elahi of the Department of Soil Science, University of Dhaka, for providing laboratory and research facilities whenever required during the whole period of research work. Professor A. Islam took the pains of going through the draft of this thesis for which I am grateful to him.

The author also wishes to express gratefulness and indebtedness to Professors S. M. Ullah and S. M. Imamul Haque, Department of Soil Science, University of Dhaka, for their encouragement and help during the whole period of research work. The author is also grateful to A. S. M. Mohiuddin, Assistant Professor, Department of Soil Science, University of Dhaka, for his help during the whole period of research programme. The author is also grateful to all the members of the teaching staff of the Department of Soil Science for their encouragement and inspiration.

The author expresses his heartiest gratefulness to Mr. S. M. Saheed, Director of the Soil Resource Development Institute, for his help and co-operation in the selection of soil series.

The authour wishes to express his gratefulness to Mr. Idris, Principal Scientific Officer, Soil Resources Development Institute, who helped in interpreting the morphological properties of the soils and also in their characterization. Appreciation is also due to Mr. Muzibul Haque, Principal Scientific Officer, Soil Resources Development Institute, for his help in the collection of soil samples in the field

The author gratefully acknowledges his indebtedness and extends his thanks to Mrs. Moonira Akhter Chowdhury, Deputy Director, Geological Survey of Bangladesh for her assistance in the X-ray diffraction analysis.

The author expresses cordial thanks to Dr. Saleque and Mr. Shamsur Rahman, senior scientific officer, Bangladesh Rice Research Institute, for their sincere assistance in chemical and statistical analysis .

Finally, the author expresses his sincere gratitude and appreciation to his wife Mrs. Roushan Ara Begum and his four children for their forbearance, encouragement and understanding during the period of this work.

Md. Aminur Rahman Mazumder

Date.21.5.1996.....

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ABBREVIATIONS

MWHC	:	maximum water holding capacity
FC	:	field capacity
PWP	:	permanent wilting point
AWC	:	available water capacity
g	:	gram
m	:	meter
cm	:	centimeter
Km ²	:	square kilometer
Km	:	kilometer
m ³ /sec	:	cubic meter per second
mg/L	:	milligram per liter
ppm	:	parts per million
m ²	:	square meter
sq. km.	:	square kilometer.
me/100g	:	milli-equivalent per 100 grams
cmol/kg	:	centimoles per killogram

CHAPTER-1

INTRODUCTION

INTRODUCTION

Historically many of the great civilizations of the world originated and flourished in the floodplains of big rivers. The reason for this was the abundance of fertile alluvial soils on the one hand and the availability of plenty of water for irrigating the crop lands on the other. The importance of a river to the growth of civilization, therefore, is immense.

Bangladesh is a land of rivers. Total number of rivers in this country is more than 200. The major part of Bangladesh can be considered as an agglomeration of floodplains. In this country at the present time a large number of floodplains of many rivers, big and small and having alternating seasonal flooding and drying conditions comprise around 80% of its territory. Most of the 9.0 million hectares of fabulously fertile agricultural lands in Bangladesh occur on the floodplains.

As noted above the landmass of Bangladesh on the alluvial soils is marvelously criss-crossed by innumerable rivers and rivulets. The river system in this country often plays a positive role by ensuring production of farm and forest products and also by facilitating transfer of goods and passengers with rivercrafts of different varieties. In Bangladesh the entire ecological and socio-ecological dimensions are influenced by land and water management practices. But the system has often been perilously influenced with calamities that reached the country in the form of floods and drought from time to time.

The Brahmaputra is a majestic international river that enters Bangladesh from its north eastern border with Assam (India). This is the only major river that originates on the northern slope of the mighty Himalayas and that ultimately has fallen to the Bay of Bengal after flowing through four countries—Tibet, China, India and Bangladesh. The Brahmaputra is a shifting type of river which has changed its course in the past. It is 2900

Chapter I Introduction

kilometer long and carries huge quantities of water and sediment loads derived from the various geological formations over which it flows. The Brahmaputra sediments are known to be highly micaceous and the water is slightly acidic. The Brahmaputra on entering Bangladesh has branched off into two channels. At present main channel of the Brahmaputra river in Bangladesh is Jamuna, which flowing southward meets the Padma (Ganges) near Goalanda. The old Brahmaputra, which was the main channel of this river even two hundred years ago (Rennell, 1781), streams southeast to meet the Meghna river at Bhairab Bazar and Padma near Chandpur and ultimately flows to the Bay of Bengal in the south.

The total area of Brahmaputra floodplain in Bangladesh is estimated to be around 1.6 million hectares, i.e, approximately one-ninth of the country's total area, wherein three main agroecological regions have been identified (Brammer et al.,1988). These agroecological regions are: Active Brahmaputra-Jamuna floodplain, Young Brahmaputra and Jamuna floodplain, and Old Brahmaputra floodplain.

The old Brahmaputra river in Bangladesh is now almost a dead river during the dry season. But during the monsoon season it still carries huge quantity of water and sediments and inundates its floodplains and nourishes the soils. The soils of the old Brahmaputra floodplain are relatively stable and mature. The greater Mymensingh district more or less forms the core of the old Brahmaputra floodplain where the soils have been known to be traditionally fertile under the centuries old agricultural practices. Land use here has been characterized by the paucity of water supply during the dry season and excess water during the rainy season. Flooding, therefore, is a serious problem in the rainy season as also the drought is in the dry season. Cropping intensity in the Brahmaputra floodplains is more than 180 percent which indicates that most of the soils here are used almost throughout the year.

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It is believed that this characterization of the selected soils of the Brahmaputra floodplain in the family category of the US Soil Taxonomy will go a long way in being useful to the soil scientists, agronomist, farm research scientists and the agricultural extension workers involved in agricultural development, as well as in agrotechnology transfer programmes. For, it is an established fact today that the pedogenetic information about soils is a prerequisite for sound and sustainable land management.

The soil resource of the old Brahmaputra floodplain have been surveyed under the reconnaissance soil survey scheme in which about 37 soil series were identified (SRDI Staff, 1974-1975). In the present research work seven pedons belonging to the seven extensive soil series of the old Brahmaputra floodplain have been studied with the following aims and objectives:

- ◆ To study the environmental settings and the morphological and physical characteristics of the selected pedons.
- ◆ To furnish basic information on the chemical and mineralogical properties of the soils and to provide a scientific data base for national land use planning.
- ◆ To throw light on the probable genetic processes that were responsible for the formation of these soils and to make an attempt to characterize them at the family level of the U.S. Soil Taxonomy.
- ◆ To attempt an evaluation of the fertility status of these soils.

CHAPTER-2

REVIEW OF LITERATURE

REVIEW OF LITERATURE

It was felt essential to know the findings of research works carried out on floodplain soils elsewhere by scientists on their different aspects such as on morphological, physical, chemical and mineralogical properties. A brief review of available literature on the above properties of floodplain soils with special reference to those on the Brahmaputra floodplain is presented below.

2.1. General Characteristics Of Floodplain Soils

Some of the important characteristics of the floodplain soils are the intractably complex patterns in which they often occur, their fabulously rich mineralogical composition, the rapidity of profile development and the dominant influence of hydrology on their morphological features and their agricultural potentials.

Floodplain landscapes are not always really flat. Often a number of micro relief features occur there which include a succession of broad ridges (levees) and depressions (backswamps or old channels). Often the sandy or silty materials occupy the ridges and clayey materials occupy the depressions, but the relative proportions of the different textured materials vary considerably between and within the floodplains. In general, the Brahmaputra river deposits are mainly silty clay loams on ridges and silty clays in depressions.

Differences in elevation influence the depth and duration of seasonal flooding on different parts of the landscape, as well as the position of the dry season ground water table. The variation in hydrological condition, coupled with differences in soil permeability and moisture holding capacity, associated with different soil textures, mainly determine the kinds of crops that can be grown. The above differences also determine the kinds of rabi crops that can be grown in rotation or in intermixture with rice. Undeniably,

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therefore, both the soils and land-use patterns are often complex and highly variable on floodplain landscapes.

Development of soil profile can be extraordinarily rapid, except in permanently wet sites and sites on active floodplains receiving regular addition of new alluvium. Ripening and oxidation of raw alluvium apparently take place within 2-3 years, and homogenization by soil fauna (specially earthworms) destroys alluvial stratification to 25-50 cm within about 25 years (Brammer, 1971). In materials heavier than light silt-loams, prismatic structure develops in the subsoil under the influence of seasonal wetting and drying whereas clayey materials may develop a blocky structure. Ped faces quickly become coated with gleyans comprising unoriented clay, fine silt and humus eluviated from the topsoil. Brammer (1971) pointed out that within a span of 25 years, a cambic horizon may form in floodplain sediments.

Within about the same period, non-calcareous soils begin to show a seasonal fluctuation in topsoil reaction: neutral when reduced, medium to strongly acid when aerated. Calcareous sediments are rapidly decalcified in the topsoil, but the more-loamy soils stay calcareous for several centuries due to constant mixing by the soil fauna (Brammer, 1971). In noncalcareous soils, there is generally a rapid differentiation between topsoil and subsoil textures.

The soils developed on the Brahmaputra floodplain, one of the most agriculturally important floodplains in Bangladesh have been studied by a number of workers on various aspects (SRDI Staff, 1965-86; Islam and Lotse, 1986; Ali et al., 1992; and Ali, 1994). Some soils on the Brahmaputra floodplain have less clay in the topsoil than in the subsoil (SRDI Staff, 1965-86). Loss of clay from the topsoil seems to be due, at least partly, to clay decomposition by ferrolysis process (Brinkman, 1970, 1977). In the oldest noncalcareous soils there is clear evidence of degradation and the occurrence of unbleached sand and silt specks and coatings in the plough pan and upper subsoil. On better-drained floodplain ridges, there is clay eluviation from the topsoil to the subsoil.

2.2. Morphological Properties of Floodplain Soils

Studies of the morphological features of soils during the field work are of prime importance for their identification, because they are believed to have resulted from the pedogenic processes. The morphological characteristics that are included in this review are colour, texture, structure and flood coatings.

2.2.1. Soil colour

Colour is the most conspicuous feature of any soil, and is one of the most important and useful characteristics for its identification. Soil scientists commonly use grey colours (chroma ≤ 2) as an indicator of seasonally/ permanently saturated and reduced soil conditions. Singh et al. (1989) concluded on the basis of morphological characteristics that the poorly drained floodplain soils have hue greyer than 10YR, value 5-6 and chroma less than 2, whereas moderately to well drained soils have redder hues and higher chromas. Studies of Daniels et al. (1973) and Evans and Franzmeier, (1986) have indicated that reducing conditions result in greyish colour in poorly drained soils, and oxidizing conditions are responsible for the brighter colours in better drained soils. Studies of water table fluctuations in soils have shown that soil colours can be used as a general indicator of saturated and reduced conditions, as well as movement of groundwater table (Mackintosh and Hust 1978; Zobeck and Ritche 1984; Pickering and Veneman, 1984; Evans and Franzmeier, 1986).

The soils of the Sutlej flood basin area were extensively studied by Sehgal et al. (1968). These soil were found to be light grey to light yellowish grey even when the soils were mostly poorly drained.

Soils in Assam have been investigated for a long time. Chakrabarty et al. (1984) after an extensive study of some soils in Assam reported that the Brahmaputra alluvial soils were mainly grey (2.5Y 5/2) in colour. Sharma and Dev (1985) studied profiles from six representative soil series on different geomorphic surfaces in the riverine plain of

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the Punjab and found that the soils showed wide variation in hues ranging from 7.5YR to 5Y. The soils located in the lower terrains showed grey colours (hue 5Y) with chromas of 2 or less and were associated with numerous mottles suggesting poor drainage conditions and a fluctuating ground water table. The texture is known to affect the brightness of colour of soils. Usually the light textured soils tend to have lighter colours. At the same time the topographic location of the soils and drainage conditions also have dominant influence on colours. The alternate wetting and drying environments in the soils result in the release of iron from the Fe-bearing minerals which are concentrated in the form of mottles and / or nodules in the horizon (s) that are affected by the ground water fluctuations. In the channel soil, however, the reduction and segregation of iron has been intense enough to produce horizons dominated by grey or olive grey colours with chroma of 2 or less. Such characteristics suggest the redistribution and reorganization of iron oxyhydrates in the profile and the formation of an altered B horizon (Brammer, 1971).

Hussain and Swindale (1970) studied a large number of profiles along the coast of the Hawaiian islands having different degrees of drainage impedance. They noted that the Grey Hydromorphic Soils of the Hawaiian islands had hues ranging from 2.5Y to 10YR, values ranging from 3 to 6 and chromas ranging from 1 to 3.

From the study of the relation between soil morphology and ground water levels on a dissected North Carolina coastal plain surface, Daniels et al. (1971) indicated that the grey colours generally occurred when the soil was saturated for 50% or more of the time. Similarly, Coventry and Williams (1984) studied the quantitative relationships between morphology and current soil hydrology in some Inceptisols in Australia and observed a strong relationship between the soil colour and the current ground water table. They also found that the grey colours occurred when there was saturation of at least five weeks time and grey colours were dominant in a mottled subsoil when saturation was for at least 21 weeks.

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The relationship between water saturation and soil colour has been explained primarily by the oxidation-reduction states of Fe and Mn compounds. (McKeague, 1965; Bonner and Relston, 1968). Reduction of Fe requires exclusion of oxygen for a prolonged period of time, a population of micro-organisms and organic matter as a source of energy for the micro-organisms (Jenny, 1980; Ponnampereuma, 1985). Water saturation regulates, the distribution and form of these elements within the soil profile. As has been noted earlier a chroma of 2 or less has been used to indicate a water saturation regime free of oxygen when the soil temperature exceeds 5°C for some part of the year (Soil Survey Staff, 1975). Mokma and Cremens (1991) made an attempt to establish a relationship between saturation and B horizon colour patterns in soils of three hydrosequences in south-central Michigan, and they related colours of Bt, Btg and Bg horizons to the total percentage of time that the horizons were water saturated, and also the percentage of time that the horizons were at temperature greater than 5°C. They found that matrix colours of these B horizons changed with duration of saturation as follows : hues became more yellow or olive as duration of saturation increased; chromas tended to decrease with increasing duration of saturation at temperature exceeding 5°C; duration of saturation increased as the proportion of grey (≤ 2 chroma) mottles increased. Vepraskas and Wilding (1983) remarked that soils containing low organic matter ($< 1.0\%$) in horizons below the A1 or Ap, seasonal saturation and reduction were found to occur in horizons having dominant chromas of 2 or less along ped exteriors, whereas the mottled ped interiors might have chromas of 4 or more.

During the reconnaissance soil survey of the Gangetic alluvium SRDI Staff (1970) found that the top soil colour ranged from pale olive to olive brown in ridges and grey to very dark grey in the interridge depressions and basins. But the subsoil colours ranged from olive to olive brown in ridges and from grey to very dark grey in depressions and basins.

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Soils formed in the old Brahmaputra floodplain have surface soil colours ranging from olive to grey and olive grey in ridges and grey to dark grey in lower slope of ridges and basins. Subsoil colour ranges from grey to dark grey in ridges and grey to mixed dark grey in basins (SRDI Staff, 1974-1975).

Diwakar and Singh (1992) studied some Tal land soils developed on river borne alluvium in India and noted the development of dark brown to very dark greyish brown colours. Okusami and Rust (1992) studied the hydromorphic soils from some inland depressions, alluvial plains, and coastal sediments. A 10YR hue was observed in addition to other typical morphological features of hydromorphic soils. Redder hues within a 10YR matrix colour indicated an iron accumulation zone which reflect the aerobic/anaerobic fluctuation zone.

Sidhu et al. (1994) reported that some Entisols under different soil moisture regime in Punjab had hues 10YR. However, 2.5Y to 7.5YR hues were also observed in some subsurface horizons of the above soils. Value and Chroma of these soils varied from 3 to 7 and 2 to 6, respectively.

2.2.2. Soil structure

The importance of soil structure in soil classification and soil productivity can hardly be overemphasized. The capability of any soil for the growth of plants and its response to management depends as much on its structure as on its fertility (Khonke, 1980; Landon, 1991; and Biswas and Mukherjee, 1992).

Alternate wetting and drying situations play an important role in soil structure formation. Wetting, which leads to expansion and gelation, and drying which leads to contraction and degelation are extremely important phenomena in structure formation, and hence, in profile differentiation with respect to structure development. Wetting and

drying and expansion and contraction affect structure formation because they affect orientation of the clay particles with respect to one another and also with respect to the plant roots (Bear, 1965).

Reid et al. (1949) found that soils of saline-alkali spots contained low content of water stable aggregates and a high dispersion ratio, while soils from saline spots were similar to normal saline spots. The soils developed on the Sutlej floodplains in the Punjab (India) were found to have little structure development (Sehgal et al., 1968).

White (1966) reported that the coarse textured subsoils theoretically have more stable peds than the fine textured ones. The resistance to shearing and the bearing capacity of clay subsoils with coarser particles are greater than in the fine textured soils.

SRDI Staff (1970) reported that the young Ganges meander floodplain with loamy to clayey subsoil, occupying ridges and inter-ridge depressions have weak to strong prismatic and blocky structures. The clayey soils, occupying infilled channels and small basins, have moderate to strong prismatic and blocky structures. They also found that the loamy to clayey soils occurring on ridges and in inter-ridge depressions, have weak to strong prismatic and sometimes lenticular (wedge-shaped) structure. In the old Ganges floodplain the loamy to clayey soils occurring on ridges and in inter-ridge depressions, have weak to strong prismatic and blocky and sometimes lenticular structures. Heavy cracking clays occurring in broad basins have strong prismatic structure breaking into fine and very fine blocky structure (SRDI Staff, 1970). SRDI Staff (1974-75) further found that the moderately well to imperfectly drained subsoils have weak to moderately strong prismatic and blocky structure in the old Brahmaputra floodplain area. The imperfectly to poorly drained soils have moderately strong to very strong prismatic structure; and the poorly to very poorly drained soils have strong prismatic and blocky structures. Sharma

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and Dev (1985) observed blocky structure in the B horizon of soils formed on different geomorphic surfaces in a riverine plain of the Punjab.

2.2.3. Flood coatings

Brammer (1971) defined flood coatings as the shiny surface of soil cracks and pores formed by deposition of material washed from the soil surface or the top soil under seasonally flooded conditions. These coatings are typically continuous, thick and of a grey colour. Brammer (1971), further reported that study of thin section under the microscope indicated that they comprised clay, fine silt and humus. He noted that only the included mica flakes were well oriented and he expressed the view that the flood coatings differed from clay skins. The colour of the flood coatings were same as that of the topsoil; grey where the topsoil is grey (when wet); dark grey when the topsoil is dark grey. This indicates that the material have been derived from the topsoil and not from suspended materials in the flood water. It also indicates that the coatings are, not pressure coatings (although they can be modified by pressure in swelling clays such as those developed in the Ganges alluvium). According to Brammer (1971) the flood coating materials are believed to move from the topsoil under hydraulic pressure when the soils are flooded. The coatings are most prominently developed on horizontal as well as vertical ped surfaces in soils that are deeply flooded, and least developed in ridge soils that are only shallowly flooded for short periods. Flood coatings may develop in soils under cultivation, forest and grass land, and on floodplain as well as terrace land; the common factor in their occurrence is seasonal flooding (Brammer, 1971).

Flood coatings are common features in the seasonally flooded soils of Bangladesh. They are quite common also in the soils of the Brahmaputra floodplain. Brammer (1971) proposed the name gleyans for these coatings since the coating materials are always gleyed (reduced). SRDI Staff (1970 and 1974-1975) used the term flood coating synonymously

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with cutan in their Reconnaissance soil survey report of Mymensingh district. In these soils where cracking is common, flood coatings are enormously present.

2.3. Physical Properties of Floodplain Soils

Physical properties such as texture etc. do not change their pattern easily in comparison to the chemical properties of soils and hence impart the stable and most useful contribution on soil classification purposes and in the diagnosis, management and improvement of cultivated soils.

2.3.1 Soil texture

Soil texture is one of the most fundamental and permanent characteristics that has direct bearings on structure, porosity, adhesion, consistency and physico-chemical behaviour of soil.

Goel and Agarwal (1959) concluded that sand portion of two nonresponsive soils of Kanpur Gangetic alluvium were high at the surface and only very slight illuviation of clay was visible, variation in the silt fraction was little in different horizons. On the other hand, the responsive soils of some alluvium exhibited considerable illuviation of clay from surface downward. Lime content of soil profiles decreased with increasing soil maturity.

Sehgal et al. (1968) reported that the soils of Sutlej floodplain have texture of loamy sand to silt loam.

SRDI Staff (1970) reported that the soils on ridges and interr ridge depressions of the young Ganges meander floodplain, are silty loam to silty clay. On the other hand, the soils of ridges and inter-ridges depressions of the old Ganges meander floodplain have loam to clayey texture.

Ridge soils in Brahmaputra floodplain are silt loam to silty clay loam and in interr ridge depressions and channels they are mostly silty clay loam to silty clay subsoils

(SRDI staff 1974-75). In oldest Brahmaputra floodplain the ridge soils are silt loam to silty clay loam and basin soils are silty clay to clay in subsoil.

In a study of hydromorphic soils from inland depressions, alluvial plains and coastal sediments, Okusami and Rust (1992) pointed out that the soil texture varied quite widely with landform types.

2.3.2. Bulk density

Bulk density has great importance in understanding the physical behaviour and agricultural use of soils.

In the floodplain soils of Bangladesh the bulk densities in general vary from 1.35 to 1.50 g/cc (Joshua and Rahman, 1983). They reported that the higher bulk densities were frequently associated with the surface horizons of the medium textured soils. This has been attributed to the structural breakdown and compaction of the soils due to ploughing under wet conditions. Generally heavy textured soils show greater variability in their bulk density values, probably due to their swelling and shrinkage properties.

SRDI Staff (1965-1986) studied some soils of old Brahmaputra floodplain and reported that bulk density ranging from 1.26 to 1.40 g/cc occur in the surface soils and the bulk density ranging from 1.54 to 1.62 g/cc are associated with ploughpans. They also reported that bulk densities from 1.41 to 1.48 gm/cc have been encountered in heavy textured soil, and density tends to increase with depth in these soils.

2.3.4. Soil moisture

Soil moisture retention is strongly related to the surface area per unit mass of the soil. It is also related to the texture of the soil and the clay mineral types.

Ali et al (1966) found that most of the water was released with 1 to 2 atmospheric tension in alluvial soils. The moisture retention was mainly a function of amount and nature of clay and to some extent to organic matter.

Das et al (1974) studied water retention characteristics of 12 alluvial soil profiles from West Bengal. Gheora and Mehrauli series varying in texture from sandy loam to sandy clay loam showed increasing trend of water holding capacity with depth (42.9-58.7%). Availability of water ranged from 7.1 to 23.3 percent in Gheora and from 7.7 to 16.0 percent in Mehrauli profile.

Velayutham and Raj (1977) stated that the assessment of water requirement, planning of irrigation schedules and prediction of probable crop response to irrigation depend very much upon differences in available water capacity of soils. They found that loamy soils had maximum available water capacity followed by sandy loam and clay loam.

Joshua and Rahman (1983) studied soil moisture characteristics in four profiles of Ganges river floodplain of Bangladesh. He reported that in the moisture retention graphs of the medium textured silt loam soils, the moisture contents decrease sharply with increase in tension above 50 cm of H_2O ($P^F_{1.65}$). This sharp decrease in moisture content persists upto one atmosphere tension during which most of the stored moisture was released. The silty clay loam soils, which have more clay than the silt loam soils, do not exhibit the sharp moisture release at the tension of 50 cm water.

"Soil moisture retention characteristics are the most unique among the physical properties of soils. They provide useful information about soils tilth, its structural stability, pore size distributions and magnitude and rate of water movement within the soils" (Sekhon and Arora, 1967). It has also the prime importance in soil and water management practices especially for policy planning in irrigations purpose (Velayutham and Raj, 1977).

The variation in water content at different tensions within the profiles may be due to variation in nature and amount of clay minerals and organic matter content of these soils. Diwakar and Singh (1992) also suggested that clay fractions might be dominant

modifier of the water content at higher energies of retention. Soil water tension at higher tension is mainly a function of amount and nature of clay (Joshua and Rahman, 1983).

2.4. Chemical Properties of Floodplain Soils

The chemical properties mainly deal with the chemical composition of the soil materials and indicates the nature and extent of weathering and stage of development of soils. They indicate the mineralogical composition of the soil materials. These properties give an idea about the nutrient contents of a soil.

2.4.1. Soil reaction

Soil reaction is the most important single physico-chemical characteristics which have a great influence on many physical, chemical and mineralogical properties of the soil. Suitability of soil as a medium for plant growth and desirable micro-organisms depends upon whether the soil is acid, neutral or alkaline and, therefore, this property receives special emphasis in pedogenesis and classification of soil.

Ponnamperuma (1965 and 1972) observed that when an aerobic soil was submerged, its p^H decreased during the first few days, reached a minimum, and then increased asymptotically to a fairly stable value a few weeks later of 6.7 - 7.2 in a 1 : 1 soil water suspension or 6.5 - 7.0 in the soil solution. He reported that the overall effect of flooding is an increase in p^H of most acid mineral soils which is due to the reduction of Fe^{+3} or Fe^{+2} and the decrease in p^H of alkaline soils which is due to CO_2 accumulation.

The increase of p^H with depth was described as the characteristic feature of the gley soils in Ohio by George et al (1958). According to Akhtyrsev and Stepanishchev (1963) the characteristics of alluvial meadow soils of bottom land of the Altar River in the forest-plain region of the Mordovian Autonomous Republic was their high degree of saturation with cations and a neutral or mild alkaline reaction. An increase of p^H with depth was also

observed by Chakraborty et al. (1984) while they were studying the morphology and physico-chemical properties of some alluvial soils of Assam.

Sehgal et al (1968) observed a p^H of 7.9 - 9.1 in soils of the Sutlej floodplain of Punjab. Obukhova et al (1970) noted that the p^H of some meadow-gley soils of Burma was slightly acidic to neutral during the rainy season but acidic during the dry season. Medvedev and Belitsina (1973) noted that the p^H of the ground water in floodplain landscape of the middle ridges of the Ob River ranged from 7.3 to 7.6. Khamparia et al. (1984) stated that the p^H of the alluvial soils (Entisols) of Gird region of Madhya Pradesh ranged between 6.7 and 9.2. Ponnampereuma (1985) reported that the decrease in p^H of sodic soils on flooding alleviates Ca and Mn deficiencies.

On flooding the pH values of soils may undergo change. Ponnampereuma (1975) reported that the upland soils, unlike the submerged soils, are not able to adjust their p^H levels to the favourable range of 6.5 to 7.0. This means that manganese and aluminium toxicities can occur in strongly acid soils and iron deficiency in alkaline soils.

Kumar et al (1981) found that after one week of submergence the p^H of hill soils increased and of "tarai" soils decreased. Such that after the third week, the p^H of all the soils approached neutrality (6.9 to 7.2). The range for initial soil p^H of the hill soils was from 6.0 to 6.6 and that of "tarai" soil was 7.3 to 7.6.

Hussain and Chowdhury (1980) studied the physical and physico-chemical properties of some soils from the moribund Ganges delta in Bangladesh and found that the reaction of the soil is neutral to slightly alkaline with a pH in the range of 6.7 to 8.0. The pH values increased slightly with depth. Rahman et al. (1992) observed similar feature in some soils from calcareous Gangetic alluvium. In the noncalcareous soils of Bangladesh this feature is even more regular (Brammer, 1971).

Hussain et al. (1982) studied the properties and genesis of some pedons from the Tiperra surface and observed that the soils were strongly acid at the surface and the pH gradually increased with depth in the pedons. The gradual increase of pH with depth is an

important characteristic feature of the Brahmaputra floodplain soils in Bangladesh (Brammer, 1971).

Raychaudhuri et al.(1963), and Walia and Chamuah (1992) observed that the flooded soils of the Brahmaputra valley in Assam were slightly acidic to neutral in reactions and the pH increased with depth.

2.4.2 Organic matter

Many important soil properties, including absorption and retention of water, reserves of exchangeable bases, capacity to supply N, P and other nutrient elements to growing crops, stability of soil structure, adequacy of aeration and the innumerable reactions that occur during pedogenesis are influenced to some degree by the organic matter contents in soils.

The function of organic matter in the soils is both direct and indirect. It's direct role is concerned with the provision of plant nutrients through decomposition and mineralization. It's indirect role is associated with humification and effects on most of the chemical and biochemical processes, by which the chemical, physico-chemical, physical and mechanical properties of soils are influenced (Neue and Mamaril, 1985).

Mujib (1968) reported 1.37 percent organic matter in some soil of Brahmaputra as well as Meghna alluvium of Bangladesh. Saheed and Hussain (1992) reported that both organic carbon and total nitrogen contents in the mineral wet land soils in Bangladesh were low. More than half of the soils had organic carbon content in the range of 0.5 to 1 percent.

According to the classification proposed by BARC (1989), the percentage of organic matter within the limit of 1.0 -1.7 fell in the low range (Appendix-4). SRDI (1965 -86) analyzed about 11,000 samples from 2500 representative soil profiles covering agriculturally important areas of Bangladesh and found that the organic matter contents of soils were generally low ; it ranges from 0.3 to 1.5 percent in upland soils, 1.5 to 2.0 in medium low land areas and 2.0 to 3.5 percent in the low land areas. In Bil areas, this fraction was about 4.0 percent (Rahman, 1990). Huq (1990) also commented that most

agricultural soils of Bangladesh have low organic matter content.

Gupta et al. (1984) found organic carbon in decreasing order with depth in the profiles from 0.57 to 0.09 percent, while the p^H increased with depth in Danker grey hydromorphic soils of lower Gangetic plains in India.

Walia and Chamuah (1992) reported that the flood affected soils of Brahmaputra valley have moderate quantity of organic matter (more than 1%). Sidhu et al. (1994) remarked that the organic carbon content of the floodplain Entisols of Punjab decreased irregularly with depth indicating their stratified nature.

2.4.3. Cation exchange capacity

Next to photosynthesis, cation exchange phenomena are the most important reactions in the whole domain of agriculture. Cation exchange capacity (CEC) is considered as an index of soil fertility. It plays an important role in the genetic processes of soils.

Gupta and Misra (1970) reported that the cation exchange capacity of Gwalior soils ranged from 11.4 to 21.3 me/100g having textures from clay to sandy loam. Chatterjee and Dalal (1976) reported that the cation exchange capacity of Bihar and West Bengal soils decreased with depth (from 10.2 to 4.1 me/100g).

Wells and Davy (1966) noted that the cation exchange capacity of the forest floor materials was highly dependent on the saturated cations used in the determination. The cation exchange capacity value obtained by them were significantly correlated with the nitrogen content of the soils. Maketie and Virri (1965) showed that CEC at p^H 7.0 was dependent on the amount of organic matter present. Schachtschabel and Rengen (1966) elucidated the fact that the cation exchange capacity of soil increased with increasing organic matter content.

SRDI Staff (1974-75) reported that the cation exchange capacity of the topsoil of most of the Brahmaputra floodplain soil with less than 2 percent organic matter ranged

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SRDI Staff (1974-75) reported that the cation exchange capacity of the topsoil of most of the Brahmaputra floodplain soil with less than 2 percent organic matter ranged from 9 - 23 m.e. and that of the subsoils was usually slightly higher ranging from 10 -28 me/100 g of soil. These values slightly increased with depth due to the increased clay content.

Pathak and Patal (1980) in some salt affected soils of Kaira district of Gujrat found the range of CEC from 11.0 - 21.0 me/100g where clay content ranged from 25 to 55 percent.

Thawale et al. (1991) found that the CEC of the soils of agricultural school farm at Sawangi ranges from 35.7 to 62.8 me/100g indicating the montmorillonitic nature of clay minerals. Walia and Chamuah (1992) reported that the CEC of the flood affected soils of Brahmaputra valley showed an irregular trend (ranges between 6.6 and 18.0 m. e/100 g of soil).

2.4.4. Exchangeable cations

Brinkman (1970) reported that during the anaerobic phase of soils, free iron is reduced with concurrent oxidation of organic matter and formation of hydroxyl irons. The Fe^{++} displaces the cations and the displaced cations are leached.

The cations such as Ca^{++} , K^+ , Na^+ and Mg^+ are known to be sensitive criteria of leaching intensities in weathering and soil formations (Wright et al, 1955).

It has been reported that, under the gleization process of soil formation, exchangeable Mg^{++} becomes the dominant cations in the exchange complex (Sunders, 1959). Kanehiro and Chang (1956) noted that as the gleization process progresses, the exchangeable $\text{Ca}^{++}/\text{Mg}^{++}$ ratio tends to approach unity. In the grey hydromorphic soils of Hawaii, the exchangeable $\text{Ca}^{++}/\text{Mg}^{++}$ ratio was 1.5 (Hussain and Swindale, 1974).

Submergence a soil causes an increase in the concentration of ions in the soil solution , as indicated by the rise in specific conductance (Ponnampereuma,1964). In a

reduced soil these ions are chiefly Ca^{++} , Mg^{++} , K^+ , and Na^+ which are not involved in the reduction process; the increase in their concentration is a secondary effect of submergence and reduction, chiefly solvent action of CO_2 and cation - exchange reaction (Ponnamperuma, 1964).

Islam et al. (1974) studied some rice soils of Bangladesh and found that the exchangeable Ca^{++} concentration first increased after submergence and then decreased. He noted that the velocity and magnitude of increase of exchangeable Ca^{++} varied in different soils. In all soils, the peak values were obtained in the ninth week of submergence followed by a gradual decrease. Exchangeable magnesium and potassium concentration followed more or less similar trends. Mehedi (1992) also found the same results in some submerged soils of Bangladesh.

Walia and Chamuah (1992) found that the exchange complex of the flood affected soils of Brahmaputra valley are dominantly saturated with Ca and Mg cations followed by Na and K. In the study of hydromorphic soils from inland depressions, alluvial plains and coastal sediments, Okusami and Rust (1992) stated that the general cation distributions are $\text{Ca} > \text{Al} \geq \text{H} > \text{Mg} > \text{K} \geq \text{Na}$ (inland depressions); $\text{Ca} > \text{Mg} \geq \text{Al} > \text{Na} > \text{H} > \text{K}$ (alluvial plains); and $\text{Al} > \text{Mg} > \text{Ca} > \text{H} > \text{Na} \geq \text{K}$ (coastal plain).

2.4.5. Major nutrients

Brar and Sekhon (1985) studied a large number of soils from the Indus basin belt in Punjab, Haryana and Uttar Pradesh. They studied reserved K levels in soils in relation to organic carbon, clay and texture.

The total K in the alluvium of Brahmaputra floodplain and in the surface - water gley of grey terrace soils ranged from 1.39 and 2.29 percent respectively (Habibulla et al., 1980). Total soil K as revealed from 29 rice growing soil series of Bangladesh, the amount ranged from 1.04 to 3.12 percent (Islam et al., 1988). K status of 12 extensively occurring agricultural soils from northern region of Bangladesh were determined and the total K ranged from 1.53 to 3.04 percent (Elahi et al., 1993).

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et al (1992) studied the properties of four pedons from Bhola district and observed that the available nitrogen ranged from 42 to 95 ppm, available phosphorus from 6 to 12 ppm and available potassium from 200 to 452 ppm. The concentration of available nitrogen, phosphorus and potassium is higher near the surface and decreases downward in the profile.

Chowdhury et al.(1992) indicated that soils of Bangladesh are rich in total K (ranges between 1.0 and 3.1 percent with a mean of 2.2) but very poor in available K. They further pointed out that the readily exchangeable potassium varied between 8 and 189 ppm with an average of 53 and were comparable with the findings of other workers (Oliveira et al., 1971; Islam et al.,1975; Ghosh and Gosh, 1976; and Singh et al., 1983). Exchangeable potassium accounted for 0.03 to 0.65 percent of total K and had significant relationships with clay and CEC of the soils.

Hossain et al. (1989) indicated that available N bear a significant positive correlation with organic matter and total N in some submerged soils of Bangladesh.

2.4.6 Micronutrients

The nature of parent materials and the degree of weathering have a bearing on the total micronutrient status; whereas pH , organic matter, soil texture, CaCO_3 and type of clay mineral markedly control the availability of micronutrients in soils (Graham, 1953; Swaine and Mitchel, 1960; Wells, 1960 and Hodgson, 1963).

Biswas (1953) found uniform distribution of total Mn in old alluvium. Total Mn also increased with the increase in clay content and depth. The amount of total Mn was maximum in the zone of accumulation of lime concretions which restricted Mn movement. Agarwal and Motiramoni (1965) indicated that alluvial soils of Madhya Pradesh contained 1-2 and 22-36 ppm of available and total Cu, respectively.

Working with Bangladesh soils Islam and Ullah (1973), and Islam and Islam (1973) observed a sharp increase in the concentration of iron followed by a steep decline with time of submergence. The peak values and time varied with soil properties.

John et al (1974) observed that both total and DTPA extractable Zinc, decreased with increasing depth. Extractable Zn was positively correlated with total Zn, organic matter, clay content and CEC; while negatively correlated with soils pH , base saturation and sand content.

Gotoh and Patrick (1974) found that the increase in water soluble and exchangeable iron was favoured by a decrease in both redox potential and pH . They reported that the distribution of water soluble and exchangeable iron was highly pH dependent. Chatterjee and Dalal (1976) indicated that Bihar and West Bengal soils had higher total iron in the surface than in lower layers.

Mitra and Mandal (1983) studied 35 surface soil samples from the rice fields of alluvial tract of West Bengal and reported that under air dried condition, the amount of water soluble and exchangeable ferrous iron was practically nil in almost all soils. A survey of the alluvial soils of union territory at Delhi was conducted to evaluate DTPA extractable zinc, copper and manganese. Majority of the soils was found to be marginal or deficient in zinc (Shukla and Rattan, 1985).

Sakal et al. (1988) studied the distribution of available Zn, Cu, Fe and Mn in old alluvial soils as related to certain soil characteristics. They found Zn deficiency in the old alluvial soils of Bihar. They further stated that available Zn, Cu, Fe and Mn were significantly and negatively correlated with pH and positively with organic carbon. From the stepwise regression analysis they indicated that the availability of Zn and Cu was dominantly controlled by organic carbon.

Ahmed (1989) indicated that the DTPA extractable Zn and Cu ranged between 0.58 and 1.90 ppm, 0.07 and 0.86 ppm respectively in some soils of Bangladesh. The author also observed a significant positive correlation between percent clay and DTPA extractable Zn only. Hassan (1991) studied some micronutrient contents in some Bangladesh soils. He noted that the available Zn and Mn showed high correlations

($r=+0.661$ and 0.854 , respectively) with the total amounts indicating thereby the genetic richness of these soils in Zn, Mn and Cu.

Diwakar and Singh (1992) studied the Tal land soils of Bihar and observed that the variations in total micronutrients appear to be associated with the parent materials, organic carbon, clay and pH of the soils. The values of both the DTPA-Zn and DTPA- Cu have decreased down the depth. The DTPA- Fe is higher in young alluvial soils whereas DTPA- Mn is higher in old alluvial soils indicating its relations with the higher clay contents. The total Zn in clay is higher than in the associated soils, whereas total Cu shows almost similar values with the associated soils. The total Fe is higher and total Mn is lower in the clay fraction than the whole soil.

2.4.7. Free oxides of iron, aluminium and manganese

Oades (1963) stated that the primary iron minerals in soils usually occurred in the coarse fractions and separation of the clay fraction will serve to exclude most primary minerals. The iron oxides, iron salts and iron associated with organic matter are collectively termed free iron in soils. He also stated that in well drained soils the bulk of the iron oxides resides in the clay fraction and this is more or less evenly distributed throughout the soils profile, as might be expected in normal oxidative weathering. In poorly drained soils the free iron is again associated with the clay fractions which tends to occur as accumulations in clay pans and illuvial horizons. Oades (1963) further stated that the iron nodules or concretions appear to have been formed by the presence of alternate oxidation and reducing conditions suggesting that their precipitation is physico-chemical in nature. A second group of iron concretions owes their precipitation by biological processes. These are the iron concretion associated with root channels. Lavroy (1950) observed that in the rhizosphere of the root system of reeds the grey gleyed soil became coloured red with ferric oxide in the form of a tube of iron oxide round the root. He carried out laboratory experiments to show that plant roots are capable of oxidizing ferrous iron.

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Bartlett (1961) has also shown that plant roots are capable of oxidizing iron and observed that the rhizosphere system of hydrophytic plants tend to be more efficient in producing oxidative conditions in the soils than mesophytic types. The iron compound was hydrolyzed form of ferric sulphate. Similar mottles and tubular formations were described by Clark et al. (1961), the iron compounds in this case being jarosite and iron polysulphides. Bloomfield (1952) and Schroeder and Schwertmann (1955) observed the association of iron concretions with root channels and Crompton (1952) pointed out that this association is a characteristics of many poorly drained soils. The orange brown colour is, however, usually associated with dead roots and while the roots are still living a pale blue or grey colour develops around them that only turns yellow on the apparent death of the roots (Balls, 1951).

Oades (1963) further stated that the most commonly occurring oxides are goethite and hematite, maghemite and lepidocrocite. Goethite is the predominant oxide in temperate regions. Lepidocrocite appears to be limited to the orange-brown mottles characteristic of gley soils (Brown, 1953; Kamoshita and Iwasa, 1959; Schwertmann, 1959b, Schwertmann and Taylor, 1977) and is generally reasonably well crystallized. He also pointed out that the movement, deposition and consequent accumulation of iron compounds are characteristic feature of poorly drained soils.

Iron plays an important role in soil chemistry being involved in numerous reactions affecting the chemical and physical properties of the soils. The contents and forms of Fe and Mn in soils and their vertical distribution in the soil profiles reflect the trend and peculiarity of the soil formation processes (Orlov, 1992)

Granick (1959) reported that the amount of free iron in soils depends largely on the soil p^H and redox potential. In acid soils Fe is usually in ferrous forms which are available to plants, but in neutral or alkaline soils it is oxidized to ferric iron which may be so insoluble that plants have difficulty in absorbing enough, e.g. at p^H_7 , the solubility of $Fe^{(iii)}$ is only 10^{-17} moles per litre, while that of $Fe^{(ii)}$ is 10^{-4} moles per litre.

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Joffe (1966) stated that the surface enrichment of free iron oxide was probably due to the fact that ferrous iron is oxidized easily to form free iron oxide at the surface; but in the subsoil the ferrous iron does not change.

The movement of manganese oxide and its distribution in the soil profiles were significant criteria in a pedogenic study as it behaves almost like iron oxide (Joffe, 1966). Mandal (1960), however, reported that the course of transformation of manganese was different from that of iron. Daniel et al (1962) stated that poor drainage condition was probably the important factor that cause the decrease in free manganese oxide content in the top soils.

McKeague (1965) stated that the low free iron oxide is neither due to leaching of iron nor to the accumulation of iron in mottles but presumably resulting from reduction.

Kojima and Kawaguchi (1968a, b) studied iron oxide minerals occurring in mottles found in rice soils of Japan and tropical Asia. Hematite ($\text{-Fe}_2\text{O}_3$) was not positively detected even in the samples from tropical Asia, while goethite (-FeOOH) was found in many samples regardless of their origin. Lepidocrocite (-FeOOH) was dominant in most Japanese rice soil samples, but was not detected in samples from tropical Asia. The reason for that difference is unknown.

Brinkman (1970) reported that during the anaerobic phase of soils, free iron is reduced with concurrent oxidation of organic matter and formation of hydroxyl ions. The resulting ferrous iron displaces cations and the displaced cations are leached as is the case in the formation of ferrolysed soils.

Hussain and Swindale (1974) reported that under the gleization process of soil formation, free iron and manganese oxides were found to be preferentially concentrated near the surface and specially above the zone of fluctuating ground water table.

Ottow (1973) reported that in waterlogged rice soils $\text{Fe}(\text{ii})$ ions are formed by reducing ferric oxides by different heterotrophic organisms.

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Juo et al. (1974) reported that the active Fe decreases with the increase of profile depth, suggesting that the larger proportions of Fe oxides are present as crystalline forms in the lower horizons of well drained profiles. They also reported about the co-migration of clay and Fe oxides from A to B horizon in some Nigerian soils.

Schwertmann and Fitzpatrick (1977) observed that the hydromorphic soils (pseudogleys) in a poorly drained highland mountainous climate of Natal (South Africa) contained appreciable amounts of lepidocrocite. Its occurrence appears to be restricted to imperfectly drained lower positions on southern (cooler) slopes at an altitude between 1.300-1.900 m. In these positions, Fe is reduced under anaerobic conditions leading to lepidocrocite formation on reoxidation. Goethite is closely associated with lepidocrocite and increases on approaching better aerated microzones such as root channels and textural boundaries where it usually forms crusts. Goethite is generally less crystalline than lepidocrocite.

Schwertmann and Taylor (1977) reported that the weathering of iron-bearing primary minerals in soils is known to release structural iron through hydrolytic oxidation. In the pH range that usually occur in soils, the released iron is precipitated as oxides, hydroxides, or oxyhydroxides (Garrels and Christ, 1965). Soils contain variable amount of free oxides and amorphous, or x-amorphous constituents (Ghabru et al., 1990). Schwetman and Taylor (1977) further noted that even at low concentrations in a soil, iron oxide have a high pigmentation power and determine the colour of many soils. Thus soil colour, as determined by the type (Schwertman and Lentze, 1966) and distribution of iron oxides within a profile, is helpful in explaining the soil genesis and is also an important criteria for naming and classifying many soils.

The amounts of free oxides in soils is very important in evaluating mineral weathering and pedogenic changes in soils (Mc Keague and Day, 1966; Hussain, 1968; Blume and Schwertmann, 1969; Hussain and Swindale, 1974; and Santos et al., 1986).

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Karim (1984) studied three typical Bangladesh rice soils i.e. (i) Madhupur, non calcareous dark grey floodplain soil (Aeric Fluveentic Haplaquepts); (ii) Habiganj, grey floodplain soil (Fluvaquentic Haplaquepts); and (iii) Kashimpur, shallow red brown terrace soil (Rhodic Paleudults) and found that $\text{Fe}^{(ii)}$ ion ranged between 0.92×10^{-4} and $1.94 \times 10^{-4} \text{ ML}^{-1}$. He noted that the Habiganj soil contained the highest amount of Fe_2O_3 (goethite).

Bhattacharyya and Ghosh (1986) studied 14 soils from India representing Entisol, Alfisol, Vertisol and Ultisol. They found that Entisols contained relatively less amount of oxalate soluble iron oxides while Alfisols and Vertisols contained greater amount of amorphous iron oxides.

Birnie and Paterson (1991) examined the distribution, mineralogy and morphology of the iron and manganese oxides in an imperfectly drained Scottish soil, with a diffuse Fe/Mn pan using electron microscopy, X-ray diffraction and chemical dissolution. The Fe oxide mineralogy above and within the Fe-pan was dominated by lepidocrocite, with subsidiary amounts of ferrihydrite. In the Mn-pan itself, ferrihydrite was present and below this, goethite predominated. Vernadite was the main manganese oxide mineral within the Mn-pan.

2.4.8. Total analysis

The chemical analyses of soils consisted of total chemical analysis of the soils as a whole, which include both products and reactants is important for the purpose of evaluating soil development. It could be assumed that the nonclay fractions represent the reactants and the clay fraction represent the products (Barshad, 1965).

Driskell (1954) studied three representative alluvial soils in the lower Mississippi floodplains and found variations in the contents of oxides of Si, Fe, Mg, K, Ca and Na as well as in the ratios of $\text{SiO}_2/\text{R}_2\text{O}_3$, $\text{SiO}_2/\text{Al}_2\text{O}_3$, $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ in the soils and the clay fractions thereof. These soils differed in both chemical and mineralogical properties.

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Hussain and Swindale (1974) noted that in the Hawaiian grey hydromorphic soils, the $\text{SiO}_2/\text{R}_2\text{O}_3$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios of the soils increased with increasing degree of hydromorphism. The $\text{SiO}_2/\text{R}_2\text{O}_3$ and $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratios in the fine clays of these soils increased with increasing degree of hydromorphism.

Wilding et al (1977) stated that silica occurs as six distinct minerals: quartz, tridymite, cristobalite, coesite, stishovite, and opal. Due to its resistance to weathering and ubiquitous nature, quartz is the most abundant mineral in most soils and occurs in nearly every locality on the earth. Recent aquatic sediments show decrease in silica content with particle size. The silica content is generally concentrated in sand and silt fractions with secondary quantities in the clay fraction. Both sand and silt fractions of most soils are dominantly silica (Arnaud and Whiteside, 1963; Borchardt et al. 1968; Hill and Shearin, 1969; Huizing, 1971). Silica exert a secondary influence on most physicochemical properties in soils including surface area, ion exchange, moisture retention, plasticity, cohesion and adhesion, shrinking and swelling etc.

Quartz has been utilized by numerous investigators to assess parent material uniformity, as index for quantitative evaluation of soil formation and as the stable member of a mineral ratio which expresses the degree of weathering (Arnaud and Whiteside, 1963; Barshad, 1964; Al-Janabi and Drew, 1967; Redmond and Whiteside, 1967; Sudom and Arnaud, 1971).

Hsu (1977) pointed out that a number of crystalline aluminium hydroxides, oxyhydroxides and oxides are found in nature. Among the three polymorphism of aluminium hydroxides, only gibbsite is common in soils and bauxitic deposits. Bayerite and nordstrandite were identified in soils during the seventies (Goldbery and Loughman, 1970; Davis and Hill, 1974).

From the study of the genesis of soils on different geomorphic surfaces in a riverine plain of Punjab, Sharma and Dev (1985) pointed out that Si was the most abundant element (39.8 to 74.0% SiO_2) comprising half (mean 50.4% SiO_2) of the total mineral

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matter in these soils and the other dominant elements in decreasing order of abundance were Al, Fe, Na, K, Ca and Mg. They also observed that the floodplain areas showed no definite trend of elemental distribution with depth.

Chatterjee and Dalal (1976) indicated that the alluvial soils in Bihar and West Bengal were higher in total Fe_2O_3 content near the surface than that in the lower layers. No definite sequence in the distribution of Fe with depth was noted probably due to young nature of the alluvial deposits.

Jha et al. (1984) examined the distribution of micronutrients in some calcareous soils and found that the total Fe had been accumulated in low land soils. Fraction of the total Fe in available form was also the highest in the lowland profile apparently due to prolonged submergence and reducing conditions and high clay content while higher pH and calcareousness reduced the availability of Fe in upland soil profile. Total Fe showed a positive relationship with total Mn and available P. No definite sequence in the distribution of Fe with depth was noted probably due to young nature of the alluvial soils.

The importance of titania as an index mineral in pedogenesis has been recognized long ago. Since then many authors have worked on the profile distribution of this element in different soils and in their respective clay fractions.

It is generally known that the TiO_2 content is highest in the finer fraction (Jackson and Sharman, 1953; Brain 1976; Hutton, 1977 and Hussain and Islam, 1979). The resistance to pedochemical weathering of titanium in the various finer fractions have been attributed to its very low solubility, the acidity must be very high before the solution of titanium goes into solution. Titanium may also combine readily with other constituents in the soil. Joffe (1966) mentioned the possibility of the formation of Fe TiO_3 (ilmenite). Hence, the movement of TiO_2 in solution during pedogenesis would not be expected to occur. However, the accumulation of TiO_2 in the B-horizon of certain soils were possible through mechanical movement (Authors).

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Hussain and Swindale (1974) stated that TiO_2 in soils ranged from 0.6 to 5.0 percent. The TiO_2 content was higher in the non-calcareous soils and was uniformly distributed within the profile.

Mazumder (1976) worked on some deep water rice soils of Bangladesh and indicated that the TiO_2 content of the colloidal fraction of the soils was around 1.49 percent. He also observed that the distribution of TiO_2 from the surface downward followed closely the sequence of sand/silt ratio. From the study of eight land types viz. foot hills, alluvial fans, sand-bars, covered floodplain, upper terrace, lower terrace, channel and river floodplain in the north-east of Punjab, Sharma and Dev (1985) observed that the TiO_2 content in whole soils ranged from 0.27 to 2.16 percent. The distribution of TiO_2 content from the surface downward followed closely the sequence of sand/silt ratio which was irregular in nature. The irregular distribution pattern of TiO_2 content indicated widespread stratification's.

Hussain and Islam (1979) studied the TiO_2 contents of a number of soils and clays from Bangladesh and reported mean TiO_2 contents of 0.67 and 1.14 percent for the whole soils and clay fraction, respectively. Singh and Mishra (1994) stated that the TiO_2 content of the soils of the Indo-Gangetic Plain of Bihar ranged from 0.6 to 1.1 percent.

2.5. Mineralogical Properties of Floodplain Soils

The mineralogical properties of clay in soils is a function of the different factors of weathering, the dominant among them are climate and parent material. It would, therefore, reflect the nature of weathering process the soil has undergone and indicate to what extent it is in conformity with the climatic factors.

Tropical and Sub-tropical soils showed large variation with the climatic conditions with respect to clay minerals. Matsuska and Sherman (1950) observed that kaolinite was dominant in sub-tropical soils.

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Floodplain soils contain varying quantities of sand, silt and clay fractions. Each of these fractions contain a number of minerals. Huizing (1971) studied the mineralogy of sand fraction of a large number of soils from the Brahmaputra floodplain. He noted that the Old Brahmaputra sand fraction are relatively uniform in composition. He found the weatherable minerals in the sand fraction of the Brahmaputra alluvium to be 28 percent. According to him the biotite : total mica ratio in the sand fraction of the Brahmaputra sediments was 0.65. He also reported a total mineralogical composition of the sand fraction of the Brahmaputra alluvium as follows :

Sediments	Percentages of minerals in sand						
	Non transparent	Aggregate	Heavy minerals	Mica	Alkali-felspar	Plagio-clase	Quartz
Brahmaputra alluvium							
Sample-1	6	2	6	12	10	10	54
Sample-2	6	1	2	12	16	13	50

Habibullah et al.(1971) studied the clay mineralogy of some seasonally flooded soils of Bangladesh and noted that mica and kaolinite were present in all the soils but vermiculite was present only in few.

Brinkman (1977) found that in the soils of the old Brahmaputra floodplain easily weatherable minerals comprise about 30 percent, one third of which was mica. He found from x-ray diffraction data that vermiculite accounts for about 45% of the clay fraction in the lowest horizon and this was progressively upward replaced by soil chlorite and finally increased to 30 percent in the surface horizon. He roughly estimated 30 percent illite, 40 percent kaolinite, 20 percent vermiculite and 10-20 percent inter-stratified minerals in the clay fraction of these soils.

Hassan and Razzak (1981) and Ali (1994) reported high content of mica, kaolinite and smectites in the clay fraction of soils formed on the Gangetic floodplain. Islam and

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Lutse (1986) identified smectite along with mica as the dominant mineral in the clay fraction of some soils developed on the Gangetic alluvium. However, Subramaniam and Jha (1988) reported abundance of kaolinite followed by illite and chlorite in the fresh water zone of Hoogly estuary in West Bengal. Research on clay mineralogical composition of some soils from the Indus river plain in Punjab was carried out by Razzak and Herbillon (1979).

Kapoor et al. (1982) studied the clay mineralogical composition of soils from four profiles developed on alluvium by using x-ray diffraction technique and found the dominance of illite followed by mixed-layer minerals, chlorite, smectites, chloritic smectite and vermiculite. The illite present in the soils was found to consist of both the dioctahedral and trioctahedral varieties and the latter appeared to have undergone transformation to smectite-like minerals through an intermediate stage of interstratification.

Puri et al. (1983) studied the silt and clay mineral composition in some alluvial soils from Uttar Pradesh. They found that these soils were moderately fine textured and moderately to well drained with a predominance of mica followed by chlorite, smectite and vermiculite. They concluded that the origin of these minerals were pedogenic rather than geogenic.

Vinayak et al. (1984) investigated the clay mineralogy of three typical salt-affected soils of the Indo-Gangetic plains by X-ray diffraction and chemical techniques. They found that illite was the dominant clay mineral in all the soils. He characterized the above saline soils by the presence of smectite as a second dominant mineral. Minor amounts of chlorite and kaolinite were present in all the soils. According to them, imperfect drainage might have resulted in the transformation of illite to smectite in these soils. Illite, kaolinite and chlorite in these soils were probably inherited. The differences in clay mineralogy between the salt affected soils and the associated cultivated soils appeared to be pedogenic rather than lithogenic.

Amin (1984) studied the clay mineralogy of some soils from Brahmaputra alluvium and noted illite, kaolinite and mixed layer of smectites-illite were the dominant minerals in the clay fraction.

White (1985) studied the clay mineralogy of some representative soils of the Brahmaputra floodplain of Bangladesh. From the x-ray diffraction data he reported that among the Brahmaputra floodplain soils, an exclusive combination of mica-kaolinite-vermiculite has been found in the younger member of the soils. He stated that apparently most of these kaolinite and mica minerals are parts of the original alluvial deposition, while vermiculite and smectite are the products of in-situ weathering. The relatively older soils of the old Brahmaputra floodplain, with a mild acidic environment have traces of chlorites but no smectite.

White (1985) also reported that the Gangetic alluvium are calcareous and mainly occur as meander floodplain, ridges, basins and old channels. They are dominant in mica, vermiculite and smectite minerals in clay fractions. The soils of the Ganges tidal floodplain are dominated by mica with some kaolinite and smectite.

Park and Han (1985) studied the distribution of clay minerals in some recent alluvial soils of Korea and noted that there were 50% illite, 21% kaolinite, 17% intergrade minerals, and 8% chlorite.

Yoothong et al. (1986) reported that the clay mineralogy of alluvial soils consisted mainly of kaolinite, montmorillonite and illite. Some interstratified clay minerals, and small quantities of vermiculite, chlorite, goethite and quartz were also present.

Esu (1989) studied the soils within the levees, backswamps and terraces of the Hadejia river in Nigeria. He stated that kaolinite, smectite, mica, polygorskite, quartz and K-feldspars were the dominant minerals in the clay fraction.

Mian (1990) noted that Sonatala and Ghatail soil series of Brahmaputra alluvium contain almost equal amounts of kaolinite and illite in their topsoil, subsoil and

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substratum. These soils contain small amount of vermiculite and chlorite. He also reported that the Sara and Ghior soil series of the Ganges floodplain contained 40-60% illite and 20-40% kaolinite with considerable quantity of smectite.

Sawhney and Sehgal (1992) studied the clay mineral composition of some alluvial soils of the Punjab and concluded that illite is the predominant mineral in all the soils. This was due to the presence of micas in the alluvium, forming the parent material of these soils. This was followed by the presence of kaolinite in soils of inter-channel areas. The presence of kaolinite throughout the profiles in all the soils suggested that the mineral has been brought along with alluvium which formed the parent material of these soils. A critical perusal of the report showed that Alfisols had low kaolinite content than the less developed Inceptisols. Since the kaolinite content in both the rice and the associated non-rice soils was comparable, irrespective of the environmental conditions induced by submergence, it appeared that the kaolinite is inherited and was not probably the result of transformation of 2:1 to 1:1 type mineral.

Saheed and Hussain (1992) reported that the clay minerals in the floodplain soils of Bangladesh have been derived exclusively from their parent materials. They commented that neosynthesis of smectites was believed to be possible in the calcareous soils of the Gangetic alluvium, because the chemical environment was suitable for their synthesis.

In some Hawaiian soils, Hussain and Swindale (1970) reported a direct relationship between the degree of hydromorphism and the occurrence of iron-rich smectite. Since under hydromorphic conditions, solubility of Fe^{+2} increases manifold it might enter into the octahedral layer of smectites by isomorphous substitution. In the soils of the Gangetic alluvium, this mechanism of mineral transformation might have taken place (Saheed and Hussain, 1992).

Acquaye et al. (1992) studied some soil profiles from the Accra plains of Ghana and found smectite as the dominant clay minerals in all the soils. They reported that the

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presence of smectite is in agreement with the CEC and swelling properties of the soils. The level to very gently undulating landscape, the semi-arid conditions, high pH, and poor drainage of the soils for a long period of time might have ensured the accumulation of bases and, therefore, the formation of smectite.

Ali (1994) studied the effect of alternate wetting and drying cycles on pedogenic processes and also on clay mineral alteration in some Bangladesh soils. He stated that the Gangetic alluvial soils were found to contain clay minerals like smectite, illite, chlorite and kaolinite. Their contents varied with respect to their location. In the Brahmaputra floodplain soils he noted that the dominant clay minerals were illite, chlorite and kaolinite. Small amount of vermiculite was also present in the surface horizons of some profiles. A small amount of smectite was also detected in few subsoils.

Okusami and Rust (1992) studied some hydromorphic soils from inland depressions, alluvial plains and coastal sediments in Nigeria and noted that kaolinites dominated the clay mineralogy in the surface soils, although the subsoils of some pedons formed in alluvium and coastal sediments were rich in smectite.

Smectites and expandable minerals, in general, are the major products of weathering under weathering conditions of medium intensity in the temperate climate where the drainage is poor to moderately good (Velde, 1985; and Jackson, 1959). The attainment of fully expandable species by weathering is frequently observed to be preceded by a mixed layered structure. Both di- and trioctahedral mixed-layer minerals are known to occur in soils. At times, regularly ordered interlayering between micas or chlorites and expanding layers are found (Churchman, 1980). A weathering sequence for phyllosilicates has been established and this indicates that their relative stabilities in soils are as follows : mica, chlorite > mixed layered expandable, non expandable > fully expandable smectite > kaolinite + Al, Fe oxides (Jackson, 1959). This sequence has been illustrated in Figure-1.

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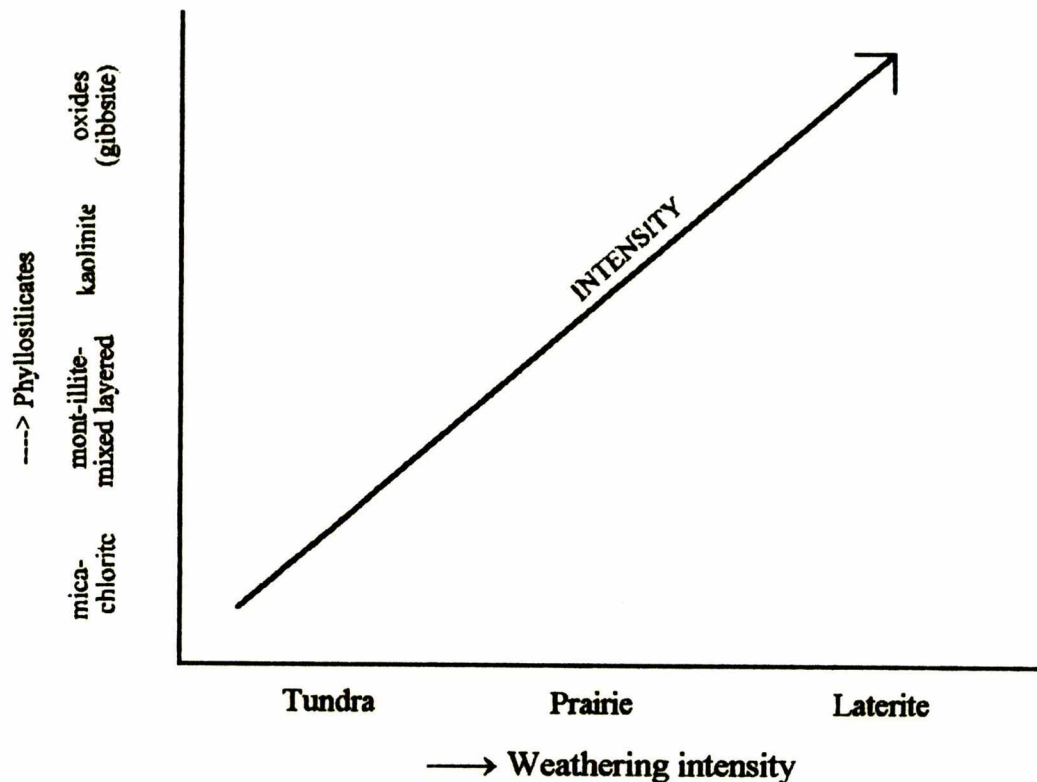


Fig.1. Sequence of relative phyllosilicate stabilities shown as a function of relative weathering intensity. (After Jackson, 1959).

Velde (1985) further pointed out that the use of phase diagrams can be made in order to explain the apparently paradoxical relationship between dioctahedral mica and vermiculites and montmorillonites in weathering and diagenesis. It was observed that illite and dioctahedral micas are degraded or altered to form montmorillonites during weathering (Milot, 1964; Weaver, 1959 ; and Dunoyer de Segonzac et al., 1970). Upon burial and initial diagenesis , the smectite fraction decreases, being replaced apparently by illite. There is an apparent symmetry observed in weathering and diagenetic processes. This observation has led to the idea that smectite represents a metastable form of mica which may return to its initial form when exposed to sea water sedimentation and burial ; it becomes reconstituted upon diagenesis (Weaver, 1959). Figure-2 shows two arrows representing possible paths taken by individual phases during the two alteration processes. Arrow a shows the evolution of the mica component as alkalis, principally when

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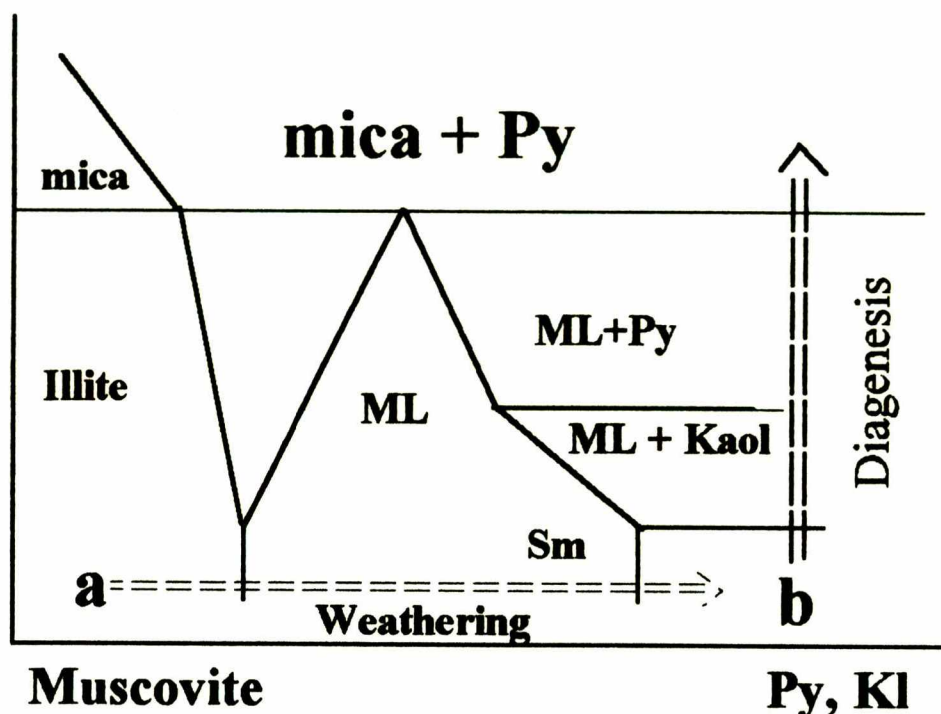


Fig-2 : Representation of a simplified mineral weathering system. (Mineral evolution due to chemical weathering is indicated by arrow **a**. Phase assemblage is indicated by arrow **b** which occurs during burial diagenesis. Phases represented are illite, mica; Py = pyrophyllite; ML = mixed layered smectite - illite; Sm = smectite; Kl = kaolinite).

potassium is removed from a mineral via weathering processes and as the bulk composition of the system allows the formation of first a mixed layered phase then a smectite. This sequence has been observed in many weathering profiles of soil. The removal of alkalis from the mica is not only a change necessary to produce smectite. In order to maintain charge balance, the octahedral ions must become more positive in charge, either by ionic substitution (divalent or trivalent ions) or by oxidation of iron in the natural system. As the total alkalis diminish beyond the limit of smectite bearing assemblages, kaolinite becomes apparent in the clays. Should the weathering be rapid, that is, should alkali removal be rapid, kaolinite could appear with only a small amount of the compositionally intermediate smectite phase present in a narrow horizon. However, in slower processes an apparent degradation sequence has been traced on the phase diagram (Velde, 1985).

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Mall and Mishra (1994) stated that the fine sand mineralogy of Gangetic alluvial soils of Bihar is dominated by light minerals in the order : quartz > feldspar > muscovite. Heavy fraction contains mainly opaque minerals, biotite and garnet, although zircon, apatite, rutile and chloritized mica are also present in some soils. Biotite and feldspar are the main weatherable minerals. Fine sand fraction from the river beds contain garnet, opaque minerals, quartz, feldspar and muscovite.

2.6. Pedogenesis of Floodplain Soils

The floodplain soils in most cases are seasonally water saturated and they are dry in the rest of the year. Periods of water saturation vary from soil to soil depending on topography and on set of monsoon. Many floodplain soils are irrigated during the dry season for producing grain crops. The fluctuating ground water tables play important role in the genesis of these soils. The pedogenetic processes in the floodplain soils are varied and complex in most cases.

The name gley was introduced by Thorp and Smith (1949) as a new name for the "Wiesenboden" great soil group in the soil classification system of the United States. It was defined as follows :

"An intrazonal group of poorly drained Hydromorphic soil with dark colour organic mineral horizon of moderate thickness underlain by mineral gley horizons."

Joffe (1949) quoted Vysotskii who gave the popular Russian idea of gley as " a more or less compact, sticky loam or clay material which is not, however, as sticky as the loam or clay, frequently with a more or less clearly pronounced light greenishblue ting."

In the U. S. D. A. Soil Survey Manual (Soil Survey Staff, 1951), a gley horizon has been defined as "a layer of intense reduction, characterized by the presence of ferrous iron and neutral grey colour that commonly change to brown upon exposure to the air". The gleization process involves saturation of the soils with water for long period in the presence of organic matter.

In Europe several definitions of gley are given in the international vocabulary of soil science. In English gley is "Yellow and grey mottling in the soil produced by partial oxidation and reduction of iron caused by intermittent water logging." The definition in German, Spanish, Portuguese, Italian and Dutch are essentially the same as above. In France it is a "Greenish grey colouration produced in the soils by the partial reduction of iron compounds under the influence of an-aerobic conditions created by the intermittent presence of water."

Features of gleization is expressed by the presence of mottling caused by the alternate oxidation and reduction conditions. The general agreement regarding the characteristic morphological features of hydromorphic soils may be presented as follows :

- ◆ Dark coloured organic mineral horizon of moderate thickness.
- ◆ Presence of reddish brown and yellowish brown mottles and grey coating along ped faces.
- ◆ Greenish grey or bluish grey gley horizons in the subsoil zone.
- ◆ Brown or greyish brown B-horizon enriched in sesquioxide; often not present.
- ◆ Cloddy structure in the top soil.
- ◆ Absence of any structure in the subsoil.

Brinkman (1977) noted that surface water gley soils are extensively developed on the seasonally wet landscapes. They are acid hydromorphic soils with albic horizons and containing less clay than the deeper horizons, and with a seasonally fluctuating pH in the surface horizon. The oldest of the Holocene floodplain landscapes in Bangladesh have soils in which only the upper 10 or 15 cm have less clay and contain some albic materials. Soils on younger floodplains where alluvial sedimentation is insignificant have seasonally acid A horizons, without substantial loss of clay. On old landscapes, puddling for rice cultivation apparently accelerates the process giving rise to the albic horizon and concentrates them in the ploughed layer and plough pan.

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The formation of an albic horizon has rarely been reported in paddy soils, particularly in the recent sedimentary formation in which the majority of paddy soils are distributed. Thus, it is still premature to consider the classification of paddy soils with an expression of ferrolysis (Brinkman, 1977).

The surface water gley soils also occur on many other floodplains in Bangladesh (Brammer and Brinkman, 1977). The Tista, old Brahmaputra and the northeastern part of the Meghna river floodplains as well as the old Meghna estuarine floodplain contain soils in which the surface horizon has an anomalously low clay content and seasonally fluctuating pH. Other soils in these floodplains, older basin clays in the Ganges river and tidal floodplains and most soils in the Jamuna (Young Brahmaputra) floodplain have a seasonally fluctuating pH in the surface horizon but have no evidence of clay loss.

Brammer and Brinkman (1977) correlated surface water gley soils in Bangladesh with the hydromorphic soils on the floodplain landforms occurring widely in southeast Asia (e.g. Moorman, 1961; Van der Kevie, 1972), degraded rice soils of Burma, (Karmanov, 1968); Aquarizems of Japan (Kyuma and Kawaguchi, 1966) and with Anthraquic epipedon (Dudal and Moorman, 1964) that forms in a soil long used for seasonal wetland rice cultivation. Hydromorphism is the common soil forming process in all these soils.

When reducing condition due to water saturation prevails for a long period of time the regime is defined as the aquic soil moisture regime (Soil Survey Staff, 1975). The aquic soil moisture regime implies a reducing regime that is virtually free of dissolved oxygen because the soil is saturated with ground water or by water of the capillary fringe. Reduction and gleying processes that result from biological activity under anaerobic environments constitute only part of the properties diagnostic for soils with aquic moisture regime (Smith, 1965).

Surface water gley or pseudogley or inverted gley are the principal morphological properties of soils that develop under aquic moisture regime. Dudal (1965) reported the existence of inverted gley in well drained soils that was used for wetland rice cultivation.

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When soils that have a non-aquic moisture regime are brought under wetland rice cultivation by irrigation, the surface horizons of such soils develop a gleying phenomenon that is called inverted gley. In this case, the morphological properties of an aquic soil moisture regime are imposed on the upper part of the profiles while the lower horizons reflect free drainage of the original profile (Saheed and Hussain, 1992). Dudal and Moorman (1964) termed this artificial man-induced water regime as "anthraquic" and the superficial soil horizon that formed under this water regime was called "anthraquic epipedon." The above authors defined anthraquic epipedon as the surface soil layer altered by ploughing in soils used for wetland crops, especially rice. It comprises both the cultivated layer and the underlying ploughpan. Both the layers are puddled, have grey base colours and are strongly iron stained along root channels. The cultivated layer is strongly reduced when waterlogged or flooded. In the waterlogged soils of Bangladesh there is commonly a strongly oxidized layer and in places a coating of iron oxides, but no iron pan, at the base of the ploughpan (Brammer, 1971). It has been noticed that the anthraquic epipedon forms in the floodplain soils of Bangladesh under an imposed aquic moisture regime having prolonged period of rice cultivation (Ali 1994).

Karmanov (1966), Wada and Matsumoto (1973) and Mitsuchi (1974) found that poorly drained low land soils do not change much, when used as paddy land. Moorman (1980) reported that a large proportion of the rice soils in the major and minor alluvial plains of south and east Asia belong to various great groups of the Aquepts and Aquepts suborders. He stated that alteration of diagnostic characteristics may, however, take place locally in the pedons of wet rice lands which remain submerged for long periods. Moorman (1978) also noted that in flooded soils the subsurface horizon may develop neutral grey colours due to continuous waterlogging and absence of oxygen. This is seen in double and triple-cropped irrigated rice land on fine clayey Inceptisols. Such soils may lose the characteristics required to classify them as Inceptisols, particularly the diagnostic cambic horizon, and they may become Aquepts.

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Moorman (1980) further postulated that the change in soil moisture regime under paddy cultivation is most fundamental in moderately well to well drained soils, where a surface and subsurface gley developed which is not connected continuously with a subsoil gley. Moorman and Van Breemen (1978) termed this specific soil moisture regime as anthraquic. In taxonomic terms it can be defined as periodic man-induced water saturation of the solum to a depth of at least 40 cm without corresponding periodic water saturation and reduction in the horizons below. The soil material in the surficial horizons, submitted to an anthraquic moisture regime shows the same colours of low chroma in the matrix or in the mottles as defined for the aquic suborder in soil taxonomy (Soil Survey Staff, 1975). The lower horizons, however, do not show these low chroma colours, indicating the absence of longer period of water saturation and reduction. Moorman (1978) made a formal proposal to introduce the term "anthraquic" soil moisture regime in soil taxonomy .

Hassan (1984) studied the soil formation in the floodplain areas of Bangladesh and observed that the soil formation in this region takes place in several stages. Initially, the sediments have low bulk density and high water content. In the ripening stage moisture is lost irreversibly resulting in an increase in bulk density. Subsequently, the sediments become homogenized due to bioturbations. At this stage the formation of soil structure begins due to alternate seasonal shrinking and swelling caused by wetting and drying in the wet and dry seasons, respectively. Soils of this region possess either A-C type of profile, or locally an A-(B)-C type of profile. Biotic factor, depending on the duration of dry and wet periods contribute to the soil structure formation. Effects of other soil forming factors become diffused due to high ground water table and juvenility of the soils. In most cases the attributes of parent materials dominate the soil properties.

In Germany, redoximorphic (or hydromorphic) soils are differentiated according to their water regimes into surface water influenced soils, ground water influenced soils, and subhydric - soils (Miickenhausen, 1977; Blume and Schlichting, 1985; Working group on soil systematics, 1985). Typical surface-water influenced soils are the pseudogleys

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(surface water gleys), typical ground-water influenced soils are the Grundwasserboden (Ground-water gleys). There are pronounced differences in the morphology of pseudogleys and gleys, induced by different air and water regimes, and also in their ecology and utilization (Schlichting, 1972). Other soil classification systems also differentiate between them; e.g., in France (Duchaufour, 1977) and in Britain (Avery, 1980).

According to Blume (1988) in a typical pseudogley the aggregate surfaces of the clayey B horizon are bleached and depleted of Fe/Mn oxide, whereas the cores are enriched with brown to orange Fe and blackish Mn oxides. The matrix of the less clayey and/or less dense topsoil, however, is grey and Fe and Mn are concentrated in concretions of different sizes. Thus the distribution pattern of Fe/Mn oxides is internally oriented against the ped and the soil surface (=inped- redoximorphism). Pedogenic Fe(ii) /Mn(ii) compounds are absent. In contrast to this pattern, the permanently wet subsoils of a typical ground-water gley is low in Fe and Mn or is enriched with pedogenic Fe (ii) compounds (= reductomorphism). Further up in the profile, with oxidizing conditions, Fe/Mn oxides are concentrated on aggregate surfaces and walls of larger pores (= exped-redoximorphism). In some pseudogleys exped-redoximorphism as well as inped-redoximorphism can be observed. This is typical for intergrades between pseudogleys and gleys. Also, above a dense plough pan, rusty surfaces of aggregates can be observed after a heavy rainfall, not only in pseudogleys, but also in well drained soils. In a typical pseudogley, water stagnation is produced by a slowly permeable layer. In this dense subsoil, roots and microbes are concentrated on the surfaces of peds. This favours reductive conditions during water stagnation, and reduced Fe and Mn diffuse into the cores and will be oxidized there. Slow changes between reductive and oxidative conditions will favour the formation of weak mottles, while quicker changes favour concretions. Total bleaching of the topsoils (typical for strong gleys) will occur during prolonged water saturation because Fe will leave the soil laterally under these circumstances.

Mitsuchi (1992) pointed out that in well drained soils with a non-aquic moisture regime, qualitatively new processes start to operate when the soil is used for wet cultivation of rice. Some of these processes are (1). Surface gleying and subsurface grayizations, (2). development of iron (and manganese) accumulation horizons, (3). formation of ploughpan, (4). accumulation of poorly humified organic matter, (5). chloritization of 2:1 type clay minerals, and (6). redistribution of exchangeable bases. Among these, surface gleying and subsurface grayization that extend from the surface downward and the development of iron (and manganese) accumulation horizons are most important and readily visible.

2.7. Classification of Floodplain Soils

Soils are classified by common properties for the purpose of systematizing knowledge about soils and determining the processes that control similarity within a group and dissimilarities among groups (Gupta 1981). There are many international soil classification systems of which USDA soil taxonomy (Soil Survey Staff, 1975) is widely used and have been found useful for agrotechnology transfer. This system has been very widely followed for classification of Bangladesh soils.

SRDI Staff (1965-86) while surveying the soils of Mymensingh district found that almost all floodplain soils have characteristic topsoils which are seasonally wet, and gleyed and have prominent iron staining along root channels. These topsoils consist of a massive or cloddy plough layer at the surface underlain by a massive and compact ploughpan. They observed that the ploughpan, formed in older soils often has strong iron stain at its base. These stains/iron cutans have been developed by continuous ploughing and puddling for rice cultivation and prolonged seasonal flooding. They commented that these topsoils can not be correlated satisfactorily with the diagnostic epipedons described in soil taxonomy.

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The above authors further reported that the most of these soils have cambic B horizon, which was identified on the basis of destruction of the alluvial stratification, development of prismatic or blocky structure, usually with the peds coated by the flood cutans and strong oxidation within the peds. Because of grey mottling and moist colours on ped faces of the soils, they were classified as Haplaquepts according to the USDA classification system. The soils having proportion of mottles with chromas higher than 2 and covering more than 40 percent of matrix were classified in the aerice subgroup. They observed that some profiles of Ghatail series have vertic properties. They are clayey down to 100 cm or deeper and have some slickensides and wedge shaped peds in the subsoil. These soils could not be classified in the vertic sub-group because slickensides were not close enough to intersect and cracks of one cm or more wide at a depth of 50 cm were not found to develop.

Inceptisols are usually moist and have weakly developed natural soil horizons that do not represent significant illuviation or eluviation or extreme weathering (Soil Survey Staff, 1975). Many of these soils are young, although they are always older than Entisol. These soils have no spodic, argillic, natric, calcic, gypsic, salic or oxic horizon, but have conductivity of the saturation extract of less than 2 mmhos/cm at 25°C and have one or more of the following : a histic, umbric or ochric epipedon; a cambic horizon, a fragipan or a duripan. These soils have an appreciable accumulation of organic matter and there must be some evidence that the parent materials have been sufficiently altered by pedogenesis (Hussain, 1992; Soil Survey Staff, 1994).

Murthy et al. (1962) examined the morphological characteristics of four soil profiles from the alluvial soils in the Ganges river plains of Central Uttar Pradesh and according to the USDA soil classification system they put some of them in the Haplaquent great group and others into the Haplaquoll great group as these have very high pH due to their drainage impedance.

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Floodplain soils that are used for rice cultivation have been considered as artificial hydromorphic soils (Kanno, 1962), hydromorphic associates of the respective great soil groups (Sivarajasingham, 1963), an anthraquic great soil group (Dudal and Moormann, 1964), anthropic subgroup of the great soil groups (Dudal, 1965), aquorizems (Kyuma and Kawaguchi, 1966), land use phases of original hydraquic sub-groups (Otowa, 1973) and lowland paddy soils (Mitsuchi, 1974). According to Mohr et al. (1972) the rice soils in south and southeast Asia and Japan are diverse and have been classified into seven soil orders of US soil taxonomy, such as Entisols, Inceptisols, Vertisols, Alfisols, Ultisols, Oxisols and Histosols.

Kanno (1978) commented that the soils whose properties have been greatly changed by rice cultivation should be classified as independent great group, whereas the rice soils in which the inherent characteristics of the preceding soils have been dominantly maintained should be classified as the sub-groups of the preceding great group. This idea closely resembles that of Mitsui (1966).

Rice soils are mostly found on the floodplains and alluvial lowlands in humid regions. This implies that in the genesis of rice soils the soil material factor is of primary importance. Rice soils are inundated in natural way or water is easily introduced by gravity. Therefore, most rice soils are either Entisols or Inceptisols, which have undergone little soil formation (Kyuma, 1978).

Murthy (1978) stated that rice is the most extensively cultivated food crop of India, and grows under a wide range of rainfall and on a wide variety of soils. The most important of them are the floodplains and the alluvial - derived soils. In India the Sutlej - Ganga alluvial plain runs first in rice production.

Paramananthan (1978) stated that the areas where wetland rice was traditionally cultivated were alluvial soils and floodplains or simply as rice growing areas. Rice growing soils in Malayasia have not been classified beyond subgroup level. According to the classification of Thorp and Smith (1949) most of the soils would be classified as Low

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Humic gleys and in the Hydromorphous sub-order of Intrazonal soils. Ng (1968) attempted to classify the rice soils of peninsular Malaysia according to the system proposed by Kanno (1962).

According to Paramanathan (1978), most of the rice soils of Malaysia fall into the two sub-orders of US Soil taxonomy. These sub-orders are : Aquent and Aquepts. A few of the soils fell into the order Ultisols.

SRDI Staff (1974 -1975) correlated Melandaha and Dhamrai series as Typic Haplaquepts; Silmandi, Sonatala, Lokdeo and Ghatail series as Aeris Haplaquepts and Sherpur series as Aquic Ustochrepts in the USDA soil taxonomic system. Zijssvelt (1980) and Hussain, (1992) attempted to correlate the major soil series of Bangladesh into the family category.

The term anthraquic is used to denote a soil moisture regime that is man-induced and is mainly caused by artificial submergence. It seems appropriate to consider the soils with an anthraquic moisture regime at the subgroup level, as has been proposed by several authors (Dudal and Moorman 1964; Dudal, 1965; Kawaguchi and Kyuma, 1974, Moormann, 1980; and Moorman et al., 1985). The level of subgroup seems adequate because the man-induced moisture regime is merely superimposed and does not entail substantial changes in the basic soil characteristics, especially as regards the subsoil. Moreover, the land use can readily be changed from rice to dryland crops, causing the surface gley features to become relict or even to disappear.

Kyuma et al. (1988) stated that the soils utilized for aquatic rice cultivation, i.e. the paddy soils, are either naturally or artificially waterlogged for at least three months every year or more. The effect of waterlogging is particularly drastic for those soils that do not have a naturally-occurring aquic moisture regime and in which an "inverted gley" morphology, induced by artificial submergence, is a readily visible change. This change should be taken into consideration when the soils are classified. An "Anthraquic" soil moisture regime has been proposed and defined to handle this situation. Soils with an

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anthraquic moisture regime should be classified at the subgroup level. A diagnostic surface horizon has also been proposed, to recognize morphological changes induced by artificial submergence. The "hydragric" horizon is defined in terms of the eluviation-illuviation pattern of iron and manganese. Soils with a hydragric horizon should be classified at the great group level. An irrigation induced pseudogleying or gray-ization is another feature that occurs in non-aquic, slowly permeable soils used for aquatic rice cultivation. This is yet to be defined in terms that differentiate it from natural pseudogleys.

Singh et al. (1989) studied the genesis and classification of soils in an alluvial complex of Varanasi district of Uttar Pradesh and classified the soils as Typic Ustifluvents, Vertic Ustochrepts, Fluventic Ustochrepts, Aquic and Udic Haplustalf and Aeric Ochraqualfs under USDA soil taxonomy. These soils qualify for placement under Eutric Fluvisols, Eutric Cambisols, Gleic Cambisols, Vertic Cambisols and Brunic Luvisols according to FAO/Unesco soil legends. Suggestion for inclusion of Thapto subgroup in Ustifluvents in soil taxonomy to classify some soils has been made.

Sawhney and Sehgal (1989) studied the taxonomy of rice and associated non-rice cultivated soils of Punjab and observed that the rice growing soils have little morphological difference with soils not growing rice to influence their taxonomy. Rice cultivations under Punjab conditions, does not alter the diagnostic features of the soils, except affecting the surface horizon(s). Hence their classifications may not differ from their non-rice associates upto at least the first four categories. The soils studied have been classified in two orders (Inceptisols and Alfisols), two sub-orders (Ochrepts and Ustalfs), two great groups (Ustochrepts and Haplustalfs) and five subgroups of Aquic Ustochrepts, Udic ustochrepts, Typic Ustochrepts, Typic Haplustalfs and Udic Haplustalfs. For a rational classifications of rice soils, new phase, viz., "anthraquic" has been introduced within the system to highlight man induced reduction conditions in the surface horizon of these soils.

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Walia and Chamuah (1992) stated that the upland soils of the flood affected areas of Brahmaputra valley showing the development of cambic horizon are keyed out as Inceptisols. Further, these soils qualify for Ochrepts sub-order due to Ochric epipedon and Dystrochrept great group as the base saturation is less than 60 percent. Similarly, soils of lowland, flat land and levee are also Inceptisols as they show the formation of gleyed structural Bg horizon. At great group level these soils are categorized as Aquepts as they exhibit characteristics associated with wetness such as greying colour and mottles but these soils lack sulphuric, umbric and mollic epipedons, and fragipan and duripan horizons and are classified as Haplaquepts. Soils of flood channels and meandering scars are stratified and put under Entisols due to the absence of any diagnostic horizon. Flood channels soils are characterized by irregular distribution of organic carbon and classified as Fluvent at the suborder level and Udifluent at great group level owing to udic moisture regime. Soils of meandering scars qualify for Aquents suborder due to aquic characteristics and Fluvaquents at great group level because of irregular distribution of organic carbon.

Hussain (1995) noted that the soils of the Brahmaputra alluvium have been used for rice and jute cultivation for centuries. These two crops have been grown in the past at the time the soils were naturally wet. Flooding during the rainy season was a natural feature for centuries. The formation of ploughpan in these soils is a long time phenomenon here. Another important feature of these soils is the flood coating. The composition and manner of orientation of flood coatings have not been subjected to any serious study. Properties of these flood coatings should be studied in closer detail (Hussain, 1995). The concept of "Aquarizems" was first developed in Japan (Kawaguchi and Kyuma, 1977). Bangladesh has an usually large area under paddy cultivations where the soils may be quite similar to the Aquarizems. Refinement of the definition and critical properties of these kinds of soils can be formulated in this country.

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Deturck and Somasiri (1992) studied the rice soils of Sri Lanka with Anthraquic features and remarked that the submergence of Aquic Hapludult and Aquic Haplustalfs for paddy rice cultivation results in the formations of a surface gley horizon and this forms a continuum with groundwater gley horizons. These soils with man-induced aquic conditions can not be distinguished readily from soils with an endoaquic soil moisture regime. Therefore, they do not require a new taxa.

D'costa and Muchena (1992) stated that the wet soils in Kenya are soils which are saturated with water at some period or throughout the year in most years. They showed evidence of reducing conditions and endoaquic, epiaquic, or both conditions. These soils generally occupy flat or depressed areas, plains, and valleys, including seasonal swamps and marshes with poor or restricted drainage. The wet soils in Kenya cover about 5 million hectares or about 8.3% of Kenya's land surface. They are developed from diverse materials of variable age, compositions, mineralogy, texture, soil reactions and fertility, largely from sediments brought from higher grounds. The major wet soils, according to the USDA soil taxonomy system, can be classified in eight suborders as follows: Fibrists, Hemists, Sapristis, Aquents, Aquepts, Aquolls, Aqualfs, and Aquults.

Szogi and Hudnall (1992) stated that the term "aquic condition" was defined by the International Committee on Aquic Moisture Regime (ICOMAQ Committee) to replace the "aquic regime" in Soil Taxonomy and the keys of Soil Taxonomy. The "endo-, epi-, and anthric saturation" terms have been proposed as part of the modifications to the "aquic regime." In classifications of soils in Louisiana according to "Endoaquic and Epiaquic" concepts the objectives of study of the above authors were: 1) to identify "endo" and "episaturations" and ii) to identify the co-existence of epi- and endosaturation in the same profile, based on the measurement of saturation and reduction and the presence of redoximorphic features. Three soils Commerce silt loam (fine-silty, mixed, non-acid, thermic, Typic Fluvaquents), Crowley silt loam (fine, montmorillonitic, thermic, Typic Albaqualfs) with an irrigated and nonirrigated variant, and Verdum silt loam (fine-silty,

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mixed, thermic, Glossic Natraqualfs), were investigated with piezometers, tensiometers, and platinum electrodes at different soil depths and with rain gauges. Reduction was tested with α - α' dipyridyl as an indicator of reduced iron in the soils. The Commerce silt loam was determined to be endosaturated. It was affected by a ground water table above 50 cm in 31% of the observations. The Crowley silt loam was classified as having episaturations or, alternatively, as being anthric saturated. This soil was under controlled flooding conditions and fulfilled one of the ICOMAQs definitions for anthric saturation : a surface horizon having colour value >4 and chroma <2 . The nonirrigated variant also was considered as having aquic conditions, since a failure in the drainage system returned the soils to aquic conditions temporarily. The Verdun silt loam had both a perched and a ground water table that merged in the winter. It was classified as endosaturated. They further proposed that these soils will be classified in the aquic suborder if the aquic conditions (reduction, saturation, and redoximorphic features) are present in at least 7 out of 10 years.

Mitsuchi (1992) remarked that rice soils having iron and manganese accumulation horizon and/or thick “greyzed” subsurface horizons should be separated at the great group level. Separation at sub-group level seems appropriate for rice soils where only surface horizons are affected by seasonal gleying.

Okusami and Rust (1992) studied some hydromorphic soils from inland depressions, alluvial plains and coastal sediments of Nigeria, and classified most of the soils as Inceptisols and Entisols. According to them the Entisols and Inceptisols of the humid tropical world may needed a new prefix at the subgroup level so as to differentiate the soils that have significant horizon differentiation attributable to hydromorphic status. Equivalent FAO-UN (1988) units are Fluvisols, Gleysols, and Planosols. A classification of stagnosols is suggested as a replacement for the Planosols. This is an alternative to a classification of Gleysols with orthic and stagnic sub-units.

CHAPTER-3

MATERIALS AND METHODS

MATERIALS AND METHODS

This chapter includes relevant information about the soils collected for the investigation together with the short accounts of the experimental methods.

3.1 Materials

The area, that has been included in this study, belongs to the Brahmaputra floodplain in Bangladesh. Brahmaputra floodplain covers almost the whole of greater Mymensingh district and a small part of the greater Dhaka district. Major portion of this floodplain is seasonally flooded to different depths and is principally used for jute and rice cultivation.

According to Islam and Islam (1956), the Brahmaputra floodplain comprises the parts of greater districts of Comilla, Noakhali, Sylhet, Mymensingh, Dhaka and Chittagong districts (Fig. 3).

FAO -UNDP (1988) published an agroecological map of Bangladesh in which the area of the Brahmaputra floodplain has been mentioned as 1.6 million hectares (Fig 4). The Brahmaputra floodplain was divided into three agroecological regions.

During the survey of Rennell (1760-70), the Brahmaputra used to flow through the greater Mymensingh district following the present course of the old Brahmaputra river (Plate -1). Due to a catastrophic earth-quake and tectonic disturbance in 1830 (Rab, 1992), it abandoned its course and started to flow along the present course of the Jamuna river (Fig. 5).

The soils of the Brahmaputra floodplain have been surveyed under the reconnaissance soil survey scheme by the SRDI Staff (1965-1986), and 37 soil series were identified (Table-1). The total area of the Brahmaputra floodplains is about 1,358,849 hectares (BBS, 1994). Seven extensive soil series (Table-1) have been included for the present study that comprises about 69% of the total Brahmaputra floodplain.

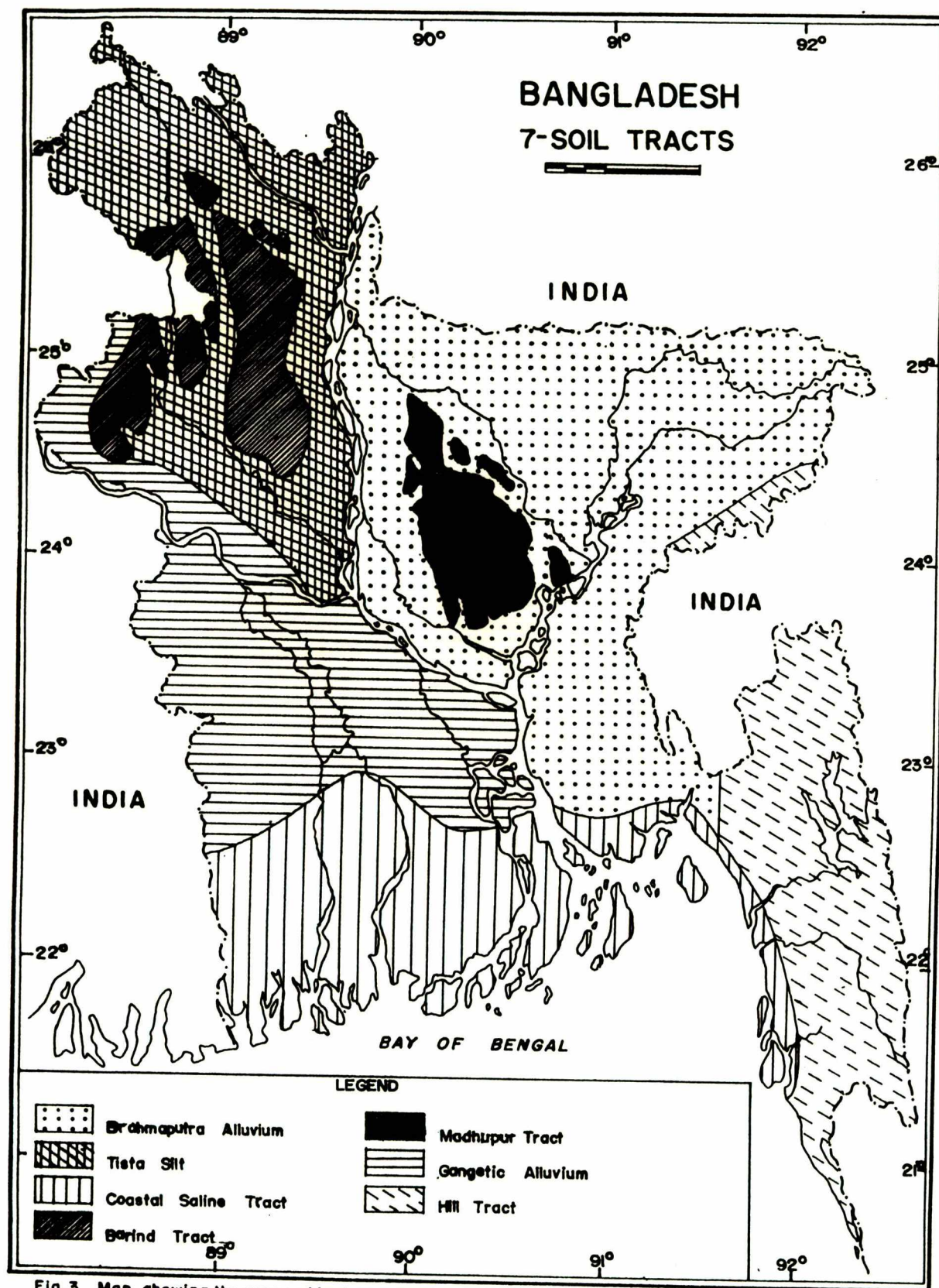


Fig.3. Map showing the geographical distribution of the Brahmaputra alluvium in Bangladesh (After Islam and Islam, 1956).

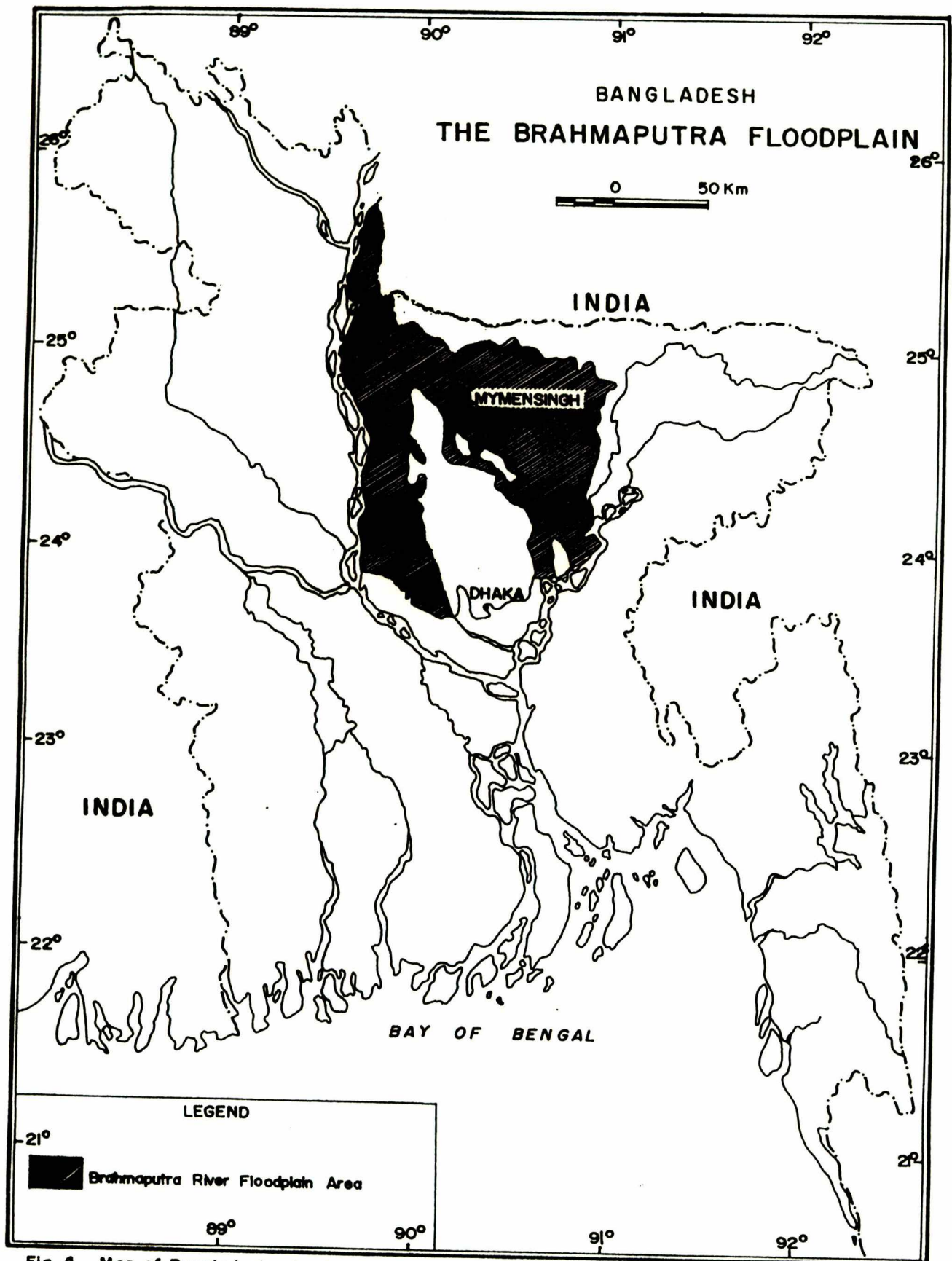


Fig. 4 . Map of Bangladesh showing the Brahmaputra floodplain (After FAO - UNDP, 1988.)

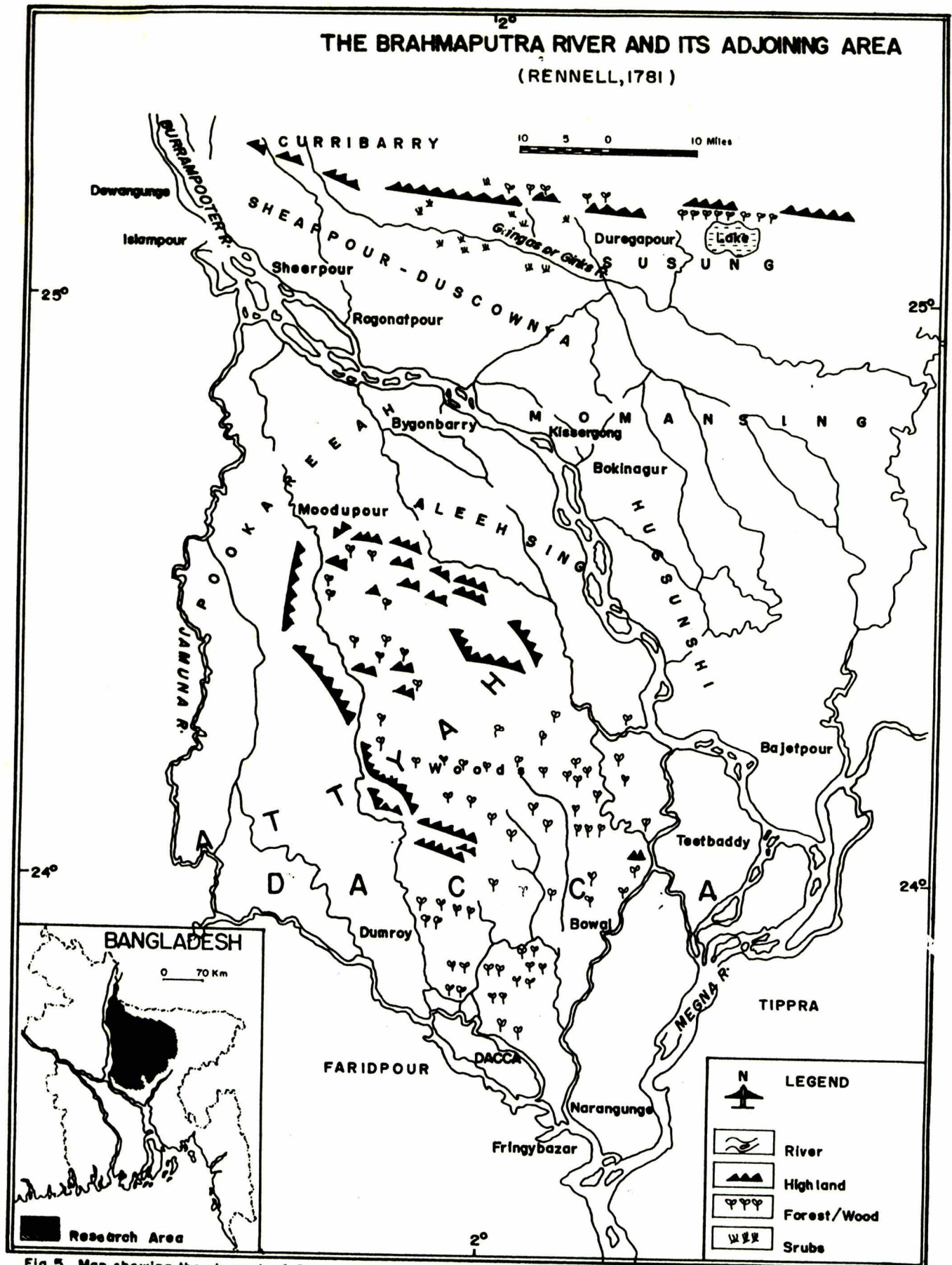


Fig.5. Map showing the channel of Brahmaputra river (Rennell,1781). In the inset map of Bangladesh.

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1.a. A photograph of a typical riverine landscape of the old Brahmaputra river.



1.b. A photograph of the riverbank landscape of the old Brahmaputra river.

Plate No. 1

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Table-1 : List of soil series under Brahmaputra Floodplain of Bangladesh*.

Sl. No.	Soil Series	Area (hectares)	Sl. No.	Soil Series	Area (hectares)
1.	Barar Char	10,119	20.	Mohanganj	4,930
2.	Barhatta	810	21.	Nakla	12,812
3.	Balina	32,597	22.	Nandail	7,442
4.	Dhamrai**	1,16,539	23.	Naraibag	53,681
5.	Diarkandi	1,074	24.	Phulpur	1,250
6.	Dulalpur	1,528	25.	Rampal	6,190
7.	Ghatail**	2,27,016	26.	Sonatala**	2,15,368
8.	Gorargaon	11,093	27.	Sherpur**	36,678
9.	Gouripur	3986	28.	Silmandi**	2,00,610
10.	Ichamati	59	29.	Shamganj	2,043
11.	Iswarganj	1,360	30.	Singair	36,270
12.	Jamalpur	591	31.	Sabhar Bazar	83,280
13.	Kendua	11,189	32.	Sribardi	3,623
14.	Kajla	25,298	33.	Sandy Brahmaputra alluvium	23,546
15.	Khaler Char	5,063	34.	Silty Brahmaputra alluvium	30,717
16.	Kanchanpur	6,568	35.	Tarakanda	4,290
17.	Kamarkhanda	15,149	36.	Tengarchar	18,641
18.	Lokdeo**	1,37,999	37.	Turag	711
19.	Melandaha**	8,729	Grand total		13,58,849

* Compiled on the basis of the works of 1. SRDI Staff (1965 -1986) and 2.FAO -UNDP (1988).

** Selected pedons for study.

Chapter III Materials and Methods

The reconnaissance soil survey reports(1974 -1975) and maps of greater Mymensingh and Dhaka districts were used as the base materials for field work in this study. Toposheets and recent aerial photographs wherever available of these areas were also used for the field work.

3.1.1. Location of the soil sampling sites.

The sampling sites approximately lie in between 24°14' to 24°45' N-latitudes and between 90°10' and 90°35'E longitudes (Figs. 6 and 7).The exact location and the environmental characteristics of the soils studied have been presented in Table-2.

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3.2. The Methods

3.2.1 Field methods

A pit of 100 cm x 150 cm upto parent material not extending 200 cm was excavated for each soil sampling site.

For understanding the detailed soil properties, the soil profiles were studied and described morphologically in situ according to the method of Soil Survey Manual of Soil Survey Staff (1951). The study covered the surrounding environmental conditions and present land use (Table-2). The total area of the studied soils is slightly less than a million hectares. All these soils are fertile and presently are being used mainly for the production of rice, except the sherpur soil where winter vegetables are grown. The morphological properties such as colour, texture, structure, consistence, p^H , boundary, calcareousness, etc. of the soil samples were determined. An attempt was made to correlate tentatively the soils in the different systems of classification. (Table-3)

A total of fifty four soil samples, on horizon basis, from seven selected pits were collected for laboratory analysis.

3.2.2 Laboratory methods

Soil samples from each horizon of the profile were collected in thick double polythene bags. The bags were sealed properly precluding moisture loss from the samples and transferred as quickly as possible to the laboratory for relevant analyses.

Prior to analysis, the representative soil samples were spread on a piece of polythene paper and big lumps were broken and air dried under shade. The soil samples were then gently ground with rolling wooden rod and passed through 2mm (10 mesh) sieve and mixed thoroughly. The samples were then preserved in plastic pots for laboratory analyses.

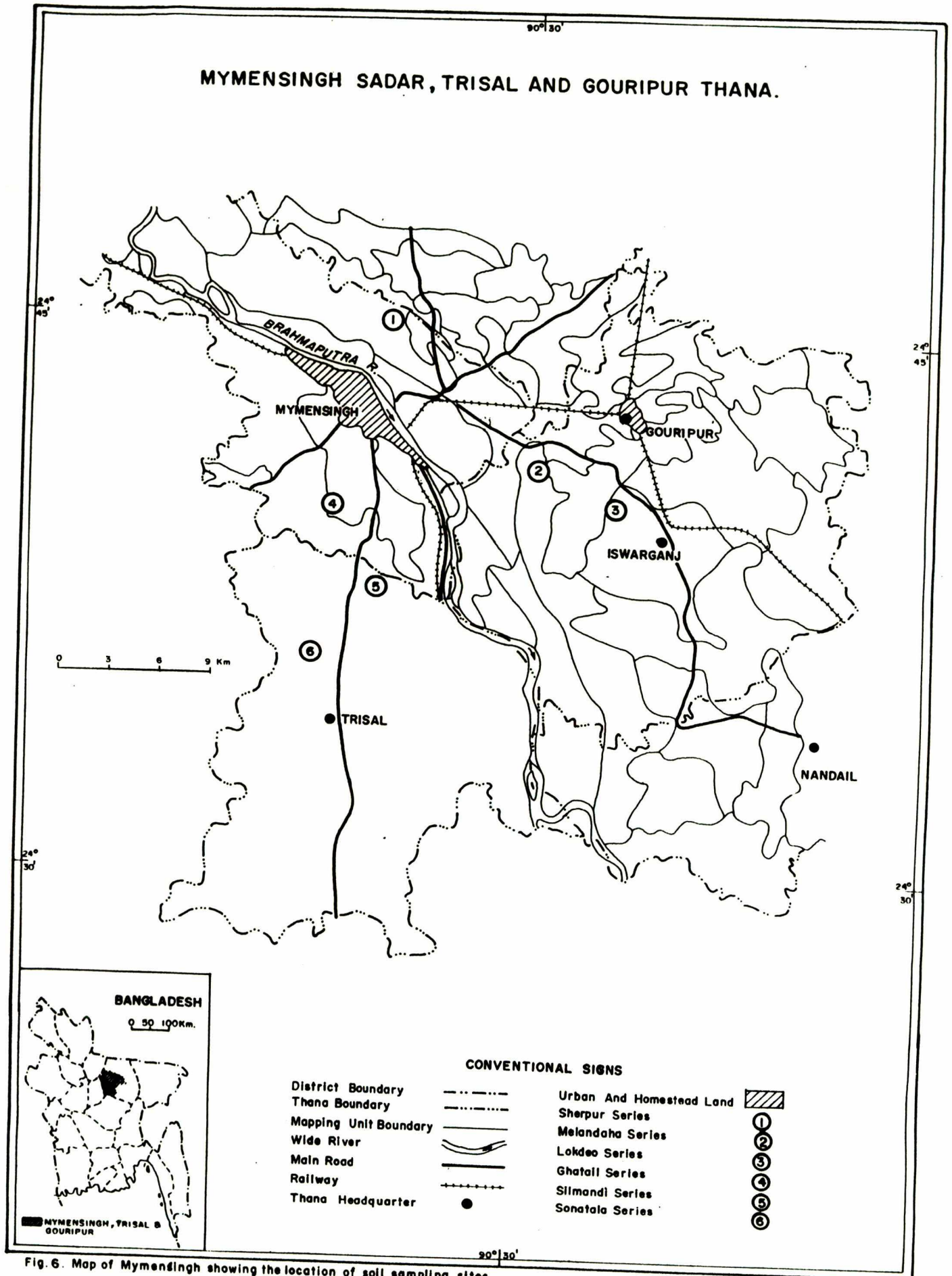


Fig. 6. Map of Mymensingh showing the location of soil sampling sites.

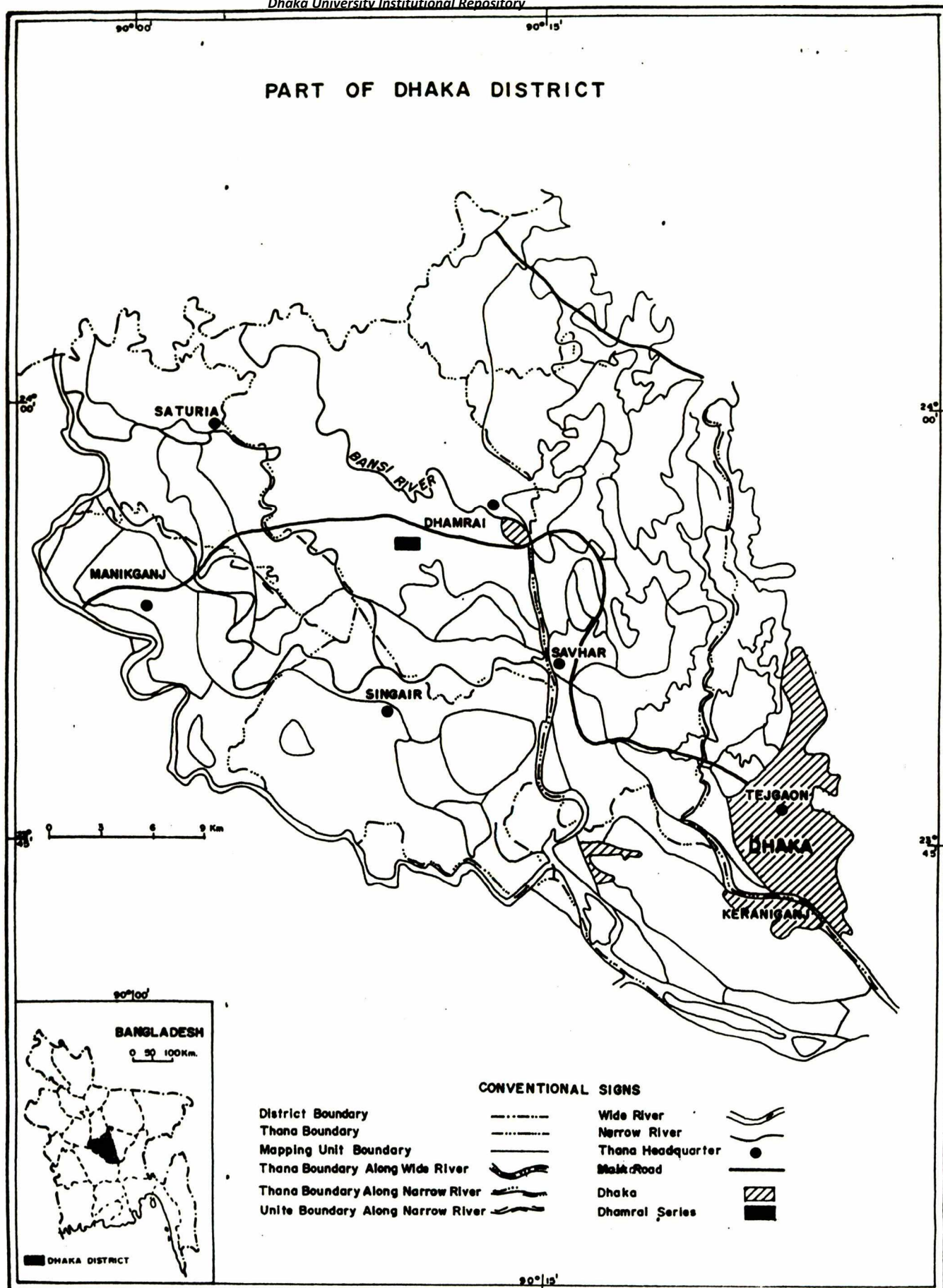


Fig.7. Map showing the location of sampling site of Dhamrai soil series .

Table-2. Environmental characteristics of the studied soil.

Soil series	Characteristics									
	Location	Agroecological region (FAO/UNDP, 1988)	Physiography	Relief	Drainage	Flooding	Ground water	Erosion	Permeability	Vegetation & Land use
1	2	3	4	5	6	7	8	9	10	11
Melandaha	Char-Choramara, Gouripur, Mymensingh.	Young Brahmaputra Floodplain	Young Brahmaputra Floodplain	Middle slope of nearly level ridge	Poorly drained	30-60 cm for 2 to 3 months in the monsoon	Not found within auger depth	Nil	Moderate	Aus/Jute-T. Aman-Rabi crops.
Dhamrai	Kailia, Dhamrai Thana, Dhaka.	Young Brahmaputra Floodplain	Young Brahmaputra Floodplain	Nearly level ridge	Poorly drained	90-120 cm for 2 to 3 months in the monsoon	Not found within auger depth	Nil	Moderate	Aus-T. Aman-Rabi crops.
Sonatala	Churkhai, Mymensingh sadar, Mymensingh.	Old Brahmaputra Floodplain	Old Brahmaputra Floodplain	Nearly level ridge	Imperfectly drained	about 90 cm for more than 3 months	Not found within 125 cm	Nil	Moderate	Aus-Rabi crops; Aus-T. Aman-fallow
Silmandi	Shikarikanda, Mymensingh Sadar, Mymensingh.	Old Brahmaputra Floodplain	Old Brahmaputra Floodplain	Nearly level ridge	Imperfectly drained	10 to 15 cm for 4-7 months in the monsoon	Not found within auger depth	Nil	Moderate	Aus-t. aman-fallow
Lokdeo	Baluha, Gouripur, Mymensingh.	Old Brahmaputra Floodplain	Old Brahmaputra Floodplain	Nearly level ridge	Poorly drained	30 - 50 cm for 1 to 2 months in the monsoon	Not found within 125 cm	Nil	Moderately slow	T. Aus-T. Aman-fallow.
Ghatail	Digarkanda, Mymensingh sadar thana, Mymensingh.	Old Brahmaputra Floodplain	Old Brahmaputra Floodplain	Nearly level basin	Poorly drained	40 - 70 cm for 2 to 3 months in the monsoon	Not found within 122 cm	Nil	Slow	Transplanted aman - Fallow
Sherpur	Char-Haripur, Mymensingh sadar, Mymensingh.	Old Brahmaputra Floodplain	Old Brahmaputra Floodplain	Nearly level upper part of ridge	Moderately well drained	Annually flooded land above normal flood level	Not found within auger depth	Nil	Moderately rapid	Aus/Jute-Rabi vegetables-Fallow

Chapter III Materials and Methods

Table-3. Correlation of the selected soil series from Brahmaputra floodplain in different systems of classification.

Soil series (SRDI Staff, 1965-1986)	Soil Tracts (Islam and Islam, 1956)	General Soil Type system (Brammer, 1971)	FAO/Unesco Legend/Soil Sub-unit* (FAO/Unesco, 1988)	USDA Soil Taxonomy (Sub groups)
Melandaha	Brahmaputra Alluvium	Noncalcareous Grey Floodplain soil	Cromi-Eutric Fluvisols	Typic Haplaquepts.
Dhamrai	Brahmaputra Alluvium	Noncalcareous Grey Floodplain soil	Chromi-Eutric gleysols	Typic Haplaquepts.
Sonatala	Brahmaputra Alluvium	Noncalcareous Grey Floodplain soil	Chromi-Eutric gleysols	Aeric Haplaquepts.
Silmandi	Brahmaputra Alluvium	Noncalcareous Grey Floodplain soil	Chromi-Eutric gleysols	Aeric Haplaquepts.
Lokdeo	Brahmaputra Alluvium	Noncalcareous Dark-grey Floodplain soil	Chromi-Eutric gleysols	Aeric Haplaquepts.
Ghatail	Brahmaputra Alluvium	Noncalcareous Dark-grey Floodplain soil	Vertic-Eutric gleysols	Aeric Haplaquepts.
Sherpur	Brahmaputra Alluvium	Noncalcarious Brown Floodplain soil	Orthi-Eutric Cambisols	Aquic Eutrochrepts

*Brammer (1988)

Chapter III Materials and Methods

3.3.2.1. Methods of physical analyses

Hygroscopic moisture

Hygroscopic moisture content of soils were determined by drying the air-dried soils in an oven at 105-110°C for 24 hours (Page, 1982)

Particle size distribution

The Particle size analysis of soils were made by combination of sieving and hydrometer methods as described by Day (1965). Textural classes were determined using Marshall's triangular coordinate curve as devised by USDA, (1951).

Bulk density (D_b)

Bulk density of soil was determined by core method as described by Blake (1965a).

Particle density, (D_p)

Particle density of soil was determined by Pycnometer methods as described by Blake (1965b).

Total porosity (f)

Total porosity of soil was calculated from the data of particle density and bulk density using the formula below as described by Stickling (1956), according to the following formula:

$$\% \text{ porosity} = \left(1 - \frac{\text{Bulk density}}{\text{particle density}} \right) \times 100$$

Hydraulic conductivity

Hydraulic conductivity of the soils was determined in the laboratory on undisturbed saturated core samples by constant head method as described in the Project Technical Guide No. 20 of the Soil Survey Project of Pakistan (Huizing, 1970)

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n-value

The n-value was calculated using the formula below :

$$n = (A - 0.2R)/(L + 3H)$$

Where, A is the percentage of water in the soil at field condition, calculated on a dry-soil basis; R is the percentage of silt plus sand; L is the percentage of clay; and H is the percentage of organic matter (USDA, 1975)

Soil moisture retention

Soil moisture retention at 0.01, 0.33 and 15 bar were measured from undisturbed core samples through pressure plates by compressing air with the help of a pressure regulator as described by Richards (1949).

Maximum water holding capacity (MWHC)

Maximum water holding capacity of soils was determined by the method of Piper (1950).

Available water storage capacity (AWSC)

The percentage of available moisture storage was calculated from difference between percentage moisture content at $\frac{1}{3}$ bar and 15 bars.

Loss on ignition (L.O.I)

Loss on ignition in soils and clays was determined by using a muffle furnace and ignited for 2 hours at 900°C (Piper, 1950).

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3.3.2.2. Methods of chemical analyses

Soil reaction (soil pH)

Soil pH was measured electrochemically at a soil-water ratio of 1:2.5 using a Corning (model -7) glass electrode pH meter.

Organic carbon

The organic carbon content of soils was determined volumetrically by wet-oxidation method of Walkley and Black (1934).

Total nitrogen

The total nitrogen in soils was determined by Kjeldahl's method as described by Jackson (1973).

Total and available major nutrients

Total P and K were estimated after fusion of soil with sodium carbonate (Piper, 1950).

Available N in soils was extracted with IN KCl and determined by micro distillation method as described by Jackson (1973).

Available P in the soil was extracted by Troug's method and P in the extract was measured colorimetrically by developing blue colour as described by Jackson (1973).

Available K was extracted by *IN* NH₄OAc at pH 7.0 (Pratt, 1965) and K in the extract was determined by Gallenkamp flame photometer.

Total and available micronutrients

Total Fe, Mn, Cu and Zn were estimated after fusion of soil with sodium carbonate (Piper, 1950). Available Fe, Mn, Cu and Zn were extracted with DTPA reagent (Lindsay and Norvell, 1978). Both total and available Fe, Mn, Cu, and Zn were measured by atomic absorption spectrophotometer.

Chapter III Materials and Methods**Dithionite extractable iron, aluminium and manganese**

Free oxides of iron (Fed), aluminium (Ald) and manganese (Mnd) were extracted by sodium dithionite-citrate system buffered with sodium bicarbonate as proposed by Mehra and Jackson (1960). After extraction, Fe and Mn were determined by atomic absorption spectrophotometer and aluminium was determined colorimetrically by developing orange colour with aluminon reagent. (Chapman and Pratt, 1961).

Acid oxalate extractable iron, aluminum and manganese

For determining oxalate extractable iron (Feo), aluminium (Alo) and manganese (Mno), the procedures of Blakemore et al (1987) and USDA-SCS (1972) were followed for the extraction. Fe, Al and Mn were then determined with atomic absorption spectrophotometer.

Cation exchange capacity (CEC)

Cation exchange capacity of soils was determined with 1N NH_4OAc method buffered at pH 7 Jackson (1973).

Exchangeable cations (Na^+ , K^+ , Ca^{++} , Mg^{++})

The exchangeable cations were determined in 1N NH_4OAc (pH 7.0) extract of soils as described by Jackson (1973). Ca^{++} and Mg^{++} were measured by atomic absorption spectrophotometer, while Na^+ and K^+ were analyzed by Gallenkamp flame photometer.

Base saturation percentage (BSP)

The base saturation percentage was calculated using the following formula.

$$\text{Base saturation percentage} = \frac{\text{Total exchangeable bases}}{\text{Cation exchange capacity}} \times 100$$

Exchangeable hydrogen (H^+)

Exchangeable hydrogen was determined following the method of Page (1982).

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3.3.2.3. Methods of mineralogical analyses

Three soil samples representing Ap (top), B2 (subsoil) and C (substratum) from each soil profile were selected for the determination of mineralogical composition in clay fraction.

Dispersion and separation of clay fraction

To concentrate clay fraction the soils were thoroughly dispersed. To achieve successful dispersion the following pretreatments were used for the removal of flocculating and cementing agents.

Carbonate and organic matter removal

The soil samples were treated with 1N NaOAc-acetic acid buffer (pH 5.0) to destroy the free carbonates (Jackson, 1967) and organic matter was destroyed by 30% H₂O₂ treatment (Jackson, 1967).

Removal of iron and manganese

Free oxides of Fe and Mn were removed from soils by the citrate-bicarbonate-dithionite extraction method as described by Aguilera and Jackson (1953) and Mehra and Jackson (1960).

After removing soluble salts, carbonates, organic matter, MnO₂ and Fe₂O₃, the soils were dispersed with dilute sodium carbonate solution at pH 9.5 (Jackson, 1975) and the clay fraction (<2 μ) was separated by sedimentation decantation processes as described by Jackson (1975).

Slide preparation and clay mineral identification

The clay samples were Mg- and K- saturated by repeated washings with normal solutions of MgCl₂ 6H₂O and KCl, respectively. The excess of the saturating solutions

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was washed out with 99% alcohol and acetone until free of Cl⁻ and the saturated samples were stored in water. One ml of K-clay suspension and one ml of Mg- clay suspension were smeared on two separate glass slide (2.5 × 8cm) to prepare oriented clay specimens. These oriented samples were air dried for about 24 hours. Mg- saturated air dried clay slides were glycerol solvated in vacuum in an atmosphere of glycerol; the K-saturated air dried clay slides were heated at 550°C for two hours. All these treated and saturated air dried clay samples were subjected to X-ray diffraction analysis using a GEOL X-ray diffractometer with Ni-filter. CuK α radiation obtaining at 30KV, 20mA with a scanning speed of 2°2 θ per minute was used.

Identification of clay minerals were made mainly on the basis of their characteristic basal reflections (Jackson, 1975).

Semiquantitative estimation of clay minerals was the next step, utilizing the peak height and width. This was found to be useful for determining the relative abundances of minerals.

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3.3.2.4. Fusion analysis of soil and clay fractions

The fusion analysis entails the determination of the total elemental estimate of the inorganic components of soils and clays. The clay fraction was separated and purified from the soils according to the methods outlined in previous section.

The clay fraction thus obtained were dried, ground and passed through 100 mesh sieve. A weighed amount of this purified clay was used for fusion analysis.

Silica: Silica in both soils and clays was determined by the method of fusion analysis by Piper (1950).

Iron, aluminium, calcium, magnesium, potassium, titanium, phosphorous and manganese were determined from the HCl extract of the fuse as follows:

Aluminium: Aluminium was determined colorimetrically by developing orange colour with Aluminon reagent (Chapman and Pratt, 1961; and Pratt and Bair, 1961).

Titanium: Titanium was determined colorimetrically by developing yellow colour with 30% H_2O_2 (Black, 1965).

Phosphorus: Phosphorous was determined colorimetrically by ammonium paramolybdate-potassium antimony tartarate- ascorbic acid blue colour method of Page (1982).

Iron, manganese, calcium, magnesium and potassium.

The determination of total iron, calcium, magnesium and manganese were made by atomic absorption spectrophotometer (Jackson, 1973) and total potassium by a Gallenkamp flame photometer (Jackson, 1973).

CHAPTER - 4
ENVIRONMENTAL SETTINGS AND FIELD
STUDY OF THE SOILS

ENVIRONMENTAL SETTINGS AND FIELD STUDY OF THE SOILS

4.1 The Pedogenic Factors

For the establishment of findings on pedological investigation, information of environmental conditions of the soils under study are inevitable and with this end in view, an attempt has been made to record the available informations on climate, hydrology, geology, topography, and the present management.

4.1.1. Climate

The area investigated, has a typical humid tropical monsoon climate (Brammer,1971). It has three main seasons (i) the rainy season from May to October during which about 90 percent of the total annual rainfall is received; (ii) the dry or winter season from November to February which has very little rainfall and has the lowest temperatures and humidities of the year; and (iii) the hot season from March to April which has the highest temperature and evaporation rates of the year. The on set and end of the rainy season, however, may vary from year to year. Rains may commence anywhere between mid-April and early June and they may end anywhere between end of September and mid-November. May and October may occasionally be almost rainless, and there may be dry periods of two weeks or more during the rainy season (Manalo,1975).

The two sampling locations namely Mymensingh and Dhamrai are respectively nearest to Mymensingh and Dhaka Meteorological Department. The data from these two places are included in the present study (Tables 4 and 5 ; and Figures 9 and 11).

Table-4. Climatic data for Mymensingh

Records	Months												Annual
	Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
R in mm	7	17	45	139	302	464	370	396	353	172	15	2	2296
T in $^{\circ}\text{C}$	18.8	20.5	25.0	28.8	28.3	28.3	28.8	28.8	28.3	27.2	23.3	20.0	25.5
E in mm	53.3	66.0	104.1	132.1	111.8	91.4	88.9	81.3	96.5	109.2	73.7	53.3	1062
Humidity (H)	72	68	58	60	77	84	85	85	84	79	78	79	76
S. D in mm	4.7	6.3	10.1	11.0	6.5	4.7	4.3	4.6	4.5	5.4	5.1	4.0	6.0
Lang's rain factor	-	-	-	-	-	-	-	-	-	-	-	-	90
Prescott's soil boundary factor	-	-	-	-	-	-	-	-	-	-	-	-	21.5
Mayer's N.S.Q	-	-	-	-	-	-	-	-	-	-	-	-	383
Transeau ratio	-	-	-	-	-	-	-	-	-	-	-	-	2.2

R denotes mean rainfall and stands for precipitation (P)

T denotes mean air temperature

E denotes mean evaporation

H denotes mean percent humidity

S.D. denotes saturation deficit in mm of mercury.

Lang's rain factor = P in mm (annual)/ T in $^{\circ}\text{C}$ (mean annual)Prescott's soil boundary factor = P in inches/0.7 (S.D in inches)Meyer's N.S.Q. = P in mm (annual)/S.D in mm at the mean annual temp.Transeau's P/E ratio = P in inches/Evaporation in inches.

Table-5. Climatic data for Dhaka

Records	Months												Annual
	Jan	Feb	Mar	Apl	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
R in mm	10	25	55	148	239	341	323	341	232	141	18	4	1883
T in °C	18.3	21.1	26.1	30.0	28.8	27.7	28.3	28.3	27.7	27.2	22.7	19.4	25.5
E in mm	48.8	68.6	121.9	142.2	129.5	104.1	99.1	91.4	88.9	81.3	53.3	53.3	1082
Humidity (H)	67	63	59	65	76	82	82	82	81	76	72	73	72
S. D in mm	5.5	7.0	10.2	10.1	6.9	5.3	5.1	5.0	5.6	6.4	6.2	4.6	6.5
Lang's rain factor													74
Prescott's soil boundary factor													16.3
Mayer's N.S.Q													289
Transeau ratio													1.7

Foot note same as in Table-4.

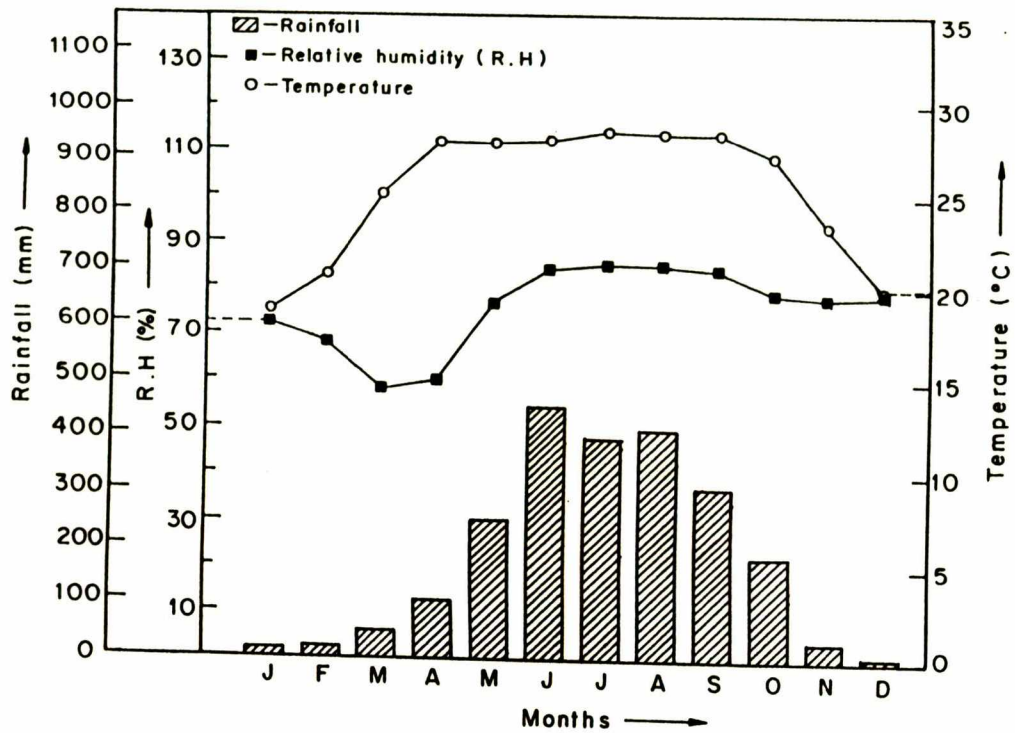


Fig. 8 Climatic data of Mymensingh showing the monthly ranges in rainfall, relative humidity and temperature.

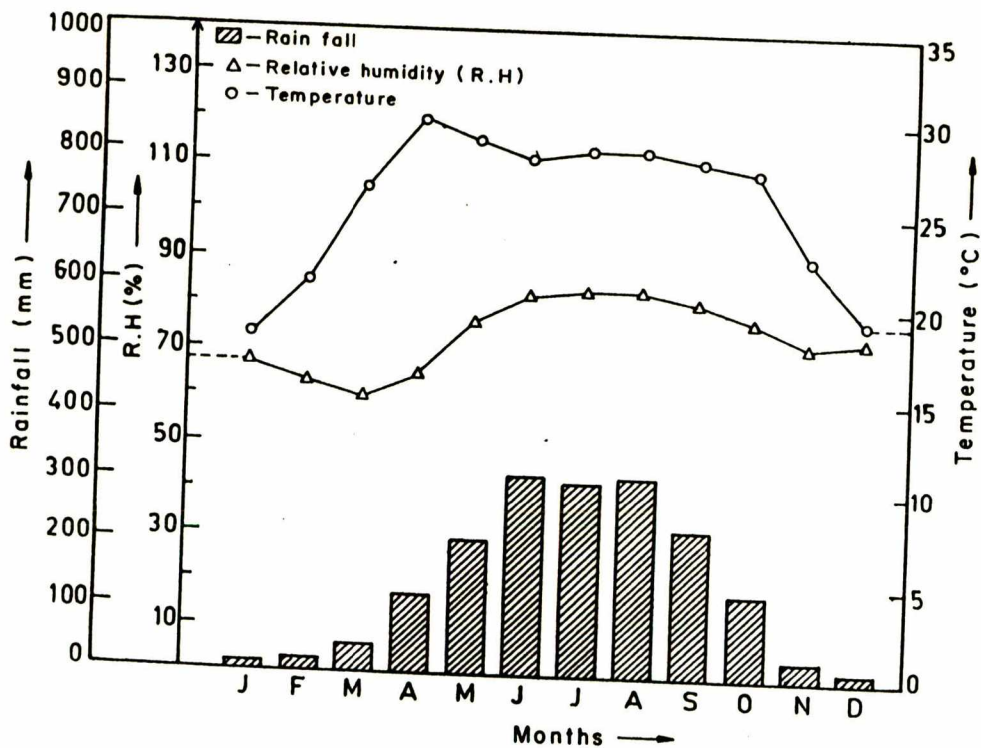


Fig. 9 Climatic data of Dhaka showing the monthly ranges in rainfall, relative humidity and temperature.

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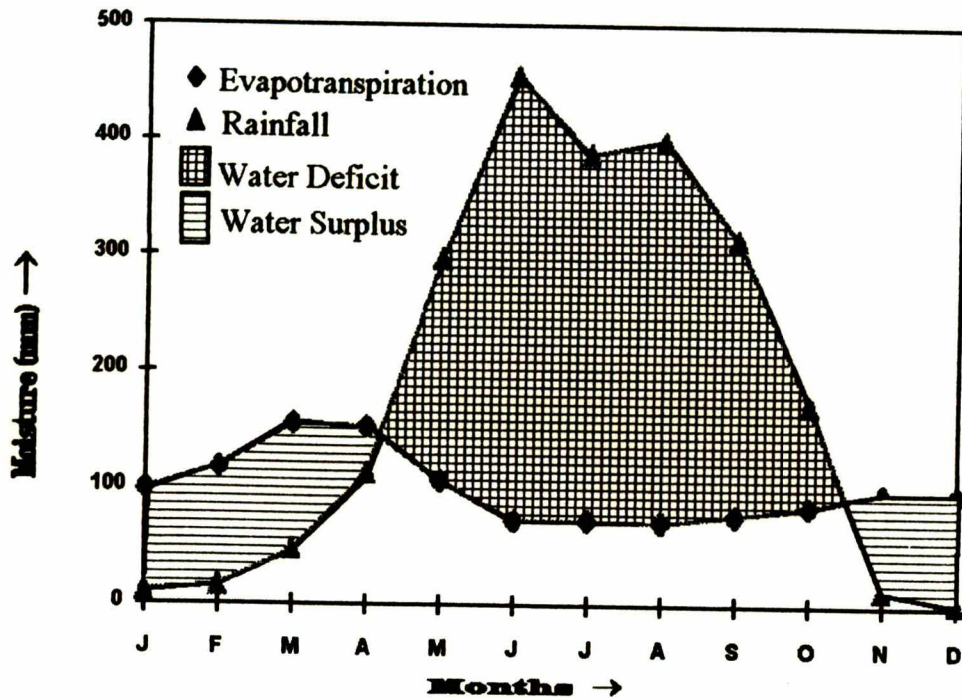


Fig. 10. Climatic data and the soil water balance of Mymensingh.

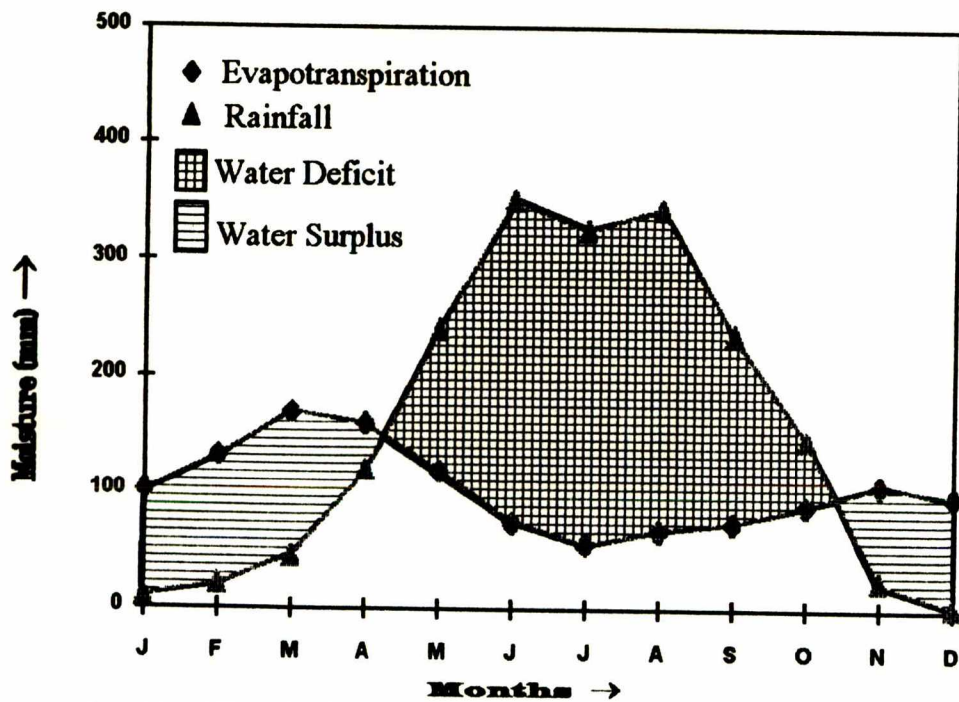


Fig. 11. Climatic data and the soil water balance of Dhaka.

The total annual rainfalls are 2296mm and 1883mm respectively for Mymensingh and Dhaka (Tables- 4 and 5). During the monsoon months rainfall is frequent and occasionally heavy. The highest rainfall comes during the months of June, July and August, while in December and January, the area receives no rainfall.

The temperature ranges from 19°C to 29°C with a mean annual temperature of 25°C for Mymensingh and from 18°C to 30°C with a mean annual temperature of 25.5°C for Dhaka. (Tables- 4 and 5). Temperature varies with season, being the highest in the premonsoon and monsoon seasons (April to July), and lowest in the winter season (December to January).

Mean monthly relative humidity is the highest during the monsoon months of May upto October, when it ranges from 77 to 85 percent for Mymensingh and from 76 to 82 percent for Dhaka respectively. This gradually comes down to seventies during the winter months and finally to the lowest, from 58 to 60 percent for Mymensingh and 59 to 65 percent for Dhaka respectively during March to April. Afternoon humidity frequently fell below 40 percent in the premonsoon season.

Mean annual evaporation is 1062 mm for Mymensingh and 1082 for Dhaka, respectively and the rate of monthly evaporation is highest during March-May (104-132 mm for Mymensingh and 104-142 mm for Dhaka, respectively).

The information cited above has very little significance in pedogenic work. The work of Karim and Hossain (1957) on the climatic indices of Bangladesh has contributed valuable information for pedogenic investigation. From Tables 4 and 5 it is evident that the rainfall in the area is high. Such high rainfall indicates that leaching can take place in the soils under present study for part of the year.

As the rainfall is, high its distribution pattern is important for the proper evaluation of the effectiveness of moisture throughout the year (Tables- 4, 5 and 6). According to Ahmed (1958) the climatic region of the area under the present investigation should be regarded as humid tropical.

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The temperature remains pretty high all through the year. The period of high temperature corresponds to the period of high rainfall which means that the wet season is attended by the warmer months of the year and the dry season by the winter months. As a result, the pedochemical weathering processes are more active during a substantial part of the year.

4.1.2. Hydrology

The Brahmaputra river is the predominating factor controlling the hydrology of the area under the investigation. The old Brahmaputra river crosses the area surveyed from north west to south east.

Normally, the flood-level of the Brahmaputra river rises rapidly in April-May due to the increased discharge. The other rivers also swell at the same time of the year and flow in spate for a few days at a time after heavy pre-monsoon or monsoon rainfall in the catchment area. River-level and discharge are usually at their peak in July and August. Most of the river courses appear to be rather stable, except in some local changes in the old Brahmaputra near Husseinpur and Gaffargaon areas.

The floodplains of Bangladesh in general are affected by seasonal flooding. Depth and duration of the flooding vary with topographical position and are mainly controlled by the water-levels of the main rivers and their tributaries and distributaries. Ridges remain mainly above normal flood level or seasonally shallowly flooded for a period ranging from a few days upto 4-5 months. Basins and basin depressions are flooded more deeply and for a longer period.

On the older Brahmaputra floodplains, flooding is mainly due to stagnation of local run-off in the monsoon season. However, flood levels are controlled by the rainy-season water levels of the old Brahmaputra river and its tributaries and distributaries. These changes are normally gradual, and even in deep basins deep-water aman rice varieties can be grown without much danger of crop damage or loss. Basins that

Table-6. Climatic data and soil water balance for Mymensingh and Dhaka .

Name of the station	Parameter	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug	Sep.	Oct.	Nov.	Dec.	Annual
Mymensingh	Max °C	25.2	27.6	32.0	33.8	32.8	31.2	31.3	31.3	31.5	30.7	28.7	26.4	30.2
	Potential Evapotranspiration (mm)	98.4	1181	155.3	153.0	106.3	72.6	72.6	71.4	77.6	85.5	96.8	96.8	1204
	Rainfall (mm)	11.7	16.3	46.5	113.3	296.7	456.4	388.4	399.8	314.7	172.0	13.7	2.0	2232
	Surplus					190.4	383.8	315.8	328.4	237.1	86.5			
	Stress	86.7	101.8	108.8	39.7							83.1	94.8	
	Max °C	25.3	28.3	32.8	34.4	33.5	31.5	30.1	30.9	31.3	30.7	28.7	25.9	30.3
Dhaka	Potential Evapotranspiration (mm)	100.7	131.6	170.4	159.8	118.1	74.3	55.1	66.9	73.7	88.9	106.9	96.2	1243
	Rainfall (mm)	10.9	21.3	45.7	118.9	240.3	351.3	326.1	344.9	236.7	145.8	23.9	2.3	1868
	Surplus					122.2	277.0	271.0	278.0	163.0	56.9			
	Stress	89.8	110.3	124.7	40.9							83.0	93.9	

Source : (Manalo, 1975.)

remain wet for greater part of the dry season or throughout the dry season are normally used for boro rice cultivation.

Ground water is believed to be readily available at shallow depths throughout the floodplain areas and use of hand tubewells are quite common.

Insufficient dry season discharges from the rivers limit local irrigation possibilities. Survey of groundwater resources are urgently needed, therefore, to determine the extent to which tubewell irrigation may supplement the available dry season river flow and storage in basin depressions.

4.1.3. Geology

The area under investigation is occupied by a relatively smooth, nearly level to gently undulating landscape of floodplain ridges and basins consisting of unconsolidated river borne sediments lying between 5 to 15 meters above mean sea level.

Brammer et al. (1988) has divided the whole of Brahmaputra floodplain into the following agroecological regions (Fig. 12):

a. Active Brahmaputra - Jamuna floodplain	-	319,000 hectares
b. Young Brahmaputra -Jamuna floodplain.	-	529,400 hectares
c. Old Brahmaputra floodplain	-	723,000 hectares

Total = 1,634,400 hectares

a. Active Brahmaputra -Jamuna floodplain

This unit locally forms a zone along the old Brahmaputra river. It consists of a complex, rather irregular landscape of floodplain ridges and inter-ridges depressions with fresh spill deposits along the active channels. A large part of the sediments underlying this unit was deposited during high floods in 1954 and 1955. The whole landscape is

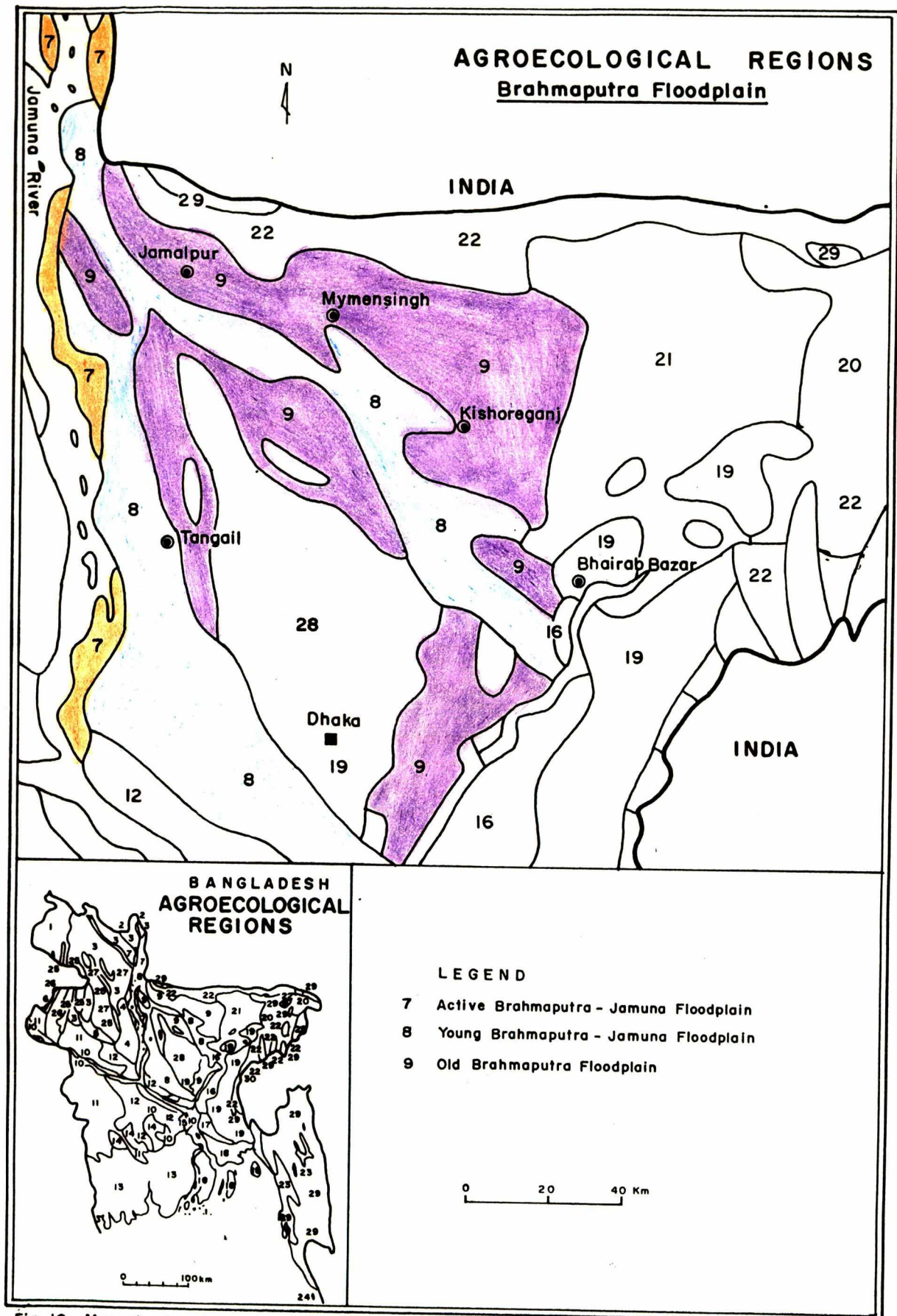


Fig. 12. Map showing the agroecological regions of the Brahmaputra floodplain. In the inset the Agroecological regions of Bangladesh.
Source: FAO - UNDP, 1988.

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seasonally flooded by the Brahmaputra river water and is exposed to river erosion or burial by fresh deposits in each monsoon season.

b. Young Brahmaputra -Jamuna floodplain

This unit is found in the north and north-western part of the area under present study. It comprises a relatively high landscape, mainly above normal flood level, of broad smoothed-out levee-channel complexes. The sediments underlying this unit (Kishorganj, Pakundia, Katiadi, Bajitpur, Hussainpur, part of Bhairab, Gaffargaon and Muktagacha police stations) are characterized by their fine-sandy texture, a few cm to a few meters below the surface. They probably represent old channels and associated charlands, dating from a time before the major diversion of the Brahmaputra river into its present Jamuna course some 200 years ago. The southern continuation of this landscape is underlain by more silty and clayey sediments. Locally there are small pockets of younger, mostly finely stratified, sandy and silty deposits showing a rather irregular relief of low narrow ridges and small infilled channels. Part of the sandy sediments appear to have originated from deep sandy substrata and may have reached the surface through fissures in the upper layers. According to local information, these deposits date from 1897, the year of the great Assam earthquake. The effects of this earthquake, which occurred in the monsoon season, seem to have been disastrous (Krishnan, 1965). Alternatively, these younger sediments may have been deposited at the same time following sudden changes of river courses and land levels caused by the earthquake. Sand 'volcanoes' were reported to have occurred again locally during the Bihar earthquake of 1934, but the effects of this earthquake were considerably less pronounced than that of 1897 (Brammer, 1988).

c. Old Brahmaputra floodplain

This unit comprises the broad, smoothed-out floodplain ridges complex with associated broad basins. In general, the ridges were found to become narrower and the

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basins broader and deeper on going from west to east. Small basins were often found to contain thick mucky surface layers which indicate that active alluvium depositions have long ceased. The age of the old Brahmaputra floodplain sediments is not known but is, in any case, many hundreds of years old.

4.1.4. Physiography

The area under the investigation is occupied by a relatively smooth, nearly level to gently undulating landscape of floodplain ridges and basins. During monsoon season the area remain flooded for a period of at least 3-5 months. Both external and internal drainages are poor.

4.1.5. Age

The Geological history of the area under the investigation indicates that the soils of this area are relatively young and the age of soils of this region are at least 200 years old (Brammer, 1964).

4.1.6. Vegetation

No natural vegetation is present in the area under the investigation, as the land is under cultivation, except some patches of the basin, where there are remnants of tall grasses and reeds (SRDI Staff 1974-75). Rice is by far the most important and extensive crop grown in this area. Shallowly flooded areas where water can be kept by small bunds, are used mainly for boro followed by transplanted aman. Where sufficient dry season moisture is available, dry land crop is often grown after the aman harvest. Where flooding becomes too deep for transplanted aman, or where rapid rise of the flood level may cause damage or loss of crops in most years, deep water aman, sometimes mixed with aus, is grown. The basins in the Brahmaputra floodplain where sufficient water for dry season irrigation is available are used for boro cultivation. On highland where water can not be

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kept on the land, only aus followed by a dryland rabi crop is grown. Jute is the principal cash crop and usually replaces about 20 percent of the aus crop on highland and medium highland areas.

Rabi crops mainly include mustard (*Brassica juncea* Coss), til (*Sesamum indicum* L), lentil (*Lens esculenta* Moench), khesari (*Lythyrus sativus* L), mung (*Phaseolus aureus* Roxb), chillis (*Capsicum frutescens* L), potatoes (*Solanum tuberosum* L) etc. Sugarcane (*Saccharum officinarum* L) occupies a sizable area on highlands. Homestead sites, generally on artificially raised platforms, are intensively used for bananas, year round vegetables, fruit trees and rice nurseries.

4.2. Report of The Field Study of The Soils Under Investigation

After preliminary field study seven soil profiles, each representing one typical soil series, were selected for morphological and laboratory investigations. The names of the selected soil series are given according to the naming of SRDI Staff (1965-86). These are:

<u>Soil series</u>	<u>Area in hectares</u>
♦ Melandaha	8,729
♦ Dhamrai	116,539
♦ Sonatala	215,368
♦ Silmandi	200,610
♦ Lokdeo	137,999
♦ Ghatail	227,016
♦ Sherpur	36,678

MORPHOLOGICAL DESCRIPTION OF THE SOILS

The soil profiles were morphologically described in the field and their environmental and general morphological properties are given below :

MELANDAHA SERIES

The Melandaha soil series consists of intermittently to seasonally flooded, imperfectly to poorly drained, weakly developed, medium textured soils occupying summit to upper slope of gently to very gently undulating ridges usually on the young Brahmaputra floodplain. They have a grey to olive-grey, finely mottled, silt loam subsoil with weak prismatic structure (Plate-2).

Depth to the substratum ranges from 30 to 60 cm. Topsoil colour is usually grey including some iron staining along root channel. The texture of the topsoil is usually silt loam occasionally silty clay loam. The subsoil colour is generally grey occasionally olive-grey and texture is usually silt loam occasionally very fine sandy loam. The texture of the substratum ranges from loam to silt loam occasionally silty clay loam.

The Melandaha soils differ from Sonatala soils in their greyer colour, weaker profile development and from Silmandi, Dhamrai and Lokdeo soils in their coarser texture, weaker structure and lighter consistence.

These soils occur throughout the Brahmaputra floodplain area and occupy about 8,729 hectares.

These soils are mainly used for aus-transplanted aman-rabi crops/fallow. Rabi crops include mustard, lentil, chillies, potatoes etc. Part of the aus is replaced by jute. Droughtiness in the late dry season intermittent wetness or shallow flooding in the monsoon provide slight agricultural limitations. With modern management including dry season irrigation and the balanced use of suitable fertilizers, these soils could produce high yields of annual and perennial dry land crops throughout the year. (Perennial crops only in the highland phase).

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Typifying Pedon - Melandaha Series - Cultivated

Location : Village: Char Ghoramara; Thana: Gouripur; Mymensingh

(Photo no. and Stop no. 26⁷⁵³⁵⁻¹⁵⁶/_{98W})

Topography : Middle slope of nearly level ridge

Drainage : Poor. Seasonally flooded upto 30 to 60 cm for 2 to 3 months.

Land use: Aus/Jute- Transplanted Aman- Fallow.

Parent material : Brahmaputra alluvium.

Land capability sub -class : IIw.

Taxonomic classification : Entisols.

Horizon	Depth (cm)	Description
Apg1	0-9	Grey (5Y 5/1) moist with few fine distinct yellowish brown mottles; <u>silt loam</u> ; massive; friable moist; few coarse tubular pores; iron staining along root channel; few medium roots; pH 6.5; abrupt smooth boundary
Apg2	9- 15	Olive-grey (5Y 5/2) moist with common fine distinct yellowish brown mottles; <u>silt loam</u> ; massive; firm moist; few medium tubular pores; few medium roots; pH 7.0; abrupt smooth boundary
Bwg1(?)	15-28	Grey (5Y 5/1) moist with common fine distinct yellowish brown mottles; <u>silt loam</u> ; weak very coarse prismatic, friable moist, few medium tubular pores; few common roots; pH 7.5; abrupt smooth boundary
Bwg2(?)	28- 36	Grey (5Y 5/1) moist with common medium distinct yellowish brown and few fine distinct dark yellowish brown mottles; <u>silt loam</u> ; weak very coarse prismatic; friable moist; few medium tubular pores; few fine roots; pH 7.5; abrupt smooth boundary.

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- 2C1 36-46 Light grey (5Y 7/1) moist; loamy sand; remnants of stratification; loose; pH 7.5; abrupt smooth boundary.
- 2C2 46-57 Light olive-brown (2.5Y 5/6) moist loamy sand; remnants of stratification; loose; pH 7.5; abrupt smooth boundary
- 3A1b.(?) 57-72 Dark yellowish brown, olive-brown and dark brown colour; loam; very friable moist; pH 7.5; abrupt smooth boundary
- 4C 72-100+ Olive-grey; loamy sand; loose; pH 7.5+.

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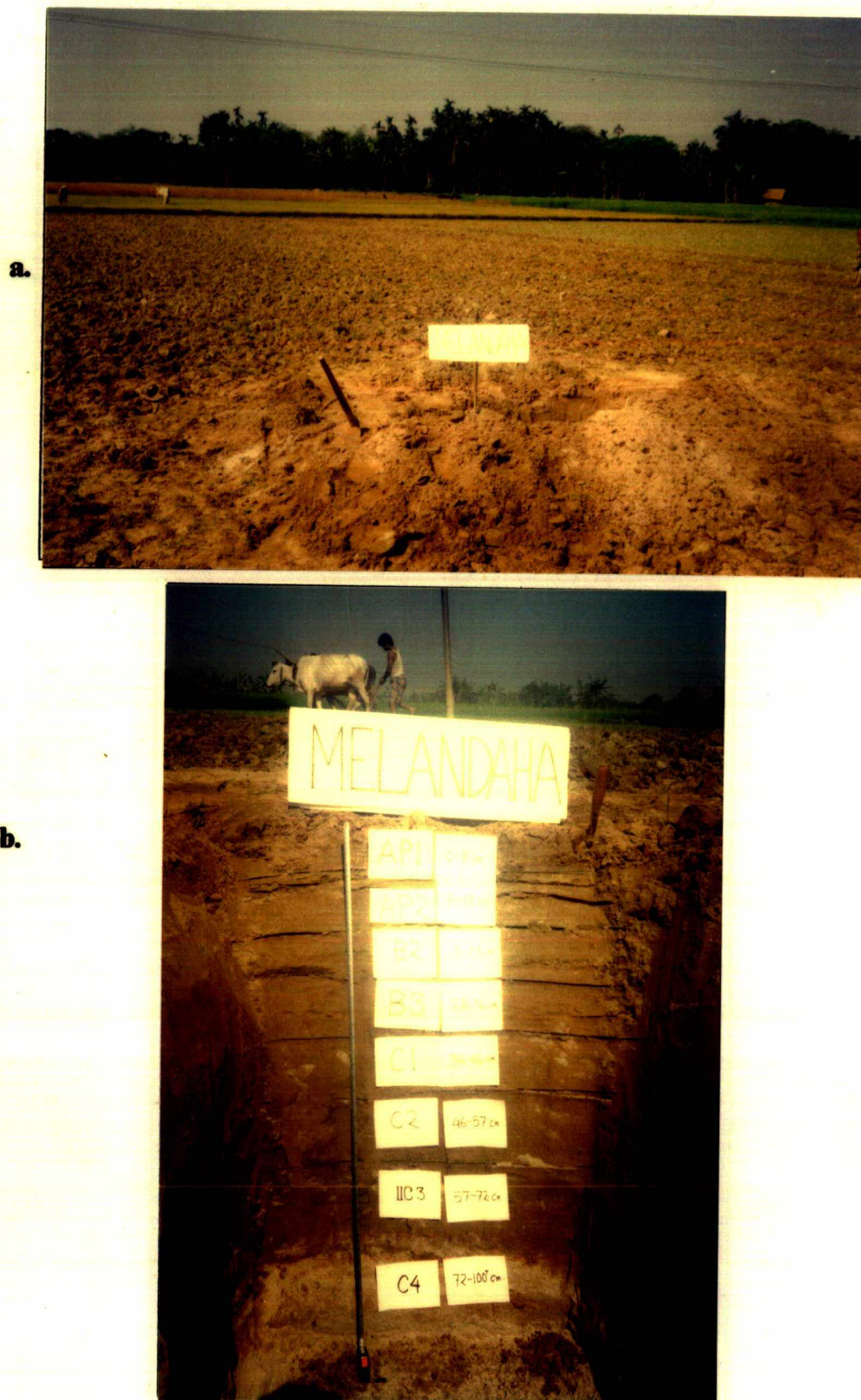


Plate No. 2. Melandaha soil : a. Vegetation. b. Soil profile

DHAMRAI SERIES

The Dhamrai soil series comprises seasonally flooded, poorly drained soils developed in moderately fine textured alluvium occupying ridges in the young Brahmaputra floodplain. They have a grey to olive-grey, finely mottled, friable silty clay loam subsoil with moderate coarse prismatic and blocky structure and prominent grey ped cutans along ped faces (Plate-3).

Depth to the substratum ranges from 30 to 60 cm. Topsoil colour ranges from grey to olive-grey and texture from silt loam to silty clay loam. Texture of the subsoil is usually silty clay loam. In the subsoil the structure varies from moderate to strong, coarse to very coarse prismatic usually breaking to angular blocky with broken to continuous, thin to moderately thick, grey to olive-grey cutans along vertical and horizontal ped faces and pores. The substratum is usually medium to coarse textured and stratified.

The Dhamrai soils differ from Sonatala and Melandaha soils in their finer texture, stronger structure and heavier consistence.

The Dhamrai soils also differ from closely similar Silmandi soils in their greyer colour and generally having stratified substratum at a shallow depth.

These soils occur throughout the Brahmaputra floodplain area and occupy about 116,539 hectares.

The Dhamrai soils are used for a number of cropping sequences of which mixed aus and broadcast aman-rabi crops, aus/Jute-rabi crops etc. are the most extensive one.

Seasonal flooding, occasional rapid rise and/or flow of flood water, risk of river erosion or burial by new alluvium provide moderate agricultural limitation. Under modern management, investment on flood protection and large scale irrigation is not advisable because of the risk of river erosion. However, use of suitable fertilizers and provision of small scale irrigation for dry land rabi crops or boro would be justified.

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Typifying Pedon - Dhamrai Series - Cultivated

Location :Village - Kailia; Thana: Dhamrai, Dhaka.

(Photo no. and Stop no. 1/36 - 0024)

Topography : Middle slope of gently undulating ridge.

Drainage: Poor. Seasonally flooded upto 90 to 120 cm for 3 to 4 months.

Land use: Aus- transplanted aman-fallow.

Parent material : Brahmaputra alluvium.

Land capability sub -class : IIw.

Taxonomic classification : Inceptisols.

Horizon	Depth (cm)	Description
Apg1	0-10	Grey (5Y 5/1) moist with common fine and medium distinct dark yellowish brown mottles; <u>silt loam</u> ; massive, firm moist; common fine tubular pores; many fine roots; pH 6.5; abrupt smooth boundary.
Apg2	10-15	Grey (5Y 5/1) moist with common fine and medium distinct dark yellowish brown mottles; <u>silt loam</u> ; massive; firm moist; common fine tubular pores; common fine roots; pH 7.0; abrupt smooth boundary.
Bwg1	15- 33	Olive-grey (5Y 5/2) moist with common fine distinct dark yellowish brown mottles; <u>silty clay loam</u> ; moderate coarse prismatic breaking into blocky; friable moist; broken moderately thick grey cutans along vertical ped faces and pores; common fine tubular pores, common fine roots; pH 7.5; clear, smooth boundary
Bwg2	33-43	Olive-grey (5Y 5/2) moist with common fine distinct dark yellowish brown mottles; <u>silty clay loam</u> ; moderate coarse prismatic; friable moist; continuous moderately thick grey cutans along vertical ped

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- faces and pores; common fine tubular pores, few fine roots; p^H 7.5; clear, smooth boundary.
- Cg1 43-63 Olive-grey (5Y 5/2) moist with common fine distinct yellowish brown and dark yellowish brown mottles; silty clay loam; weak very coarse prismatic; firm moist; few fine tubular pores; remnants of stratification; p^H 7.5; gradual smooth boundary.
- Cg2 63 - 88 Olive-grey (5Y 5/2) moist with common fine distinct yellowish brown and dark yellowish brown mottles; silty clay loam; massive; coarsely stratified, firm moist; p^H 7.5; gradual smooth boundary.
- Cg3 88 - 113 Olive-grey (5Y 5/2) moist with common fine distinct yellowish brown and dark yellowish brown mottles; silty clay loam; massive; coarsely stratified; firm moist; p^H 7.5; diffuse smooth boundary.
- 2Cg4 113-126+ Olive (5Y 5/3) moist with common fine distinct dark brown and few fine faint grey mottles; silt loam; massive; coarsely stratified; friable moist; p^H 7.5.

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a.



b.



Plate No. 3. Dhamrai soil : a. Vegetation. b. Soil profile

SONATALA SERIES

The Sonatala soil series comprises intermittently and seasonally flooded, somewhat poorly drained soils developed in medium textured Brahmaputra alluvium on the upper slopes of ridges on the old Brahmaputra floodplain. They have very friable silt loam with an overall pale olive-brown appearance when dry but greyer when wet. Grey coatings may be present along root channels and occasionally along vertical cracks (Plate-4).

Depths to substratum ranges from 25 to 75 cm. The topsoil texture ranges from loam to silt loam and colour from grey to light olive-grey, sometimes olive-grey or olive. In the subsoil, the oxidation colour is generally dark yellowish brown to olive-brown, occasionally strong brown or dark brown; it usually occupies about 40-60 percent of the soil mass, rarely less than 40 percent. The subsoils texture is silt loam, rarely loam or very fine sandy loam. Structure in the subsoil is mostly weak to moderate coarse to very coarse prismatic and blocky. The substratum is usually medium textured, occasionally coarse textured.

These soils occur throughout the Brahmaputra floodplain area and occupy about 215,368 hectares.

Sonatala series differ from Silmandi and Dhamrai series in being lighter texture and consistence; and from Melandaha in their browner colour.

These soils are mainly used for Aus/Jute- rabi crops or aus- transplanted aman - fellow. Rabi crops include pulses, chilies, brinjal, mustard, Khesari, etc. Part is used for sugarcane.

Droughtiness in late dry season and intermittent or seasonal shallow flooding provide slight agricultural limitations for most of these soils. With the use of suitable fertilizers and provision of dry-season irrigations, high yields could be obtained of one or two wet-land Kharif crops, and one dry land rabi crops per year. Alternatively, with provision of open field drains in addition, the high land phase could produce good annual and perennial dry land crops.

Typifying Pedon- Sonatala Series - Cultivated**Location** Village: Churkhai ; Thana : Mymensingh sadar, Mymensingh.(Photo no. and Stop no. 26⁷⁵³³⁻¹⁰⁶_{96W})**Topography** : Nearly level ridge.**Drainage**: Imperfect. Flooded upto 5 to 6 cm for 7 to 10 days in the monsoon.**Land Use** : Aus-Rabi crops or Aus- Transplanted Aman -Fallow.**Parent material** : Brahmaputra alluvium.**Land capability sub-class** : IIDw.**Taxonomic classification** : Inceptisols.

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Horizon	Depth (cm)	Description
Apg1	0-10	Grey (5Y 5/1) moist with common fine distinct olive-grey and strong brown mottles; <u>silt loam</u> ; massive; friable moist; few coarse tubular pores; few medium roots; p^H 6.8; abrupt smooth boundary.
Apg2	10-17	Grey (5Y 5/1) moist with common fine to medium distinct yellowish brown mottles; <u>silt loam</u> ; <u>massive</u> ; firm moist; few coarse tubular pores; few medium roots; p^H 7.0; abrupt smooth boundary.
Bwg1	17 - 35	Light olive-brown (2.5Y 5/4) and olive-grey (5Y 5/2) moist with few fine distinct strong brown mottles; <u>silt loam</u> ; weak to moderate, coarse to medium angular blocky; friable moist; continuous thin to moderately thick grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine roots; p^H 7.0; abrupt smooth boundary.
Bwg2	35 - 47	Olive-grey (5Y 5/2) moist with common fine distinct light yellowish brown and few fine distinct strong brown mottles; <u>silt loam</u> ; weak to moderate coarse prismatic breaking into coarse and medium angular

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- blocky; friable moist; continuous thin to moderately thin grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine roots; p^H 7.0; abrupt smooth boundary.
- Bwg3 47 - 59 Olive (5Y 5/3) moist with common fine to medium distinct dark yellowish brown and few fine distinct dark brown mottles; silt loam; weak coarse prismatic breaking into coarse and medium angular blocky; friable moist; continuous thin to moderately thick grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine roots; p^H 7.0+; abrupt smooth boundary.
- Cg1 59 - 77 Olive-grey (5Y 5/2) moist with common fine to medium distinct dark yellowish brown and few fine distinct dark brown mottles; silt loam; massive; friable moist; few medium tubular pores; two cm thick light grey sandy pocket; p^H 7.0+ clear smooth boundary
- Cg2 77 - 93 Olive-grey (5Y 5/2) moist with common fine distinct dark yellowish brown and few fine distinct strong brown mottles; very fine sandy loam; massive; friable moist; few medium tubular pores; p^H 7.0+; clear smooth boundary
- Cg3 93 - 125+ Olive (5Y 5/4) moist with common medium distinct to common fine distinct dark brown and few fine distinct yellowish brown mottles, silt loam; massive; friable moist; p^H 7.0+.

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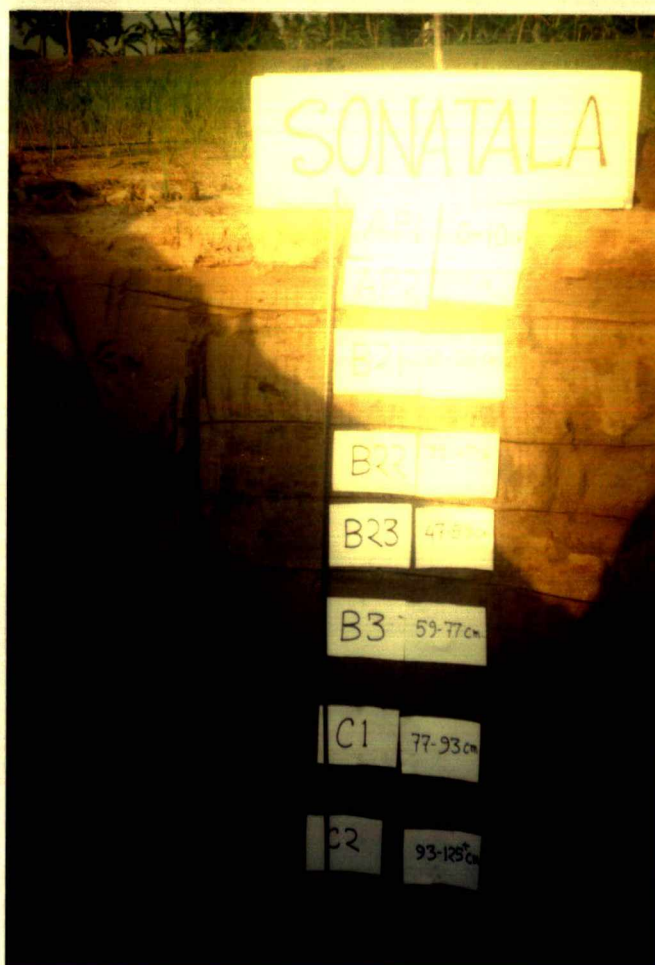


Plate No. 4. Sonatala soil : a. Vegetation. b. Soil profile

SILMANDI SERIES

The Silmandi series comprises intermittently to seasonally flooded imperfectly to poorly drained soils developed in moderately fine textured old Brahmaputra alluvium occupying upper to middle slope of ridges. They have a mixed grey and yellowish brown to dark yellowish brown silty clay loam sub soil with moderate to strong prismatic and blocky structure and grey ped cutans (Plate-5).

Depth to the substratum ranges from 30 to 60 cm. The topsoil texture ranges from silt loam to silty clay loam and colour from grey to olive-grey. In the subsoil, the oxidation colour ranges from yellowish brown to dark yellowish brown and occasionally strong brown and occupies approximately 40 percent of the soil mass. The structure of the subsoil varies from moderate to strong, coarse prismatic breaking into coarse and medium angular blocky and the consistence varies from friable to firm. The substratum is mostly medium textured and rarely fine textured.

These soils differ from associated Sonatala soils occupying slightly higher topographic position, in their finer texture, stronger structure, heavier consistence; and from Dhamrai soils in being more developed browner colour. They differ from Lokdeo soils in their grey rather than dark grey matrix and from Ghatail soils in their lighter texture, weaker structure and grey rather than dark grey matrix colour.

These soils occur throughout the Brahmaputra flood plain area and occupy about 200,610 hectares.

These soils are mainly used for aus/jute-transplanted aman-rabi crops/fallow. Rabi crops include mustard, lentil, khesari, chillis etc.

Seasonal intermittent to shallow flooding and droughtiness in late dry season provide moderate limitations for agricultural development. With dry season irrigation and balanced use of required fertilizers, these soils could be used for two improved wetland kharif and a dryland rabi crop per year. With open field drains in addition, the highland soils could be used for both annual and perennial dryland crops.

Typifying Pedon - Silmandi Series - Cultivated

Location : Village : Shikarikanda; Thana: Mymensingh sadar, Mymensingh

(Photo no. and Stop no. 41⁷⁵³³⁻¹⁰⁶/_{96W})

Topography : Nearly level ridge.

Drainage : Imperfect. Remain moist/wet upto 10-15 cm for 4-7 days in the rainy season.

Parent material : Brahmaputra alluvium.

Land Use : Aus-Trasplanted Aman-fallow.

Land capability sub-class : IIDw.

Taxonomic classification: Inceptisols.

Horizon	Depth (cm)	Description
Ap _{g1}	0 - 10	Grey (5Y5/1) dry with common fine distinct strong brown and few fine distinct yellowish brown mottles; <u>silt loam</u> ; massive; friable moist; few medium tubular pores; few medium roots; pH 6.5; abrupt smooth boundary.
Ap _{g2}	10-16	Grey (5Y5/1) moist with common fine distinct light yellowish brown and olive-brown mottles, <u>silt loam</u> ; massive; firm moist; few medium tubular pores; few medium roots; pH 7.0 ; abrupt smooth boundary
Bwg ₁	16 - 38	Grey (5Y 5/1) and light olive-brown (2.5Y 5/6) moist with few fine distinct strong brown and yellowish brown mottles; <u>silty clay loam</u> ; moderate coarse to medium angular blocky; friable moist; continuous thick dark grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine roots; pH 7.0 ; abrupt smooth boundary.

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- Bwg2 38 - 47 Olive-grey (5Y 5/2) moist with common fine distinct light olive-brown and yellowish brown mottles; silt loam; weak coarse angular blocky; friable moist; continuous thin grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine roots; p^H 7.0+; abrupt smooth boundary.
- Bwg3 47 - 61 Olive - grey (5Y 5/2) moist with common fine distinct olive-brown and dark brown mottles; silt loam; weak coarse angular blocky; friable moist; few medium tubular pores; few fine roots p^H 7.0+; clear smooth boundary
- Cg1 61 - 74 Olive-grey (5Y 5/2) moist with common fine distinct light yellowish brown and light olive-brown mottles; silt loam; massive; friable moist; few medium tubular pores; few fine roots; p^H 7.0+; clear smooth boundary.
- Cg2 74 - 90 Olive-grey (5Y 5/2) to light yellowish brown and light grey mottles; very fine sandy loam; massive; friable moist; p^H 7.0+; clear smooth boundary.
- Cg3 90 - 110+ Olive (5Y 5/4) moist with common fine distinct olive-grey mottles; silt loam; massive; friable moist; p^H 7.5.

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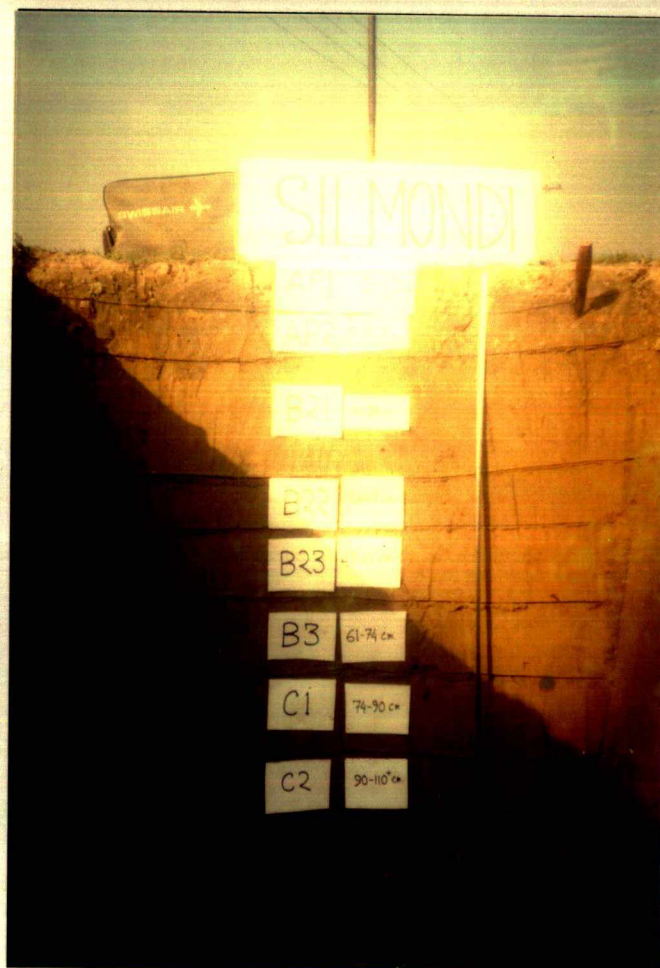


Plate No. 5. Silmandi soil : a. Vegetation. b. Soil profile

LOKDEO SERIES

The Lokdeo series comprises seasonally flooded, poorly drained soil developed in moderately fine textured sediments occupying ridges in the oldest Brahmaputra floodplain. They have a mixed dark grey and olive-brown to yellowish brown, silty clay loam to clay loam subsoil with moderate to strong prismatic and blocky structure and dark grey ped cutans (Plate-6).

Depth to the substratum ranges from 30 to 60 cm. Top soil colour is usually grey occasionally dark grey and texture ranges from silt loam to silty clay loam. The colour of the subsoil is dark grey, occupies about 60% of the soil mass and the mottle colour includes olive-brown, light olive-brown and yellowish brown. In the subsoil, the structure ranges from moderate to strong, prismatic to angular blocky. The texture of the substratum ranges from sandy loam to silty clay loam.

Lokdeo soils differ from associated Sonatala soils occupying relatively higher position in their finer texture, stronger structure, heavier consistence and also in their dark grey rather than grey ped cutans. They differ from Ghatail soils occupying lower sites in their coarser texture and heavier consistence. They differ from similar textured Silmandi and Dhamrai soils in their dark grey rather than grey matrix and cutan colours.

These soils occur throughout the Brahmaputra flood area and occupy about 137,999 hectares.

The Lokdeo soils are mainly used for double cropping of aus- transplanted aman-fallow, with some aus-transplanted aman-rabi crops. Rabi crops include wheat, mustard, lentil etc. Locally they are used for either mixed aus and broadcast aman-fallow or single crop of boro-fallow.

Intermittent wetness to seasonal flooding, droughtiness in the late dry season, and locally irregular relief provide moderate agricultural limitations. With dry season irrigation and balanced use of suitable fertilizers, most of these soils could give high yields of two improved transplanted rice crops per year.

Typifying Pedon - Lokdeo Series- Cultivated

Location :Village : Baluha, Thana: Gouripur, Mymensingh.

(Photo no. and Stop no. 1/ $\frac{7535-27}{97E}$)

Topography : Nearly level ridge.

Drainage : Poor. Remain wet upto 30 to 50 cm for 1 to 2 months in the monsoon.

Land Use: Transplanted Aus-Transplanted Aman- Fallow.

Parent material : Brahmaputra alluvium.

Land capability sub-class : IIw.

Taxonomic classification : Inceptisols.

Horizon	Depth (cm)	Description
Apg1	0-10	Grey (5Y 5/1) dry with common fine distinct yellowish brown mottles; <u>silt loam</u> ; massive; hard dry; ; common fine tubular pores; few medium roots; pH 6.5; abrupt smooth boundary
Apg2	10-17	Grey (5Y 5/1) moist with common fine distinct dark grey and few fine distinct yellowish brown mottles; <u>silt loam</u> ; massive; firm moist; few fine tubular pores; few medium roots; pH 6.5+; abrupt smooth boundary
Bwg1	17-31	Grey (5Y 5/1) moist with many fine distinct dark grey and few fine distinct yellowish brown mottles; <u>silty clay loam</u> ; moderate coarse prismatic breaking into coarse and medium angular blocky; firm moist; continuous moderately thick dark grey cutans along vertical and horizontal ped faces; few medium tubular pores; few fine and medium roots; pH 7.0; abrupt smooth boundary.
Bwg2	31-56	Olive-grey (5Y 5/2) moist with common medium distinct olive and few fine distinct yellowish brown mottles; <u>silty clay loam</u> ; weak to

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		moderate very coarse prismatic breaking into weak coarse angular blocky; firm moist; continuous moderately thick grey cutans along vertical ped faces; few medium tubular pores; few fine roots; p^H 7.0; clear smooth boundary
Bg3	56-70	Olive (5Y 5/3) moist with many fine distinct olive-grey and few fine distinct yellowish brown mottles; <u>silty clay loam</u> ; weak very coarse prismatic; friable moist; continuous thin grey cutans along vertical ped faces; few medium tubular pores; few fine roots; p^H 7.0; clear smooth boundary.
Cg1	70-90	Olive (5Y 5/3) moist with common fine distinct dark brown mottles; <u>silt loam</u> ; massive; friable moist; few coarse tubular pores; p^H 7.0; clear smooth boundary.
Cg2	90-110	Olive (5Y 5/3) moist with common fine distinct yellowish brown and few fine distinct dark brown mottles; <u>silt loam</u> ; massive; friable moist; p^H 7.5; clear smooth boundary.
Cg3	110+	Olive (5Y 5/3) moist with common fine distinct olive-grey mottles; <u>silt loam</u> ; massive; friable moist, p^H 7.5.

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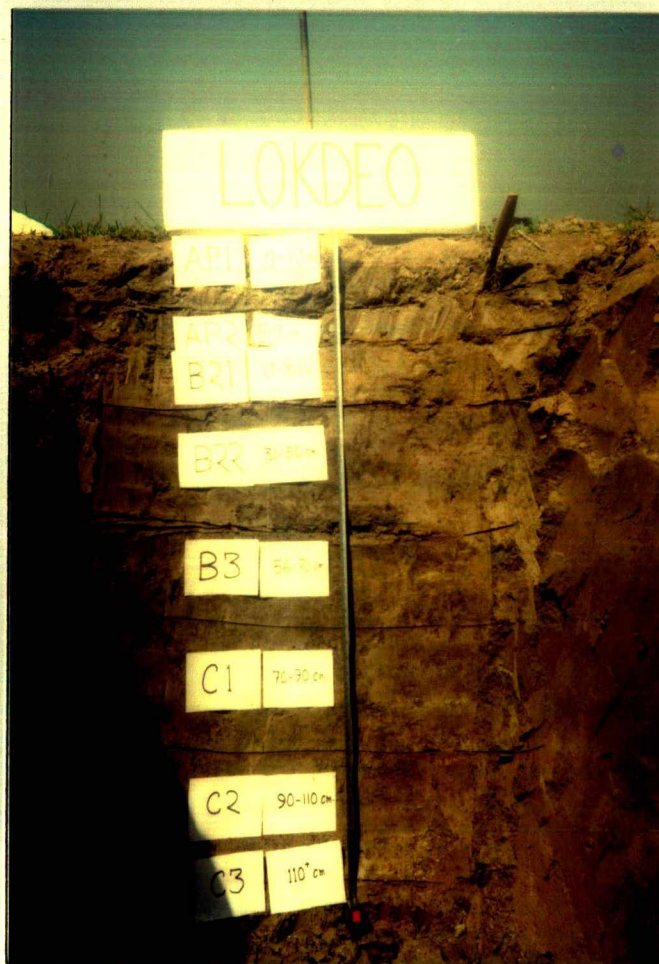


Plate No. 6. Lokdeo soil : a. Vegetation. b. Soil profile

GHATAIL SERIES

The Ghatail soil series comprises seasonally flooded and poorly drained soils developed in fine textured oldest Brahmaputra alluvium, occupying lower slope of ridges to very gently undulating basins. They have a dark grey silty clay to clay subsoil with strong prismatic and angular blocky structure and moderately thick dark grey cutans along vertical and horizontal ped faces (Plate-7).

Depth to the substratum ranges from 30 to 90 cm. The topsoil colour varies from grey to dark grey; and the texture ranges from silty clay loam to silty clay. In the subsoil, the oxidation colour is mainly yellowish brown and occasionally olive-brown and/or dark yellowish brown; and the reduced colour is usually dark grey, occasionally very dark grey. Texture of the subsoil ranges from silty clay to clay; structure is strong coarse prismatic usually breaking to strong coarse and medium angular blocky with moderately thick to thick dark grey cutans along ped faces. The substratum is generally olive to olive-brown; occasionally yellowish brown and texture of the substratum ranges from silt loam to silty clay loam, occasionally silty clay to clay.

The Ghatail soils differ from Sonatala, Silmandi and Lokdeo soils in their finer texture, stronger structure and heavier consistence.

These soils occur throughout the Brahmaputra floodplain area and occupy about 22,7016 hectares.

These soils are mainly used for aus- transplanted aman-fallow.

Seasonal flooding, dry season droughtiness and heavy consistence provide moderate limitations for agricultural development.

With irrigation and balanced use of suitable fertilizers, the medium highland soils could be used for two improved wet land paddy including boro.

Typifying Pedon- Ghatail series - Cultivated.

Location Village: Digarkanda; Thana: Mymensingh sadar, Mymensingh.

(Photo no. and Stop no. 12 $\frac{7535-23}{97E}$)

Topography : Nearly level basin.

Drainage: Poor. Seasonally flooded upto 40 to 70 cm for 3 to 4 months in the monsoon.

Land use : Transplanted Aman-Fallow

Parent material : Old Brahmaputra alluvium.

Land capability sub-class : III wd.

Taxonomic classification : Inceptisols.

Horizon	Depth (cm)	Description
Apg1	0-10	Grey (5Y 5/1) dry with common fine distinct yellowish brown and strong brown mottles; <u>silty clay</u> ; massive; very hard dry; few fine tubular pores; few medium roots; pH 6.0; abrupt smooth boundary.
Apg2	10-18	Dark grey (2.5Y 4/1) moist with common fine distinct yellowish brown and few fine distinct grey mottles; <u>clay</u> ; massive; very firm moist; few very fine tubular pores; few medium roots; pH 6.5; abrupt smooth boundary
Bwg1	18-33	Dark grey (5Y 4/1) moist with many fine distinct yellowish brown and few fine distinct dark brown mottles; <u>clay</u> ; strong coarse to medium prismatic breaking into medium to fine angular blocky; very firm moist; continuous thick dark grey cutans along vertical and horizontal ped faces, few fine tubular pores; few medium roots; pH 7.0+; abrupt smooth boundary.
Bwg2	33-51	Dark grey (5Y 4/1) moist with common medium distinct yellowish brown and few fine distinct dark yellowish brown mottles; <u>clay</u> ;

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		strong coarse to medium angular blocky; continuous thick dark grey cutans along vertical and horizontal ped faces; few fine tubular pores; few fine roots; p^H 7.0; abrupt smooth boundary.
Bwg3	51- 73	Yellowish brown (10Y 5/8) moist with common fine distinct olive-grey and few medium distinct dark grey mottles; <u>silty clay</u> ; moderate very coarse prismatic breaking into weak medium angular blocky; firm moist; continuous thick dark grey cutans along vertical and horizontal ped faces; few coarse tubular pores; few fine roots, p^H 7.0+; abrupt smooth boundary.
Cg1	73-91	Olive-grey (5Y 5/2) moist with common fine distinct yellowish brown and few fine distinct dark brown mottles; <u>silty clay loam</u> ; weak to moderate very coarse to coarse prismatic; firm moist, continuous thick dark grey cutans along vertical ped faces; common fine tubular pores; p^H 7.0+; clear smooth boundary.
Cg2	91-103	Olive (5Y 5/3) moist with common medium distinct light olive-grey and few medium distinct yellowish brown and few fine distinct dark brown mottles; <u>silty clay loams</u> ; massive; firm moist, continuous thin grey cutans along vertical ped faces; few coarse and medium tubular pores; krotovinas presents; p^H 7.0+; clear smooth boundary.
Cg3	103-125+	Olive (5Y 5/3) moist with common medium distinct light olive-grey mottles; <u>silt loam</u> ; friable moist; common fine tubular pores; p^H 7.0+.

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b.



Plate No. 7. Ghatail soil : a. Vegetation. b. Soil profile

SHERPUR SERIES

The Sherpur series comprises moderately well drained soils developed in medium textured old Brahmaputra alluvium occupying summit of nearly level ridges. They have a dark yellowish brown to olive brown, friable, silt loam subsoil with weak to moderate prismatic structure and patchy to broken, thin grey to brown cutan along vertical ped faces and pores (Plate-8).

Depth to the subsoil ranges from 30 to 60 cm. The colour of the topsoil ranges from olive-grey to olive-brown. The colour of the subsoil ranges from olive to dark yellowish brown and the texture usually silt loam. The subsoil has weak to moderate, coarse to very coarse prismatic structure breaking into coarse and medium blocky with thin to moderately thick patchy to broken, grey or greyish brown occasionally yellowish brown; cutans along ped faces and pores.

These soils differ from associated Silmandi soils in their coarser texture, weaker structure, lighter consistence, better drainage, browner colour and finally occupying higher topographic sites. They also differ from Lokdeo soils in the similar manner. The Sherpur soils differ from closely similar Sonatala soils in their browner colour and relatively better drainage and from Melandaha soils in their brown rather than grey over all colour and better drainage.

The Sherpur soils occur throughout the old Brahmaputra floodplain area and occupy about 36,678 hectares.

These soils are mainly used for aus or jute followed by rabi crops such as mustard, lentil, blackgram, potatoes, sweet potatoes and tobacco. Occasionally transplanted aman succeeds aus when there is enough rainfall during transplantation time. Locally, fruit trees like banana, pineapple and vegetables are also grown in this soil.

Droughtiness in dry season provides slight to moderate limitations for agricultural use of the soils. With balanced use of suitable fertilizer and dry season irrigation, high yielding dry land rabi crops could be grown in addition to one or two wetland kharif crops grown at present. Alternatively, with provision of open field drains in addition, good annual and perennial dryland crops could be grown .

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Typifying Pedon - Sherpur Series - Cultivated

Location : Village : Char Haripur; Thana: Mymensingh sadar, Mymensingh.

(Photo no. and Stop no. 1/ $\frac{7535-158}{98W}$)

Topography : Nearly level upper part of ridge.

Drainage : Moderately well; Above normal flood level.

Parent material : Brahmaputra alluvium.

Land Use: Aus/Jute - Rabi vegetables/sometimes fallow

Land capability sub-class : IIDd .

Taxonomic classification : Inceptisols.

Horizon	Depth (cm)	Description
Apg	0-14	Grey (2.5Y 5/1) moist with common medium distinct dark yellowish brown and few fine distinct dark brown mottles; <u>silt loam</u> ; massive; friable moist; few medium roots; pH 5.5; abrupt smooth boundary.
Bwg1	14-29	Olive-brown (2.5Y 4/4) moist with few fine distinct yellowish brown and few fine distinct olive-grey mottles; <u>silt loam</u> ; moderate very coarse to coarse prismatic breaking into weak coarse to medium angular and subangular blocky; friable moist; continuous thin olive brown cutans along vertical and horizontal ped faces; few medium tubular pores; earthworms activity; few fine and medium roots; pH 6.0; abrupt smooth boundary
Bwg2	29-47	Olive-brown (2.5Y 4/4) moist with common medium dark yellowish brown and few fine distinct olive-grey mottles; <u>silt loam</u> ; moderate coarse prismatic breaking into weak coarse to medium angular and subangular blocky; friable moist; continuous thin; olive-brown

- cutans along vertical and horizontal ped faces; few medium tubular pores; few medium roots; pH 6.0; abrupt smooth boundary.
- Bwg3 47-66 Light olive-brown (2.5Y 5/4) moist with common fine distinct dark yellowish brown and few fine distinct olive-grey mottles; silt loam; weak very coarse prismatic breaking into weak coarse angular blocky; friable moist; continuous thin olive-brown cutans along vertical and horizontal ped faces; few medium tubular pores; krotovina present; pH 6.0; clear smooth boundary
- Cg1 66-96 Light olive-brown (2.5Y 5/4) moist with common medium prominent dark brown and common fine distinct olive-grey mottles; silt loam; massive; friable moist; continuous thin light olive-brown cutans along cracks; few medium tubular pores; soft-iron and manganese concretions; pH 6.5; clear smooth boundary
- Cg2 96 - 122+ Olive-grey (5y 5/2) moist with common fine distinct yellowish brown and few fine distinct dark brown mottles; silt loam; massive; friable moist; pH 6.5

Chapter IV Environmental Settings and Field Study of the Soils

a.



b.



Plate No. 8. Sherpur soil : a. Vegetation. b. Soil profile

CHAPTER- 5

RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

5.1. Morphological Properties of the Soils

An attempt has been made to look into the morphological characteristics of the soils studied from the Brahmaputra floodplain to see whether they reflect the influence of the existing soil forming factors.

It seems expedient to summarize here the salient morphological features of the soils under the present investigation (Table- 7).

- ♦ The surface soils of all profiles have loamy texture with grey (2.5Y 5/1, moist) colours and were slightly acidic in reaction.
- ♦ The subsoil horizons were characterized by neutral to slightly alkaline reaction. The colour ranges from grey to olive grey with common fine distinct strong brown to yellowish brown mottles. Their texture varies from silt loam to silty clay loam . Some grey cutans along the vertical ped faces are present.
- ♦ The profiles also showed the presence of flood coatings and mottles (mostly reddish brown) along the old root channels and pore walls.
- ♦ Weak to massive structure existed in the top soil.
- ♦ Strong, coarse to medium angular blocky structures were seen in the subsoil.

A brief account of the pertinent soil forming factors prevailing in the area under investigation are given below :

- ♦ The climate of the area is humid tropical monsoon with an annual rainfall of more than 2200mm.
- ♦ As the soils of the area is presently under cultivation natural vegetation could not be traced.
- ♦ The area has nearly flat topography.
- ♦ Parent materials consist of unconsolidated alluvium of recent age.
- ♦ Age is at least 200 years. (Brammer, 1964).
- ♦ Poor internal and external drainage condition exist in these soils and they are irrigated during the dry season for production of an extra rice crop.

Table-7. Coded Morphological properties of the soils

Soils	Horizon	Depth (cm)	Munsell colour		Texture	Structure	Consistence	Boundary
			Matrix colour	Mottles				
Melandaha	APg1	0-9	5Y 5/1 (moist)	f ₁ d yb	sil	m	mfr	as
	APg2	9-15	5Y 5/2 (")	c ₁ d yb	sil	m	mfi	as
	Bwg1(?)	15-28	5Y 5/1 (")	c ₁ d yb	sil	1 vc pr	mfr	as
	Bwg2(?)	28-36	5Y 5/1 (")	c ₂ d yb+f ₁ d dyb	sil	1 vc pr	mfr	as
	2C1	36-46	5Y 7/1 (")	-	ls	ramnants of stratification	loose	as
	2C2	46-57	2.5Y 5/6 (")	-	ls	"	loose	as
	3A1b(?)	57-72	dyb (")	-	1	"	mvfr	as
	4C	72-100+	og (")	-	ls	"	wss, wpo, wloose	-
Dhamrai	APg1	0-10	5Y 5/1 (moist)	c ₁ -2 _d dyb	sil	m	mfr	as
	APg2	10-15	5Y 5/1 (")	c ₁ -2 _d dyb	sil	m	mfi	as
	Bwg1	15-33	5Y 5/2 (")	c ₁ d dyb	sicl	2cpr	mfi	as
	Bwg2	33-43	5Y 5/2 (")	c ₁ d dyb	sicl	2cpr	mfr	as
	Cg1	43-63	5Y 5/3 (")	c ₁ d yb + c ₁ d dyb	sicl	1vc pr	mfr	as
	Cg2		5Y 5/2 (")	c ₁ d yb + c ₁ d dyb	sicl	m	mfi	as
	Cg3	63-88	10 YR 5/3 (")	c ₁ d yb + c ₁ d dyb	sicl	m	mfi	as
	2Cg4	88-113	5Y 5/3 (")	c ₁ d db + f ₁ f g	sicl	m	mfi	as
		113-126+			sil	m	mfr	-
Sonatala	APg1	0-10	5Y 5/1 (moist)	c ₁ d og + stb	sil	m	mfr	as
	APg2	10-17	5Y 5/1 (")	c ₁ -2 _d yb	sil	m	mfi	as
	Bwg1	17-35	2.5Y 5/4 + 5Y 5/2 (")	f ₁ d stb	sil	1-2 c-m abk	mfr	as
	Bwg2	35-47	5Y 5/2 (")	c ₁ d lyb + f ₁ d stb	sil	1-2 cpr/c-m abk	mfr	as
	Bwg3	47-59	5Y 5/3 (")	c ₁ - ₂ d dyb + f ₁ d db	sil	1 cpr/c-m abk	mfr	cs
	Cg1	59-77	5Y 5/2 (")	c ₁ - ₂ d dyb + f ₁ d db	sil	m	mfr	cs
	Cg2	77-93	5Y 5/2 (")	c ₁ d dyb + f ₁ d stb	vfsi	m	mfr	cs
	Cg3	93-125+	5Y 5/4 (")	c ₁ -2 _d db + f ₁ d db	sil	m	mfr	-

Continued next page

TABLE-7. CONTINUED

Soils	Horizon	Depth (cm)	Munsell colour		Texture	Structure	Consistence	Boundary
			Matrix colour	Mottles				
Silmandi	Ap _{g1}	0-10	5Y 5/1 (dry)	c ₁ d stb + f ₁ d yb	sil	m	mfr	as
	Ap _{g2}	10-16	5Y 5/1 (moist)	c ₁ d lyb + c ₁ d ob	sil	m	mfi	as
	Bw _{g1}	16-38	5Y 5/1 + 2.5Y 5/6 (")	f ₁ d stb + yb	sicl	2c-m abk	mfr	as
	Bw _{g2}	38-47	5Y 5/2 (")	c ₁ d lob + yb	sil+	1 c-m abk	mfr	cs
	Bw _{g3}	47-61	5Y 5/2 (")	c ₁ d ob + db	sil	1 c-m abk	mfr	cs
	C _{g1}	61-74	5Y 5/2 (")	c ₁ d lyb + lob	sil	m	mfr	cs
	C _{g2}	74-90	5Y 5/2 (")	-	vfsil	m	mfr	cs
	C _{g3}	90-110+	5Y 5/2 (")	c ₁ d og	sil	m	mfr	-
Lokdeo	Ap _{g1}	0-10	5Y 5/1 (dry)	c ₁ d yb	sil	m	dh	as
	Ap _{g2}	10-17	5Y 5/1 (moist)	c ₁ d dg + f ₁ d yb	sil	m	mfi	as
	Bw _{g1}	17-31	5Y 5/1 (")	m ₁ d dg + f ₁ d yb	sicl	2c pr/c-m abk	mfi	as
	Bw _{g2}	31-56	5Y 5/2 (")	c ₂ d o + f ₁ d yb	sicl	1-2 vc pr/c abk	mfi	as
	B _{g3}	56-70	5Y 5/3 (")	m ₁ d og + f ₁ d yb	sicl	1 vc pr	mfi	cs
	C _{g1}	70-90	5Y 5/3 (")	c ₁ d db	sil+	m	mfr	cs
	C _{g2}	90-110	5Y 5/3 (")	c ₁ d yb + f ₁ d db	sil	m	mfr	cs
	C _{g3}	110+	5Y 5/3 (")	c ₁ d og	sil	m	mfr	cs
Ghatall	Ap _{g1}	0-10	5Y 5/1 (dry)	c ₁ d yb + stb	sic	m	dvh	as
	Ap _{g2}	10-18	2.5 y 4/1 (moist)	c ₁ d yb + f ₁ dg	c	m	mvfi	as
	Bw _{g1}	18-33	5Y 4/1 (")	m ₁ d yb + f ₁ d db	c	3c-m pr/ m-f abk	mvfi	as
	Bw _{g2}	33-51	5Y 4/1 (")	c ₂ d yb + f ₁ d dyb	c	3c-m abk	mvfi	as
	Bw _{g3}	51-73	10 YR 5/8 (")	c ₁ d og + f ₂ d dg	sic	2 vc pr/c-m abk	mfi	cs
	C _{g1}	73-91	5Y 5/2 (")	c ₁ d yb + f ₁ d db	sicl+	1-2 vc-cpr	mfi	cs
	C _{g2}	91-103	5Y 5/3 (")	c ₂ d log + f ₂ d yb + f ₁ d db	sicl	m	mfi	cs
	C _{g3}	103-125+	5Y 5/3 (")	c ₂ d log	sil	m	mfr	cs
Sherpur	Ap _g	0-14	2.5Y 5/1 (moist)	c ₂ d dyb + f ₁ d db	sil	1 vc pr/ 1c sabk	mfr	as
	Bw _{g1}	14-29	2.5Y 4/4 (")	f ₁ d yb + f ₁ d og	sil	2vc-cpr/1c-rs abk	mfr	as
	Bw _{g2}	29-47	2.5Y 4/4 (")	c ₂ d yb + f ₁ d og	sil	2cpr/1c-m sabk	mfr	as
	Bw _{g3}	47-66	2.5Y 5/4 (")	c ₁ d dyb + f ₁ d og	sil	1vc pr/1csabk	mfr	cs
	C _{g1}	66-96	2.5Y 5/4 (")	c ₂ p db + c ₁ d og	sil	m	mfr	cs
	C _{g2}	96-122+	2.5Y 5/2 (")	c ₁ d yb + f ₁ d db	sil	m	mfr	-

An examination of the profile characteristics (Table-7) of the studied soils indicates that the gleying process is in operation as is evident from the presence of gleyed/or pseudogleyed layers. The presence of these horizons along with the mottles near the upper part also indicate that these have hydromorphic properties (Joffe, 1949).

The morphological character (Table-7) of the profiles leads one to draw conclusion in favour of hydromorphic nature of these soils, yet one can not be sure about the actual group of soils to which these soils belong, unless the factors responsible for the formation as well as the other chemical, physico-chemical and mineralogical properties are thoroughly examined.

Among the five pedogenic factors, the role of climate in moulding the characteristics of the present soils is significantly active during the dry months as in that season, the soils become oxidized. The rainy season, which is confined in a period of about six months, supplies sufficient rainwater for seasonal flooding (Manalo, 1975). Because of seasonal flooding the soils under the present study may be considered as climatogenically sub-dued. (Joffee, 1966). Reduction of the entire profile prevails during the rainy season.

The parent materials are unconsolidated alluvium of sub-recent to recent age with annual siltation from the flooding water. The prevalence of warm climate during the dry season has accentuated the rate of weathering to eventually bring about a speedy development of soil profiles particularly when the supply of moisture has never been a limiting factor. But the effect of climate becomes sub-dued during the monsoon period. River water from the upstream along with the local rainwater causes seasonal flooding and then local hydrology takes the lead in the soil formation process.

The effect of natural vegetation in the soil genesis is limited to the supply of organic matter because the soils have been under continuous cultivation. Moreover, cultivation may cause mechanical breakdown of soil clods, mixing up of uppermost layers

and puddling in some cases. These mechanical manipulation might help mechanical movement of soil colloidal particles downward.

The formation of variously coloured mottles is generally associated with seasonal fluctuation of ground water table (Mc Keage, 1965). Field evidence suggests that the degree of development of grey colours and mottling may differ considerably in soils of apparently similar moisture regime. It seems reasonable, therefore, to attribute such difference in development of mottled horizons, at least in part, to the nature of the parent materials.

The flood coating on ped faces may possibly due to mechanical down washing of material from the soil surface when the soils are flooded and ploughed (Brammer, 1979). This does not seem to be any indication of eluviation of clay from the top soil as in the case of cutans.

Thus, it seems quite clear that the pedogenic factors pertinent to the soils under the investigation were responsible for the development of some morphological features.

5.2. Physical Properties of the Soils

The physical properties of soils under the investigation are discussed below :

5.2.1 Particle size distribution

5.2.1.1. The non-clay fraction

The results of particle size distribution in the soils studied have been presented in Table-8. The sand contents in the studied soils vary within very wide limits. Quantity of sand ranges from 3 to 90 percent with the mean of 26 percent. These results are in agreement with the findings of SRDI staff (1965 -86). The highest value of sand is found in Melandaha soil while the lowest value is found in Lokdeo soil. Based on the sand content the pedon studied show the following gradation:

Melandaha > Silmandi > Sonatala >Dhamrai >Sherpur > Ghatail >Lokdeo

The vertical distribution pattern of sand fraction in these pedons shows an irregular trend (Table -8). In Melandaha soil sand content of the surface horizon is 44 percent which increases to 90 percent in the C1 and C2 horizons. In the Dhamrai profile sand content of the surface horizon is 45 percent which decreases to 10 percent in the Bwg1 and Bwg2 horizons. On the basis of the vertical distribution of sand it can be generally concluded that the parent materials of the present soils are heterogeneous.

The silt content has assumed a significant status in these soils. The general level of silt content is high ranging from 8 to 80 percent with a mean value of 56 percent. Silt is the dominant fraction in all the soils except Melandaha. The highest mean silt content within the profile is observed in the Lokdeo soil (75 percent) whereas the lowest in the Melandaha soil (36 percent). Such a high level of silt is due to their geogenic origin. Based on the percent silt content, the pedons show the following gradation:

Lokdeo>Sonatala >Dhamrai >Sherpur >Silmandi >Ghatail >Melandaha

Chapter V Results and Discussion

The distribution pattern of silt fraction in the pedons show an irregular trend .There is no significant trend in the distribution of silt in the profiles except in the Melandaha profile.

The sand/silt ratio of the present soils varies from 0.05 to 11.0. The highest mean sand/ silt is found in the Melandaha soil whereas the lowest ratio is found in the Lokdeo soil. The vertical distribution pattern of this ratio is, like before, heterogeneous and this leads to conclude that soil materials are stratified.

5.2.1.2. The clay fraction

The percentage of clay in the pedons studied ranges from 2 to 64 percent with a mean value of 18 percent (Table-8). The quantity of clay in most soils of the Brahmaputra floodplain is thus quite low. The highest average value is observed in the Ghatail profile whereas the lowest value is in the Melandaha profile. Based on the clay content the pedons show the following gradation :

Ghatail > Dhamrai > Lokdeo > Sherpur > Sonatala > Silmandi > Melandaha

The vertical distribution of clay content is irregular in all the profiles (Table-8). Perhaps, this is the result of restricted movement of the clay downward due to poor drainage condition and the shortage of clay . The distribution of clay in the profiles, thus, reflect geological process rather than a pedological feature.

Impoverishment of clay in the upper horizons of profile is a common feature in some seasonally flooded Bangladesh where ferrolysis is a common soil forming process (Brammer, 1964; Brinkman, 1970). In the Ghatail and Sherpur profiles surface impoverishment of clay is noticed.

The textural classes of the soils studied show a wide variation. It ranges from sandy to clayey in texture. This variation in textural classes of soils is a common feature in the floodplain areas of Bangladesh. Usually the soils of the levee areas are sandy and those in the backswamp areas are clayey (Brammer, 1971).

Table-8. Particle size distribution and textural classes of the soils.

Soils	Horizon	mm												Sand/ silt Ratio	Textural Class
		Total			Sand					Silt		Clay			
		sand (2-0.05)	Silt (.05-.02)	Clay (.002)	Coarse (2.0-0.5)	Medium (0.5 - 0.25)	Fine (0.25-.10)	Very fine (0.10-0.05)	Coarse (.05-.02)	Fine (.02-.002)	Coarse <.002-.001)	Fine <.001			
Melandaha	Ap _{g1}	44	51	5	-	2.0	18.0	20.0	22.0	29.0	1.0	4.0	0.86	sil	
	Ap _{g2}	41	52	7	-	5.0	16.0	20.0	21.0	31.0	3.0	4.0	0.79	sil	
	Bw _{g1} (?)	41	52	7	1.0	4.0	17.0	19.0	18.5	33.5	3.0	4.0	0.79	sil	
	Bw _{g2} (?)	41	53	6	1.0	10.0	17.0	13.0	19.0	34.0	2.0	4.0	0.77	sil	
	2C ₁	90	8	2	0.50	37.5	54.0	5.0	2.0	-	-	1.0	11.00	s	
	2C ₂	89	9	2	1.0	5.0	84.0	6.0	2.0	1.0	-	1.0	10.00	s	
	3A1b(?)	45	51	4	-	1.5	12.0	32.0	32.5	20.5	0.5	1.0	0.88	sil	
	4C	88	10	2	-	28.0	63.0	4.0	2.0	2.0	-	1.0	8.80	s	
Mean	60	36	4	-								4.26	-		
Dhamrai	Ap _{g1}	45	43	12	-	7.0	24.0	14.0	19.0	24.0	4.0	8.0	1.06	1	
	Ap _{g2}	10	62	28	-	2.0	3.0	5.0	32.0	30.0	6.0	12.0	0.16	sicl	
	Bw _{g1}	10	60	30	-	2.0	5.0	3.0	29.0	31.0	5.0	12.0	0.17	sicl	
	Bw _{g2}	10	58	32	-	-	3.0	5.0	25.0	35.0	3.0	9.0	0.17	sicl	
	C _{g1}	12	58	34	-	-	8.0	4.0	33.0	25.0	3.0	1.0	0.26	sicl	
	C _{g2}	40	50	10	-	-	10.0	30.0	30.0	20.0	7.0	3.0	0.80	sil	
	C _{g3}	35	50	15	-	-	15.0	20.0	28.0	22.0	18.0	7.0	0.70	sil	
	2C _{g4}	15	67	18	-	-	5.00	10.0	36.0	31.0	6.0	12.0	0.22	sil	
Mean	22	56	22	-	-							0.43	-		
Sonatala	Ap _{g1}	37	54	9	0.4	1.8	10.8	24.0	27.2	26.8	1.3	7.7	0.68	sil	
	Ap _{g2}	31	55	14	0.4	1.4	7.5	21.7	24.0	31.0	1.5	12.5	0.56	sil	
	Bw _{g1}	25	59	16	0.3	1.3	3.4	20.0	26.4	32.6	2.2	13.8	0.42	sil	
	Bw _{g2}	26	59	15	0.2	2.0	6.6	17.2	21.0	38.0	2.2	12.8	0.44	sil	
	Bw _{g3}	15	69	16	0.2	1.5	3.0	10.3	14.0	55.0	3.0	13.0	0.22	sil	
	C _{g1}	21	64	15	0.5	1.4	3.1	16.0	27.0	37.0	3.0	12.0	0.33	sil	
	C _{g2}	42	50	8	0.3	1.3	5.2	35.0	36.0	14.0	2.0	6.0	0.84	sil	
	C _{g3}	44	49	7	0.3	2.0	5.5	37.0	36.0	13.0	1.0	5.0	0.90	sil	
Mean	31	57	12									0.54	-		

Continued next page

Table-8. Continued

Soils	Horizon	mm											Sand/ silt Ratio	Textural Class
		Total			Sand			Silt		Clay				
		sand (2-0.05)	Silt (.05-.02)	Clay (.002)	Coarse (2.0-0.5)	Medium (0.5 - 0.25)	Fine (0.25-.10)	Very fine (0.10-0.05)	Coarse (.05-.02)	Fine (.02-.002)	Clay			
											Coarse (.002-.001)	Fine <.001		
Silmandi	Ap1	22	58	20	-	2.0	3.0	17.0	23.0	35.0	4.0	16.0	0.38	Sil
	Ap2	28	50	22	-	-	3.0	24.0	18.0	31.5	4.5	18.0	0.56	l
	Bwg1	27	52	21	-	-	5.0	22.0	24.0	28.0	5.0	16.0	0.52	sil
	Bwg2	36	59	5	-	-	4.0	33.0	43.0	16.0	1.0	4.0	0.61	sil
	Bwg3	52	44	3	-	-	33.5	20.0	42.0	11.5	0.5	2.0	1.18	l
	Cg1	56	40	4	-	-	8.0	48.0	27.5	13.0	1.5	2.0	1.40	l
	Cg2	66	30	4	-	-	26.0	48.0	9.5	15.5	-	1.0	2.20	sl
Cg3	30	67	3	-	-	2.0	28.0	43.0	24.5	1.0	1.5	0.45	sil	
Mean	40	50	10	-	-	-	-	-	16.9	61.0	0.70	13.9	0.91	-
Lokdeo	Ap1	7	78	15	0.71	0.66	1.39	4.74	16.9	61.0	0.70	13.9	0.09	sil
	Ap2	6	72	22	-	0.50	2.5	3.30	13.3	58.4	6.00	16.0	0.08	sil
	Bwg1	6	71	23	-	0.50	1.50	4.00	17.0	54.0	3.0	19.0	0.08	sil
	Bwg2	7	70	23	-	0.12	1.25	6.13	14.7	55.5	5.0	17.5	0.10	sil
	Bg3	8	80	12	-	-	1.00	7.67	31.4	50.8	3.8	6.0	0.10	si
	Cg1	4	79	17	-	-	0.25	1.25	7.7	73.5	4.5	13.0	0.05	si
	Cg2	4	79	17	-	-	0.30	1.50	10.5	70.5	5.0	12.0	0.05	si
Cg3	5	69	26	-	-	1.0	2.50	11.5	59.0	7.0	19.0	0.07	sil	
Mean	6	75	19	-	-	-	-	-	3	44	16.0	34	0.07	-
Ghatall	Ap1	4	46	50	-	0.5	1.3	1.2	3	44	16.0	34	0.09	sic
	Ap2	3	41	57	-	0.1	0.2	1.7	2	40	14.0	43	0.07	sic
	Bwg1	3	33	64	-	0.1	0.4	1.5	3	31	13.0	51	0.09	c
	Bwg2	4	36	60	-	0.3	0.9	1.1	2	36	11.5	48.5	0.11	c
	Bwg3	6	48	46	-	0.2	0.5	5.3	6	42	14.0	32.0	0.12	sic
	Cg1	12	57	31	-	1.5	3.2	7.3	19	38	6.0	25.0	0.21	sic
	Cg2	18	65	17	--	1.6	3.8	12.6	32	33	3.0	14.0	0.28	sic
Cg3	26	62	12	-	1.6	5.3	17.1	28	34	2.0	10.0	0.42	sic	
Mean	10	49	41	-	-	-	-	-	-	-	-	-	0.17	-
Sherpur	Ap1	12	80	8	1.0	2.0	2.0	7.5	33.5	49.0	2.5	2.5	0.15	si
	Bwg1	13	78	9	-	1.0	2.0	10.0	33.0	45.3	1.70	7.0	0.17	sil
	Bwg2	8	72	20	-	0.50	0.50	7.0	8.0	64.0	7.5	12.5	0.11	sil
	Bwg3	4	57	39	-	0.00	1.0	2.0	8.5	48.5	16.0	24.0	0.07	sil
	Cg1	12	73	15	-	0.00	1.0	11.0	29.0	44.5	6.0	8.5	0.16	sil
	Cg2	21	70	9	-	-	1.0	20.0	36.0	36.0	3.0	4.0	0.30	sil
	Mean	12	72	16	-	-	-	-	-	-	-	-	-	0.16
Grand mean		26	56	18	-	-	-	-	-	-	-	-	0.93	-

5.2.2. Moisture at field condition

The moisture contents at field condition of the pedons ranged from 6 to 29 percent with a mean value of 21 percent (Table -9). The highest mean moisture of the profiles is observed in the Sherpur soil whereas the lowest mean moisture is observed in the Lokdeo soils. Burrows and Kirkham (1958) observed variation in field moisture values with the variation in texture of different soils. They stated that the increase of field moisture of the soils can be attributed to the increase of clay content with depth. During the collection of soil samples, the lower horizons were wet, whereas the upper horizons were relatively dry. The vertical distribution pattern of the moisture at field condition is more or less uniform within the profiles except those of Lokdeo soils. The Lokdeo soil was relatively dry at the time of sampling.

5.2.3. Hygroscopic moisture

Hygroscopic moisture of the soils varies from 0.2 to 3.8 percent with mean value of 1.6 percent (Table-9). The hygroscopic moisture content in the present soils, in general, are rather low. The highest hygroscopic moisture percent are record in the Ghatail series. The soils of the Melandaha series contain the lowest hygroscopic moisture. Such a variation in moisture content retained by air-dry soils is possibly due to the difference in their clay and organic matter contents. The relationship between the hygroscopic moisture contents and the amount of clay in the soils is presented in Fig.13. From the figure it is clear that the clay contents of the soils show a positive correlation ($r=+0.84^{**}$) with the hygroscopic moisture content.

The oven dry/ air dry (OD/AD) ratio of the present soils vary within the range of 0.94 to 1.0 with a mean value of 0.98 (Table-9). The highest mean of oven dry/ air dry ratio among the profiles are found in Melandaha and the lowest in Dhamrai and Ghatail soils. The OD/ AD ratio is dependent on the quantity and type of clay minerals present in the soil. A significant negative correlation ($r= - 0.64^{**}$) was found between OD/ AD ratio and the percent clay of the soils under the present study (Fig. 14). As stated previously the oven dry moisture of the soils is controlled by the clay content of the soils.

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Table-9. Some physical properties of the studied soils.

Soils	Horizon	Depth (cm)	OD/AD ratio	Hygroscopic moisture (%)	Moisture at Field condition (%)	Loss on ignition (L.O.I) (%)	n Value (%)
Melandaha	APg1	0-9	0.99	0.6	25	4.9	0.51
	APg2	9-15	0.99	0.6	26	2.9	0.85
	Bwg1(?)	15-28	0.99	0.7	25	3.1	0.76
	Bwg2(?)	28-36	0.99	0.6	25	7.9	0.85
	2C1	36-46	1.00	0.2	21	2.2	0.76
	2C2	46-57	0.99	0.3	21	4.1	0.79
	3A1b(?)	57-72	0.99	0.6	22	3.0	0.80
	4C	72-100+	0.99	0.2	21	1.8	0.72
	Mean		0.99	0.5	23	3.7	0.75
Dhamrai	Apg1	0-10	0.94	1.4	18	11.4	0.10
	Apg2	10-15	0.97	2.5	20	5.8	0.17
	Bwg1	15-33	0.97	2.5	21	6.4	0.23
	Bwg2	33-43	0.97	2.9	20	4.5	0.17
	Cg1	43-63	0.98	2.4	23	8.3	0.63
	Cg2	63-88	0.98	2.9	22	4.5	0.36
	Cg3	88-113	0.98	1.5	24	4.3	0.44
	2Cg4	113-126+	0.98	3.0	29	6.5	0.41
	Mean		0.97	2.4	22	4.8	0.31
Sonatala	Apg1	0-10	0.99	0.8	19	4.1	0.10
	Apg2	10-17	0.99	0.9	20	2.3	0.18
	Bwg1	17-35	0.98	1.3	21	4.6	0.24
	Bwg2	35-47	0.99	1.2	20	3.7	0.18
	Bwg3	47-59	0.98	1.6	23	4.2	0.34
	Cg1	59-77	0.98	1.5	20	5.1	0.18
	Cg2	77-93	0.99	0.8	21	2.0	0.29
	Cg3	93-125+	0.99	0.8	20	4.0	0.30
	Mean		0.98	1.1	21	4.0	0.22

Continued next page

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Table-9. Continued

Soils	Horizon	Depth (cm)	OD/AD ratio	Hygroscopic moisture (%)	Moisture at Field condition (%)	Loss on ignition (L.O.I) (%)	n Value (%)
Silmandi	Apg1	0-10	0.98	1.4	29	6.7	0.58
	Apg2	10-16	0.98	1.5	29	8.6	0.57
	Bwg1	16-38	0.99	1.2	28	5.8	0.54
	Bwg2	38-47	1.00	1.0	24	3.8	0.80
	Bwg3	47-61	0.99	0.8	22	2.7	0.84
	Cg1	61-74	0.99	0.6	21	3.3	0.62
	Cg2	74-90	0.99	0.7	22	3.8	0.69
	Cg3	90-110+	0.99	1.2	21	6.9	0.66
	Mean		0.98	1.1	24	5.2	0.66
Lokdeo	Apg1	0-10	0.99	1.5	6	7.5	0.51
	Apg2	10-17	0.99	1.5	9	7.4	0.25
	Bwg1	17-31	0.98	1.5	10	6.8	0.20
	Bwg2	31-56	0.98	1.4	10	5.7	0.18
	Bg3	56-70	0.99	1.2	11	3.9	0.65
	Cg1	70-90	0.98	1.5	12	5.8	0.25
	Cg2	90-110	0.98	1.7	14	6.8	0.17
	Cg3	110+	0.98	2.0	14	7.9	0.11
	Mean		0.98	1.5	10	7.4	0.29
Ghatali	Apg1	0-10	0.97	3.2	16	10.6	0.12
	Apg2	10-18	0.96	3.5	20	10.5	0.21
	Bwg1	18-33	0.96	3.8	21	9.4	0.21
	Bwg2	33-51	0.97	3.4	22	9.5	0.22
	Bwg3	51-73	0.97	3.0	23	9.1	0.25
	Cg1	73-91	0.98	2.3	23	6.9	0.28
	Cg2	91-103	0.98	1.8	27	4.8	0.58
	Cg3	103-125+	0.98	2.0	28	5.0	0.82
	Mean		0.97	2.9	22	8.2	0.34
Sherpur	Apg	0-14	0.99	0.8	21	2.6	0.24
	Bwg1	14-29	0.99	0.9	25	3.4	0.62
	Bwg2	29-47	0.98	2.0	26	8.9	0.59
	Bwg3	47-66	0.98	1.5	29	8.1	0.46
	Cg1	66-96	0.97	2.6	28	11.0	0.63
	Cg2	96-122+	0.97	1.5	27	7.9	0.77
	Mean		0.98	1.5	26	7.0	0.55
Grand mean			0.98	1.6	21	5.7	0.44

5.2.4. Loss on ignition (LOI)

The LOI ranges from 1.8 to 11.4 percent with an average value of 5.7 percent (Table-9). The highest value of loss on ignition is found in the Ghatail soils which also contain higher percentage of clay whereas the Melandaha soils have the lowest value which have low contents of clay. The LOI values have been found to be positively correlated ($r = +0.67^{**}$) with the percent clay content in the studied soils (Fig. 15). A significant positive correlation ($r = +0.48^{**}$) was also found between loss on ignition and percent organic matter contents of the soils (Fig. 16).

A careful examination of loss on ignition (LOI) of soils show that higher values are encountered in the surface soils where organic carbon too has registered higher values than the subsurface soils. This is in agreement with the findings of Karim (1954) who noted that LOI of soils may be taken as an approximate measure of organic matter in absence of any combustion data, provided the consideration of data is restricted to soils which do not possess any lime. The loss on ignition is usually dependent on a number of factors such as organic matter, CaCO_3 and the type and relative abundance of the clay minerals (Khan 1954, Quasem 1956 and Hussain, 1961).

5.2.5. Particle density

Particle density of the soils ranged from 2.50 to 2.71 g/cc with a mean of 2.65 g/cc (Table - 10). These findings were in accord with the results reported by BARC (1991). Slightly higher particle densities were found in the subsoils than those in the surface. Higher values of particle density (2.70 - 2.72 gm/cm^3) in the subsoils of some Bangladesh soils was reported by Huizing (1970). The higher particle densities in the subsoils is probably due to their change in mineralogical composition.

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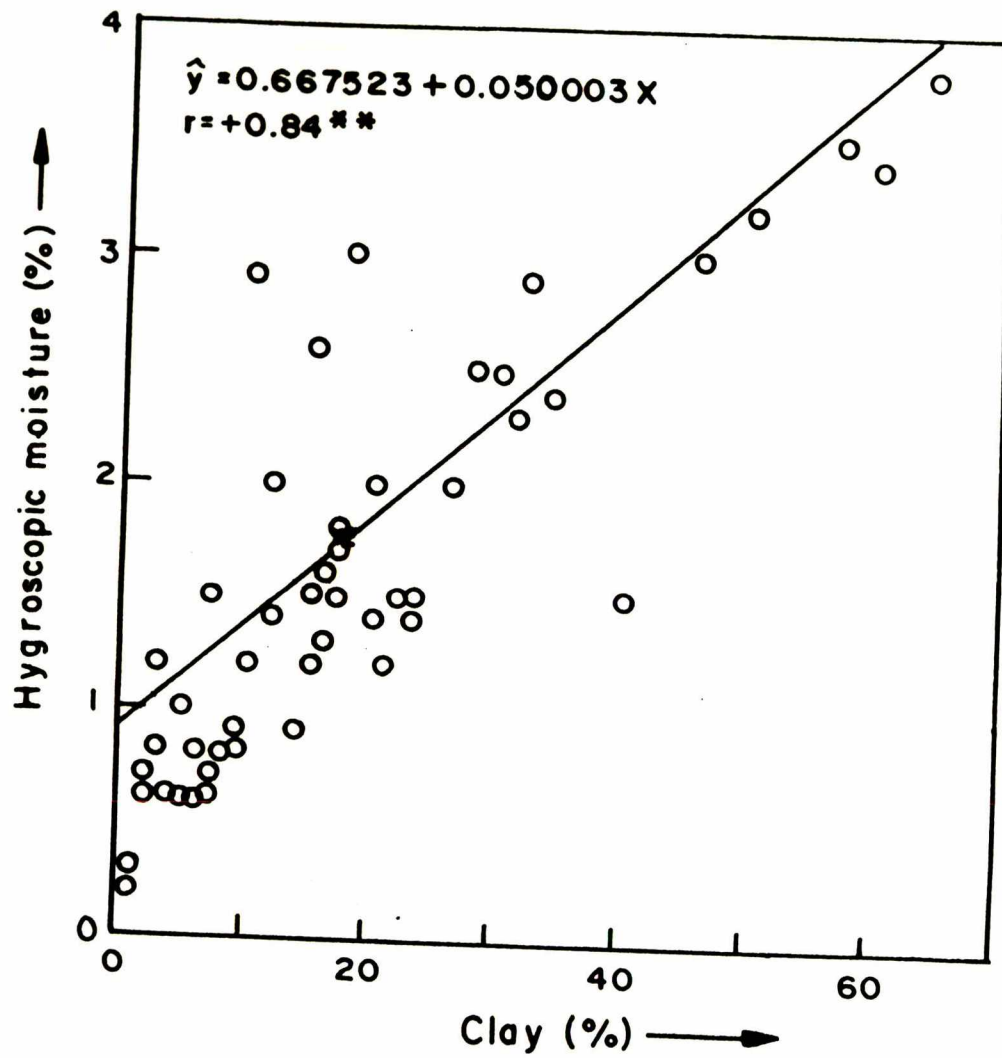


Fig. 13. Correlation between percent clay and hygroscopic moisture in the soils under investigation.

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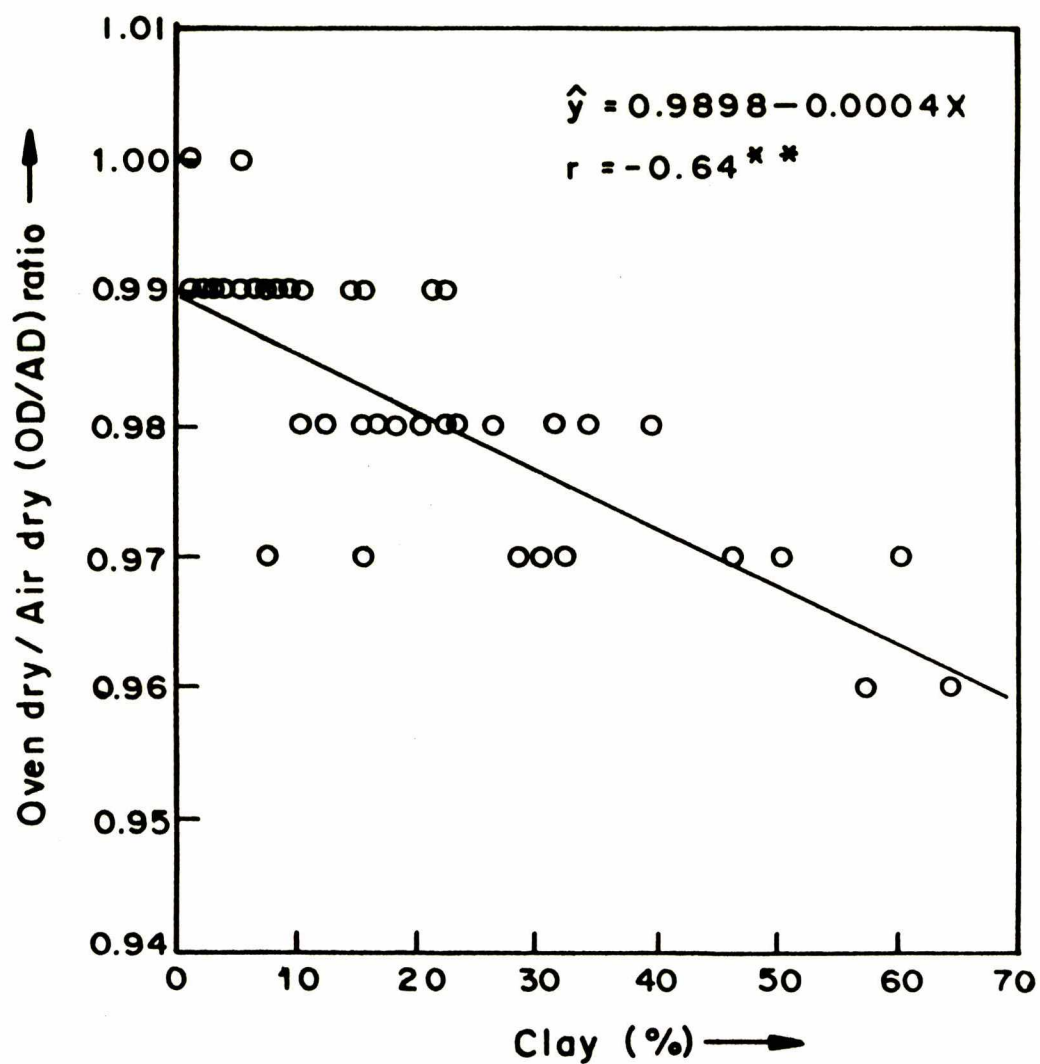


Fig.14. Correlation between percent clay and oven dry /air dry (OD/AD) ratio in the studied soils.

5.2.6. Bulk density and porosity

Bulk density and porosity are the two important properties that indicates the manifestation of the structural conditions of the soils. Data presented in Table-10 show that the bulk densities of the soils vary from 1.18 to 1.65 g/cc with a mean of 1.40 g/cc. These values are slightly higher than those presented by Kawaguchi and Kyuma (1969a and 1969b); Tanaka and Yoshida (1970); and Van Breemen (1976). These values are comparatively higher in the Ap2 horizons than in the Ap1 horizons of all the soils under the investigation. These higher bulk density values are thought to be due to compaction by ploughing and decrease of organic matter content (Landon, 1991).

The porosity of the soils ranges from 38 to 53 percent with a mean value of 47 percent (Table- 10). Total porosity values were comparatively higher in the Ap2 horizons than in the Ap1 horizon in all the soils except the Lokdeo profiles.

The high bulk density and low porosity in the Ap2 horizons of these soils is due to formation of a compact plough layer at the shallow depth of the soils. Joshua and Rahman (1983) and Rahman et al. (1992) reported that higher bulk densities could be attributed to the structural breakdown and compaction of the soils due to ploughing under wet condition. Similar results were also obtained by Xing and Dudas (1992) in some floodplain soils of China and the reason as they stated was high content of organic matter which caused high porosity through the development of granular structure.

Dolgov (1966) evaluated the soils on the basis of bulk density values. According to his criterion, most of the horizon of the soils of Brahmaputra floodplain are medium compact and only the surface horizons of Sherpur and Ghatail series can be considered as loose.

Kachinskii (1965) developed a scale for evaluating total porosity of surface soils. According to his criteria, the total porosity of the surface horizons was excellent in Melandaha, Sherpur and Ghatail, and satisfactory in Sonatala, Lokdeo, Silmandi and Dhamrai series. The data presented in table 10 and indicated higher bulk densities were

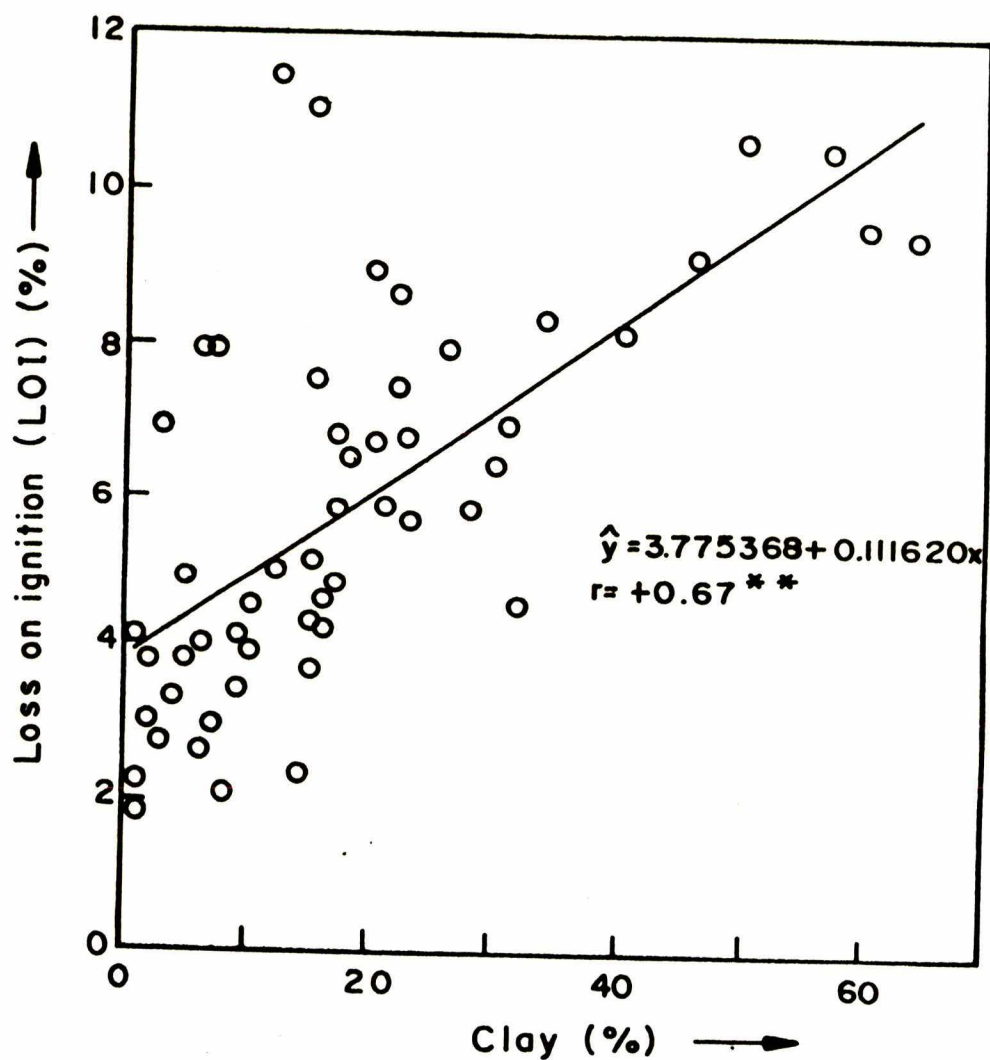


Fig. 15. Relationship between percent clay and loss on ignition (LOI) percent in the soils under investigation.

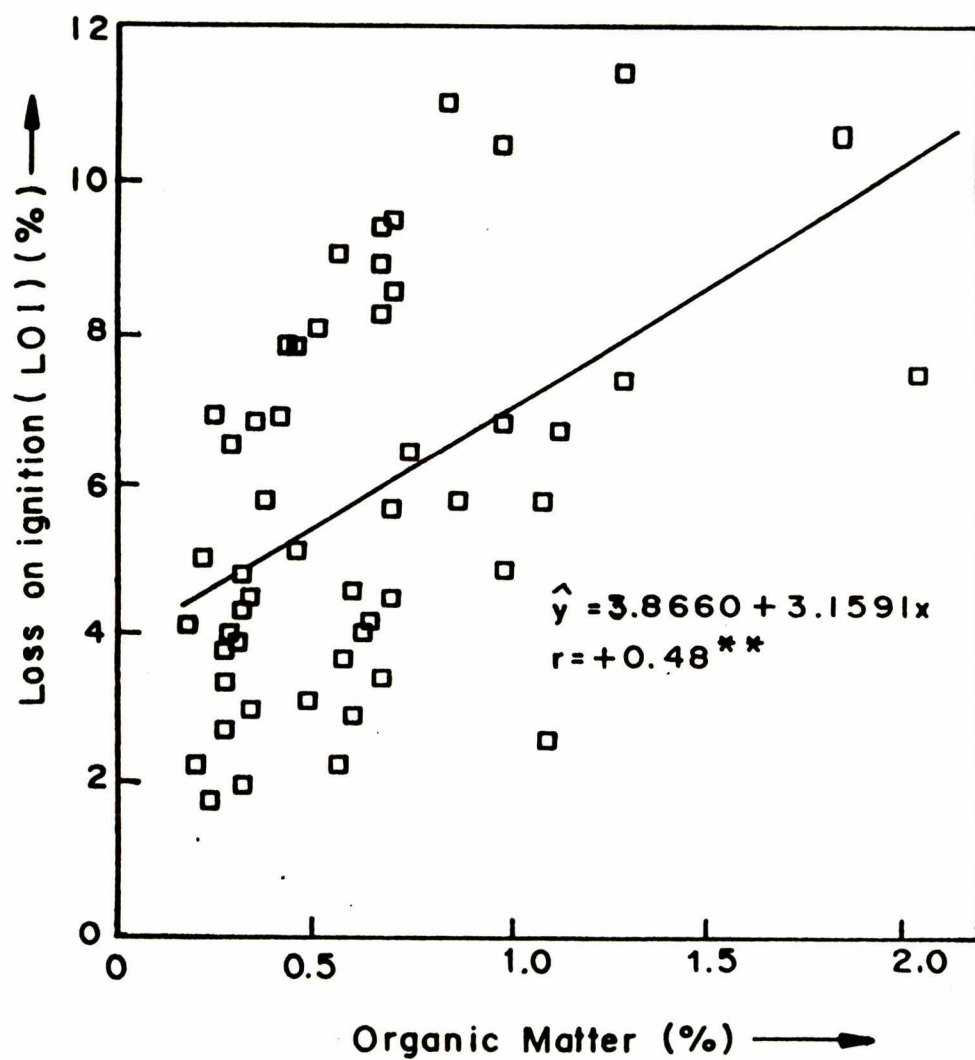


Fig. 16. Relationship between percent organic matter (O.M) and percent loss on ignition (LOI) of the soils under investigation.

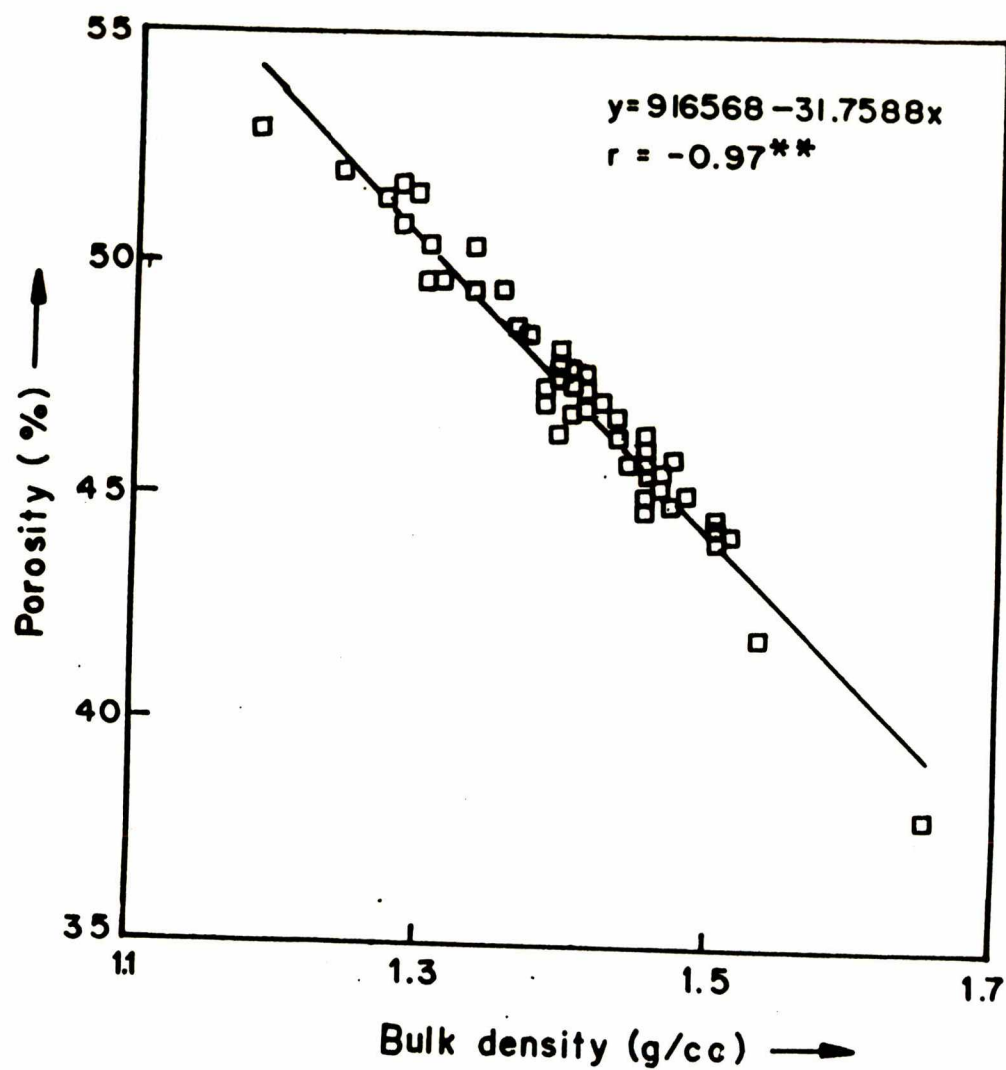


Fig. 17. Relationship between bulk density (Db) and percent porosity in the studied soils.

closely followed with higher organic matter contents. This relation is in agreement with the findings of Joshua and Rahman (1983) and Chittleborough et al. (1984).

A significant negative correlation ($r = -0.97^{**}$) was found between bulk density and porosity in the studied soils (Fig. 17). It means that the higher the porosity the lower is the bulk density and vice versa which may be due to clay and organic matter content of the soils.

5.2.7. n-value

Results of n-value have been presented in Table-9. The rate of ripening of the soil profiles under study may be characterized by the n-value. According to Soil Taxonomy (Soil Survey Staff, 1975) the n-value refers to the relation between the quantity of water at field condition and the quantities of clay and humus contents in the soils.

Soils included in the present study have the n-value ranging from 0.10 to 0.85 with a mean value of 0.44 percent (Table-9). The highest n-value among the profiles is found in Melandaha and the lowest in Lokdeo soils. This value is dependent on the clay present in the soil. These soils are in a ripe condition (Pons and Zonneveld, 1965). The n-value has been used as a criteria for separation of the soils of Inceptisols and Entisols. The soil of Entisols should have, between 20 - 50 cm below the mineral soil surface and n-value of 0.7 or more in one or more sub-horizon. On the other hand, Inceptisols have n-value of <0.7 to a depth of at least 50 cm. Thus, all the soils under the present investigation except Melandaha series can be placed in the Inceptisols order and the Melandaha series in the Entisols order.

There was a negative relationship ($r = -0.54^{**}$) between clay content and the n-value (Fig. 18).

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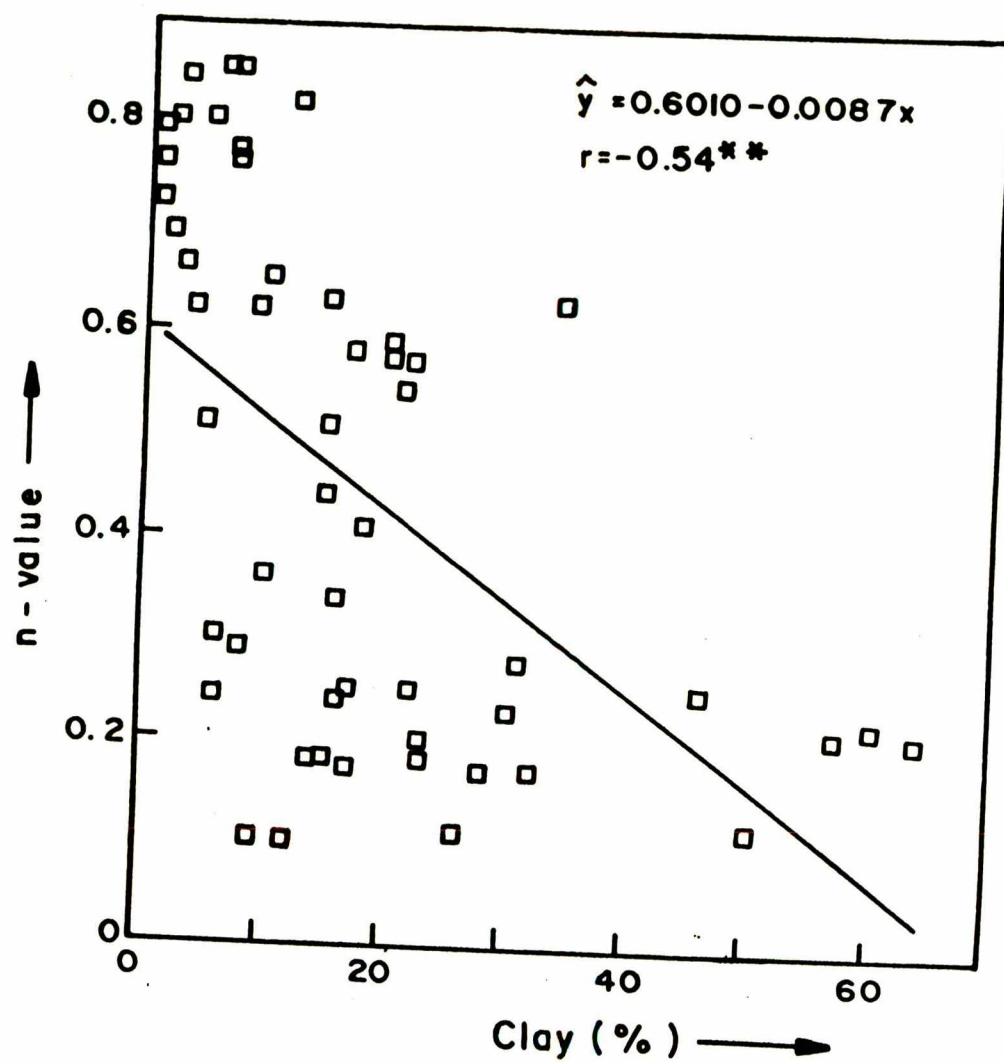


Fig. 18. Relationship between percent clay and n-value in the studied pedons.

Table-10. Particle density, bulk density, total porosity and hydraulic conductivity of the studied soils.

Soils	Horizon	Depth (cm)	Particle density (Dp) gm / cc	Bulk density (Db) gm / cc	Total porosity (%)	Saturated hydraulic conductivity cm/hr.
Melandaha	Apg1	0-9	2.66	1.29	52	0.45
	Apg2	9-15	2.65	1.44	46	0.73
	Bwg1(?)	15-28	2.62	1.45	45	0.91
	Bwg2(?)	28-36	2.67	1.50	44	1.02
	2C1	36-46	2.68	1.41	47	ND
	2C2	46-57	2.68	1.45	46	ND
	3A1b(?)	57-72	2.66	1.47	45	1.08
	4C	72-100+	2.69	1.48	45	14.02
	Mean		2.66	1.44	46	-
Dhamral	Apg1	0-10	2.59	1.39	47	0.21
	Apg2	10-15	2.63	1.53	42	0.16
	Bwg1	15-33	2.66	1.65	38	0.09
	Bwg2	33-43	2.69	1.50	44	0.04
	Cg1	43-63	2.70	1.51	44	0.44
	Cg2	63-88	2.71	1.47	46	ND
	Cg3	88-113	2.70	1.45	46	ND
	2Cg4	113-126+	2.68	1.46	46	ND
	Mean		2.67	1.49	44	-
Sonatala	Apg1	0-10	2.62	1.30	50	0.27
	Apg2	10-17	2.68	1.43	47	0.00
	Bwg1	17-35	2.66	1.37	48	0.14
	Bwg2	35-47	2.68	1.40	48	0.10
	Bwg3	47-59	2.67	1.35	49	ND
	Cg1	59-77	2.69	1.41	48	3.56
	Cg2	77-93	2.66	1.45	45	ND
	Cg3	93-125+	2.65	1.46	45	ND
	Mean		2.66	1.39	48	-

Continued next page

Table-10. Continued

Soils	Horizon	Depth (cm)	Particle density (Dp) gm/cc	Bulk density (Db) gm/cc	Total porosity (%)	Saturated hydraulic conductivity cm/hr.
Silmandi	Apg1	0-10	2.58	1.24	52	0.22
	Apg2	10-16	2.60	1.31	50	0.00
	Bwg1	16-38	2.62	1.38	47	0.00
	Bwg2	38-47	2.63	1.33	49	0.15
	Bwg3	47-61	2.66	1.41	47	ND
	Cg1	61-74	2.67	1.45	46	ND
	Cg2	74-90	2.66	1.39	48	0.76
	Cg3	90-110+	2.68	1.42	47	ND
	Mean		2.64	1.37	48	-
Lokdeo	Apg1	0-10	2.61	1.27	51	0.20
	Apg2	10-17	2.65	1.36	49	0.16
	Bwg1	17-31	2.66	1.40	47	0.00
	Bwg2	31-56	2.65	1.41	47	0.00
	Bg3	56-70	2.68	1.39	48	ND
	Cg1	70-90	2.70	1.50	44	0.11
	Cg2	90-110	2.68	1.45	46	ND
	Cg3	110+	2.66	1.43	46	ND
	Mean		2.66	1.40	47	-
Ghatail	Apg1	0-10	2.50	1.18	53	0.30
	Apg2	10-18	2.60	1.38	47	0.00
	Bwg1	18-33	2.58	1.30	50	0.05
	Bwg2	33-51	2.63	1.40	47	0.10
	Bwg3	51-73	2.65	1.28	52	ND
	Cg1	73-91	2.61	1.45	44	ND
	Cg2	91-103	2.68	1.46	46	ND
	Cg3	103-125+	2.69	1.48	45	0.00
	Mean		2.62	1.37	48	-
Sherpur	Apg	0-14	2.60	1.28	51	0.24
	Bwg1	14-29	2.58	1.30	50	0.17
	Bwg2	29-47	2.68	1.33	50	0.32
	Bwg3	47-66	2.68	1.42	47	0.27
	Cg1	66-96	2.65	1.39	48	ND
	Cg2	96-122+	2.68	1.40	48	0.25
	Mean		2.64	1.35	49	-
Grand mean			2.65	1.40	47	-

5.2.8. Hydraulic conductivity

Hydraulic conductivity is very important to predict the nature of soils as it is related to pore size, textural class, structural types and the fluid properties.

Hydraulic conductivity of saturated soils determined by constant head method are presented in Table-10. It is evident from the data presented in the table-10, that there is no definite trend in the variation of hydraulic conductivity values with increasing depth of the profile of different soil profiles because of the heterogeneous nature of the soils.

Hydraulic conductivity was in general higher (0.20 to 0.45 cm /h) in the top soil than that in the subsoil and this may be attributed to compactness caused by prolonged ploughing under irrigation. Karim et al. (1988) reported that hydraulic conductivity is relatively high in the coarse textured soils and low in the heavy textured soils.

5.2.9. Moisture retention properties of soils

The moisture contents retained by the soils at different suctions have been presented in Table -11. The moisture at 0 tension or 0.01 kPa which correspond to maximum water holding capacity (MWHC) ranged from 38 to 53 percent with a mean value of 47 percent. The highest mean value among the profiles is found in the Sherpur soil and the lowest in the Dhamrai profile. Based on maximum water holding capacity the pedons studied show the following gradation :

Sherpur > Ghatail > Silmandi > Sonatala > Lokdeo > Melandaha > Dhamrai

The vertical distribution of maximum water holding capacity in these pedons show an irregular pattern (Table - 11). Maximum water holding capacity is more or less higher in the surface horizons of all the pedons.

Field capacity (FC) corresponding to moisture content at a tension of 33 kPa ranged between 17 and 46 percents with a mean value of 39 percent. The highest mean value of field capacity is 43 percent, and is found in Sherpur soil. The lowest mean value of field capacity is 27 percent and is found in Melandaha soil.

The vertical distribution of moisture contents at field capacity (F C) shows an irregular decrease with depth (Table - 11). The surface horizons of few profiles contain higher amount of moisture at 33 kPa tension in all the soils than the subsurface horizons.

The percentage of moisture at 1500 kPa suction which corresponds with permanent wilting point (PWP) and have been presented in Table - 11. The values ranged from 1 to 22 percent with a mean value of 11 percent. The highest mean moisture at 1500 kPa is found in the Ghatail profile and the lowest mean is found in the Melandaha profile. The vertical distribution of permanent wilting point of the Melandaha, Silmandi, Lokdeo and Ghatail soil show irregular pattern. In Dhamrai and Sherpur profiles higher values are observed in the subsurface horizon than in the surface horizons. In Sonatala soil an increase of moisture content at permanent wilting point occurs in the B - horizon.

A significant positive correlation ($r=+0.76^{**}$) was found between percent clay and percent moisture retained by the soils at 15 bar pressure (Fig.19). This indicates that the moisture content at 15 bar pressure is controlled by the clay content of the soils.

The available water capacity (AWC) ranges from 15 to 39 percent with a mean value of 28 percent. The highest mean value of available water capacity is observed in Sherpur and Sonatala soils whereas the lowest value is observed in Melandaha soils.

The vertical distribution pattern of the available water capacity are irregular. In Sonatala, Silmandi and Ghatail soil the distribution is more or less uniform.

The results of clay/ 15 bar moisture have been presented in Table - 11. The ratio vary from 0.2 to 3.5 with an average value of 1.6. The highest mean value is observed in Dhamrai soil whereas the lowest mean is found in Silmandi.

The vertical distribution of clay/ 15 bar ratio shows an irregular pattern (Table - 11).

Table-11. Moisture holding capacities of the soils under investigation

Soils	Horizon	Soil moisture constants (% by volume)				Clay 15 bar moisture
		MWHC	FC	PWP	AWC	
		0.01 kPa	0.33 bar tension (33 kPa)	15 bar tension (1500 kPa)	Available water capacity % (0.33-15bar)	
Melandaha	Apg1	52	38	5	33	1.0
	Apg2	46	37	6	31	1.2
	Bwg1(?)	45	30	8	22	0.9
	Bwg2(?)	44	31	6	25	1.0
	2C1	47	23	2	21	1.0
	2C2	46	20	1	19	2.0
	3A1b(?)	41	20	2	18	2.0
	4C	45	17	2	15	1.0
	Mean	46	27	4	23	1.3
Dhamrai	Apg1	47	37	7	30	1.7
	Apg2	42	36	9	27	3.1
	Bwg1	38	32	10	22	3.0
	Bwg2	44	40	10	30	3.2
	Cg1	44	39	11	28	3.1
	Cg2	46	37	11	26	0.9
	Cg3	46	37	10	27	1.5
	2Cg4	46	37	9	28	2.0
	Mean	44	37	10	27	2.3
Sonatala	Apg1	50	36	7	29	1.3
	Apg2	47	37	7	30	2.0
	Bwg1	49	44	9	35	1.8
	Bwg2	48	42	9	33	1.7
	Bwg3	49	38	7	31	2.3
	Cg1	48	39	7	32	2.1
	Cg2	46	37	6	31	1.3
	Cg3	45	36	6	30	1.2
	Mean	48	39	7	31	1.7

Continued next page

Table-11. Continued

Soils	Horizon	Soil moisture constants (% by volume)				Clay 15 bar moisture
		MWHC	FC	PWP	AWC	
		0.01 kPa	0.33 bar tension (33 kPa)	15 bar tension (1500 kPa)	Available water capacity % (0.33-15bar)	
Silmandi	Apg1	52	40	12	28	1.7
	Apg2	50	40	10	30	2.2
	Bwg1	47	43	16	27	1.3
	Bwg2	49	45	9	36	0.6
	Bwg3	47	41	9	32	0.4
	Cg1	46	40	10	30	0.4
	Cg2	48	38	12	26	0.3
	Cg3	47	40	13	27	0.2
	Mean	48	41	11	30	0.9
Lokdeo	Apg1	51	46	14	32	1.1
	Apg2	49	43	10	33	2.2
	Bwg1	47	40	10	30	2.3
	Bwg2	47	42	12	30	1.9
	Bg3	48	40	10	30	1.2
	Cg1	44	41	11	30	1.5
	Cg2	46	40	12	28	1.4
	Cg3	46	41	15	26	1.7
	Mean	47	42	12	30	1.7
Ghatail	Apg1	53	46	19	27	2.6
	Apg2	47	42	20	22	2.8
	Bwg1	50	43	22	21	2.9
	Bwg2	47	41	22	19	2.7
	Bwg3	52	43	20	23	2.3
	Cg1	44	36	18	18	1.7
	Cg2	46	42	14	28	1.2
	Cg3	45	39	13	26	0.9
	Mean	48	42	19	23	2.1
Sherpur	Apg	51	44	5	39	1.6
	Bwg1	49	39	8	31	1.1
	Bwg2	50	44	13	31	1.5
	Bwg3	47	43	11	32	3.5
	Cg1	47	43	15	28	1.0
	Cg2	48	44	17	27	0.5
	Mean	49	43	12	31	1.6
Grand mean		47	39	11	28	1.6

horizons. In Sonatala soil an increase of moisture content at permanent wilting point occurs in the B - horizon.

A significant positive correlation ($r=+0.76^{**}$) was found between percent clay and percent moisture retained by the soils at 15 bar pressure (Fig.19). This indicates that the moisture content at 15 bar pressure is controlled by the clay content of the soils.

The available water capacity (AWC) ranges from 15 to 39 percent with a mean value of 28 percent. The highest mean value of available water capacity is observed in Sherpur and Sonatala soils whereas the lowest value is observed in Melandaha soils.

The vertical distribution pattern of the available water capacity are irregular. In Sonatala, Silmandi and Ghatail soil the distribution is more or less uniform.

The results of clay/ 15 bar moisture have been presented in Table - 11. The ratio vary from 0.2 to 3.5 with an average value of 1.6. The highest mean value is observed in Dhamrai soil whereas the lowest mean is found in Silmandi.

The vertical distribution of clay/ 15 bar ratio shows an irregular pattern (Table - 11).

The variation in water content at different tension within the profile may be due to variation in nature and content of clay minerals and organic matter content of these soils. Diwaker and Singh (1992) also suggested that clay fractions might be dominant modifier of the water content at higher energies of tension. Soil water retention at higher tension is mainly a function of the amount and nature of clay (Ali et al., 1966; Joshua and Rahman, 1983).

Except the available water capacity , the values for the rest of the moisture constants increased with the corresponding increase in clay content. The available water capacity is observed to be maximum in the layer of silty textural group. The importance of silt fractions in widening the range of available water capacity has also been recognized by Diwakar and Singh (1992).

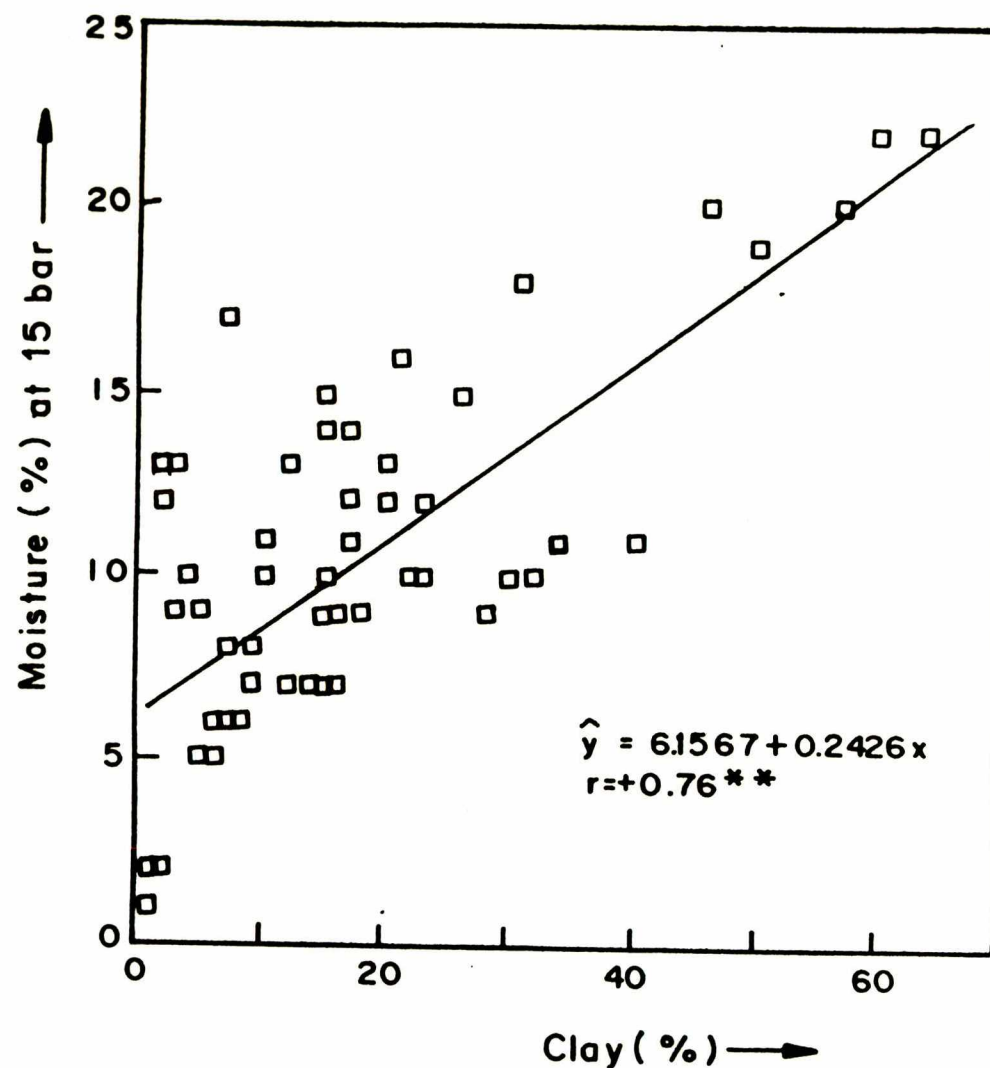


Fig. 19. Relationship between percent clay and percent moisture at 15 bar retained by the soils under the present investigation.

5.3 Chemical Properties of the Soils

5.3.1. Soil reaction (pH)

SRDI Staff (1965 -86) prepared a soil pH map for Bangladesh. . Zijssvelt (1980) attempted an arrangement of soil series of Bangladesh into family category where soil reaction was an important parameter. It has a profound influence on many factors connected with the suitability of a soil for plant growth (Truog,1961) and hence special emphasis has been given on it.

The pH of the Brahmaputra floodplain soils ranges from 5.39 to 7.85 (Table-12). Nevertheless , all the pedons are acidic to near neutral. The highest mean value of pH is found in Ghatail profile whereas the lowest mean is found in Melandaha profile.

The vertical distribution of pH in the pedons studied show a regular distribution pattern which is smaller near the surface and increases with depth except Sonatala soils (Table -12). In the Sonatala soils, the pH value is more or less uniform throughout the profile.

The increase of pH with depth is a common feature of many of the seasonally flooded soils of Bangladesh (Mujib, 1968; Brammer, 1971; and Matin, 1972). This has been attributed to the oxidation-reduction condition of the soils (Ponnamperuma, 1972). With the receding of the ground water table the ferrous iron is oxidized and the pH naturally drops first in the surface horizon or upto the oxidized zone. From the subsoil zone the soluble bases have only restricted movement where the internal drainage is poor. As a result the pH of the subsoils tends to remain at a higher level. The variations observed in soil pH was related to variations in exchangeable calcium, magnesium, iron, aluminium, free iron oxide and organic matter of the soils (Mustafa et al., 1971).

When IN KCl solution was used for determination of pH in the soils, there was a substantial decrease in pH values than measured in distilled water. This decrease in pH value has been denoted as Δ pH. All these Δ pH values were negative and ranges from - 0.56 to -1.60 with a mean value of -1.22 (Table -12).

Table-12. Chemical properties of the soils of Brahmaputra floodplain

Soils	Horizon	pH H ₂ O	pH KCl	Δ pH	Organic carbon %	Organic matter %	Total nitrogen %	C/N ratio
Melandaha	Apg1	5.39	4.41	-0.98	0.79	1.36	0.09	9
	Apg2	6.06	5.04	-1.02	0.34	0.59	0.06	6
	Bwg1(?)	6.22	5.13	-1.09	0.27	0.47	0.05	5
	Bwg2(?)	6.18	5.00	-1.18	0.24	0.41	0.05	5
	2C1	6.60	5.42	-1.22	0.21	0.36	0.02	11
	2C2	6.22	5.65	-0.57	0.20	0.34	0.02	10
	3A1b(?)	6.52	5.38	-1.14	0.19	0.33	0.02	10
	4C	6.98	6.03	-0.95	0.13	0.22	0.02	7
	Mean	6.27	5.25	-1.01	0.28	0.51	0.04	8
Dhamrai	Apg1	5.67	4.65	-1.02	0.74	1.28	0.09	8
	Apg2	5.67	4.83	-0.93	0.62	1.07	0.09	7
	Bwg1	6.38	5.37	-1.01	0.43	0.74	0.09	5
	Bwg2	6.58	5.35	-1.23	0.40	0.69	0.09	4
	Cg1	6.69	5.29	-1.40	0.38	0.66	0.06	6
	Cg2	6.82	5.38	-1.44	0.19	0.33	0.05	4
	Cg3	6.85	5.43	-1.42	0.18	0.31	0.04	5
	2Cg4	6.95	5.55	-1.40	0.16	0.28	0.04	4
	Mean	6.46	5.23	-1.23	0.42	0.67	0.07	6
Sonatala	Apg1	6.96	5.33	-1.13	0.64	1.10	0.08	8
	Apg2	7.08	6.01	-1.07	0.42	0.72	0.06	7
	Bwg1	7.05	5.58	-1.47	0.34	0.59	0.05	7
	Bwg2	6.98	5.53	-1.45	0.33	0.57	0.06	6
	Bwg3	6.93	5.39	-1.54	0.37	0.64	0.06	6
	Cg1	6.88	5.38	-1.50	0.26	0.45	0.04	7
	Cg2	6.84	5.24	-1.60	0.28	0.48	0.03	9
	Cg3	6.97	5.42	-1.55	0.26	0.45	0.03	9
	Mean	6.96	5.48	-1.41	0.36	0.62	0.05	7

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Table-12. Continued

Soils	Horizon	pH H ₂ O	pH KCl	Δ pH	Organic carbon %	Organic matter %	Total nitrogen %	C/N ratio
Silmandi	Apg1	6.05	5.28	-0.77	0.75	1.29	0.08	9
	Apg2	6.64	5.79	-0.85	0.40	0.69	0.07	6
	Bwg1	6.58	5.75	-0.83	0.50	0.86	0.07	7
	Bwg2	6.79	5.70	-1.09	0.35	0.60	0.03	12
	Bwg3	6.89	5.71	-1.18	0.25	0.43	0.02	12
	Cg1	6.84	5.74	-1.10	0.25	0.43	0.02	12
	Cg2	6.88	5.70	-1.18	0.15	0.26	0.02	8
	Cg3	6.80	5.46	-1.34	0.14	0.24	0.02	7
	Mean	6.68	5.64	-1.04	0.35	0.60	0.04	9
Lokdeo	Apg1	5.53	4.81	-0.72	1.18	2.03	0.13	9
	Apg2	6.24	5.67	-0.57	0.74	1.28	0.10	7
	Bwg1	6.30	5.74	-0.56	0.57	0.98	0.09	6
	Bwg2	6.40	5.63	-0.77	0.40	0.69	0.08	5
	Bg3	6.50	5.43	-1.07	0.27	0.47	0.07	4
	Cg1	6.56	5.36	-1.20	0.21	0.36	0.05	4
	Cg2	6.50	5.27	-1.23	0.20	0.34	0.05	4
	Cg3	6.54	5.22	-1.32	0.26	0.45	0.07	4
	Mean	6.32	5.39	-0.93	0.46	0.82	0.08	5
Ghatali	Apg1	5.99	4.88	-1.11	1.07	1.84	0.12	9
	Apg2	7.10	5.93	-1.17	0.56	0.97	0.10	6
	Bwg1	7.62	6.10	-1.52	0.38	0.66	0.08	5
	Bwg2	7.80	6.43	-1.37	0.40	0.69	0.07	6
	Bwg3	7.83	6.42	-1.40	0.32	0.55	0.06	5
	Cg1	7.85	6.32	-1.53	0.21	0.36	0.05	4
	Cg2	7.82	6.43	-1.37	0.18	0.31	0.03	6
	Cg3	7.80	6.33	-1.47	0.12	0.21	0.03	4
	Mean	7.47	6.10	-1.37	0.40	0.70	0.07	6
Sherpur	Apg	5.70	4.12	-1.58	0.73	1.26	0.08	9
	Bwg1	6.18	4.55	-1.53	0.48	0.83	0.06	8
	Bwg2	6.10	4.50	-1.60	0.38	0.66	0.09	4
	Bwg3	5.97	4.41	-1.56	0.29	0.50	0.06	5
	Cg1	6.09	4.56	-1.53	0.48	0.83	0.09	5
	Cg2	6.20	4.60	-1.60	0.25	0.43	0.05	5
	Mean	6.4	4.45	-1.56	0.43	0.75	0.07	6
Grand mean		6.60	4.43	-1.22	0.38	0.66	0.06	7

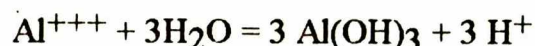
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The highest mean ΔpH values within the profiles were found in Sonatala soils and the lowest in the Lokdeo soils.

The distribution pattern of ΔpH within the soil profile is irregular and the ΔpH value is lower in the surface than in the subsurface.

The K^+ in KCl solution will replace exchangeable H^+ on clay surfaces and this displaced H^+ will tend to depress the pH of the soil-water suspension.

Nye et al (1961) in their study of ion exchange reactions reported that high content of Al^{+++} from the octahedral layer of 2 : 1 type expanding lattice clays was replaced by K^+ ion in the exchange sites of clays. This Al^{+++} undergoes a reaction with water molecules as follows :



The H^+ ions thus produced will help in depressing the pH values of the external soil solution further.

When ΔpH values were plotted against pH H_2O a significant negative correlation ($r = -0.40^{**}$) was observed (Fig. 20).

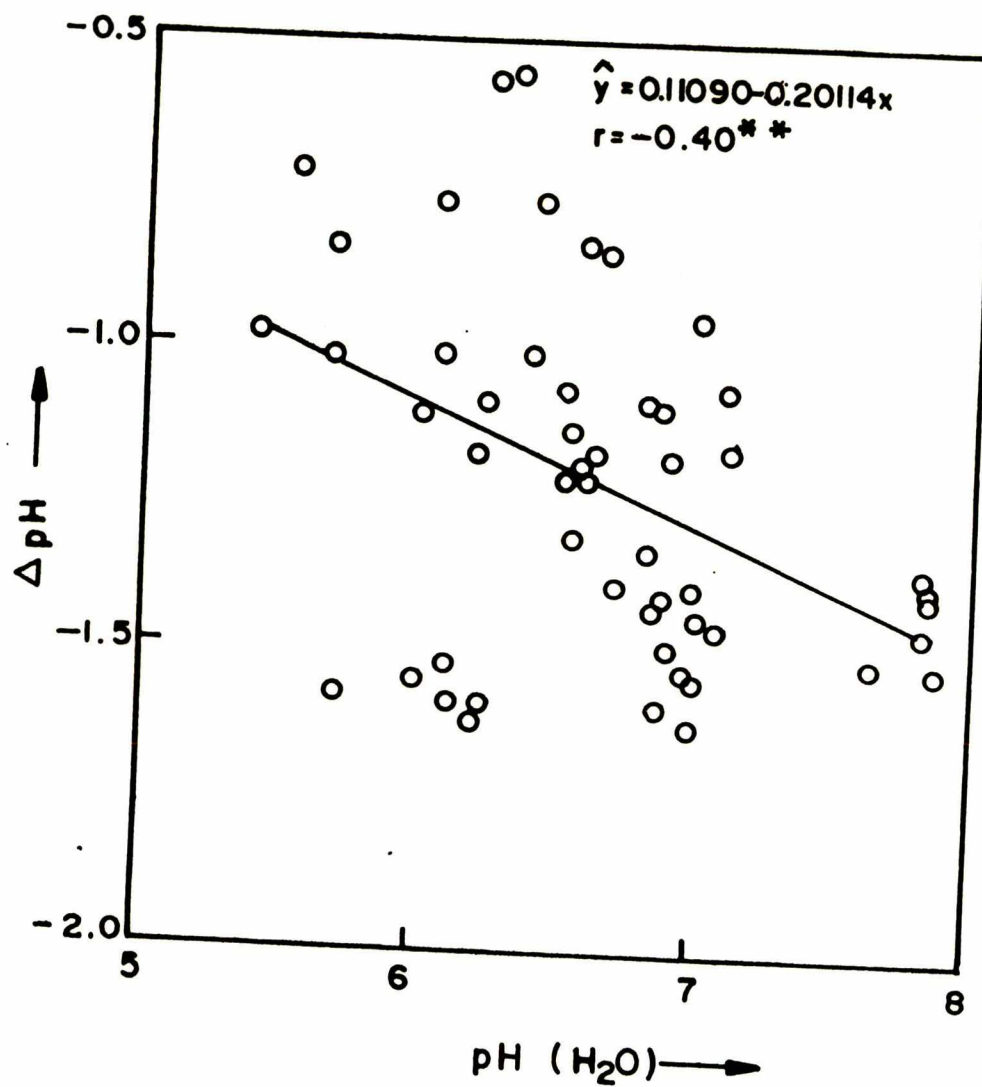
A positive correlation ($r = +0.80^{**}$) was also found between pH H_2O and pH KCl (Fig. 21).

The negative ΔpH values indicates that the colloids in the soils have a net negative charge (Uehara and Keng,1975).The ΔpH values of the soils under the present investigation are considered high (mean ΔpH - 1.22) for soils having a mean clay content of 18 percent. The high negative ΔpH further suggests that the soil colloids have a low point of zero charge (ZPC) (Uehara and Keng,1975).

5.3.2 Organic carbon and total nitrogen

Organic matter is the life of the soil and is the store house of plant nutrients. It is the primary source of available nitrogen and to a lesser degree, it is also the source of phosphorus, iron, and sulphur. Role of organic matter on improvement of soil structure,

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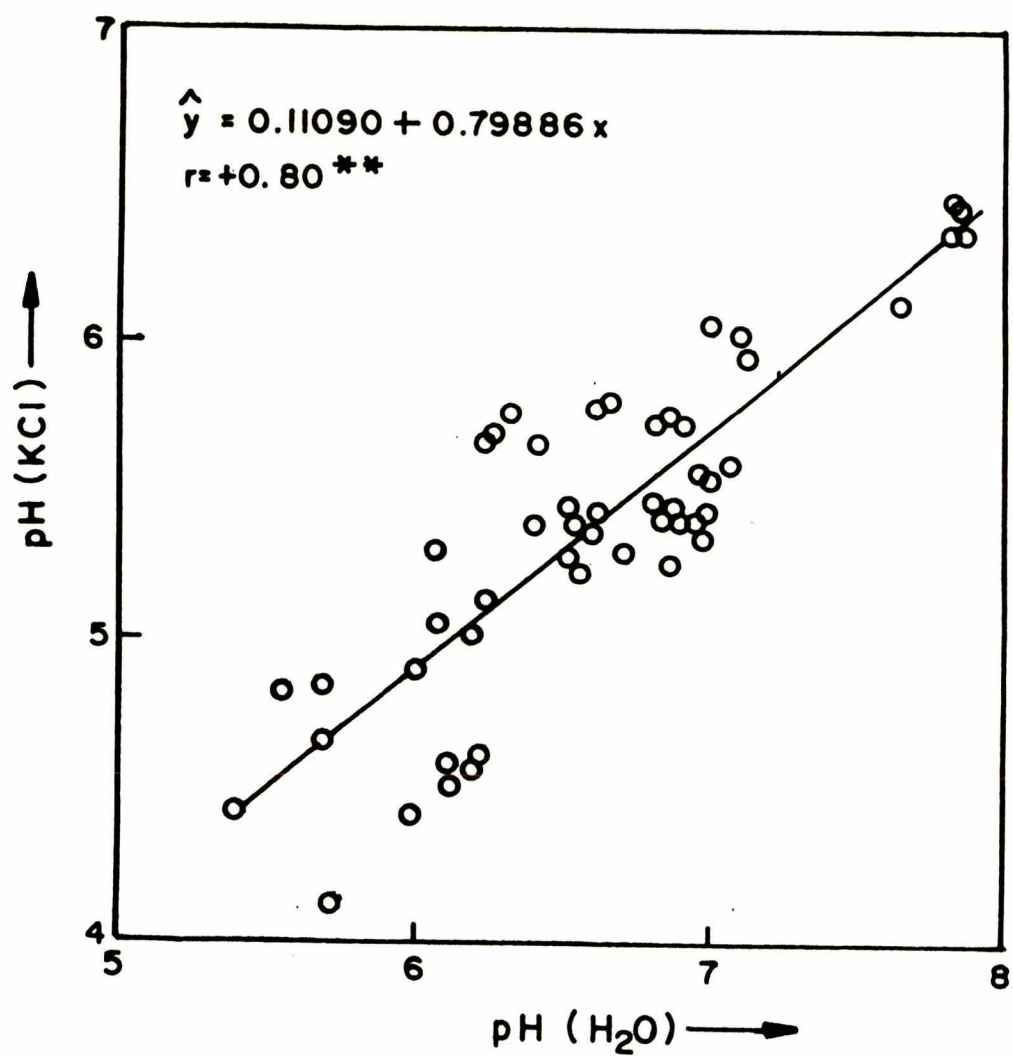


Fig. 21. Relationship between pH H₂O and pH KCl in the soils under investigation.

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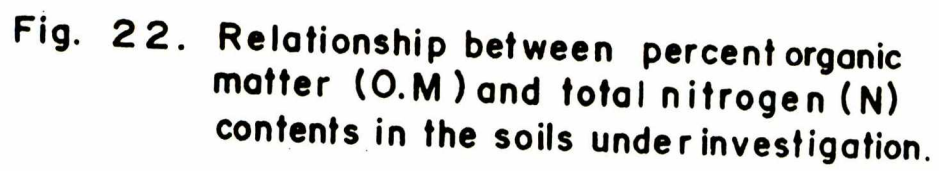
water and nutrient holding capacities in light soil, release of available nutrients from native source, control of soil erosion, and supply of food and energy for beneficial soil microbe are well established (Islam, 1993). Organic matter is a key diagnostic criteria of those soils in which organic matter accumulation in the soil is a dominant pedogenic process (Buol et al., 1980).

The organic carbon content ranges from 0.12 to 1.18 percent with a mean value of 0.38 percent (Table-12). The high amount of organic carbon occurs in the soils of the Lokdeo series. The highest mean value of organic carbon occurs in the soils of Lokdeo series whereas the lowest mean is found in Melandaha soil. The organic carbon content in these soils is rather low (BARC, 1989). The low content of carbon is presumably caused by rapid decomposition of organic residues owing to the prevalence of high temperature and rainfall coupled with higher cropping intensity. The organic carbon content in the studied soils show the following gradation in decreasing order :

Lokdeo > Sherpur > Dhamrai > Ghatail > Sonatala > Silmandi > Melandaha

The organic carbon content in the present soils show a general tendency of decrease with depth, but the decrease is, however, not gradual (Table-13). The organic carbon content of surface horizons of the pedons is higher than those in the subsurface horizon. The higher organic carbon in the surface horizons might be due to maximum root activity of biomass as well as natural and artificial additions of fresh and partly decomposed organic material in the form of manure and crop residues. The highest content of organic carbon is found in the surface soil of Lokdeo profile whereas the lowest content is found in Sonatala profile.

The total nitrogen content in the present soils ranges from 0.02 to 0.13 percent (Table-12). The mean value for total nitrogen is 0.06 percent. Like before as with organic



carbon, the highest mean value of nitrogen content within the profile is found in Lokdeo soil whereas the lowest amount is found in Melandaha soil.

The vertical distribution pattern of total nitrogen follows closely the sequence of organic carbon (Table-12). Surface soil of the studied pedon contain the higher amount of nitrogen than the underlying horizons except the Sherpur soils.

A highly significant correlation ($r = +0.93^{**}$) was found between percent organic matter and percent total nitrogen content in the studied soils (Fig.22).

The values of organic carbon and total nitrogen is in accord with the findings of Idris(1975),who observed similar results in the Ganges floodplain soils.

The C/N ratio ranges from 4.0 to 12 (Table-12). The highest mean C/N ratio is found in the Melandaha soil whereas the lowest value is found in Lokdeo soil.

Distribution pattern of C/N ratio value in the profiles from the surface downward show an irregular pattern with depth in most of the soils (Table-12). The irregular distribution of C/N ratio value in the profiles is due to the different degree of decomposition at various horizons.

5.3.3 Cation exchange capacity and exchangeable actions

5.3.3.1 Action exchange capacity (CEC)

The CEC is a very important physicochemical property of soils for predicting their quantity and type of clay minerals and their nutrient holding capacity (Landon,1991). It also plays a vital role in determining the trend and type of pedogenic processes of soils (Buol et al.,1980). The weathering stage of soils can also be predicted by their cation exchange capacity.

The cation exchange capacities of the soils under the present investigation range from as low as 3.41 to as high as 21.84 cmol /kg soil with a mean value of 10.10 cmol/kg soil (Table-13). The reason for such low CEC values is due in most cases to their low clay content (Sidhu et al. 1994). The highest mean value of CEC among the profiles is found

in the Ghatail soils and the lowest in the Melandaha soil. The cation exchange capacity of soils of the Gangetic alluvium is much higher than that of the Brahmaputra alluvium (Hossain, 1995).

The variation of CEC values of the pedons studied reflects the important influence of both clay and organic matter content of these soils. The distribution patterns of cation exchange capacity with depth in the profiles show an irregular trend like those of clay and organic matter (Table - 13).

The index of weathering ($IW = CEC / \text{Clay ratio}$) of these soils is found to vary from 0.31 to 2.77 with a mean index of 0.81 (Table -13). Such a wide range in the above ratio indicates a wide variation in the type of minerals of the clay fraction in these soils.

A significant positive correlation ($r = +0.87^{**}$) has been found between CEC and percent clay (Fig. 23). A positive correlation ($r = +0.30^{*}$) is also found between percent organic matter and cation exchange capacity of the soils (Fig-24). However, the degree of correlation coefficient between CEC and clay is appreciably higher than that between CEC and organic matter. This result is in accord with the findings of Lavti et al. (1969) and Landon (1991), who found that the CEC was significantly correlated with clay and organic matter, but clay is contributing the most.

The soils under study have relatively lower CEC as compared to the CEC of soils developed under similar climatic condition (Dudal and Bramao, 1965). The CEC of mineral soils may range, in accordance with the clay content, from a few to 50 to 60 me per 100g, whereas the CEC of organic soils may exceed 200 cmol/kg (Wiklander, 1965). Karim and Islam (1956) reported that the average CEC of clay and silt fractions of the soils and sediments of Bangladesh was 27 and 12 cmol/kg, respectively. This indicates that the silt fraction of Bangladesh soils have cation exchange capacity. This is possibly due to the occurrence of considerable quantity of mica which are in different stages of weathering (Jackson, 1965).

Table-13. Results of cation exchange capacity and exchangeable cations in the studied soils.

Soils	Horizon	Exchangeable cation (cmol/kg soil)							$\text{Ca}^{++}/\text{Mg}^{++}$ ratio	CEC/Clay ratio.
		Ca^{++}	Mg^{++}	Na^{+}	K^{+}	H^{+}	CEC	TEB		
Melandaha	Apg1	2.84	1.11	0.32	0.10	2.12	6.76	4.37	2.56	1.35
	Apg1	3.50	1.22	0.26	0.10	1.61	6.76	5.08	2.87	0.96
	Bwg1(?)	3.72	1.52	0.26	0.10	1.01	6.65	5.60	2.45	0.95
	Bwg2(?)	3.50	1.15	0.26	0.10	1.58	6.66	5.01	3.04	1.11
	2C1	1.10	0.30	0.13	0.10	1.01	3.12	1.63	3.67	1.56
	2C2	1.40	0.53	0.13	0.08	1.35	3.64	2.16	2.64	1.82
	3A1b(?)	1.56	0.57	0.32	0.10	1.05	3.64	2.55	2.74	0.91
	4C	1.54	0.68	0.26	0.08	0.75	3.41	2.56	2.26	1.70
	Mean	2.40	0.88	0.24	0.09	1.31	5.08	3.62	2.78	1.29
Dhamrai	Apg1	4.39	1.32	0.58	0.23	2.20	8.84	6.52	3.32	0.73
	Apg2	4.87	1.61	0.55	0.21	1.40	8.84	7.24	3.02	0.31
	Bwg1	5.55	1.84	0.58	0.18	1.56	9.88	8.15	3.01	0.32
	Bwg2	5.31	1.81	0.55	0.21	2.10	10.92	7.88	2.93	0.34
	Cg1	5.31	2.30	0.58	0.21	2.18	11.44	8.40	2.30	0.34
	Cg2	5.55	2.43	0.62	0.23	2.52	11.96	8.83	2.28	1.19
	Cg3	3.98	1.71	0.49	0.21	4.30	11.96	6.39	2.33	0.79
	2Cg4	4.34	2.01	0.52	0.22	3.21	10.58	7.09	2.15	0.58
	Mean	4.91	1.88	0.56	0.21	2.43	10.55	7.56	2.67	0.57
Sonatala	Apg1	2.77	1.15	0.55	0.13	2.20	6.89	4.60	2.41	0.74
	Apg2	2.77	1.38	0.42	0.13	1.60	6.50	4.70	2.01	0.46
	Bwg1	3.24	1.74	0.55	0.16	2.18	8.15	5.69	1.86	0.50
	Bwg2	3.70	2.15	0.58	0.16	1.58	8.19	6.59	1.72	0.54
	Bwg3	4.19	2.76	0.55	0.13	2.08	9.85	7.63	1.52	0.61
	Cg1	5.09	2.70	0.58	0.13	1.75	9.50	8.50	1.88	0.63
	Cg2	2.54	1.55	0.42	0.16	0.58	5.50	4.67	1.64	0.68
	Cg3	2.20	1.35	0.16	0.13	1.10	5.30	3.84	1.63	0.75
	Mean	3.31	1.97	0.48	0.14	1.43	7.48	5.90	1.83	0.61

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Table-13. Continued

Soils	Horizon	Exchangeable cation (cmol/kg soil)							Ca ⁺⁺ /Mg ⁺⁺	CEC/Clay
		Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	H ⁺	CEC	TEB	ratio	ratio.
Silmandi	Apg1	4.19	2.30	0.52	0.13	3.10	10.44	7.14	1.82	0.52
	Apg2	5.09	1.51	0.52	0.10	3.12	10.92	7.22	3.37	0.49
	Bwg1	5.09	1.32	0.49	0.10	2.35	9.88	7.00	3.85	0.47
	Bwg2	4.87	1.51	0.35	0.08	0.59	7.50	6.81	3.22	1.50
	Bwg3	4.87	1.32	0.29	0.08	1.14	7.80	6.56	3.69	2.60
	Cg1	2.30	2.08	0.32	0.08	2.12	7.80	4.78	1.10	1.95
	Cg2	2.56	2.21	0.26	0.05	2.52	7.80	5.08	1.16	1.95
	Cg3	3.55	2.51	0.26	0.05	1.85	8.32	6.37	1.41	2.77
	Mean	4.06	1.84	0.37	0.08	2.09	8.80	6.37	2.45	1.53
Lokdeo	Apg1	5.31	1.91	0.58	0.18	2.21	10.92	7.98	2.78	0.73
	Apg2	5.55	2.48	0.52	0.13	1.85	11.00	8.68	2.23	0.50
	Bwg1	4.63	2.19	0.49	0.13	4.23	11.96	7.44	2.11	0.52
	Bwg2	5.99	2.86	0.49	0.16	2.83	12.48	9.50	2.09	0.54
	Bg3	5.09	2.60	0.42	0.10	4.51	13.00	8.21	1.95	1.08
	Cg1	5.55	2.92	0.46	0.13	4.13	13.52	9.06	1.90	0.79
	Cg2	6.47	3.57	0.49	0.13	1.85	13.52	10.66	1.81	0.79
	Cg3	7.41	3.58	0.62	0.18	0.15	13.00	11.79	2.06	0.50
	Mean	5.74	2.76	0.50	0.14	2.72	12.42	9.20	2.11	0.58
Ghatail	Apg1	6.03	2.30	0.84	0.24	6.94	17.16	9.41	2.62	0.34
	Apg2	8.18	3.32	1.27	0.18	4.50	17.68	12.95	2.46	0.32
	Bwg1	7.43	3.03	1.04	0.24	7.74	20.80	11.74	2.45	0.32
	Bwg2	8.89	3.55	1.01	0.21	7.74	21.84	13.66	2.50	0.36
	Bwg3	6.99	3.45	0.88	0.18	8.86	20.80	11.50	2.02	0.45
	Cg1	6.61	2.80	0.94	0.13	4.96	16.12	10.48	2.36	0.52
	Cg2	5.33	2.43	0.98	0.10	0.05	8.92	8.84	2.19	0.52
	Cg3	4.63	2.07	0.81	0.10	1.18	8.84	7.61	2.23	0.73
	Mean	6.76	2.87	0.97	0.17	5.24	16.52	10.77	2.35	0.44
Sherpur	Apg	3.20	1.78	0.68	0.10	3.48	9.36	5.76	1.79	1.17
	Bwg1	5.09	1.75	0.52	0.10	1.78	9.36	7.46	2.90	1.04
	Bwg2	7.17	2.39	0.42	0.18	1.19	11.44	10.16	3.00	0.57
	Bwg3	4.40	1.38	0.39	0.16	4.82	11.55	6.25	3.19	0.29
	Cg1	3.02	1.59	0.42	0.13	3.82	9.36	5.16	1.90	0.62
	Cg2	4.39	2.18	0.39	0.16	1.54	8.84	7.12	2.01	0.98
	Mean	4.54	1.67	0.35	0.14	2.90	9.88	6.66	2.63	0.77
Grand mean		4.55	1.98	0.50	0.14	2.58	10.10	6.35	2.41	0.82

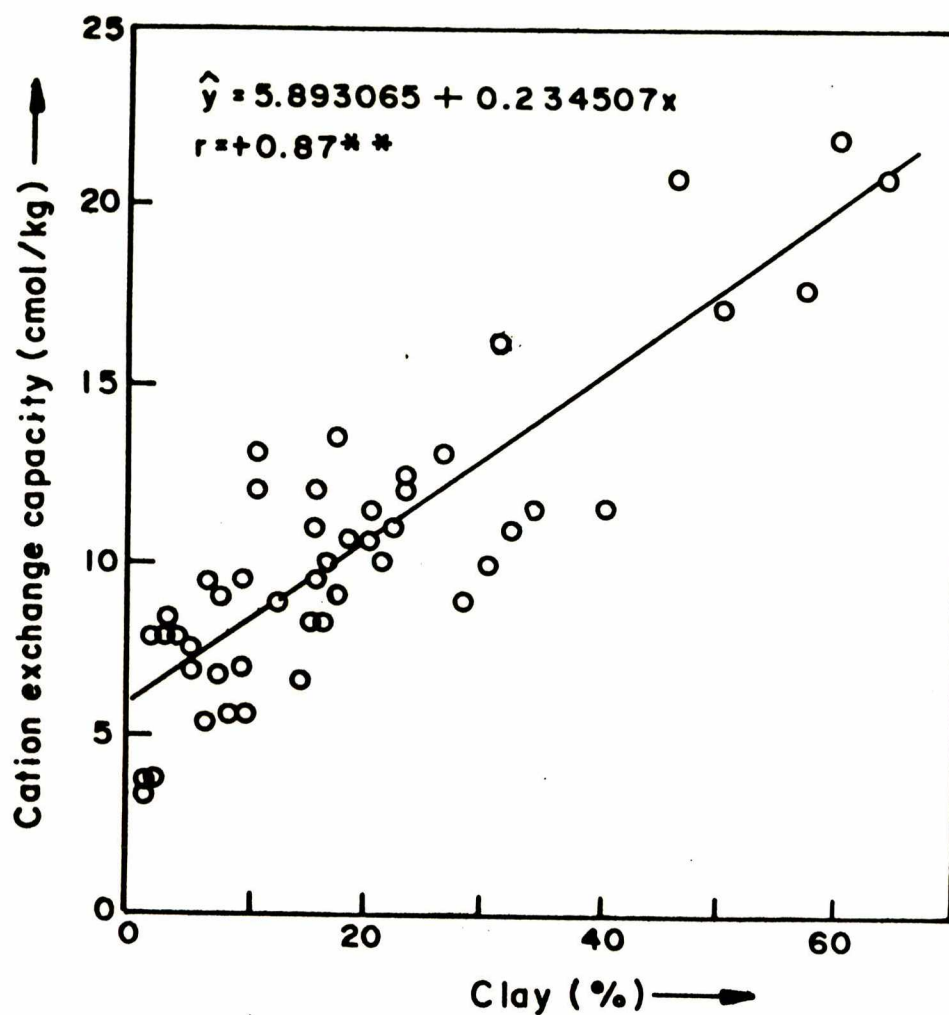


Fig. 23. Correlation between percent clay and cation exchange capacity in the studied soils.

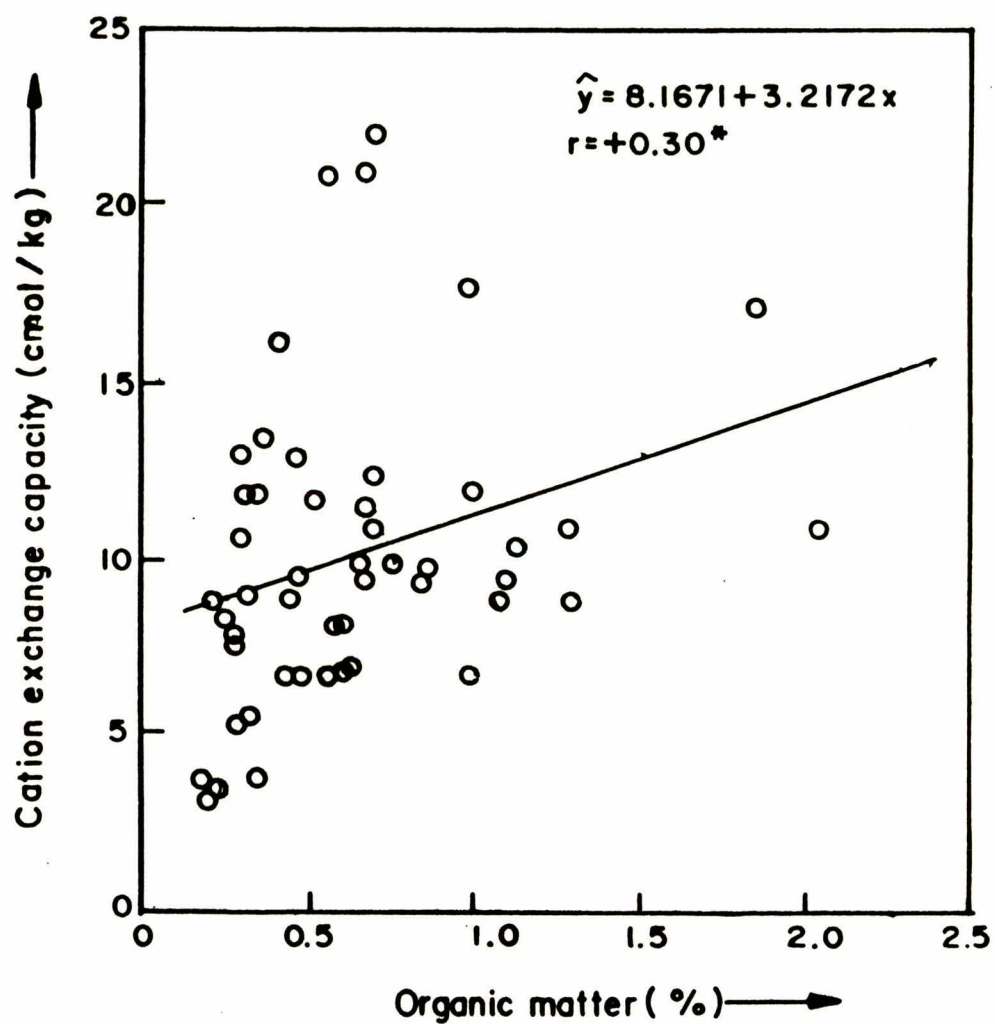


Fig. 24. Relationship between organic matter and cation exchange capacity in the soils under study.

5.3.3.2. Exchangeable hydrogen (H^+)

The exchangeable H^+ content ranges from 0.05 to 8.86 cmol/kg soil with an average value of 2.58 cmol/kg soil. The highest mean value of exchangeable H^+ among the studied profiles is found in the Ghatail profile and the lowest in the Melandaha profile.

In all the profiles the exchangeable H^+ is high near the surface. This kind of distribution pattern of exchangeable H^+ is typical for most of the seasonally flooded non-calcareous soils of Bangladesh (Brammer, 1971). The vertical distribution pattern of exchangeable H^+ in the pedons studied shows a non-uniform decrease with depth (Table -13).

Usually in the Tropical and Sub-tropical soils the amount of exchangeable H^+ is low (Dudal and Bramaio, 1965) but the soils under study are found to contain much higher exchangeable H^+ content. (Table-13).

5.3.3.3. The exchangeable bases

The exchange complex of all the soils are dominantly saturated with Ca^{++} . The exchangeable Ca^{++} contents range between 1.10 and 8.89 with a mean of 4.55 cmol/kg soil (Table-13). Calcium occupies more than 60 percent of the total exchange positions in all the soils except the Sonatala profile (Table-14).

The vertical distribution of exchangeable Ca^{++} in the profiles show an irregular trend. It is observed that all the profiles contain lower amounts of Ca^{++} in their surface due to leaching of Ca^{++} downwards. Consequently, higher values of Ca^{++} content is found in the subsoils due to their leaching from the surface horizons and subsequent accumulation in the lower horizons..

The exchangeable magnesium contents in the soils vary from 0.30 to 3.58 cmol/kg soil and the mean value is 1.98 cmol/kg soil (Table-13). The highest mean exchangeable Mg^{++} value within the profiles is found in the Lokdeo soil and the lowest in the

Table14. Relative percentage composition of the exchangeable metal ions and base saturation percent in soils.

Soil series	Horizon	Depth cm	% Composition				BSP*
			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	
Melandaha	Apg1	0-9	65	25	7	2	65
	Apg1	9-15	69	24	5	2	75
	Bwg1(?)	15-28	66	27	5	2	84
	Bwg2(?)	28-36	70	23	5	1	75
	2C1	36-46	67	19	8	6	52
	2C2	46-57	65	25	6	4	59
	3A1b(?)	57-72	61	22	13	4	70
	4C	72-100+	60	28	9	3	75
	Mean	-	65	24	7	3	69
Dhamrai	Apg1	0-10	67	20	9	4	74
	Apg2	10-15	67	22	8	3	82
	Bwg1	15-33	68	22	7	3	82
	Bwg2	33-43	67	23	7	3	72
	Cg1	43-63	63	27	7	3	74
	Cg2	63-88	63	28	7	2	73
	Cg3	88-113	63	27	8	2	53
	2Cg4	113-126+	61	28	7	3	67
	Mean	-	65	25	7	3	72
Sonatala	Apg1	0-10	59	24	14	3	67
	Apg2	10-17	57	28	12	2	72
	Bwg1	17-35	58	30	10	2	70
	Bwg2	35-47	56	33	9	2	80
	Bwg3	47-59	59	29	9	2	77
	Cg1	59-77	59	30	8	2	89
	Cg2	77-93	53	31	12	3	85
	Cg3	93-125+	53	31	12	3	72
	Mean	-	57	29	11	2	76

* BASE SATURATION PERCENTAGE

Continued next page

Table-14. Continued

Soil series	Horizon	Depth cm	% Composition				BSP*
			Ca ⁺⁺	Mg ⁺⁺	Na ⁺	K ⁺	
Silmandi	Apg1	0-10	59	32	7	2	68
	Apg2	10-16	71	21	7	1	66
	Bwg1	16-38	73	19	7	1	71
	Bwg2	38-47	71	22	6	1	91
	Bwg3	47-61	74	20	5	1	84
	Cg1	61-74	48	43	7	2	61
	Cg2	74-90	50	43	5	1	65
	Cg3	90-110+	56	39	3	1	76
	Mean	-	63	30	6	1	73
Lokdeo	Apg1	0-10	67	24	7	2	73
	Apg2	10-17	64	29	6	1	79
	Bwg1	17-31	62	29	7	2	62
	Bwg2	31-56	63	30	5	2	76
	Bg3	56-70	62	32	5	1	63
	Cg1	70-90	61	33	5	1	67
	Cg2	90-110	56	39	4	1	86
	Cg3	110+	58	36	5	1	98
	Mean	-	62	34	5	1	75
Ghatail	Apg1	0-10	64	24	9	3	55
	Apg2	10-18	67	26	5	1	73
	Bwg1	18-33	65	25	6	2	56
	Bwg2	33-51	66	26	5	1	62
	Bwg3	51-73	68	24	5	1	55
	Cg1	73-91	72	22	3	1	65
	Cg2	91-103	60	27	11	1	99
	Cg3	103-125+	61	27	10	1	86
	Mean	-	65	25	8	2	69
Sherpur	Apg	0-14	56	30	12	2	62
	Bw1	14-29	68	23	7	2	80
	Bw2	29-47	70	24	4	2	89
	Bw3	47-66	70	22	5	3	55
	Cg1	66-96	59	31	8	2	55
	Cg2	96-122+	62	31	5	2	80
	Mean	-	64	27	7	2	70
Grand mean			63	28	7	2	72

staff (1974 -75) and Ali (1994). The highest mean exchangeable K^+ among the profiles is found in the Dhamrai soil, the lowest in the Silmandi soil.

The most common exchangeable cations in soils are Ca^{++} , Mg^{++} , H^+ , Na^+ , K^+ and NH_4^+ . Ca generally is the dominant cation with the relative abundance of other ions which may vary greatly depending on the conditions. In very acid soils $Al(OH)^{2+}$ may constitute a considerable part of the counterions, the proportion increasing with falling pH. On the other hand in alkali soils the content of exchangeable Na^+ is exceptionally high (Wiklander, 1965).

In an ideal soil the cationic composition in the exchange complex is as follows: Ca 65 percent; Mg 10 percent; K 5 percent; and H 20 percent (Toth, 1965). On this basis the soils under the present study may be considered as very close to the ideal.

5.3.3.4 Base saturation percentage (BSP)

Base saturation percentage of soils are very important for predicting the genetic processes in soil as well as their stages of development. The BSP values have also been used in soil classification (Soil Survey Staff, 1975). The proportion of the cation exchange capacity accounted for by exchangeable bases (Ca, Mg, K, Na) is frequently used as an indicator of soil fertility (Landon, 1991).

The base saturation percentage of the soils under the present investigation ranges between 52 and 99 with an average value of 72 (Table-14). The highest mean value among the profiles is found in Sonatala soil, and the lowest in the Dhamrai soil. Comparatively smaller values around 52 percent is presumed to be due to the rapid removal of bases from the weathering medium.

The vertical distribution patterns indicate that the base saturation percentage, in general, shows an increasing trend with depth. The BSP is found to be lower in the surface horizon of all the soils and this is considered to be due to more intense weathering and the subsequent leaching of bases from the horizons.

5.3.4. Free oxides in soils

The amount of free oxides in soils are very important in evaluating mineral weathering and pedogenic changes in soils (McKeague and Day, 1966; Blume and Schwertman, 1969; Santos et al. 1986; Seshagirao et al. 1992; and Mirabella and Carnicelli, 1992)

5.3.4.1 Dithionate extractable iron, manganese and aluminium

Free iron oxides (Fe_d)

Free Fe_2O_3 contents in the present soils vary from 0.20 to 1.70 percent with an average value of 0.89 percent (Table-15). The highest mean value of free iron oxide among the profiles studied is found in Lokdeo and the lowest value in the Melandaha soil. This low free Fe_2O_3 content is due to loss of iron from the soils during the flooding season when they undergo reduction (Bouma, 1983). The free iron contents varied from 0.4 to 1.3 percent in the Gangetic alluvium soils of Bangladesh (Ali, 1994).

Karim (1984) noted that goethite content in Bangladesh soils ranged from 0.48 to 1.20 percent. He also reported substantial substitution of iron by aluminium in the crystals of goethite mineral.

Perhaps, it should be noted that all the present soils remain flooded for varying periods during the wet season (Table-2). Moreover, all these soils are used for cultivation of aus and transplanted aman paddy when the soils remain submerged under water. During the wet season, some of the reduced dissolved iron move down along with ground water and are deposited in the B horizon of the soils in the form of mottles. Mottles, therefore, are prominent in the middle zone of the soil profiles, where oxidation and reduction conditions alternate with season (Saheed and Hussain, 1992).

The pattern of distribution of free Fe_2O_3 with depth in the profiles is irregular (Table-15). Similar results were also obtained by Deturck and Somasiri (1992) in the

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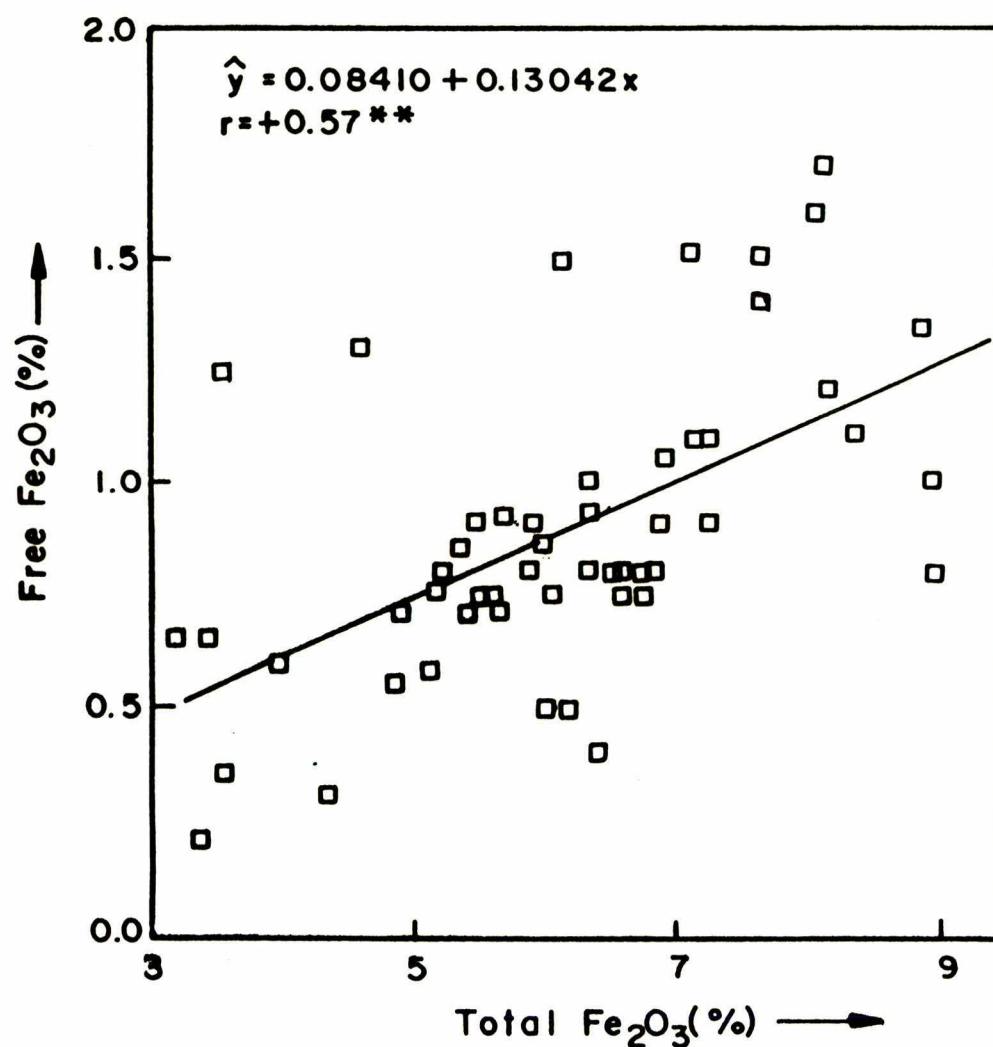


Fig. 25. Relationship between total Fe_2O_3 and free Fe_2O_3 in the soils, under investigation.

Rice soils of Sri Lanka with Anthraquic features and also by Fanning et al. (1992) in their study of micro-macromorphology of some wet soils.

Joffe (1966) reported that the surface enrichment of free iron oxide is possibly due to the fact that with the receding of the ground water table ferrous iron is oxidized easily to form free iron oxide near the surface, while in the subsoil the ferrous iron does not change.

A significant positive correlation ($r = +0.57^{**}$) was found between total and free iron contents of the soils (Fig. 25). This indicates that where the free iron oxide contents are high the total iron oxide contents are also high (Jha et al. 1984).

Free manganese oxide (Mn_d)

The movement of manganese oxide and its fixation in the soil profiles are significant criteria in a pedogenic study as manganese behaves to some extent like iron (Joffe, 1966).

The free MnO_2 contents of the soils vary from 0.002 to 0.032 percent with a mean value of 0.010 percent (Table-15). This low free manganese oxide content is probably due to intense reduction of manganese caused by flooding during the monsoon period and their subsequent removal by ground water. Daniel et al. (1962) stated that poor drainage condition is probably the important factor that caused the decrease in free MnO_2 content of the soils.

Slightly higher free MnO_2 concentration is noticed in the lower horizons of the soils (Table-15).

A positive correlation ($r = +0.58^{**}$) was found to exist between free Fe_2O_3 and free MnO_2 content in the soils under study (Fig. 26). This indicates that where the free iron oxide contents are high the MnO_2 is also high and also indicates that the same process/processes are operative in conversion of free Fe/Mn to their oxides.

Manganous ion does not oxidize as easily as iron. It moves down the profile along with the receding ground water table during the onset of dry season. After a long exposure

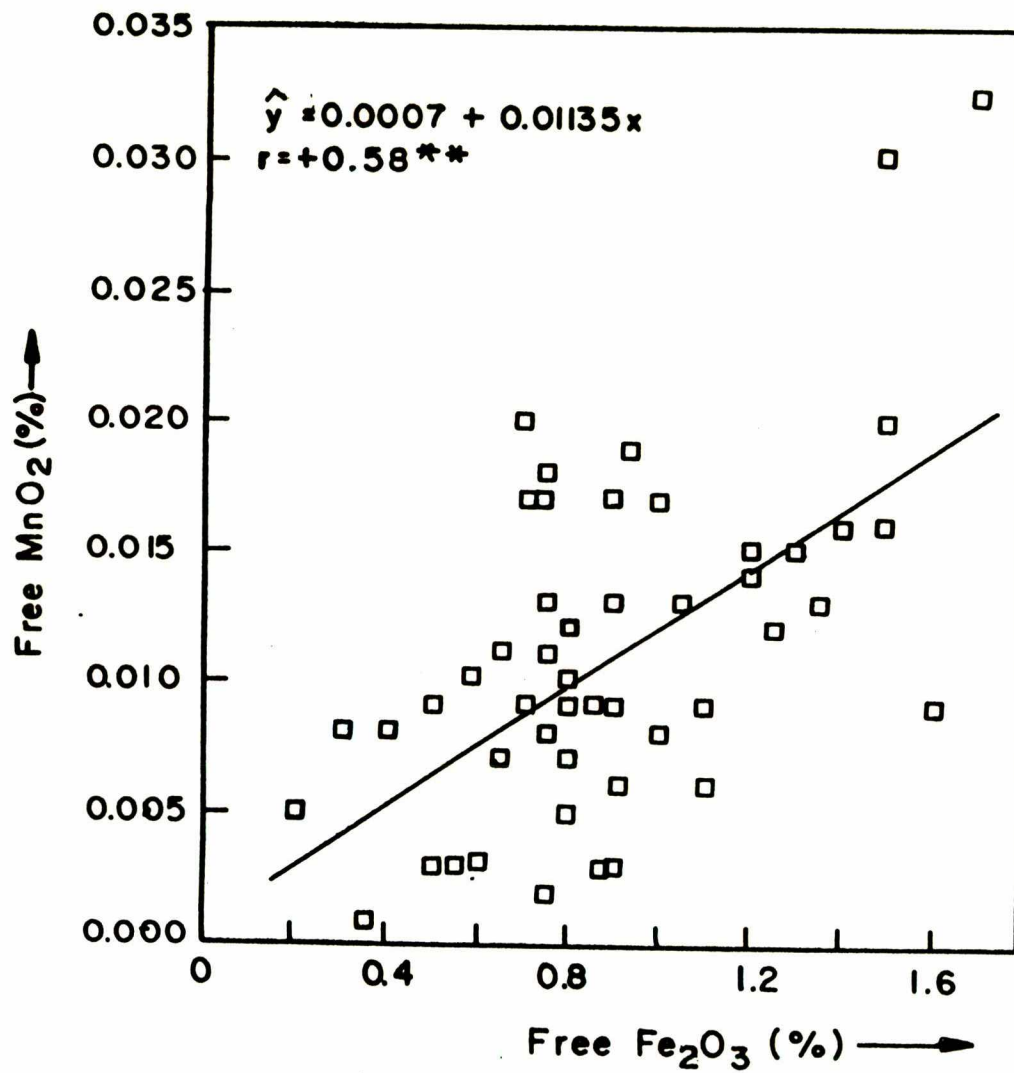


Fig. 26. Relationship between free Fe₂O₃ and free MnO₂ contents in the studied soils.

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in the dry period manganous ion get oxidized resulting in an accumulation of free manganese oxide in the subsoils.

Free aluminium oxides (Al_d)

Contents of free Al_2O_3 in the soils studied are very low. Its amount ranges from trace to 0.005 percent with an average value of around 0.002 percent (Table-15). The vertical distribution pattern of free Al_2O_3 shows an accumulation in the upper horizons of the profiles.

Gotoh (1976) reported that the extractable Al_2O_3 content gradually decreased with depth attaining the highest value in the A horizon in the older soils. He also noted that the movement of aluminium in the soils is pH-dependent.

5.3.4.2 Acid oxalate extractable iron, aluminium and manganese

Oxalate extractable part of iron (Fe_o) is highly important for predicting the relative development and drainage condition and hence the pedogenic processes of soils. The results on acid oxalate extractable iron (Fe_o), (Mn_o) and (Al_o) and its comparison with dithionite extractable Fed , Mnd , and Ald has been presented in Table-15.

Oxalate extractable iron oxide (Fe_o)

The acid oxalate extractable iron oxide (Fe_o) in the soils ranged from 0.1 to 0.90 percent with an average value of 0.46 percent (Table-15). The highest mean value of oxalate extractable iron oxide has been found in Dhamrai soil whereas the lowest in the Melandaha soil (Table -15).

The oxalate extractable iron oxide decreased appreciably with the increase of depth in Ghatail, Lokdeo and Dhamrai soils, while in other soils it is irregularly distributed with depth due to differences of alluvial sediments and leaching (Table- 15). It was noted that all the soils except Sherpur contained maximum amounts of Fe_o in their surface.

It was also found that all the soils under the present investigation contained higher Fe_d than Fe_o . As proposed by Arduino et al. (1984), Fe_o is considered active and Fe_d minus Fe_o is less active the latter probably being goethite and hematite (Karim, 1984)

Bhattacharyya and Ghosh (1986) found that Entisols contained relatively less amount of oxalate soluble iron oxide while Alfisols and Vertisols contained greater amount of amorphous iron oxide in the deferrated soils.

Oxalate extractable manganese oxide(Mn_o)

The acid oxalate extractable manganese oxide (Mn_o) in the soils studied ranged from trace to 0.019 percent with a mean value of 0.009 percent (Table-15). The highest value was found in Silmandi soil whereas the lower values were observed in Dhamrai and Ghatail soils. The oxalate extractable manganese (Mn_o) decreased appreciably with the increase of depth in Melandaha, Dhamrai, Lokdeo, Ghatail and Sherpur while in Silmandi and Sonatala it is irregularly distributed with depth due to differences of alluvial sediments and leaching (Table -15).

Oxalate extractable aluminium oxide (Al_o)

From Table-15 it is observed that the oxalate extractable aluminium oxide (Al_o) content ranges between trace to 0.006 percent with a mean value of 0.002 percent. The vertical distribution pattern of oxalate extractable aluminium oxide (Al_o) shows an accumulation in the upper horizons of the profiles (Table - 15).

Van Mensvoort et al. (1985) reported that aluminium concentrations are entirely related to pH, and toxic concentrations can occur only at pH values below 5.0.

Dolui et al (1987) studied some soils of Jalpaiguri district of West Bengal (India) and reported that oxalate extractable Al is more in illuvial horizons of the profiles due to the depositions of translocated Al-fulvate complex.

Table-15. Extractable iron, aluminium and manganese oxides in the studied soils.

Soil series	Horizon	Depth (cm)	Dithionite extractable			Oxalate extractable		
			Fe ₂ O ₃ %	Al ₂ O ₃ %	MnO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	MnO ₂ %
Melandaha	Apg1	0-9	0.65	0.004	0.007	0.57	0.004	0.016
	Apg2	9-15	0.60	0.003	0.003	0.30	0.004	0.012
	Bwg1(?)	15-28	0.75	0.004	0.002	0.18	0.006	0.008
	Bwg2(?)	28-36	0.91	0.002	0.003	0.60	0.004	0.009
	2C1	36-46	0.35	Tr	0.001	0.10	0.002	0.005
	2C2	46-57	0.30	Tr	0.008	0.11	Tr	Tr.
	3A1b(?)	57-72	0.75	Tr.	0.008	0.28	Tr.	Tr.
	4C	72-100+	0.20	0.001	0.005	0.14	Tr.	Tr.
	Mean		0.56	0.002	0.004	0.26	0.002	0.006
Dhamrai	Apg1	0-10	0.90	0.003	0.009	0.86	0.004	0.009
	Apg2	10-15	0.85	0.004	0.009	0.83	0.004	0.011
	Bwg1	15-33	0.80	0.003	0.007	0.73	0.002	0.008
	Bwg2	33-43	0.90	0.002	0.013	0.70	0.004	0.006
	Cg1	43-63	0.80	0.002	0.010	0.6	0.002	0.005
	Cg2	63-88	0.80	Tr.	0.012	0.6	Tr.	Tr.
	Cg3	88-113	0.75	Tr.	0.018	0.70	Tr.	Tr.
	2Cg4	113-126+	0.74	Tr.	0.017	0.56	Tr.	Tr.
	Mean		0.81	0.002	0.011	0.73	0.002	0.005
Sonatala	Apg1	0-10	0.55	0.004	0.003	0.83	0.004	0.014
	Apg2	10-17	0.85	0.004	0.003	0.83	0.002	0.012
	Bwg1	17-35	0.90	0.003	0.003	0.30	0.004	0.012
	Bwg2	35-47	0.93	0.002	0.019	0.20	0.002	0.011
	Bwg3	47-59	1.10	0.002	0.006	0.18	0.001	0.000
	Cg1	59-77	0.90	Tr.	0.017	0.11	Tr.	0.000
	Cg2	77-93	0.75	Tr.	0.013	0.27	Tr.	0.014
	Cg3	93-125+	0.70	Tr.	0.009	0.21	Tr.	0.012
	Mean		0.83	0.002	0.009	0.37	0.002	0.009

Continued next page

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Table-15 Continued

Soil series	Horizon	Depth (cm)	Dithionite extractable			Oxalate extractable		
			Fe ₂ O ₃ %	Al ₂ O ₃ %	MnO ₂ %	Fe ₂ O ₃ %	Al ₂ O ₃ %	MnO ₂ %
Silmandi	Apg1	0-10	0.75	0.004	0.008	0.46	0.004	0.008
	Apg2	10-16	0.80	0.003	0.005	0.37	0.004	0.009
	Bwg1	16-38	0.50	0.002	0.003	0.38	0.002	0.008
	Bwg2	38-47	0.70	0.002	0.020	0.27	0.002	0.005
	Bwg3	47-61	0.70	0.002	0.017	0.16	Tr.	0.012
	Cg1	61-74	0.65	Tr.	0.011	0.30	Tr.	0.016
	Cg2	74-90	0.58	Tr.	0.010	0.3	0.002	0.019
	Cg3	90-110+	0.91	0.001	0.006	0.16	0.002	0.012
	Mean		0.70	0.002	0.010	0.30	0.002	0.011
Lokdeo	Apg1	0-10	0.80	0.002	0.005	0.60	0.004	0.016
	Apg2	10-17	1.00	0.004	0.008	0.61	0.004	0.016
	Bwg1	17-31	0.80	0.003	0.010	0.23	0.002	0.016
	Bwg2	31-56	1.30	0.002	0.015	0.16	0.002	0.000
	Bg3	56-70	0.75	0.002	0.011	0.10	0.002	0.016
	Cg1	70-90	1.00	0.002	0.017	0.16	0.002	0.016
	Cg2	90-110	1.50	Tr.	0.030	0.23	Tr.	0.000
	Cg3	110+	1.50	Tr.	0.020	0.58	0.002	0.000
	Mean		1.55	0.002	0.014	0.33	0.002	0.009
Ghatall	Apg1	0-10	1.10	0.004	0.009	0.51	0.004	0.006
	Apg2	10-18	1.20	0.003	0.015	0.53	0.004	0.008
	Bwg1	18-33	1.60	0.002	0.009	0.43	0.004	0.009
	Bwg2	33-51	1.70	0.003	0.032	0.37	0.002	0.006
	Bwg3	51-73	1.50	0.002	0.016	0.54	0.004	0.005
	Cg1	73-91	0.80	Tr.	0.009	0.68	0.002	Tr.
	Cg2	91-103	0.50	Tr.	0.009	0.53	0.002	Tr.
	Cg3	103-125+	0.40	Tr.	0.008	0.50	0.002	Tr.
	Mean		1.10	0.002	0.013	0.51	0.003	0.005
Sherpur	Apg	0-14	0.80	0.003	0.007	0.63	0.004	0.008
	Bw1	14-29	1.25	0.004	0.012	0.66	0.004	0.006
	Bw2	29-47	1.40	0.005	0.016	0.71	0.006	0.009
	Bw3	47-66	1.35	Tr.	0.013	0.68	0.002	0.008
	Cg1	66-96	1.20	Tr.	0.014	0.90	0.002	0.006
	Cg2	96-122+	1.05	Tr.	0.013	0.30	Tr.	0.005
	Mean		1.17	0.002	0.012	0.64	0.003	0.008
Grand mean			0.89	0.002	0.010	0.46	0.002	0.009

5.3.4.3 Free iron oxides in the soil profiles as indicators of their age

The distribution of iron oxide in the profile depicts the most important and sometimes even the only indicator of what is going on the soil development. The break down of Fe-bearing minerals by chemical weathering leads to accumulation of free iron oxide in the form of amorphous iron oxides, cryptocrystalline oxides and organic bound iron and with time the rate of accumulation of free iron increases in the B horizon under leaching environment. Keeping this point in view, Arduino et al. (1984, 1986) used the ratio of Dithionite - citrate - bicarbonate extractable iron (Fe_d) to total iron (Fe_t) for the soils of different river terraces in Italy and found that the ratio did reflect the relative ages of the terraces. This method has been employed in the present study to examine the amount of chemical weathering that has taken place in the soils. The Fe_d/Fe_t ratio has been calculated and presented in Table-16. It is observed that the Sherpur series contain greater amount of free iron in the profile suggesting a higher degree of weathering than other soils. The Melandaha soils contain lesser amount of free iron and indicate a relatively lower degree of weathering.

Based on the concepts of Arduino et al. (1984, 1986) the pedons under the present study can be arranged on the basis of their age as follows :

Sherpur > Ghatail > Lokdeo > Silmandi > Sonatala > Dhamrai > Melandaha
 Well developed —————> Least developed
 (Oldest) (Youngest)

To provide a more strict comparison of the ratios, analysis of variance (ANOVA) was performed and this was followed by a multiple range test (LSD). The values of three ratios computed for each horizon i.e., Fe_d/Fe_t , Fe_o/Fe_d and F_d minus Fe_o/Fe_t were compared. The results of ANOVA and LSDs are given in Table-17 which brought out the differences in forms of iron among the soils studied. From Table 17, it is clear that there is a significant variation in Fe_d/Fe_t values among the soils studied.

Table-16.Total and extractable iron contents in the studied soils.

Soil series	Horizon	*Fe _t %	*Fe _d %	*Fe _o %	Fe _d /Fe _t x 100	Fe _o /Fe _t x 100
Melandaha	Apg1	3.77	0.45	0.40	12	11
	Apg2	4.12	0.42	0.21	10	5
	Bwg1(?)	3.91	0.50	0.13	13	3
	Bwg2(?)	3.77	0.55	0.42	15	11
	2C1	3.91	0.24	0.07	6	2
	2C2	3.70	0.21	0.08	6	2
	3A1b(?)	3.63	0.51	0.20	14	5
	4C	3.77	0.14	0.09	4	4
	Mean	3.82	0.38	0.29	10	5
Dhamrai	Apg1	3.77	0.60	0.55	16	15
	Apg2	4.12	0.59	0.58	14	14
	Bwg1	4.12	0.56	0.51	14	12
	Bwg2	4.75	0.63	0.49	13	10
	Cg1	4.54	0.56	0.47	12	10
	Cg2	4.54	0.56	0.46	12	10
	Cg3	4.68	0.52	0.49	11	10
	2Cg4	4.68	0.50	0.41	11	9
	Mean	4.40	0.52	0.49	13	11
Sonatala	Apg1	4.05	0.40	0.36	10	9
	Apg2	3.70	0.59	0.37	16	10
	Bwg1	4.12	0.49	0.31	12	7
	Bwg2	4.54	0.61	0.26	13	6
	Bwg3	5.03	0.77	0.38	15	8
	Cg1	5.03	0.63	0.47	13	9
	Cg2	3.84	0.52	0.37	13	10
	Cg3	3.98	0.49	0.35	12	9
	Mean	4.28	0.56	0.36	13	8

*Fe_t = Total iron*Fe_d = Dithionite extractable iron*Fe_o = Oxalate extractable iron

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Table-16. Continued

Soil series	Horizon	Fe _t %	Fe _d %	Fe _n %	Fe _n /Fe _t x 100	Fe _n /Fe _t x 100
Silmandi	Apg1	4.19	0.46	0.32	11	8
	Apg2	4.40	0.46	0.25	10	6
	Bwg1	4.19	0.35	0.28	8	7
	Bwg2	3.77	0.49	0.19	13	5
	Bwg3	4.12	0.49	0.11	12	3
	Cg1	3.63	0.45	0.21	12	6
	Cg2	3.56	0.41	0.23	11	6
	Cg3	3.98	0.64	0.11	16	3
	Mean	3.98	0.47	0.21	12	6
Lokdeo	Apg1	6.22	0.62	0.42	10	7
	Apg2	6.22	0.70	0.43	11	7
	Bwg1	4.68	0.56	0.16	12	3
	Bwg2	3.91	0.91	0.11	23	3
	Bg3	4.61	0.53	0.07	11	2
	Cg1	4.40	0.70	0.11	16	3
	Cg2	4.96	1.05	0.16	25	3
	Cg3	4.26	1.08	0.41	25	10
	Mean	4.90	0.77	0.23	17	5
Ghatall	Apg1	5.80	0.77	0.58	13	10
	Apg2	5.66	0.84	0.57	15	10
	Bwg1	5.59	1.15	0.21	21	4
	Bwg2	5.66	1.22	0.14	22	3
	Bwg3	5.31	1.08	0.12	20	2
	Cg1	4.75	0.63	0.08	13	2
	Cg2	4.33	0.45	0.19	10	4
	Cg3	4.47	0.36	0.15	8	3
	Mean	5.19	0.81	0.25	15	5
Sherpur	Apg	3.63	0.56	0.44	15	12
	Bwg1	3.84	0.87	0.45	23	12
	Bwg2	5.31	0.98	0.49	18	9
	Bwg3	6.22	0.94	0.47	15	8
	Cg1	5.66	0.84	0.63	15	11
	Cg2	4.82	0.73	0.21	15	4
	Mean	4.91	0.82	0.45	17	9
Grand mean		4.49	0.62	0.32	14	7

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The highest value (16.83) was found in Sherpur soils and the lowest (10.00) in the Melandaha soils. The values in Melandaha, Dhamrai, Sonatala and Silmandi soils were significantly lower than that in Sherpur. However, the values of Ghatail and Lokdeo were not found to be significantly lower than that of Sherpur soils.

Similarly, there was also a significant variation in the Fe_O/Fe_d values (Table-17). The highest value was found in Dhamrai series (88.00) and the lowest in the Lokdeo series (32.00). The values in Melandaha, Silmandi, Ghatail, Lokdeo and Sherpur soils were found significantly lower than that in the Dhamrai soils. However the value of Sonatala soils was not significantly lower than that of Dhamrai soils.

A significant variations in the Fe_d minus Fe_O/Fe_t was also observed in the studied soils (Table-17). The highest value was found in the Lokdeo series (11.70) and the lowest in the Dhamrai series (1.56). The values in Melandaha, Dhamrai and Sonatala series were significantly lower than that in Lokdeo. But the values in Silmandi, Ghatail and Sherpur series were not found to be significantly lower.

Table-17. Mean, Standard deviations and ANOVA of the ratios of iron in the pedons.

Soils	Number of cases	$(Fe_d/Fe_t) \times 100$		$(Fe_o/Fe_d) \times 100$		$(Fe_d - Fe_o/Fe_t) \times 100$	
		Mean	SD	Mean	SD	Mean	SD
Melandaha	8	10.00	± 4.17	51.25	± 21.67	4.63	± 3.01
Dhamrai	8	12.88	± 1.73	88.00	± 7.23	1.56	± 0.88
Sonatala	8	13.00	± 1.85	66.87	± 13.62	4.67	± 2.34
Silmandi	8	11.62	± 2.33	46.25	± 20.26	6.49	± 3.68
Lokdeo	8	16.62	± 6.65	32.50	± 24.19	11.70	± 6.26
Ghatal	8	15.25	± 5.23	35.87	± 25.90	10.53	± 6.67
Sherpur	6	16.83	± 2.74	56.16	± 18.36	7.59	± 2.86
Total	54	14.00	± 3.52	53.84	± 18.75	6.69	± 5.15
Observed F	-	$F_{3.82}^{**}$	-	$F_{7.47}^{**}$	-	$F_{6.10}^{**}$	-
LSD (0.01)	-	4.62	-	26.55	-	5.13	-

** = Significant at 1% level

5.3.5. Fusion analysis of the soils

Owing to paucity of information regarding the chemical nature of the parent materials of the soils under the present investigation, an attempt has been made to determine chemical composition of the soils from the fusion analysis.

The data for fusion analysis of fine earth fractions (Table -18) show that :

- ◆ the SiO_2 content varies from 61.8 to 86.1 with a mean of 71.9%,
- ◆ the Al_2O_3 content from 6.2 to 18.0 with a mean of 12.6%,
- ◆ the Fe_2O_3 content from 5.1 to 8.9 with a mean of 6.4%,
- ◆ the $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio from 4.9 to 10.1 with a mean of 7.2,
- ◆ the $\text{SiO}_2 / \text{Al}_2\text{O}_3$ ratio from 5.7 to 13.8 with a mean of 9.5, and
- ◆ the $\text{Al}_2\text{O}_3 / \text{Fe}_2\text{O}_3$ ratio from 2.3 to 4.2 with a mean of 3.1.

It may be pointed out that the silicon comprises more than two-third of the total mineral matter in these soils. The abundance of silica in the soil is due to the high content of sand and silt fraction in the soils. The highest mean value of SiO_2 content has been found in Dhamrai soil whereas the lowest in the Lokdeo profile (Table -18),

The vertical distribution of SiO_2 content in the soil profiles are, in general, irregular in nature (Table -18). This irregular distribution pattern within the profile is thought to be due to stratification of the soil parent materials.

Next to silica the most abundant element is aluminium. But the content of Al_2O_3 (mean) is relatively low which may be due to their low aluminosilicates content and high quartz contents. The highest Al_2O_3 in the profile has been found in the Ghatail profile and the lowest in the Melandaha profile.

The vertical distribution of Al_2O_3 contents in the soil profile is also irregular in nature (Table -18). The irregular distribution pattern of Al_2O_3 within the profiles is probably due to the variation in clay content as well as to alluvial nature of the soil

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materials. Gotoh and Patrick (1974) also reported that the pattern of the distribution of the total Al_2O_3 with depth closely resembled that of the distribution of clay.

The next abundant element after aluminium is iron. The highest Fe_2O_3 in the profiles were found in Lokdeo soil and the lowest in Melandaha soil. The variations of the highest and the lowest mean value is not wide.

The vertical distribution of total Fe_2O_3 content in the soil profiles is irregular in nature but in some subsoils of Melandaha, Dhamrai, Sonatala and Sherpur profiles a slight enrichment can be noticed. On the other hand slightly higher Fe_2O_3 is noticed in the topsoils of Silmandi, Lokdeo and Ghatail profiles. Higher Fe_2O_3 content in the surface horizon was observed by Chatterjee and Dalal (1976) in some alluvial soils of Bihar and West Bengal.

The $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio of the studied soils range from 4.9 to 10.1 with a mean of 7.4 (Table -18). Higher $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio in the studied pedons is found in the Melandaha profile whereas the lowest value is found in the Ghatail profile.

The distribution of $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio from the surface downward follows an irregular pattern in all the soil profiles (Table -18). The mean $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio in the studied soils is high. Such a high ratio also indicates that the little weathered primary silicates are the dominant mineral fraction in these soils.

The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio in the studied soils ranges from 6.7 to 13.9 with a mean of 9.8. Such a wide range of the above ratio indicates the heterogeneous nature of the soil materials. The highest mean of $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio in the studied soils is observed in Sonatala soils while the lowest value is found in Ghatail soil.

The vertical distribution of $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio from the surface downward follows an irregular pattern in all the studied pedons. This may indicate the existence of stratification.

Table-18. Results of fusion analysis of the whole soil

Soils	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃
					R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃
		←----- % -----→			←----- Molar ratio -----→		
Melandaha	Apg1	71.8	10.9	5.4	8.5	11.2	3.2
	Apg2	71.3	9.4	5.9	9.2	12.8	2.5
	Bwg1(?)	72.9	13.2	5.6	7.4	9.4	3.7
	Bwg2(?)	70.6	13.3	5.4	7.2	9.0	3.8
	2C1	72.0	9.5	5.6	9.3	12.8	2.7
	2C2	76.8	11.7	5.3	8.6	11.1	3.4
	3A1b(?)	79.9	11.7	5.2	9.0	11.6	3.5
	4C	70.1	9.2	5.4	9.4	12.9	2.7
	Mean	73.2	11.1	5.5	8.6	11.4	3.2
Dhamrai	Apg1	81.2	11.5	5.4	9.2	12.0	3.3
	Apg2	71.0	10.9	5.9	8.2	11.0	2.9
	Bwg1	71.5	9.8	5.9	8.9	12.4	2.6
	Bwg2	73.8	11.4	6.8	7.9	11.0	2.6
	Cg1	78.0	10.0	6.5	9.4	13.2	2.4
	Cg2	83.2	11.4	6.5	9.1	12.4	2.7
	Cg3	74.1	11.3	6.7	8.1	11.1	2.6
	2Cg4	75.3	11.3	6.7	8.2	11.3	2.6
	Mean	76.0	10.9	6.3	8.6	11.8	2.7
Sonatala	Apg1	80.2	9.8	5.8	10.1	13.9	2.6
	Apg2	75.7	10.4	5.3	9.3	12.3	3.1
	Bwg1	72.6	9.7	5.9	9.2	12.7	2.6
	Bwg2	69.2	9.9	6.5	8.4	11.9	2.4
	Bwg3	63.9	13.2	7.2	6.1	8.2	2.9
	Cg1	73.7	13.0	7.2	7.1	9.6	2.8
	Cg2	63.9	10.4	5.5	7.8	10.4	2.9
	Cg3	78.5	11.1	5.7	9.1	11.9	3.1
	Mean	72.2	10.9	6.1	8.4	11.4	2.8

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Table-18. Continued

Soils	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃
					R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃
		%			Molar ratio		
Silmandi	Apg1	69.5	13.5	6.0	6.8	8.7	3.5
	Apg2	69.2	15.0	6.3	6.2	7.8	3.7
	Bwg1	71.0	13.5	6.0	6.9	8.9	3.5
	Bwg2	71.8	11.6	5.4	8.1	10.5	3.4
	Bwg3	73.2	10.8	5.9	8.5	11.5	2.9
	Cg1	63.1	10.2	5.2	7.9	10.5	3.1
	Cg2	73.3	11.6	5.1	8.4	10.7	3.6
	Cg3	70.7	12.9	5.7	7.2	9.3	3.5
	Mean	70.2	12.4	5.7	7.5	9.7	3.4
Lokdeo	Apg1	65.7	13.7	8.9	5.8	8.1	2.5
	Apg2	68.8	14.9	8.9	5.7	7.8	2.7
	Bwg1	66.4	10.8	6.7	7.5	10.4	2.5
	Bwg2	74.0	15.2	5.6	6.7	8.3	4.2
	Bg3	64.7	13.7	6.6	5.9	7.9	3.2
	Cg1	63.3	14.9	6.3	5.7	7.2	3.7
	Cg2	64.4	10.3	7.1	7.4	10.6	2.3
	Cg3	65.2	13.2	6.1	6.5	8.4	3.4
	Mean	66.5	13.3	7.0	6.4	8.6	3.1
Ghatall	Apg1	75.8	14.3	8.3	6.6	8.9	2.7
	Apg2	65.5	16.0	8.1	5.2	6.9	3.1
	Bwg1	62.2	15.8	8.0	5.0	6.7	3.1
	Bwg2	70.1	15.9	8.1	5.6	7.5	3.1
	Bwg3	61.7	15.1	7.6	5.2	6.9	3.1
	Cg1	76.4	15.6	6.8	6.5	8.3	3.6
	Cg2	83.5	16.6	6.2	6.9	8.5	4.2
	Cg3	66.7	12.9	6.4	6.7	8.8	3.2
	Mean	70.2	15.3	7.4	5.9	7.8	3.2
Sherpur	Apg	68.9	12.6	5.2	7.3	9.3	3.8
	Bwg1	76.0	11.5	5.5	8.6	11.2	3.3
	Bwg2	78.4	16.2	7.6	6.3	8.2	3.3
	Bwg3	86.0	15.5	8.9	6.9	9.4	2.7
	Cg1	76.6	14.2	8.1	6.7	9.2	2.7
	Cg2	64.2	18.0	6.9	4.9	6.0	4.0
	Mean	75.0	14.7	7.0	6.8	8.9	3.3
Grand mean		71.9	12.6	6.4	7.4	9.8	3.1

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The highest mean value of $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ratio in the pedons studied is found in the Melandaha soil and the lowest in Dhamrai soil (Table-18). However, the highest and lowest values vary within narrow limit.

The vertical distribution pattern of $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ratio from surface downward follows an irregular pattern in all the soil profiles (Table -18).

From the vertical distribution pattern of the $\text{SiO}_2/\text{R}_2\text{O}_3$, $\text{SiO}_2/\text{Al}_2\text{O}_3$ and $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ratio of these pedons, it may be inferred that the parent materials of the soils are not homogeneous. This finding is in conformity with the previous conclusions made in connection with the particle size distribution.

The total CaO content ranges from 2.27 to 4.33 percent with a mean value of 3.14 percent (Table -19). The highest mean value of CaO content occurs in the soil of Ghatail series and the lowest in the Sherpur series. The total CaO contents in these soils are rather low. These result are in accord with the findings of Ali (1994).

The vertical distribution pattern of CaO content from the surface downward follows an irregular pattern in the soils studied (Table -19).

The total MgO content in the soils under investigation ranges from 1.16 to 3.64 with a mean value of 2.00 percent (Table -19). The highest mean value is found in Ghatail soil whereas the lowest mean is found in Melandaha soil.

The vertical distribution of MgO content in the soil profiles is, in general irregular in nature (Table -19).

The irregular distribution pattern of calcium and magnesium oxides in the soil profiles may be considered as an indication of the fact that the pedochemical weathering processes have not brought about any significant change in the distribution pattern of the minerals containing these elements. In other words, the ferromagnesian minerals had no time allowance for weathering and remained as they were when deposited by geological processes.

Table-19. Total CaO, MgO, P₂O₅ and MnO₂ content in the soils

Soils	Horizon	CaO %	MgO %	(CaO+MgO) %	P ₂ O ₅ %	MnO ₂ %
Melandaha	Apg1	3.11	1.16	4.27	0.03	0.14
	Apg2	3.12	1.55	4.67	0.05	0.13
	Bwg1(?)	3.17	2.22	5.39	0.07	0.23
	Bwg2(?)	3.11	2.30	5.41	0.03	0.15
	2C1	2.32	1.34	3.66	0.06	0.17
	2C2	3.36	1.81	5.17	0.07	0.15
	3A1b(?)	3.20	2.14	5.34	0.10	0.09
	4C	3.21	1.30	4.51	0.06	0.11
	Mean	2.95	1.73	4.68	0.06	0.15
Dhamrai	Apg1	3.13	1.97	5.10	0.15	0.10
	Apg2	3.22	2.53	5.75	0.10	0.12
	Bwg1	3.12	2.11	5.23	0.12	0.11
	Bwg2	3.12	2.55	5.67	0.12	0.13
	Cg1	3.15	2.65	5.80	0.13	0.13
	Cg2	3.09	2.52	6.61	0.12	0.14
	Cg3	3.08	2.60	5.68	0.16	0.17
	2Cg4	4.05	2.25	6.30	0.14	0.14
	Mean	3.24	2.40	5.64	0.13	0.13
Sonatala	Apg1	3.19	1.90	5.09	0.08	0.09
	Apg2	3.17	2.12	5.29	0.10	0.11
	Bwg1	3.15	2.26	5.41	0.10	0.13
	Bwg2	3.15	2.55	5.70	0.13	0.16
	Bwg3	3.16	2.94	6.10	0.15	0.18
	Cg1	3.16	1.92	4.08	0.14	0.16
	Cg2	3.22	2.39	5.61	0.16	0.13
	Cg3	3.17	2.44	5.61	0.17	0.15
	Mean	3.17	2.32	5.49	0.13	0.14

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Table-19. Continued

Soils	Horizon	CaO %	MgO %	(CaO+MgO) %	P ₂ O ₅ %	MnO ₂ %
Silmandi	Apg1	3.10	1.87	4.97	0.03	0.10
	Apg2	3.11	1.99	5.10	0.04	0.10
	Bwg1	3.13	1.71	4.84	0.04	0.08
	Bwg2	3.19	2.82	6.01	0.08	0.13
	Bwg3	2.27	1.77	4.04	0.05	0.12
	Cg1	3.15	1.84	4.99	0.06	0.08
	Cg2	2.40	1.94	4.34	0.06	0.12
	Cg3	3.18	2.14	5.32	0.06	0.11
	Mean	2.94	2.01	4.95	0.05	0.11
Lokdeo	Apg1	3.12	2.15	5.27	0.04	0.10
	Apg2	3.24	2.68	5.92	0.06	0.10
	Bwg1	3.22	1.99	5.21	0.07	0.11
	Bwg2	3.16	2.11	5.27	0.07	0.14
	Bg3	3.15	2.12	5.27	0.08	0.12
	Cg1	3.10	2.21	5.31	0.08	0.13
	Cg2	3.08	2.24	5.32	0.06	0.10
	Cg3	3.12	2.25	5.37	0.07	0.13
	Mean	3.15	2.22	5.37	0.07	0.12
Ghatali	Apg1	4.33	3.64	7.97	0.08	0.15
	Apg2	3.13	2.22	5.35	0.07	0.12
	Bwg1	3.25	2.06	5.31	0.08	0.13
	Bwg2	3.19	2.38	5.57	0.08	0.14
	Bwg3	3.20	2.60	5.80	0.10	0.23
	Cg1	3.18	2.45	5.63	0.09	0.15
	Cg2	3.21	2.44	5.65	0.14	0.17
	Cg3	3.20	2.62	5.82	0.15	0.15
	Mean	3.33	2.55	5.88	0.10	0.16
Sherpur	Apg	3.16	2.04	5.20	0.07	0.13
	Bwg1	3.15	2.10	5.25	0.03	0.16
	Bwg2	3.09	2.73	5.82	0.17	0.18
	Bwg3	3.65	2.80	6.45	0.18	0.16
	Cg1	3.24	2.60	5.84	0.15	0.13
	Cg2	3.17	2.82	5.99	0.12	0.15
	Mean	2.24	2.51	4.75	0.12	0.15
Grand mean		3.14	2.00	5.39	0.10	0.14

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Consequently, the soils may be regarded as still in the youthful stage.

It may be pointed out that the total P_2O_5 contents in the soils studied vary from 0.03 to 0.18 percent with a mean value of 0.10. The highest mean value is found in Dhamrai, Sonatala and Sherpur soils whereas the lowest mean is found in Silmandi soil. The high content of P_2O_5 in Dhamrai, Sonatala and Sherpur series might be linked with the presence of higher phosphorus in their parent materials.

The distribution pattern of P_2O_5 suggests that their amount is lower at the surface and in general, gradually increases with depth (Table -19). The low content of P_2O_5 at the surface is probably due to the utilization of phosphorus by plants or due to mobilization of them. But they show no tendency of accumulation in any depth zone of the profiles. The lower content of total P_2O_5 in the surface horizon has also been reported by Hussain et al. (1982). The causes are identified as texture, age and hydrological conditions.

5.3.6. Fusion analysis of the clay fractions

The clay fraction with a minimum settling velocity of 10^{-4} cm per second were separated from other fractions in all soil samples to carry out fusion analysis on them.

Percent SiO_2 , Al_2O_3 , Fe_2O_3 , CaO , MgO , K_2O , TiO_2 and P_2O_5 , and MnO_2 were determined.

The percent SiO_2 contents in the clay fraction of the soils studied vary from 50.8 to 56.1 percent with a mean value of 53.1 percent (Table -20). The highest mean value is found in the Lokdeo soils and the lowest in the Dhamrai soils. The variation between the lowest and the highest value of SiO_2 content is very narrow and this indicates that their mineralogical composition is more or less similar.

The vertical distribution of SiO_2 content in the clay fraction of the pedons studied is more or less uniform (Table - 20).

The percent Al_2O_3 in the pedons studied ranges from 17.8 to 24.8 percent with a mean value of 22.0 percent (Table -20). The highest mean value is found in Lokdeo soils whereas the lowest mean value is found in the Sonatala soils. The variation between the highest and the lowest value is very narrow.

The vertical distribution of Al_2O_3 content within the profiles of the pedons studied is more or less uniform (Table -20).

The Fe_2O_3 content in the clay fraction ranges from 8.4 to 11.9 percent , the average value being 9.8 percent (Table -20). A portion of this iron is present in the form of free Fe_2O_3 . The highest mean value of total Fe_2O_3 is found in Melandaha soil and the lowest in the Ghatail soil. Variation in the highest and lowest mean value is very narrow in these soils.

The distribution pattern of Fe_2O_3 content in the clay fraction of the pedons studied is more or less uniform (Table -20).

Table-20. Fusion analysis of the clay fraction

Soils	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃	L.O.I
					R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	%
		←----- % -----→			←----- Molar ratio -----→			
Melandaha	Apg1	52.1	21.2	11.8	3.1	4.2	2.8	10.9
	Apg2	54.2	22.3	11.9	3.1	4.1	2.9	10.1
	Bwg1(?)	54.8	23.7	10.9	3.0	3.9	3.4	9.1
	Bwg2(?)	52.8	24.8	10.5	2.8	3.6	3.7	10.2
	2C1	52.8	21.3	9.9	3.2	4.2	3.4	8.4
	2C2	53.3	23.4	8.9	3.0	3.8	4.1	7.0
	3A1b(?)	52.7	22.0	8.5	3.3	4.1	4.1	10.1
	4C	51.3	22.9	10.6	2.9	3.7	3.6	9.5
	Mean	52.9	22.7	10.4	3.0	3.9	3.5	9.5
Dhamral	Apg1	52.3	21.7	9.1	3.2	4.1	3.7	10.3
	Apg2	53.2	20.1	9.5	3.4	4.5	3.3	10.9
	Bwg1	51.3	21.6	8.9	3.2	4.1	3.8	11.0
	Bwg2	52.7	22.6	10.3	3.1	3.9	3.4	12.8
	Cg1	51.0	23.3	10.7	2.9	3.7	3.4	12.1
	Cg2	51.3	23.8	10.2	2.9	3.7	3.4	10.3
	Cg3	54.8	18.2	8.9	3.9	5.1	3.2	9.9
	2Cg4	51.0	19.1	9.7	3.4	4.5	3.1	8.6
	Mean	52.2	21.3	9.7	3.2	4.2	3.4	10.7
Sonatala	Apg1	53.4	17.8	10.6	3.7	5.1	2.6	14.9
	Apg2	54.6	19.2	10.6	3.6	4.8	2.8	11.9
	Bwg1	54.3	20.1	9.8	3.5	4.5	3.2	10.9
	Bwg2	55.0	18.8	8.9	3.8	4.9	3.3	11.3
	Bwg3	52.0	21.7	10.7	3.1	4.1	3.2	12.3
	Cg1	52.7	22.3	10.4	3.1	4.0	3.4	11.8
	Cg2	56.1	19.4	10.3	3.7	4.9	2.9	12.4
	Cg3	53.2	20.8	10.2	3.3	4.3	3.2	12.3
	Mean	53.9	20.0	10.2	3.5	4.6	3.1	12.2

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Table-20. Continued

Soils	Horizon	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	SiO ₂	SiO ₂	Al ₂ O ₃	L.O.I
					R ₂ O ₃	Al ₂ O ₃	Fe ₂ O ₃	%
		←----- % -----→			←----- Molar ratio -----→			
Silmandi	Apg1	53.3	19.9	9.5	3.5	4.5	3.3	12.8
	Apg2	54.2	21.3	10.3	3.3	4.3	3.3	13.0
	Bwg1	53.7	22.1	9.7	3.0	3.8	3.8	10.3
	Bwg2	54.8	22.9	8.4	3.3	4.0	4.3	11.0
	Bwg3	53.2	22.8	8.9	3.1	3.8	4.2	8.3
	Cg1	52.6	21.8	9.5	3.3	4.1	3.6	9.4
	Cg2	52.2	20.8	9.7	3.6	4.2	3.6	10.0
	Cg3	52.8	19.3	8.4	3.2	4.6	3.5	11.7
	Mean	53.4	21.4	9.3	3.3	4.2	3.7	9.7
Lokdeo	Apg1	54.3	22.2	9.4	3.3	4.1	3.7	10.7
	Apg2	53.8	22.6	10.2	3.1	4.0	3.5	11.1
	Bwg1	53.3	23.7	9.8	3.0	3.8	3.8	13.4
	Bwg2	53.0	24.3	10.7	2.9	3.7	3.6	14.5
	Bg3	52.7	22.8	10.3	3.0	3.9	3.5	12.9
	Cg1	54.7	23.6	9.7	3.1	3.9	3.8	10.9
	Cg2	54.8	24.8	10.8	2.9	3.7	3.6	11.1
	Cg3	53.3	24.6	8.8	3.0	3.7	4.4	10.9
	Mean	53.7	23.6	9.9	3.0	3.8	3.7	11.9
Ghatali	Apg1	53.4	20.9	8.9	3.4	4.3	3.7	11.3
	Apg2	52.3	22.5	9.5	3.1	3.9	3.7	11.5
	Bwg1	53.8	21.3	8.9	3.4	4.3	3.8	11.8
	Bwg2	54.4	20.7	9.1	3.5	4.4	3.6	11.7
	Bwg3	52.0	22.8	9.9	3.0	3.9	3.6	11.6
	Cg1	54.8	23.8	8.8	3.1	3.9	4.2	11.4
	Cg2	50.8	24.8	9.8	2.8	3.5	4.1	12.0
	Cg3	52.7	20.6	9.9	3.4	4.3	3.5	12.2
	Mean	53.0	22.2	9.2	3.2	4.1	3.8	11.7
Sherpur	Apg	54.6	24.1	11.1	2.9	3.8	3.4	8.5
	Bwg1	53.2	24.1	10.2	2.9	3.7	3.7	9.5
	Bwg2	52.3	22.5	8.9	3.1	3.9	3.9	7.6
	Bwg3	51.7	24.3	9.7	2.9	3.6	3.9	10.4
	Cg1	52.6	22.8	10.3	3.0	3.9	3.5	10.9
	Cg2	53.3	20.1	10.5	3.4	4.5	2.9	11.6
	Mean	52.9	23.0	10.1	3.0	3.9	3.6	9.7
Grand mean		53.1	22.0	9.8	3.2	4.1	3.1	10.8

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The $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio ranges from 2.8 to 3.9 percent with a mean of 3.2 percent (Table-20). The highest mean value is found in the Sonatala profile and the lowest in the Lokdeo profile. From these results it seems that most of the clay fractions in the soils under the investigation probably contain high amount of 2 : 1 lattice type clay minerals.

Hussain and Swindale (1974) in a study of some Gray Hydromorphic soils of the Hawaiian Island reported that the $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio of clay fraction varied from 1.5 to 2.9. They further noted that the dominant clay minerals in these soils was montmorillonite with a small amount of kaolinite. The present results of the $\text{SiO}_2/\text{R}_2\text{O}_3$ ratio is lower than those reported by the above authors.

The $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio of the clay fractions ranges between 3.5 and 4.9 with an average of 4.1. The highest mean value within the profile is found in Sonatala soil whereas the lowest value is found in Melandaha and Sherpur soils.

The $\text{Al}_2\text{O}_3/\text{Fe}_2\text{O}_3$ ratio varies from 2.6 to 4.4 with an average of 3.1. The highest mean ratio is found in Ghatail soil whereas the lowest in Dhamrai soils.

The CaO content of the clay fraction is very low (Table - 21).

The MgO content of the clay fraction ranges from 2.05 to 4.19 with a mean of 2.55 percent. These results indicate that the clay minerals are rich in magnesium. This suggests that a portion of mica present in the clay fraction is in all probability biotitic. The highest mean value of MgO content is found in Sonatala soil whereas the lowest value is noticed in Silmandi soils.

The MnO_2 content in the clays varies from 0.07 to 0.35 percent with an average value of 0.12 percent (Table -21).

The P_2O_5 contents in clays vary from 0.08 to 0.19 percent with an average value of 0.13 percent (Table-21).

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Table-21. Contents of CaO, MgO, P₂O₅, and MnO₂ in the clay fraction of the soils under investigation.

Soils	Horizon	CaO %	MgO %	P ₂ O ₅ %	MnO ₂ %
Melandaha	Apg1	Tr	3.10	0.08	0.11
	Apg2	Tr	2.85	0.09	0.12
	Bwg1(?)	0.02	2.31	0.10	0.09
	Bwg2(?)	0.01	2.05	0.08	0.10
	2C1	0.01	2.31	0.11	0.12
	2C2	0.02	2.01	0.08	0.13
	3A1b(?)	0.02	2.87	0.11	0.11
	4C	0.02	2.80	0.12	0.12
	Mean	0.02	2.54	0.10	0.11
Dhamral	Apg1	0.03	2.66	0.18	0.11
	Apg2	0.02	2.58	0.15	0.12
	Bwg1	0.01	2.61	0.16	0.11
	Bwg2	0.01	2.62	0.19	0.13
	Cg1	Tr	2.66	0.18	0.13
	Cg2	Tr	2.51	0.13	0.11
	Cg3	Tr	2.63	0.12	0.10
	2Cg4	Tr	2.49	0.11	0.10
	Mean		2.60	0.15	0.10
Sonatala	Apg1	0.03	4.19	0.15	0.35
	Apg2	0.02	3.60	0.15	0.21
	Bwg1	0.02	2.91	0.21	0.10
	Bwg2	0.01	2.09	0.15	0.11
	Bwg3	0.01	2.56	0.18	0.13
	Cg1	Tr	2.60	0.17	0.11
	Cg2	Tr	2.65	0.19	0.10
	Cg3	tr	2.78	0.18	0.12
	Mean	0.02	2.90	0.17	0.15

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Chapter V Results and Discussion

Table-21. Continued

Soils	Horizon	CaO %	MgO %	P ₂ O ₅ %	MnO ₂ %
Silmandi	Apg1	0.03	2.28	0.09	0.08
	Apg2	0.02	2.20	0.11	0.07
	Bwg1	0.03	2.19	0.12	0.07
	Bwg2	0.01	2.22	0.12	0.08
	Bwg3	Tr	2.18	0.11	0.09
	Cg1	Tr	2.15	0.08	0.07
	Cg2	0.01	2.01	0.10	0.10
	Cg3	0.01	1.97	0.12	0.11
	Mean	0.02	2.15	0.11	0.08
Lokdeo	Apg1	0.03	2.60	0.10	0.10
	Apg2	0.02	2.61	0.08	0.11
	Bwg1	0.01	2.68	0.12	0.09
	Bwg2	0.01	2.62	0.14	0.10
	Bg3	0.01	2.61	0.13	0.08
	Cg1	Tr	2.55	0.12	0.11
	Cg2	Tr	2.45	0.11	0.12
	Cg3	Tr	2.32	0.11	0.11
	Mean	0.02	2.55	0.11	0.10
Chatali	Apg1	0.03	2.05	0.14	0.08
	Apg2	0.01	2.12	0.12	0.09
	Bwg1	Tr	2.11	0.12	0.10
	Bwg2	Tr	2.59	0.10	0.08
	Bwg3	Tr	2.60	0.13	0.11
	Cg1	0.01	2.90	0.15	0.13
	Cg2	0.01	2.85	0.19	0.12
	Cg3	0.03	2.83	0.17	0.14
	Mean	0.01	2.51	0.14	0.11
Sherpur	Apg	0.01	3.01	0.17	0.11
	Bwg1	0.01	2.61	0.17	0.10
	Bwg2	Tr	2.63	0.15	0.12
	Bwg3	Tr	2.53	0.16	0.10
	Cg1	Tr	2.41	0.17	0.09
	Cg2	Tr	2.33	0.18	0.11
	Mean	Tr	2.59	0.17	0.11
Grand mean		0.02	2.55	0.13	0.12

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The loss on ignition (LOI) of the clay fraction of the soils under the present study ranges from 7.0 to 14.9 percent with a mean of 10.8 percent (Table-20). The loss on ignition of the clay fraction is found to be high. The highest mean value of loss on ignition in the clay fraction is found in Sonatala soils whereas the lowest is noticed in the Melandaha soils.

Chapter V Results and Discussion

5.3.7. Total potassium(K_2O) contents in soils and clays

The analytical data of total K_2O content of the soils under the present study have been presented in Table-22. The K_2O contents in the whole soils vary from 1.24 to 3.37 percent and the mean value is 2.50 percent. Similar results were also observed by Chowdhury et al.(1992). The above results indicate that the total potassium content is quite high, which might be due to the presence of abundant quantity of potassium bearing minerals such as micas and feldspars in the parent materials of the soils. In fact, mica flakes in some soil samples could be seen even with unaided eye in the field. Presence of mica flakes in the soil under study also indicates that these soils are relatively young. The slightly higher values of K_2O contents are observed in the soils of the Sherpur profile whereas the lowest K_2O contents are found in the Melandaha soil. This variation in K_2O content is due probably to the variation in the K-bearing minerals in their parent material (Laves, 1978; Mengel and Kirkby, 1982).

The vertical distribution of K_2O in the soil profiles are in general irregular in nature (Table-22) .Although the distribution pattern within the soil profile is irregular,there is a little accumulation of K_2O content in the B-horizon of all the soils except the Ghatail profile. In the Ghatail profile there is an accumulating tendency of K_2O content in the surface horizons of the profile.The impoverishment of K_2O from the surface horizons of Melandaha, Dhamrai, Sonatala, Silmandi, Lokdeo and Sherpur profiles suggests that the mica present in these horizons are being weathered and potassium is being lost from their interlattice space forming illite/hydrated mica. This may be caused by the seasonal flooding and fluctuating ground water table. The K is known to be highly sensitive to leaching during weathering and soil formation (Jenny, 1941). The differential differential leaching of potassium in the soils studied may be due to variation in their drainage condition. The above results are in agreement with the findings of Diwakar and Singh (1992) in some floodplain soils of India .

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Table-22. Results of total potassium contents in the soils and the clay fraction.

Soils	Horizon	Depth cm	% K ₂ O		% Mica in clay	% Illite in clay
			Soils	Clays	(Jackson, 1975)	(Karim, 1954)
Malandaha	Apg1	0-9	1.89	2.67	27	42
	Apg2	9-15	1.85	2.70	27	42
	Bwg1(?)	15-28	2.47	2.75	28	43
	Bwg2(?)	28-36	2.60	2.68	27	42
	2C1	36-46	1.82	2.90	29	45
	2C2	46-57	2.50	3.10	31	48
	3A1b(?)	57-72	2.47	3.60	36	56
	4C	72-100+	1.81	4.02	40	63
	Mean	-	2.18	3.05	31	48
Dhamrai	Apg1	0-10	2.54	3.75	37	59
	Apg2	10-15	2.60	3.53	35	55
	Bwg1	15-33	2.71	3.41	34	53
	Bwg2	33-43	2.71	3.10	31	48
	Cg1	43-63	2.56	2.90	29	45
	Cg2	63-88	2.51	3.70	37	58
	Cg3	88-113	2.56	3.78	38	59
	2Cg4	113-126+	2.51	3.98	40	62
	Mean	-	2.59	3.52	35	55
Sonatala	Apg1	0-10	2.42	2.82	28	44
	Apg2	10-17	2.45	2.80	28	44
	Bwg1	17-35	2.53	2.75	27	43
	Bwg2	35-47	2.57	2.70	27	42
	Bwg3	47-59	2.50	2.82	28	44
	Cg1	59-77	2.53	2.83	28	44
	Cg2	77-93	2.44	2.73	27	43
	Cg3	93-125+	2.49	2.70	27	42
	Mean	-	2.49	2.77	28	43

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Chapter V Results and Discussion

Table-22. Continued

Soils	Horizon	Depth cm	% K ₂ O		% Mica in clay	% Illite in clay
			Soils	Clays	(Jackson, 1975)	(Karim, 1954)
Silmandi	Apg1	0-10	1.93	2.75	27	43
	Apg2	10-16	2.62	2.80	28	44
	Bwg1	16-38	2.55	2.86	29	45
	Bwg2	38-47	2.49	2.85	28	45
	Bwg3	47-61	2.44	2.71	27	42
	Cg1	61-74	1.24	2.73	27	43
	Cg2	74-90	1.87	2.81	28	44
	Cg3	90-110+	2.58	2.69	27	42
	Mean	-	2.21	2.78	28	44
Lokdeo	Apg1	0-10	1.84	2.68	27	42
	Apg2	10-17	1.69	2.80	28	44
	Bwg1	17-31	2.28	2.73	27	43
	Bwg2	31-56	2.54	2.98	30	47
	Bg3	56-70	3.12	3.06	31	48
	Cg1	70-90	2.54	3.81	38	66
	Cg2	90-110	1.28	3.99	40	62
	Cg3	110+	2.60	4.03	40	63
	Mean	-	2.24	3.26	33	51
Ghatal	Apg1	0-10	3.33	4.05	41	63
	Apg2	10-18	3.35	3.88	39	61
	Bwg1	18-33	2.68	2.93	29	46
	Bwg2	33-51	2.65	2.71	27	42
	Bwg3	51-73	3.30	2.98	30	47
	Cg1	73-91	2.57	2.78	28	43
	Cg2	91-103	2.52	2.80	28	44
	Cg3	103-125+	2.50	2.73	27	43
	Mean	-	2.86	3.11	31	49
Sherpur	Apg	0-14	2.36	2.68	27	42
	Bwg1	14-29	2.58	2.70	27	42
	Bwg2	29-47	3.29	2.59	26	40
	Bwg3	47-66	2.61	2.65	26	41
	Cg1	66-96	3.37	2.70	27	42
	Cg2	96-122+	3.25	2.71	27	42
	Mean	-	2.91	2.67	17	42
Grand mean			2.50	3.02	31	47

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The amount of K_2O in the clay fraction varies from 2.59 to 4.05 percent and the average value is 3.02 percent (Table-22). The highest amount of K_2O in the clay fraction is observed in the Dhamrai profile while the lowest amount is found in the Sherpur profile. This variation of K_2O content in the clay fraction is due to the variations in the K bearing minerals mainly mica in the clay fraction.

The vertical distribution pattern of K_2O contents in the clay fraction is uniform in the Dhamrai, Sonatala, Silmandi, and Sherpur soils. In the Ghatail profile there is a surface enrichment of K_2O in the clay fraction. However, in the Melandaha and Lokdeo profiles there is a tendency of K_2O impoverishment in the upper horizons.

A rough estimate of illitic minerals in the clay fractions can be made from their K_2O contents by using Karim's (1954) and Jackson's (1975) method. The former author used 6.4 percent K_2O and the latter used 10 percent K_2O for 100 percent illite/mica.

In the clay fraction potassium is usually present in illitic minerals. The amount of illite mineral can be approximately estimated when it is assumed that there is no other potassium bearing minerals in the clay fraction except illite. It is clear that there is abundant illite mineral present in the clay fraction. The amount varies from 27 to 41 percent (Table-22). The highest illite content is present in the Dhamrai soil profile while the lowest amount is found in the Sherpur profile.

The mean mica content in the clay fraction of the soils found on the Brahmaputra floodplain is 31 percent according to the calculation by Jackson's method (1975) and this is about one third of the total clay mineral contents. But according to Karim's method (1954), the mean illite content in the clay fraction is 47 percent. If such a high quantity of illite present in the soils under the present investigation indicate that the supply of potassium for consumption by plants will be adequate and there will be little need for application of potassic fertilizer for optimum crop production.

*Chapter V Results and Discussion***5.3.8. Titanium (TiO_2) contents in soils and clays**

The TiO_2 contents in the soil vary from 0.61 to 1.79 percent and the average TiO_2 content is 1.17 percent (Table-23). The highest mean value within the profile was found in the Sherpur soil followed by the Ghatail soil. The lowest TiO_2 content was found in the Silmandi soil. Similar results were obtained in Cambodia, Indonesia, Malaysia, Philippines and Tropical Asia in rice soils (Kyuma, 1978). Source of this titanium is mostly titanium bearing primary minerals such as rutile, anatase and ilmenite in the parent materials.

The distribution of TiO_2 in soils from the surface downward follows an irregular pattern in all the soil profiles. Although the distribution pattern is irregular, in the Melandaha, Silmandi, Ghatail and Lokdeo profiles slight depletion of TiO_2 from the surface horizons may be noticed. Immediately below the surface a zone of accumulation of TiO_2 is observed (Table-23). This zone of accumulation may be important from pedogenetic point of view.

Under alternate oxidation and reduction conditions throughout the year, as the soils are seasonally flooded, the redistribution of TiO_2 in the soil profiles is quite possible. The reason as to why titanium is not being preferentially accumulated anywhere in the soil profiles is not clear. However, strong alternate oxidation-reduction conditions have been found to cause movement and removal of titanium in some other soils (Sherman, 1952; and Hussain and Islam, 1979).

The TiO_2 content in clay fraction ranges from 1.12 to 1.91 percent and the average value is 1.64 percent (Table-23). TiO_2 contents in the clay fraction is more than that in the whole soil. This is because most of the TiO_2 minerals occur in the clay fraction of the soils.

The highest mean value among the profiles is observed in Lokdeo soil and the lowest mean value was in the Ghatail soil. It may be noted here that TiO_2 in

Chapter V Results and Discussion

Table-23. Results of total titanium (TiO₂) contents in the soils and the clay fraction.

Soils	Horizon	Depth cm	% TiO ₂	
			Soil	Clay
Malandaha	Apg1	0-9	1.10	1.86
	Apg2	9-15	1.14	1.80
	Bwg1(?)	15-28	1.24	1.88
	Bwg2(?)	28-36	1.36	1.90
	2C1	36-46	0.69	1.83
	2C2	46-57	0.83	1.76
	3A1b (?)	57-72	1.13	1.74
	4C	72-100+	1.09	1.66
	Mean	-	1.07	1.80
Dhamrai	Apg1	0-10	0.99	1.33
	Apg2	10-15	1.13	1.47
	Bwg1	15-33	1.20	1.50
	Bwg2	33-43	1.13	1.53
	Cg1	43-63	.13	1.57
	Cg2	63-88	1.43	1.60
	Cg3	88-113	1.22	1.39
	2Cg1	113-126+	1.27	1.50
	Mean	-	1.19	1.49
Sonatala	Apg1	0-10	1.04	1.68
	Apg2	10-17	1.14	1.62
	Bwg1	17-35	1.07	1.59
	Bwg2	35-47	1.21	1.69
	Bwg3	47-59	1.39	1.66
	Cg1	59-77	1.29	1.63
	Cg2	77-93	1.22	1.67
	Cg3	93-125+	1.16	1.60
	Mean	-	1.19	1.63

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Table-23. Continued

Soils	Horizon	Depth cm	% TiO ₂	
			Soils	Clays
Silmandi	Apg1	0-10	0.61	1.62
	Apg2	10-16	0.70	1.56
	Bwg1	16-38	0.89	1.55
	Bwg2	38-47	0.82	1.55
	Bwg3	47-61	0.92	1.52
	Cg1	61-74	0.69	1.48
	Cg2	74-90	0.74	1.49
	Cg3	90-110+	0.80	1.50
	Mean	-	0.77	1.53
Lokdeo	Apg1	0-10	1.11	1.91
	Apg2	10-17	1.17	1.83
	Bwg1	17-31	1.10	1.88
	Bwg2	31-56	1.30	1.87
	Bg3	56-70	1.07	1.76
	Cg1	70-90	1.30	1.82
	Cg2	90-110	0.90	1.77
	Cg3	110+	0.80	1.85
	Mean	-	1.11	1.84
Ghatal	Apg1	0-10	1.43	1.43
	Apg2	10-18	1.33	1.48
	Bwg1	18-33	1.38	1.39
	Bwg2	33-51	1.51	1.55
	Bwg3	51-73	1.60	1.63
	Cg1	73-91	1.10	1.61
	Cg2	91-103	1.26	1.49
	Cg3	103-125+	0.98	1.12
	Mean	-	1.32	1.46
Sherpur	Apg	0-14	1.17	1.74
	Bwg1	14-29	1.26	1.70
	Bwg2	29-47	1.68	1.77
	Bwg3	47-66	1.67	1.79
	Cg1	66-96	1.79	1.88
	Cg2	96-122+	1.52	1.63
	Mean	-	1.51	1.76
Grand mean		-	1.17	1.64

Chapter V Results and Discussion

clay fraction may occur in two distinct forms. Firstly, in discrete oxide forms which usually occur as clay sized and discrete titanium oxide minerals; and secondly, titanium may occur in the octahedral layers of clay mineral (Jackson and Sherman, 1953; Brain, 1976 and Hutton, 1977), because titanium can isomorphously replace aluminium in the octahedral layer of clay lattice.

The irregular distribution of TiO_2 in the colloidal fraction indicates that the parent material is the possible source of this element in the soils. The variation in titanium content suggest heterogeneity and stratification of parent material in these soils (Smith and Wilding, 1972; Evans and Adams, 1975; Sharma and Dev, 1985).

5.4. Mineralogical Composition of Clay Fraction of the Soils

Clay mineral content is used as a classification criterion. Most intensive use of clay mineral data in the Comprehensive Soil Classification System is as one of a set of soil family differentiating characteristics. These materials are best determined by X-ray diffraction (Buol et al., 1980).

The X-ray diffractograms of clay fraction of the soils under the present investigation have been presented in Figs. 27 to 47. Minerals present in the clay fraction have been identified following the procedure of Jackson (1975). For the identification of minerals in the clay fraction it was assumed that the $17 \text{ \AA}$ peak in the glycerol solvated samples was an indication of the presence of smectite mineral. The peak at $14 \text{ \AA}$ which does not collapse when heated to 550°C indicated the presence of chlorite. The peak at $10 \text{ \AA}$ in the glycerol solvated clay samples was caused by the presence of mica. The peak at $7.2 \text{ \AA}$ disappearing on heating the sample at 550°C confirmed the presence of kaolinite mineral. A number of small peaks in the region of $10.0 \text{ \AA}$ to $14.0 \text{ \AA}$, some of which persist on glycerol solvation of the clay, suggested the presence of interstratified minerals.

The relative amounts of $7 \text{ \AA}$, $10 \text{ \AA}$ and $14 \text{ \AA}$ minerals were determined semi-quantitatively based on peak heights and peak areas of the X-ray diffractograms.

The semi-quantitative mineralogical composition of the clay fraction is presented in Table-24. From each soil profile three horizons-surface, subsurface, substratum - have been selected for X - ray diffraction analysis.

The present soils contained higher amount of mica, kaolinite, and vermiculite minerals in their clay fraction. Other minerals include chlorite with variable quantities of interstratified minerals. Small quantities of smectite are also present in the subsoils of Sonatala soil series. Although Brahmaputra alluvium have no smectite, the presence of 10% smectite was observed in the subsoils of the above soil series.

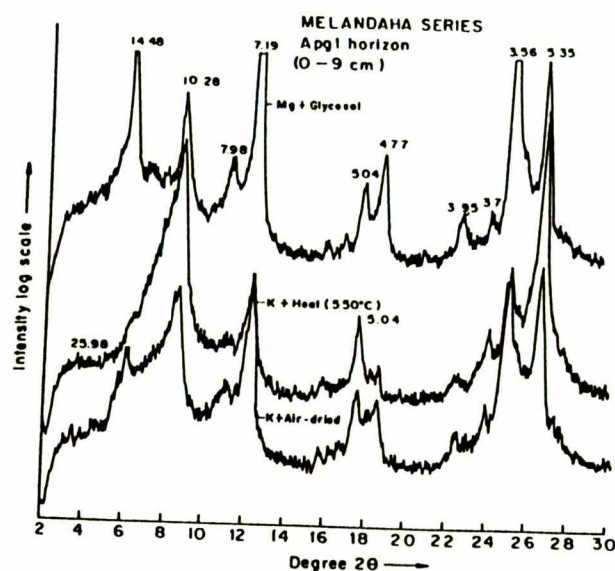


Fig 27. X-ray diffractograms of clay samples from Melandaha Soils.

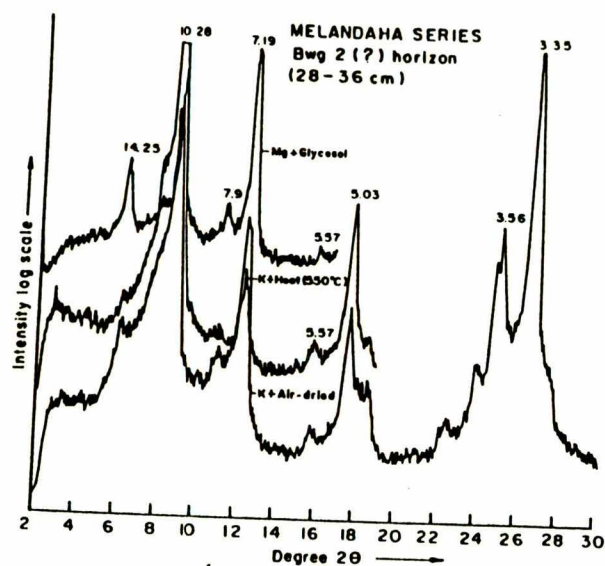


Fig 28. X-ray diffractograms of clay samples from Melandaha Soils.

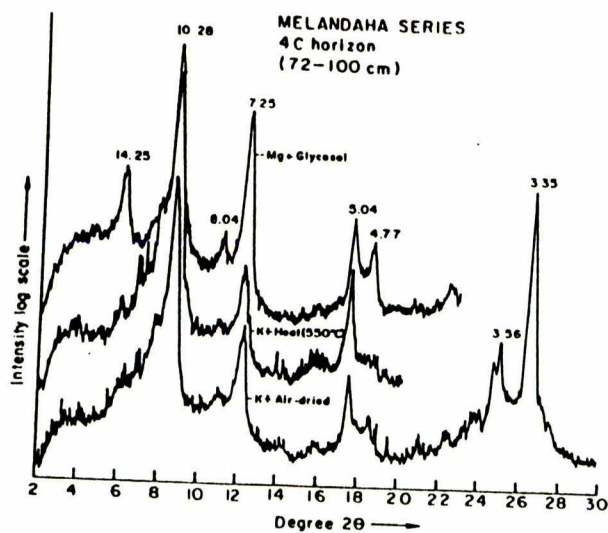


Fig 29. X-ray diffractograms of clay samples from Melandaha Soils.

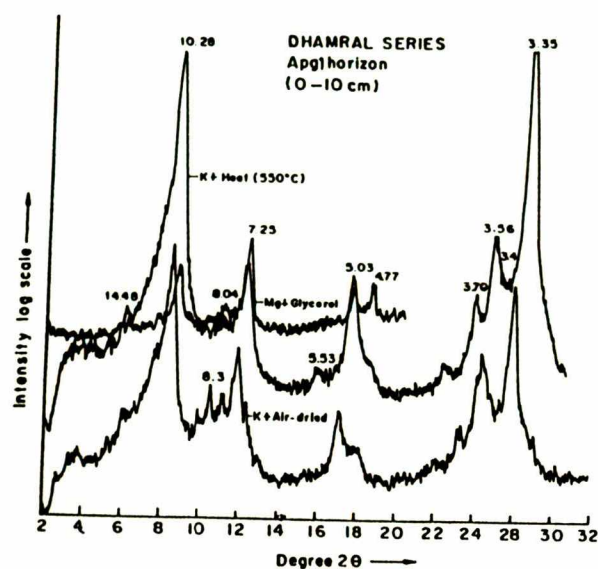


Fig. 30. X-ray diffractograms of clay samples from Dhamral Soils.

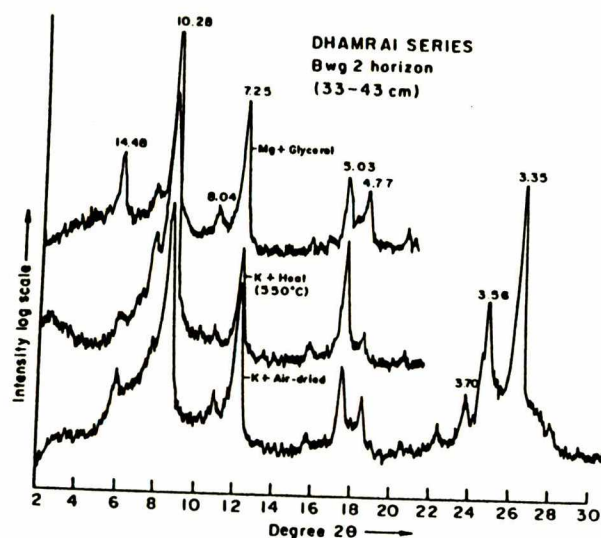


Fig. 31. X-ray diffractograms of clay samples from Dhamral Soils.

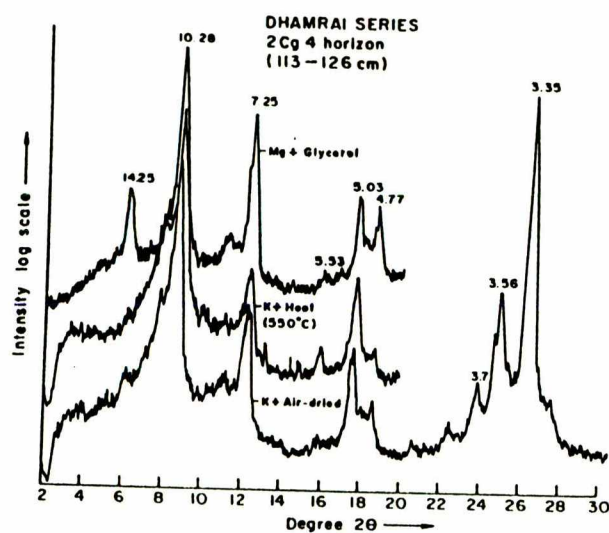


Fig. 32. X-ray diffractograms of clay samples from Dhamral Soils.

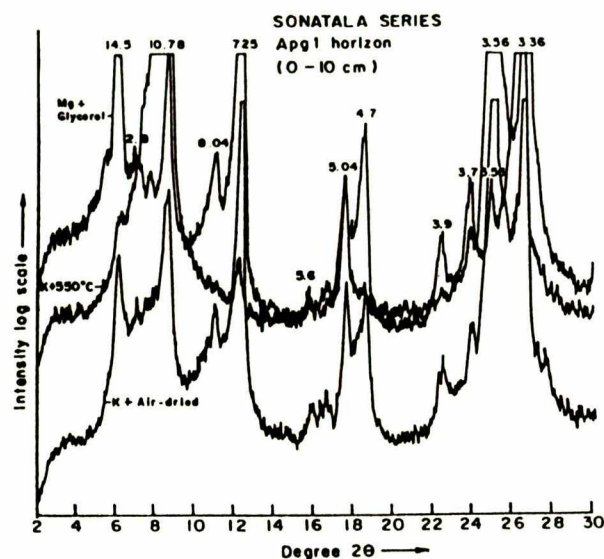


Fig. 33. X-ray diffractograms of clay samples from Sonatala Soils.

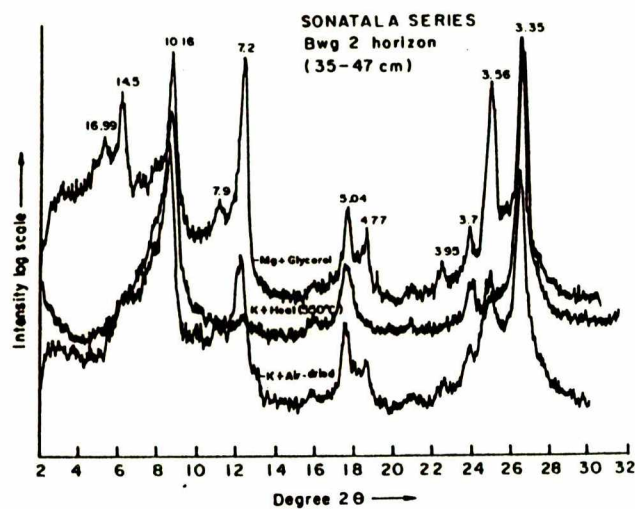


Fig. 34. X-ray diffraction patterns of clay samples from Sonatala Soils.

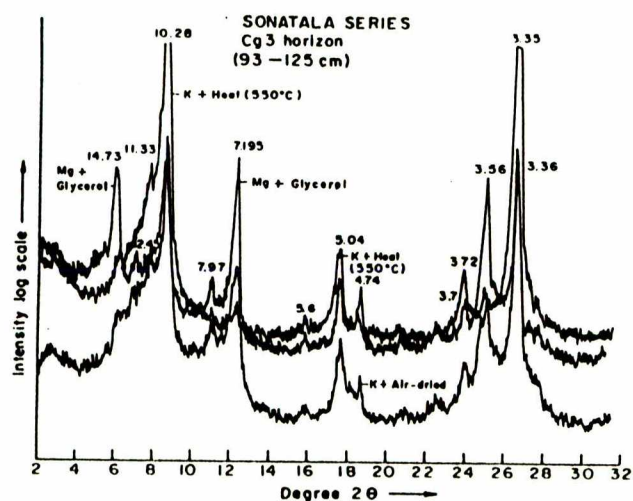


Fig. 35. X-ray diffractograms of clay samples from Sonatala Soils.

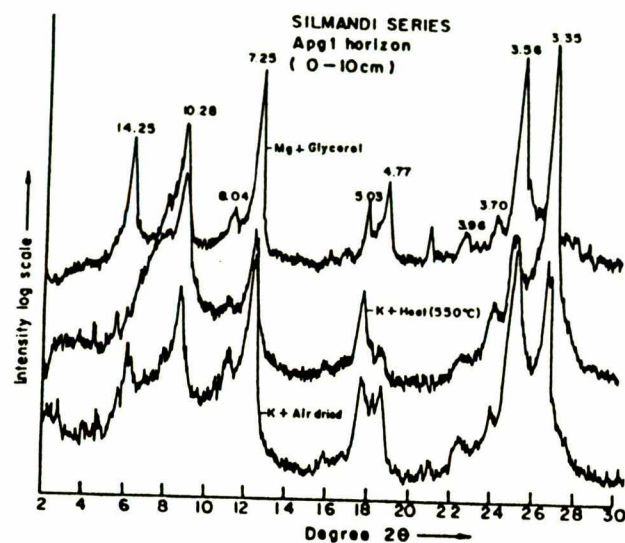


Fig. 36. X-ray diffractograms of clay samples from Silmandi Soils.

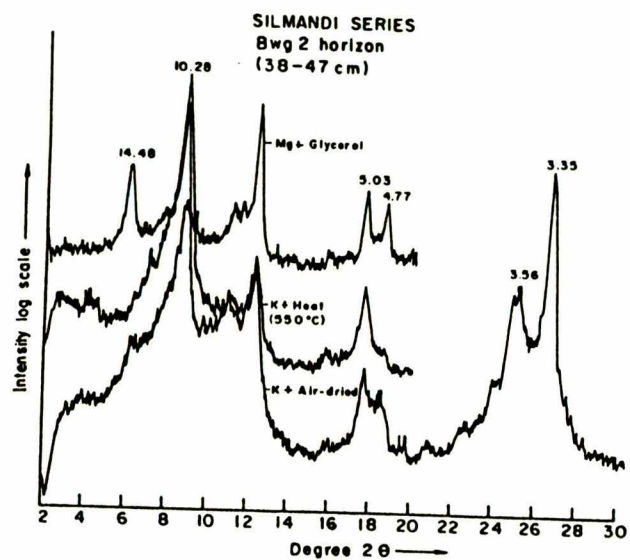


Fig. 37. X-ray diffractograms of clay samples from Silmandi Soils.

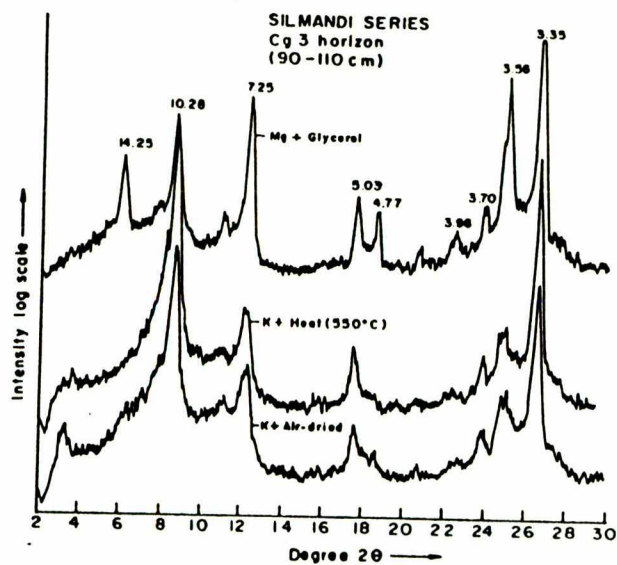


Fig. 38. X-ray diffractograms of clay samples from Silmandi Soils.

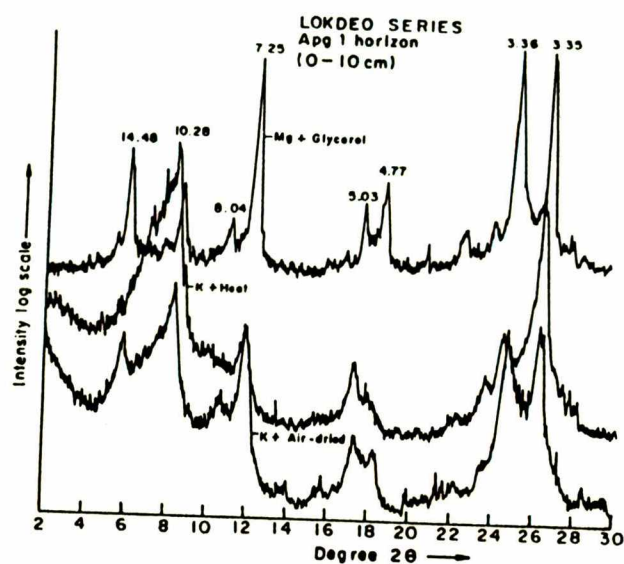


Fig. 39 X-ray diffractograms of clay samples from Lokdeo Soils.

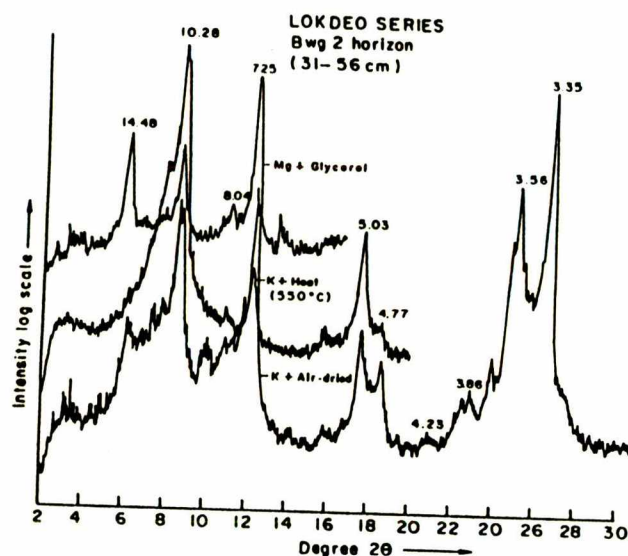


Fig. 40. X-ray diffractograms of clay samples from Lokdeo Soils.

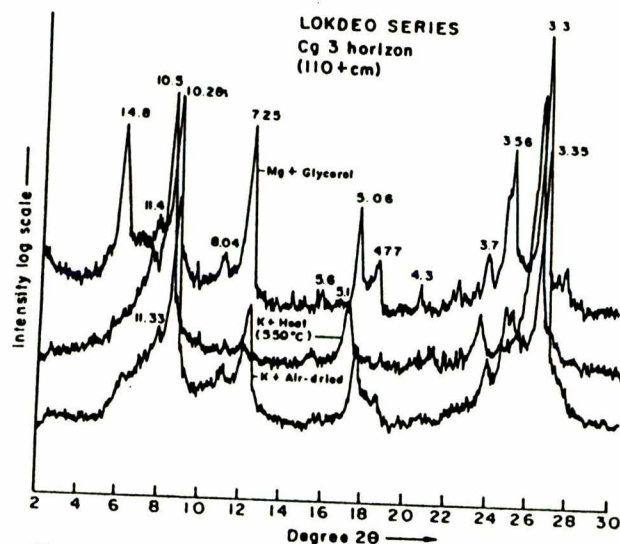


Fig. 41. X-ray diffractograms of clay samples from Lokdeo Soils.

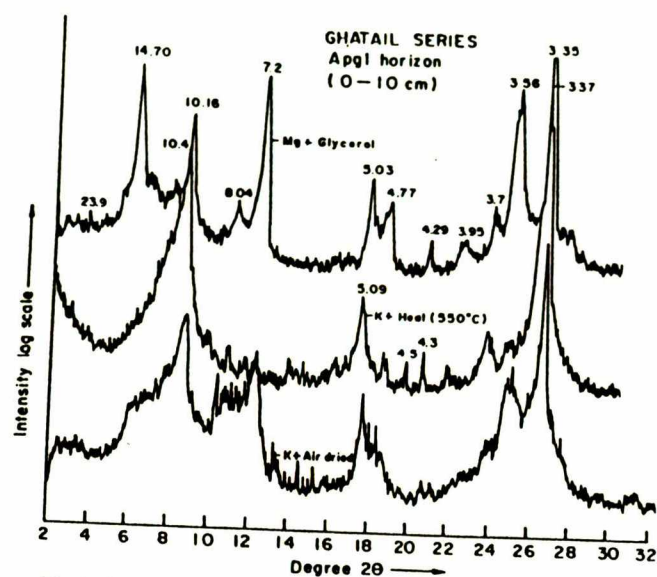


Fig. 42. X-ray diffraction patterns of clay samples from Ghatail Soils.

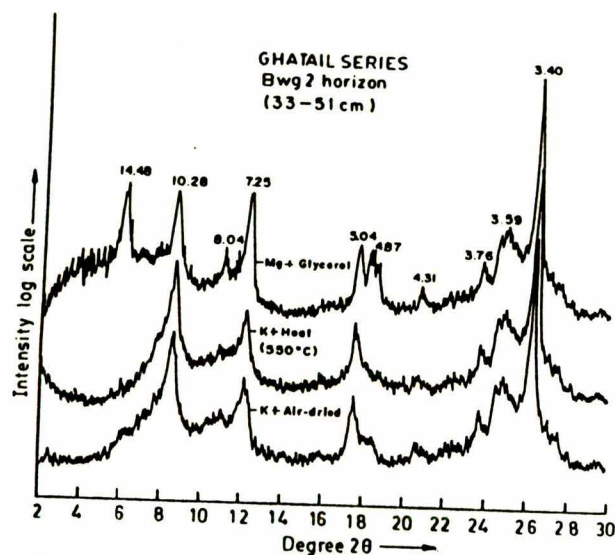


Fig. 43. X-ray diffraction patterns of clay samples from Ghatail

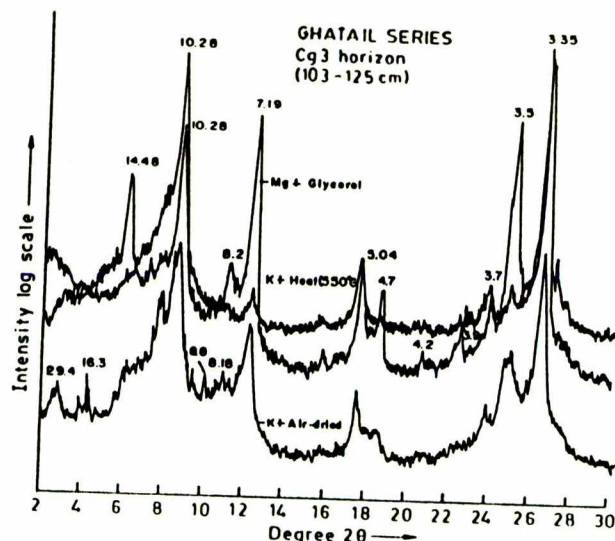


Fig. 44. X-ray diffraction patterns of clay samples from Ghatail Soils

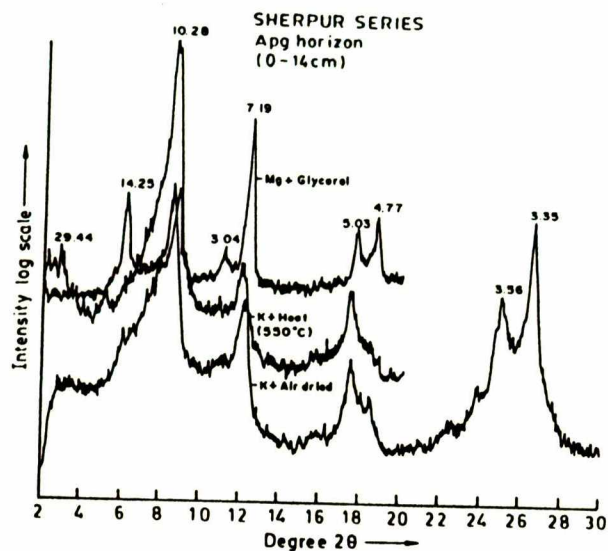


Fig. 45. X-ray diffractographic patterns of clay samples from Sherpur Soils.

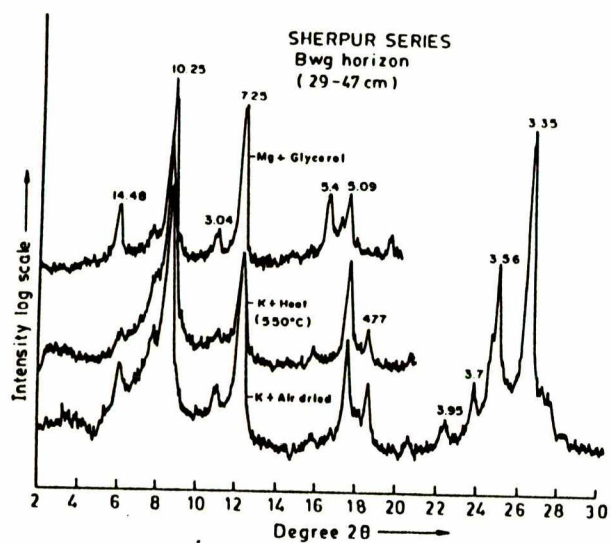


Fig. 46. X-ray diffractographic patterns of clay samples from Sherpur Soils.

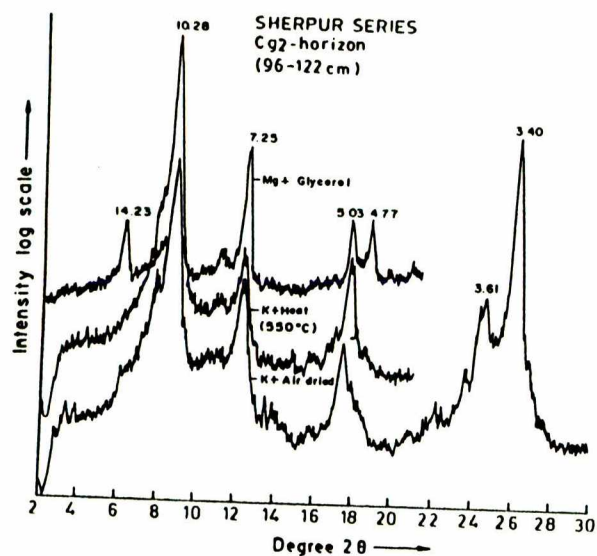


Fig. 47. X-ray diffractographic patterns of clay samples from Sherpur Soils.

White (1985) studied clay mineralogy of a large number of soils from Bangladesh and reported that mica along with kaolinite were the major clay minerals in the Brahmaputra floodplain soils, whereas smectites mostly present in the soils of the Gangetic floodplain. The formation of smectites in these soils are favoured by poor drainage, high pH and the presence of high concentration of Ca^{++} and Mg^{++} ions (Brammer, 1971; and Saheed and Hussain, 1992).

The vertical distribution of clay minerals in the Ghatail, Lokdeo and Sonatala soils indicated that there is no appreciable variation in the contents of $7.2\text{\AA}$, $10\text{\AA}$ and $14\text{\AA}$ minerals. Therefore, it can be assumed that the minerals present in these soils were possibly inherited from the parent materials.

In the Silmandi, Sherpur and Dhamrai pedons, the $7.2\text{\AA}$ mineral content is higher in the surface soil (A horizon) as compared to that in the lower horizons. The concentration of kaolinite in the surface horizons of the above soils may be due to in situ weathering processes. Thus in the above X-ray diffractogram results it appears that as a result of pedogenesis there is an increase of $7.2\text{\AA}$ mineral and a decrease of $10.0\text{\AA}$ mineral in the surface horizon of Silmandi, Sherpur and Dhamrai soils.

Soils of the Brahmaputra floodplain contains around 30 percent kaolinite (Table-24). Dixon (1977) postulated that kaolinite is one of the most widespread clay minerals in soils and are the products of acid weathering. Brady (1994) and Jackson (1964) stressed that kaolinite represents a more advanced stage of weathering than does any of the other major types of silicate clays and formed from the decomposition of silicates under conditions of moderate to strong acid weathering environment which results in the removal of the alkalies and alkaline earth metals. Mc Cracken et al. (1962) and Gupta et al. (1984) are of the opinion that kaolinite usually forms through the weathering of feldspars.

The content of mica in the Brahmaputra floodplain soils is around 40 percent (Table-24). Fanning and Keramidas (1977) pointed out that mica in most soils originate mainly from soil parent materials and tend to weather to other minerals with time. They,

Table-24. Semi-quantitative estimation of minerals in the clay fraction of the studied soils.

Soil series	Horizon	Depth (cm)	Clay mineral composition (out of 10)					
			K (7.2Å)	M (10Å)	V (14Å)	Ch (14Å)	S (17Å)	Int.
Melandaha	Apg1	0-9	2.9	3.7	2.3	Tr	-	1.0
	Bwg2(?)	28-36	3.5	3.8	2.2	Tr	-	0.5
	4C	72-100	3.0	4.5	2.0	Tr	-	0.5
Dhamrai	Apg1	0-10	3.8	4.3	1.8	-	-	Tr
	Bwg2	33-43	3.3	3.8	1.2	0.9	-	0.8
	2Cg4	113-126	3.1	4.0	1.2	0.8	-	0.8
Sonatala	Apg1	0-10	2.7	3.2	1.5	1.9	-	0.7
	Bwg2	35-47	2.7	3.2	1.3	1.0	1.0	0.8
	Cg3	93-125	3.0	3.5	1.5	1.0	-	1.0
Silmandi	Apg1	0-10	4.0	3.6	2.0	0.8	-	Tr
	Bwg2	38-47	4.1	4.0	1.8	Tr	-	Tr
	Cg3	90-110	3.1	4.2	1.8	Tr	-	0.8
Lokdeo	Apg1	0-10	3.5	3.6	1.8	0.5	-	0.6
	Bwg2	31-56	3.6	3.8	2.0	Tr	-	0.5
	C3	110	3.4	3.7	1.8	Tr	-	1.0
Ghatail	Apg1	0-10	3.0	4.2	2.5	Tr	-	Tr
	Bwg2	33-51	3.0	4.2	2.7	Tr	-	Tr
	Cg3	103-125	2.5	4.0	2.4	1.0	-	Tr
Sherpur	Apg	0-14	3.8	3.6	1.5	1.0	-	0.5
	Bwg2	29-47	3.6	4.5	1.0	0.8	-	Tr
	Cg2	96-122	3.4	4.9	1.5	Tr	-	Tr
Grand mean			3.3	3.9	2.0	-	-	-

* K= Kaolinite; M = Mica; V = Vermiculite; Ch= Chlorite; S = Smectite; Int= Inter stratified minerals (14 - 10Å); Tr = Trace.

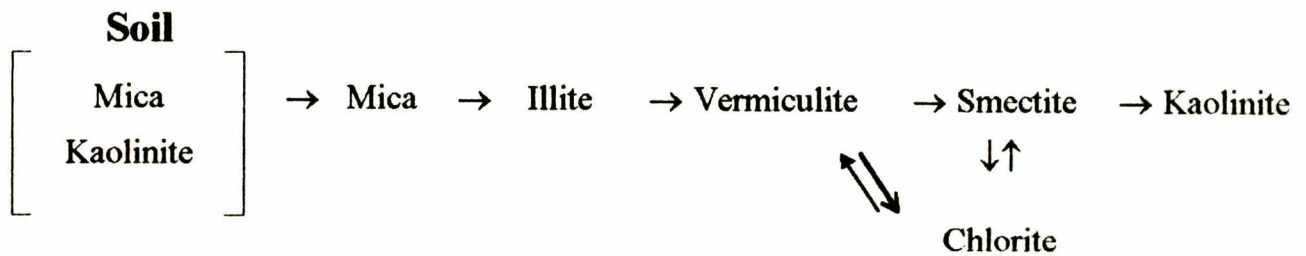
generally are more prevalent in the clay mineralogy of younger and less weathered soils (Entisols, Inceptisols, Alfisols). Also, micas tend to occur more as discrete mica particles in the less weathered soils, if such particles are present in the soil parent material, whereas in more weathered materials the mica is more commonly interstratified with expandable 2:1 minerals that may also be partially chloritized (Jackson et al., 1952; Jackson, 1964).

In the soils of the Brahmaputra floodplain, the content of vermiculite is around 20 percent (Table -24). Douglas (1977) stated that vermiculites are found under polar to tropical conditions as well as in deserts and in areas of high rainfall. They have been reported in all of the major soil groups, although found more often in soils of temperate and subtropical climates than in soils of tropical areas. Soil vermiculites are nearly always reported to accompany, or as an alteration product of muscovite, biotite or chlorite. In soils, dioctahedral vermiculite is more common than trioctahedral vermiculite (Jackson, 1959), probably indicating the relative stability of the muscovite structures, or a stability promoted by the presence of hydroxy-Al interlayers. In soils where kaolinite has long been thought to be the most abundant clay minerals (Red-yellow Podzolics; Udolls, etc.), it is recognized that hydroxy-Al-interlayered dioctahedral vermiculite is often the most abundant clay minerals in surface horizons, provided that mica was in the parent materials (Carlisle and Zelazny, 1973; Douglas, 1965; Rich and Obenshain, 1955). Vermiculite can form in many different soil environment, from a variety of parent minerals. For vermiculite to persist under intense weathering conditions or for long periods of time, the normal weathering sequence is: mica → vermiculite → hydroxy-aluminum-interlayered vermiculite (Douglas, 1977).

Sonatala soils contain around 20 percent chlorite in the surface horizon while other soils contain only traces of this mineral. Barnhisel (1977) stated that chlorites in soils are largely inherited as primary minerals, found in metamorphic or igneous rocks or occur as alteration products from minerals such as hornblende, biotite, and other ferromagnesian minerals. The abundance and frequency of occurrence of chlorites in soils are relatively low, and the geographic distribution is related to the parent materials. The low frequency may be due to the low stability of chlorite, or to the difficulty of distinguishing

small amounts of chlorite in the presence of kaolinite, vermiculite and smectite, especially if these latter minerals contain hydroxy- Al (or Fe) interlayers.

The soils under the present investigations have varying proportions of mica, kaolinite and vermiculite (Table-24). The presence of mica in these soils is indicative of the influence of micaceous parent material. The kaolinite is allogenic and remains in tact. Alteration of mica with the loss of potassium appears to be an important mineral modification in the soils of the Brahmaputra floodplain. A suggested pathway for mineral transformation in the above soils may be as follows:



The reaction of the soils of the Brahmaputra floodplain is acidic. This indicates that these soils are leached and washed. Under this chemical environment the alterations are likely to go forward in the direction of the arrows.

5.5 Nutrient Status of the Soils

5.5.1. Major nutrients :

Total N.

Nitrogen plays an important role in soil fertility. Total nitrogen in the studied soils ranged from 200 to 1300 ppm with a mean nitrogen content of 600 ppm (Table -25). The values obtained in the present study corroborated well with the findings of Amin (1990), and Palash (1995). It was observed that total nitrogen in all profiles is high in the surface horizon which gradually decreased with depth. The total nitrogen contents have significant positive correlation ($r=+0.93^{**}$) with the organic matter in soils (Fig. 22).

Total P

The total content of phosphorus in soils ranged from 79 to 807 ppm with an average mean value of 417 ppm (Table -25). These values are within the range reported by Islam and Khan (1967); Islam and Ahmed (1973); and Islam and Mandal (1977), for some agricultural soils of Bangladesh. In the Dhamrai soil the amount of phosphorus is high throughout the profile. Sonatala and Sherpur soil series have high concentration of phosphorus in the lower horizon. The content of total phosphorus varies with the variations of organic matter, total nitrogen, pH, and clay contents of the soils (Mandal and Islam, 1978).

Total K

Total potassium content in the studied soils ranged from 10,300 to 28,100 ppm and the mean value was 20,700 ppm (Table -25). The high potassium contents in the soils bears testimony to their higher amount of K-bearing mineral such as mica (Habibulla et al. 1980; White, 1985; Islam et al. 1988; Mian, 1990; Chowdhury et al. 1992; and Elahi et al. 1993). Melandaha, Silmandi and Lokdeo profiles have low content of total K in their surface horizon which may be due to depotassication process of mica which may result in the formation of illite. These are flooded soils and there is siltation of new materials every year.

Table-25.Total and available N, P and K in the studied soils.

Soils	Horizon	Total					Available		
		N	P	K	N/P	P/K	N	P	K
		ppm					ppm		
Melandaha	Apg1	900	79	15700	11.4	0.01	115	6	190
	Apg2	600	231	15400	2.6	0.01	70	7	190
	Bwg1(?)	500	295	20600	1.7	0.01	45	7	190
	Bwg2(?)	500	81	21700	6.2	0.01	57	8	190
	2C1	200	255	15200	0.9	0.02	57	8	190
	2C2	500	324	20800	1.5	0.02	60	10	152
	3A1b(?)	200	457	20500	0.4	0.02	70	10	190
	4C	200	243	15000	0.8	0.02	76	12	152
	Mean	438	244	18100	3.2	0.02	69	8	181
Dhamrai	Apg1	900	648	21200	1.4	0.03	154	5	437
	Apg2	900	429	21600	2.0	0.02	130	6	399
	Bwg1	900	549	22600	1.6	0.02	159	8	342
	Bwg2	900	506	22600	1.8	0.02	76	2	399
	Cg1	600	585	21300	1.0	0.03	108	2	399
	Cg2	600	520	20900	1.2	0.02	114	3	437
	Cg3	600	693	21300	0.8	0.03	83	4	390
	2Cg4	500	582	20900	0.9	0.04	70	2	399
	Mean	738	564	21500	1.3	0.03	112	4	400
Sonatala	Apg1	800	326	20200	2.4	0.02	134	10	51
	Apg2	640	445	20400	1.4	0.02	156	11	51
	Bwg1	550	446	21000	1.2	0.02	112	8	59
	Bwg2	440	580	21400	0.8	0.03	90	7	63
	Bwg3	530	664	20800	0.8	0.03	77	6	63
	Cg1	350	643	21000	0.5	0.03	67	6	70
	Cg2	350	718	20300	0.5	0.04	56	8	59
	Cg3	260	753	20700	0.4	0.04	34	8	60
	Mean	490	572	20700	1.0	0.03	91	8	60

Continued next page

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Table-25. Continued

Soils	Horizon	Total					Available		
		N	P	K	N/P	P/K	N	P	K
		ppm					ppm		
Silmondi	Apg1	800	145	16100	5.5	0.01	76	5.0	247
	Apg2	700	160	21800	4.4	0.01	70	4.0	190
	Bwg1	700	160	21200	4.4	0.01	108	4.0	190
	Bwg2	300	356	20700	0.8	0.02	89	3.0	152
	Bwg3	200	227	20300	0.9	0.01	96	3.0	152
	Cg1	200	243	10300	0.8	0.02	115	5.0	152
	Cg2	200	280	15600	0.7	0.02	32	7.0	95
	Cg3	200	275	21500	0.7	0.01	83	8.0	95
	Mean	412	231	18400	3.3	0.01	78	5.0	270
Lokdeo	Apg1	1300	162	15300	8.0	0.01	134	4.0	342
	Apg2	1000	275	14100	3.6	0.01	127	3.0	247
	Bwg1	900	580	19000	0.6	0.15	70	4.0	247
	Bwg2	800	325	21200	2.5	0.02	57	4.0	304
	Bg3	700	343	26000	2.0	0.02	64	2.0	190
	Cg1	500	343	21200	1.5	0.02	64	1.0	247
	Cg2	500	280	10700	1.7	0.03	51	2.0	247
	Cg3	700	295	21700	2.4	0.01	70	2.0	342
	Mean	800	325	18600	2.8	0.03	80	3.0	270
Ghatail	Apg1	1200	341	27800	2.8	0.01	112	8	101
	Apg2	850	306	27900	4.1	0.01	101	9	78
	Bwg1	560	378	22300	1.5	0.02	90	8	101
	Bwg2	560	380	22100	1.5	0.02	101	6	86
	Bwg3	450	436	27500	1.0	0.02	67	5	78
	Cg1	440	423	21400	1.0	0.02	45	6	70
	Cg2	360	620	21000	0.6	0.03	33	7	59
	Cg3	350	675	20800	0.5	0.03	30	7	217
	Mean	600	445	23850	1.6	0.02	702	7	78
Sherpur	Apg	800	314	19600	2.6	0.02	115	6	190
	Bwg1	600	195	21500	6.3	0.01	108	5	190
	Bwg2	900	727	27400	1.2	0.03	108	7	342
	Bwg3	600	807	21800	1.7	0.04	70	6	304
	Cg1	900	687	28100	1.3	0.02	76	4	247
	Cg2	500	529	27000	1.0	0.02	96	3	304
	Mean	717	540	24300	2.4	0.025	96	5.0	263
Grand mean		600	417	20700	2.2	0.02	85	6	201

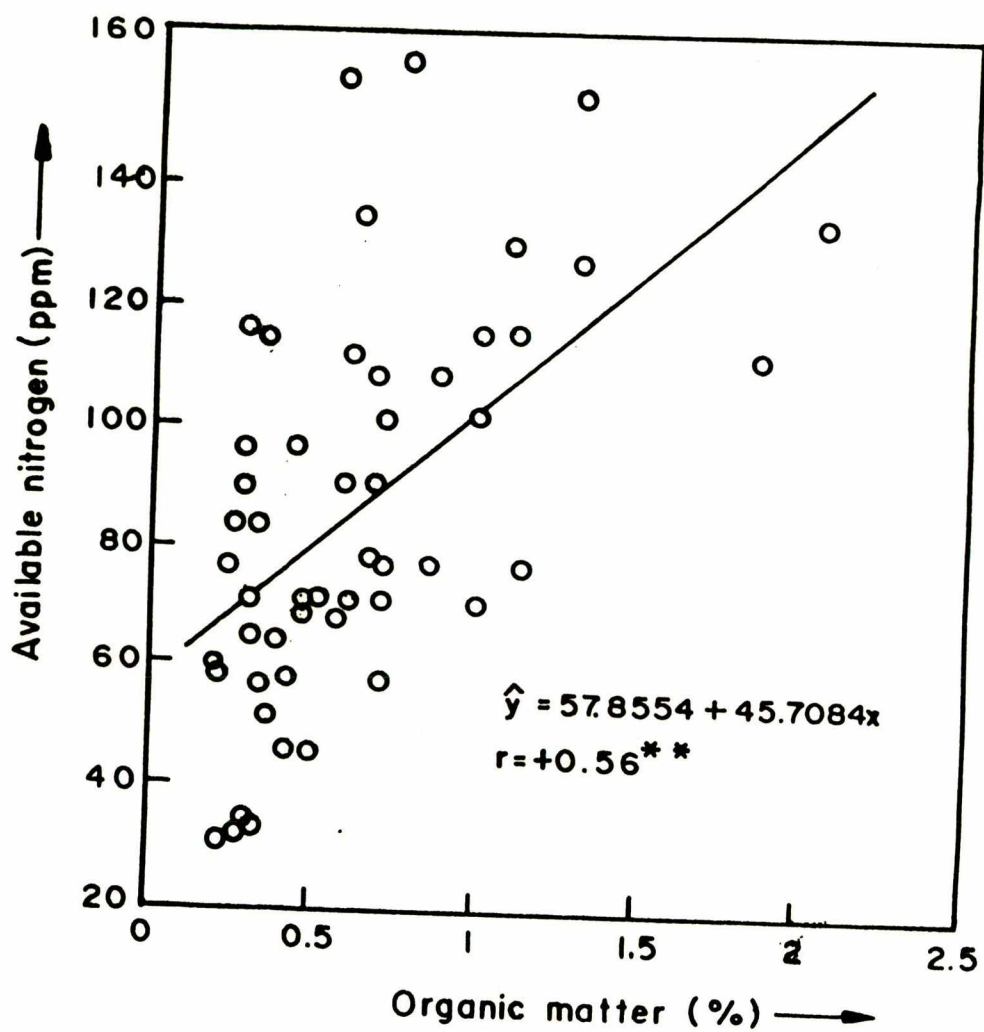


Fig. 48. Relationship between organic matter and available nitrogen (ppm) in the soils under investigation.

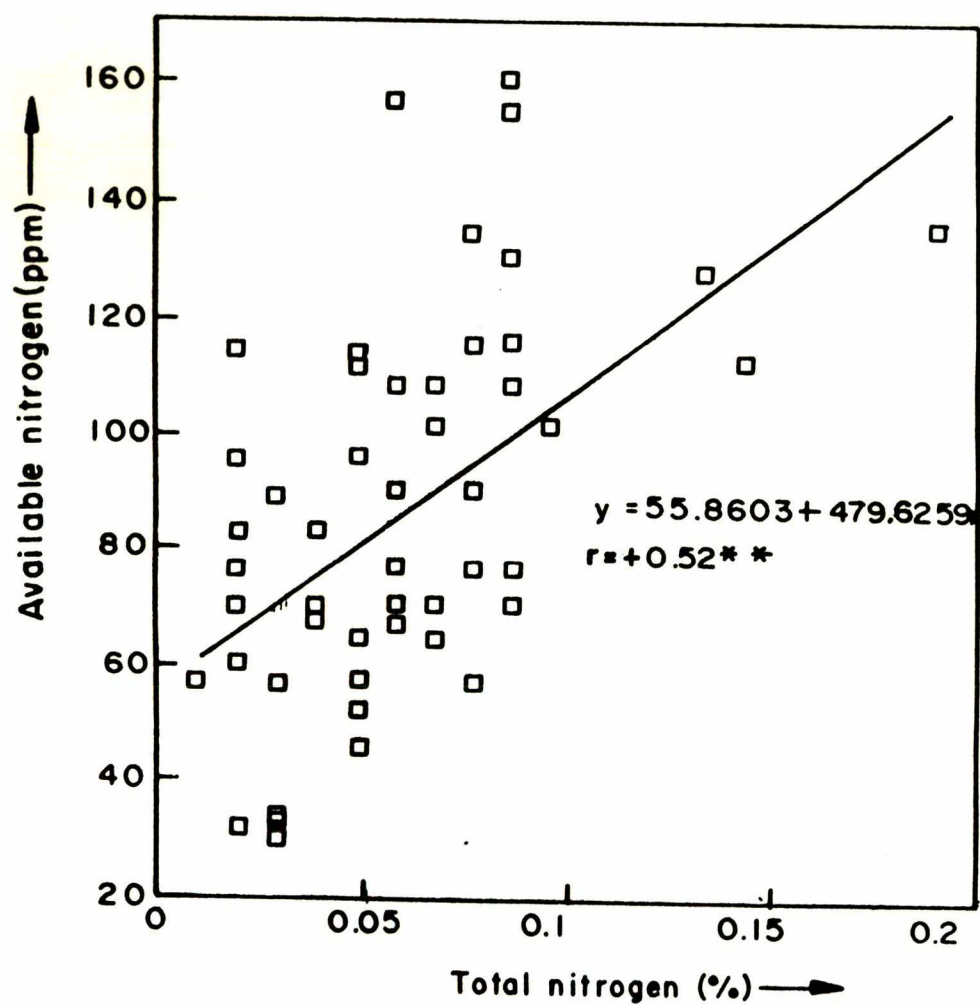


Fig. 49. Relationship between total nitrogen and available nitrogen (ppm) in the studied soils.

Available N

Available nitrogen content ranges from 30 to 159 ppm in the soils studied (Table -25). Higher concentration of available nitrogen is noticed in the surface horizons. Like total nitrogen content of the soils, the vertical distribution pattern of available nitrogen also shows a progressive fall with depth, but a slight variation is noticed in the Melandaha, Silmandi and Dhamrai profiles. A close relationship ($r=+0.56^{**}$) exist between the contents of available nitrogen and organic matter (Fig. 48) and between available nitrogen and total nitrogen ($r= + 52^{**}$) (Fig. 49). Similar relationship were also observed by Hossain et al. (1989) in some soils of Bangladesh.

Available P

Available phosphorus in the soils studied had a mean value of 6 ppm (Table -25) and fell in the low range (BARC, 1989). This result corroborated well with the findings of Palash (1995) in some submerged soils of Bangladesh. This low available phosphorus may be due to the fixation of the phosphorus. Available phosphorus is high near the surface horizon of Lokdeo profile. In other profiles, the available phosphorus is found to be irregularly distributed.

Available K

Available potassium ranges from 51 to 437 ppm in the soils and the mean value is 201 ppm (Table-25) and fall in the low range (BARC, 1989). These results agreed with the findings of Habibulla et al. (1980), and Saleque et al. (1990) in some low land rice soils of Bangladesh. The available potassium constitutes a minute fraction of the total potassium. Slightly higher concentration of available potassium is present in the upper horizons of Dhamrai, Lokdeo, Silmandi and Ghatail soils. This may be due to bio-cycling of potassium. Mineralogical analysis indicates that these soils are high in mica. Consequently, the available K content is expected to be high.

5.5.2. DTPA extractable micronutrients

Micronutrient contents of soils are dependent on the nature of parent material and degree of weathering. The results presented in Table-26 represent the total and DTPA extractable Fe, Mn, Cu and Zn in the soils studied of the Brahmaputra floodplain.

Total and available Fe.

The total contents of Fe in the studied soils range from 36,300 to 62,200 ppm (Table-26). The average total Fe contents in the profiles in decreasing order are Ghatail (51,900 ppm), Sherpur (49,100 ppm), Lokdeo (49,000 ppm), Dhamrai (44,000 ppm), Sonatala (42,800 ppm), Silmandi (39,800 ppm) and Melandaha (38,200 ppm).

The available Fe contents in the soils range from 13 to 89 ppm. The minimum content of available Fe was observed in the soils of the Silmandi series and the maximum in the Ghatail series. Considering 4.5 ppm as the threshold value of DTPA extractable Fe (Lindsay and Norvell, 1978), it may be said that all the studied soils have sufficient available Fe contents.

Total Fe also showed a positive correlation ($r=+0.63^{**}$) with the cation exchange capacity of soils. Similarly total iron showed a positive correlation ($r=+0.37^{**}$) with organic matter (Appendix-2). Available Fe correlated ($r=+0.55^{**}$) significantly with organic matter presented in Appendix 2. No definite sequence in the distribution of Fe with depth was noted probably due to youthful nature of these floodplain soils.

Total and available Mn

Total Mn content ranged from 506 to 1455 ppm in the studied soils (Table-26). The higher content of total manganese in these soils might be due to the presence of Mn bearing minerals in the parent materials (Bowen, 1979; Fairbridge and Finkl, 1979; Davis, 1980; Landon, 1991). In general, the vertical distribution of Mn in the soils under the present investigation did not show any specific trend. This feature is in agreement with the observation of Jha et al. (1984).

Table-26.Total and available (DTPA extractable) micronutrients in the soils under the present investigation.

Soils	Horizon	←—————Micronutrients (ppm)—————→							
		Total				Available			
		Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Melandaha	Apg1	85	52	886	37700	Tr.	2.03	40	58
	Apg2	82	25	882	41200	0.10	1.17	10	29
	Bwg1(?)	165	51	1455	39100	0.18	1.09	6	17
	Bwg2(?)	187	54	949	37700	Tr	1.02	5	17
	2C1	116	50	1076	39100	0.33	0.27	2	19
	2C2	109	80	949	37000	0.40	0.19	8	18
	3A1b(?)	118	26	569	36300	0.52	0.62	2	17
	4C	127	75	696	37700	0.25	0.12	2	18
	Mean	108	52	933	38200	0.22	0.81	9	24
Dhamrai	Apg1	88	53	633	37700	1.02	9.65	8	38
	Apg2	104	56	759	41200	0.59	4.58	6	18
	Bwg1	140	76	696	41200	0.51	3.13	7	18
	Bwg2	135	53	882	47500	0.51	1.34	6	18
	Cg1	144	52	882	45400	0.51	1.36	7	18
	Cg2	136	187	886	45400	0.64	2.10	6	17
	Cg3	130	104	1076	46800	0.66	2.26	6	17
	2Cg4	140	110	886	46800	0.60	1.60	7	16
	Mean	127	86	837	44000	0.63	3.25	7	20
Sonatala	Apg1	132	78	569	40500	0.73	3.60	29	69
	Apg2	107	51	696	37000	0.60	2.60	22	37
	Bwg1	110	78	882	41200	0.48	2.60	21	32
	Bwg2	155	51	1013	45400	0.72	3.10	35	39
	Bwg3	144	52	1139	50300	0.66	3.30	51	57
	Cg1	194	79	1013	50300	0.50	2.60	8	25
	Cg2	117	20	882	38400	0.40	1.50	8	31
	Cg3	109	78	949	39800	0.56	1.90	11	39
	Mean	134	61	893	42800	0.63	2.65	23	41

Continued next page

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Table-26. Continued

Soils	Horizon	Micronutrients (ppm)							
		Total				Available			
		Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Silmandi	Apg1	257	268	633	41900	0.42	2.93	20	29
	Apg2	164	137	633	44000	0.15	1.68	11	15
	Bwg1	135	179	506	41900	0.18	2.07	7	15
	Bwg2	347	208	882	37700	0.13	0.47	5	13
	Bwg3	209	306	759	41200	0.42	5.74	4	16
	Cg1	212	206	506	36300	0.35	0.90	2	13
	Cg2	226	269	759	35600	0.27	0.88	2	14
	Cg3	199	161	696	39800	0.11	0.66	2	13
	Mean	219	217	672	39800	0.25	1.93	7	16
Lokdeo	Apg1	719	351	633	62200	0.70	7.03	20	36
	Apg2	156	81	633	62200	0.41	5.08	16	18
	Bwg1	476	362	696	46800	0.36	3.20	6	17
	Bwg2	458	625	886	39100	0.15	1.64	7	15
	Bg3	264	156	759	46100	0.15	0.82	4	14
	Cg1	317	185	882	44000	0.12	1.05	4	15
	Cg2	723	633	633	49600	0.50	1.09	6	16
	Cg3	850	985	882	42600	0.36	1.37	8	15
	Mean	496	422	750	49000	0.34	2.66	9	18
Ghatail	Apg1	847	61	949	58000	1.16	9.60	79	89
	Apg2	435	53	759	56600	0.64	4.50	35	79
	Bwg1	390	82	882	55900	0.41	3.10	19	31
	Bwg2	381	60	886	56600	0.32	1.30	10	24
	Bwg3	242	82	1455	53100	0.60	1.30	54	20
	Cg1	148	81	949	47500	0.66	2.10	30	37
	Cg2	157	66	1076	43300	0.80	2.20	11	22
	Cg3	157	52	949	44700	0.52	1.60	7	20
	Mean	345	67	988	51900	0.64	3.21	31	40
Sherpur	Apg	164	205	882	36300	0.91	2.30	26	49
	Bwg1	234	284	1012	38400	0.66	1.15	20	24
	Bwg2	241	164	1139	53100	0.46	0.90	6	17
	Bwg3	603	326	1013	62200	2.04	1.17	5	17
	Cg1	455	477	882	56600	1.14	2.34	10	20
	Cg2	548	796	949	48200	0.93	1.75	11	13
	Mean	374	375	979	49100	1.02	1.60	13	23
Grand mean		258	183	865	44900	0.53	2.30	14	26

Available Mn, on the average, ranged from 2 to 79 ppm with a mean value of 14 ppm. Low content of available Mn was observed in the soils of the Silmandi and Dhamrai series and high content was found in the soils of the Ghatail series. On the basis of 1 ppm of DTPA extractable Mn as the critical limit (Lindsay and Norvell, 1978) the present soils are thought to have sufficient available Mn for good crop production. Available Mn content correlated significantly with total iron, clay, organic matter, and CEC of the soils (Appendix-2).

Total and available Cu

The total Cu content in the soils ranged from 20 to 985 ppm with a mean value of 183 ppm. The total Cu was minimum in Melandaha series and maximum in Lokdeo series.

Available Cu contents in these soils range from 0.12 to 9.65 ppm. On the basis of 0.2 ppm DTPA extractable Cu as the critical concentration (Lindsay and Norvell, 1978) it may be inferred that the present soils have adequate quantity of available Cu. Available Cu was significantly and positively correlated with clay content ($r = +0.28^*$), organic matter ($r = +0.76^{**}$) and pH H₂O ($r = +0.27^*$) (Appendix-2). Similar relationship of available Cu with pH and organic matter was reported by Sakal et al. (1988) and Ahmed (1989). Agarwal and Motiramani (1965) also reported that available Cu in soils is significantly correlated with their pH.

Total and Available Zn

The total Zn contents in the studied soils range from 82 to 850 ppm with a mean value of 258 ppm. This value is comparable to that reported by Jha et al. (1984) in some Indian soils. Maximum content of total Zn was recorded in Lokdeo profile. Total Zn

decreased with depth in Silmandi, Ghatail and Sonatala and increased with depth in Lokdeo, Melandaha, Sherpur and Dhamrai soils.

Distribution of Zn in soil profile is affected by drainage, clay and organic carbon content (John et al., 1974 and Sakal et al., 1988)

Available Zn in these soils ranges from 0.10 to 2.04 ppm with a mean value of 0.53 ppm. Taking 0.80 ppm as the critical value of available Zn in soils (Lindsay and Norvell, 1978) it may be assumed that all the soils are deficient in available Zn. The above authors noted that Zn is more available in the acidic than in the alkaline soils.

Available Zn was significantly and positively correlated with total Zn ($r = +0.30^*$), total Mn ($r = +0.61^{**}$) and total Fe ($r = +0.43^{**}$) (Appendix-2). Available Zn content also shows correlation with clay content and organic matter content (Appendix-2). Similar relationship of available zinc and percent clay was reported by Ahmed (1989).

5.5.3 Potential fertility of the soils.

“Bangladesh is a land of fertile soils”. This statement was perhaps true in the past when pressure on land was low and the food grains harvested from a single crop annually per unit area of land was adequate to feed the nation (Bhuiya, 1991). Because of the alluvial nature, most soils are probably in favourable physical condition for easy tillage and plant roots can go deeper uninterruptedly and spread in wider areas except in soils with hard plough pan. Climatic condition also contributes favourably for growing a wide range of crops.

With increasing intensity of land use during the last two decades to produce more foodgrains from the same area of soils resulted in a severe exhaustion of plant nutrients, particularly from those which were used for repeated and intensive cultivation with modern crop varieties. Good crop growth and high yield of crops depend not only on

Table-27. Amounts of organic matter and total nutrient contents in the surface horizon of the soils.

Soil Series	Depth (cm)	Organic matter %	Nitrogen (N) %	Phosphorus (P) %	Potassium (K) %	Calcium (Ca) %	Magnesium (Mg) %	Iron (Fe) %	Manganese (Mn) ppm	Copper (Cu) ppm	Zinc (Zn) ppm
Melandaha	0-15	0.98	0.08	0.02	1.56	2.22	0.82	3.94	884	38	84
Dhamrai	0-15	1.17	0.09	0.05	2.14	2.26	1.35	3.94	696	55	96
Sonatala	0-15	0.82	0.07	0.03	2.03	2.27	1.20	3.87	632	78	132
Silmandi	0-15	0.99	0.08	0.02	1.89	2.21	1.16	4.29	633	201	210
Lokdeo	0-15	1.65	0.12	0.02	1.47	2.27	1.45	6.22	633	216	438
Ghatail	0-15	1.40	0.11	0.03	2.78	2.66	1.47	5.73	854	61	847
Sherpur	0-15	1.25	0.08	0.02	2.06	2.25	1.24	3.73	947	245	199
Mean		1.18	0.09	0.03	1.99	2.30	1.24	3.71	754	128	287

physical properties of soils but also on nutrient status along with organic matter of the soil. So Knowledge about the fertility status of soils is of immense value for the improvement of crop production. Consequently, the current fertility status of the soils under the present investigation merits critical consideration. To have an approximate idea for the evaluation of the fertility status nutrient contents of soil analysis have been presented in Table-27. It has been observed that the Brahmaputra floodplain soils have nitrogen content almost comparable to that of most other agricultural soils of Bangladesh. The total contents of nitrogen and phosphorus in Bangladesh soils range from 0.01- 0.18 percent (Amin, 1990) and 200 - 850 ppm (Mandal and Islam, 1978) respectively. The results found in the present soils corroborate well with their results. With respect to total potassium contents these soils are rich (Islam and Khan, 1967; Huizing, 1970; Habibulla et al., 1971; Karim et al., 1978; Karim, 1980; Hussain and chowdhury, 1980; and Chowdhury et al., 1992). Although the amount of total potassium itself does not give a measure of the availability of this element to the plants, it gives an idea of the soil's capacity to supply potassium to plants over longer periods of time. That is, the contents of total potassium can roughly be a measure of the dynamics of this element in terms of availability to the plants (Chowdhury, 1985).

Total calcium and magnesium contents of these soils were found to be slightly higher than that of the average values reported for Bangladesh soils (Islam and Khan, 1967; and Hussain and Choudhury, 1980).

The total contents of micronutrient elements such as Fe, Mn, Cu and Zn in these soils are higher than the values reported for other Bangladesh soils (Hassan, 1991; and Khan, 1995). In addition, the contents of organic matter and the values of cation exchange capacity are comparable with those normally reported for other Bangladesh soils (BARC, 1989). The values of organic matter found in the present soils fell in the lower range (BARC, 1989). The cation exchange capacity of Melandaha and Sonatala

series fell in the low range; Dhamrai, Silmandi, Lokdeo and Sherpur series fell in the medium range; and that in the Ghatail soil fell in the high range (BARC, 1989).

According to the classification proposed by BARC (1989), the soils of the Brahmaputra floodplain were classed as moderately acid to neutral. Moreover, the clay mineralogy of the present soils are known to be dominated by an admixture of illite - kaolinite - vermiculite. The mixture of these clay minerals in the soils of Brahmaputra alluvium is a boon as these soils will not show any extreme physical property.

Furthermore, flood water of the Brahmaputra river carries high amount of silt every year which is rich in plant nutrients. It may be mentioned that in these soils multiple cropping is being practised for a long time without any addition of fertilizer. This practice has presumably reduced the fertility status, but the gain in nutrients by annual siltation during the flooding season which partially compensates the loss caused by removal of nutrients by crops.

From the above considerations one may conclude that the present soils can be classed as moderately fertile.

5.6. Genesis of the Soils under investigation

On the basis of the information obtained from the field and laboratory studies, attempt has been made to look into the pedogenic processes that are operating in the soils and also in to their classification according to the USDA soil taxonomy (Soil Survey Staff, 1994) and the FAO -Unesco legend.

In consideration of the geological history, the area wherefrom the soils have originated, may be considered to be of recent age. The environmental, morphological and chemical properties of these soils indicate clearly that the parent materials of these soils were alluvial deposits of mixed origin.

Profile characteristics of these soils indicate that their development did not proceed far. All the soils under investigation appear to be only moderately developed. This may be due to their environmental conditions and time factor. The soils may, therefore, be reasonably considered to be in its incipient stage of development. The parent materials and the conditions like poor drainage and aquic moisture regime due to submergence during the rainy season are probably the factors affecting the characteristics in some profiles. Since the soils are at their youthful stage presumably, the parent materials will play a key role in exhibiting the properties of the soils. The direct consequence of poor drainage is the retardation of leaching and little alteration of soil minerals. Apart from that, the soils have been under cultivation for a long time and thus disturbed the normal pedological processes and helped in the mechanical translocation of finer fractions downward forming the ploughpan and the flood coatings. The finer fraction blocked the pore space and restricted to some extent the movement of the products of weathering.

Seasonal submergence and drying set the condition of alternate reduction and oxidation in the soils. The elements susceptible to oxidation-reduction conditions would respond readily and eventually would impart certain characteristics like mottles to the soil. The reaction (pH) of the soils closely follows the course of oxidation-reduction condition as because the soils contain considerable amount of Fe and Mn which are subject to

change. The grey tings of the soils are probably due to the above said conditions. Another interesting feature of these soils are the presence of mottling of yellow or brown colours usually along the old root channels and pores. The horizons containing the variously coloured mottlings may be considered as evidences for weak type of gleization process.

In most of the soils, alternate wet and dry conditions produce vertical cracks leading to big prism. With the passage of time, the horizontal cracks and combined effect of flocculation, root penetration, organic matter addition and the biotic activity produces blocky structure. Translocation of fine materials from the top through the cracks along with the first floodwater made the structural aggregate more conspicuous. In Ghatail soil, the structural development is pronounced due to its congenial environment whereas in Melandaha soils it is at the initial stage indicating its youthfulness.

The development of coating along the ped faces, fissures and pores in the subsoil are typical characteristics of these soils. These coatings are not true clay skins but are flood coatings as called by Brammer (1971). They appear to have developed rapidly from the materials that were taken down from the surface under flooded condition.

Ploughpan is a soil layer compacted by tillage and occurs below 5 to 15 cm from the surface of the soil depending on the normal depth of ploughing. It is mainly formed due to continuous wetland rice cultivation (FAO,1971; Brammer,1979). It becomes thicker and harder through continous practice of transplanted rice cultivation. Ploughpan was found to develop 2 to 3 cm thick in Sonatala, Ghatail, Silmandi, Lokdeo and Dhamrai soils whereas no detectable ploughpan was found in Melandaha and Sherpur soils. The ploughpans prevent vertical water percolation, restricts aeration as well as root penetration (Brammer,1971).

The vertical distribution pattern of sand, silt and clay of these soils (Table- 8) support the preceding statements. The soil profiles with moderate to strong angular blocky structure suggests the formation of altered B (cambic) horizon in all the soils except Melandaha. However, the soils in the surface horizon have mostly massive structure.

In each soil profile, there is a trend of increasing pH with depth (Table-12). Nevertheless, in all the soils the surface horizons have acidic reaction. The surface soil acidification is due to the alternate oxidation reduction cycles in the floodplain areas (Brammer, 1971).

The colloidal complex of the soils is also well supplied with exchangeable metal ions (Table-13). The base saturation increases gradually with depth and Ca^{++} and Mg^{++} dominate the exchange complex (Table-14). Exchangeable $\text{Ca}^{++} / \text{Mg}^{++}$ ratio is, in general, around 2.39 (mean value). X-ray diffraction analysis indicates the dominance of non-expanding types of minerals in the clay fraction. Cracking, as a result, is usually weak.

The silica-sesquioxide ratio in the clay fraction indicates the presence of a considerable amount of 2 : 1 lattice type clay minerals which might be an admixture of a variable amount of mica and vermiculite. Alteration of mica to vermiculite may be a common pedochemical weathering process. Depotassication is thus common. The marked similarities in the clay mineralogy of these soils suggest that mineral weathering and /or synthesis have been quite limited and uniform. It is of interest to note that a small quantity of smectite has been detected in one pedon.

Vertical distribution of clay in the Sherpur soil profile indicates an impoverishment of clay in the surface horizons. This low clay near the soil surface may be for two reasons. It may be because of stratification or there may be destruction of clay near the surface because of the ferrolysis process. Quantity of chlorite is high in the surface horizon of this pedon.

From the characteristics discussed in the preceding paragraphs it appears that the soils under investigation are likely to be generally designated as hydromorphic in nature except the Sherpur series. However, the absence of well developed gley horizons and the higher $\text{Ca}^{++} / \text{Mg}^{++}$ ratio in these soils may lead one to cast doubt about the true hydromorphic nature of these soils. Nevertheless, it may be worthwhile to mention that the

very weak gley horizons represented only by the occurrence of mottles which is due to the seasonal drying of the soils. Weak type of gleization seems to be a process of soil formation in all these soils.

Albretch (1941) reported that gleization occurs in the zone of soils, where the three factors, such as high base saturation with ample calcium, organic matter infiltration and standing water or poor drainage operate jointly for anaerobiosis. This was later on supported by other authors (Bloomfield 1959, Stremienski 1959, Fields 1959, Grimmett, 1959 and Claridge 1959)

In conclusion, it may be said that the soils developed on the Brahmaputra floodplains show some weak marks of hydromorphism in their body. Gleization, therefore, is thought to be a process of soil formation in them. It is worth noting that parent materials of mixed origin and with a light texture and incipient age as well as annual siltation have played dominant roles in the evolution of pedogenetic processes that have been in operation in the soils under discussion.

5.7. Classification of the Soils under investigation

An endeavor has been made in this section to classify the soils on the basis of the available information. Relevant properties of these soils were matched with the criteria set out in the USDA soil taxonomy (Soil Survey Staff 1975 and 1994). As evident from the results of morphological, physical, chemical and mineralogical properties presented in chapter 4 and 5 there were variations in surface and subsurface colours, textures, structures, pH, base saturation, and clay mineralogical composition. The variation of the above properties in the soil profiles was considered very important in differentiating the soils. These soils are not bestowed with any well developed structure in the top soils. However, the presence of weakly to moderately developed coarse and medium prismatic and blocky structural elements, distinctly coated with clay, silt and humus on ped faces in the subsoils of all these profiles except Melandaha series have been used for their characterization. Occurrence of variously coloured mottles along root channels and pores is another persisting feature in all the soil series. The moderately to strongly developed structure in the subsoils of the profile is conspicuous because of mechanical translocation of fine earth's from the surface horizon. In addition, these subsoil's are devoid of rock structure. For "cambic" horizon the soil taxonomy demands the soil structure development and absence of rock structure in conjunction with the occurrence of mottling. Consequently, the structural B horizon of these soils along with the redox concentration and the regular decrease of organic matter may be designated as the cambic horizon.

The coatings that were found on the ped faces in the subsoil horizon are not true clay skins, but apparently represent mechanical downwashing of material from the surface soil. There is no indication of eluviation of clay from the topsoil and deposition of them in the subsoil. as in the case of true clay skins. Brammer (1971) has designated these materials as flood coatings.

The characteristics of the top soil are subject to mechanical manipulation during cultivation when the soil is wet. Most of these soils have been used for rice cultivation for

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centuries. As a result, structure formation is weak. These soils are seasonally gleyed and often show iron stains along root channels and at the base of plough pan. The lack of proper horizon differentiation in the soils and the variable $\text{SiO}_2 : \text{R}_2\text{O}_3$ ratios throughout the profile are the characteristics of soils at the incipient stage.

The epipedon of the soils, studied were identified as ochric epipedon.

All the soils belong to aquic moisture regime except Sherpur soil which belongs to udic moisture regime.

The formation of cambic horizons, suggests that all the soils, studied except Melandaha may be put under the Inceptisols order. In Melandaha soil series stratified layers occur within 50cm of the surface, and weak type of structure development and oxidized, and thereby may qualify for the Entisol order.

Inceptisols are sub-divided into suborders on the basis of difference in soil moisture regime, and some other extreme physical and chemical properties. The soils studied on the basis of their relevant properties can be placed into three suborders, Aquents, Aquepts and Ochrepts (Table-29). The soil series namely Dhamrai, Sonatala Lokdeo and Ghatail fall in the Aquept suborder due to their reduced colour ($\text{Chroma} \leq 2$), while Sherpur series due to its high chroma falls into the ochrept suborder.

Ochrepts are placed into the Eutrochrepts great group because of high base saturation (60 percent or more) by NH_4OAc method in some sub horizons. The soils belonging to Aquept suborder may be placed into the Endoaquepts great group because of endo saturation. Melandaha pedon may be placed under Fluvaquent greatgroup because of irregular decrease of organic carbon with depth.

At the subgroup level, Sherpur series fit in the Aquic Eutrochrepts sub group because of the presence of grey mottles within 60 cm from the surface. The soils like Silmandi, Sonatala, Lokdeo, and Ghatail fit in the Aerice Endoaquepts sub group having 50% or more matrix colour chroma ≥ 2 within 75cm depth. While Dhamrai soils fit into the Typic Endoaquept as they have 50% or more matrix colour chroma ≤ 2 within 75 cm

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depth. Melandaha series may be classed in the Typic Fluvaquents sub group because of grey matrix colour.

It should be noted here that all the above soils have hyperthermic temperature regime (Table-28).

On the basis of soil reaction, all the soils studied can be placed under the non acid class.

Mineralogical studies indicate that all the soils are mixed in origin as they do not have any particular clay minerals, which is more than 50%.

On the basis of particle size classes the Ghatail soils are classed as clayey over loamy. Dhamrai, Sonatala, Silmandi, Lokdeo, and Sherpur series are classed as loamy. The Melandaha series may be classified as loamy over sandy.

Therefore, according to the US soil taxonomy the studied soils have been characterized into the orders Entisols and Inceptisols, three sub orders (Aquents, Aquepts and Ochrepts), three great groups (Fluvaquents, Endoaquepts and Eutrochrepts,) and four sub groups and seven families (Table-29).

Similarly the seven soil pedons have been characterized in the FAO-Unesco legend at the sub unit level. For this purpose, the definitions given in the revised legend in 1990 have been used (FAO-Unesco, 1990).

Table-28. Derived values for soil classification

Soils	Surface soil colour (moist)	Subsoil colour (moist)	Subsoil Texture	Subsoil Structure	Organic carbon (decreased from top to substratum)	BSP upto 75 cm depth	pH range upto 50 cm depth	Temperature regime	Clay mineralogy class
Melandaha	Grey (5Y 5/1)	Grey (5Y 5/1)	sil	1 vc pr	0.79-0.13	64-75	5.39 - 6.22	Hyperthermic	Mixed
Dhamrai	Grey (5Y 5/1)	Olive Grey (5Y 5/2)	sicl	2cpr	0.74-0.16	72-82	5.67-6.69	Hyperthermic	Mixed
Sonatala	Grey (5Y 5/1)	Olive grey (5Y 5/2)	sil	1-2 cpr/c-m abk	0.64-0.26	66-92	6.96-6.98	Hyperthermic	Mixed
Silmandi	Grey (5Y 5/1)	Olive grey (5Y 5/2)	sicl	1 c-m abk	0.75-0.14	66-99	6.05-6.79	Hyperthermic	Mixed
Lokdeo	Grey (5Y 5/1)	Olive grey (5Y 5/2)	sicl	1-2 vcpr/1c abk	1.18-0.26	62-78	5.53-6.40	Hyperthermic	Mixed
Ghatail	Grey (5Y 5/1)	Dark grey (5Y 4/1)	c	3c-m abk	1.07-0.12	54-73	5.99-7.80	Hyperthermic	Mixed
Sherpur	Grey (2.5Y 5/1)	Olive brown (2.5Y 4/4)	sil	2cpr/1c-m sabk	0.73-0.25	42-88	5.70-6.10	Hyperthermic	Mixed

Table-29. Classifications of the studied soils

USDA Soil Taxonomy					Soil series	FAO-Unesco Legend
Order	suborder	Great group	Sub group	Family		
Entisol	Aquent	Fluvaquent	Typic Fluvaquent	Loamy over sandy, Mixed, Nonacid, Hyper thermic, Typic Fluvaquent.	Melandaha	Chromi-Eutric Fluvisol
Inceptisol	Aquept	Endoaquept	Typic Endoaquept	Loamy, Mixed, Nonacid, Hyperthermic, Typic Endoaquept	Dhamrai	Chromi-Eutric Gleysol
			Aeric Endoaquept	Loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquept.	Sonatala	Chromi-Eutric Gleysol
			Typic Endoaquept	Loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquept.	Silmandi	Chromi-Eutric Gleysol
			Aeric Endoaquept	Loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquept	Lokdeo	Chromi-Eutric Gleysol
			Aeric (Vertic) Endoaquept	Clayey over loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquept	Ghatail	Verti-Eutric Geysol
	Ochrept	Eutrochrept	Aquic Eutrochrept	Loamy, Mixed, Nonacid, Hyperthermic, Aquic Dystric Eutrochrept	Sherpur	Orhti-Eutric Cambisol

CHAPTER - 6

SUMMARY AND CONCLUSIONS

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The present investigation was undertaken to study some basic pedogenic characteristics of some soils from the Brahmaputra floodplains of Bangladesh which may serve as useful reference points. The first step in this investigation was to study the environmental settings and the morphological and physical characteristics of the pedons. The second was to furnish more basic information on the physical, chemical and mineralogical properties of the soils. The third stage was to throw light on the probable genetic processes that have been in operation for the formation of these profiles. Finally, an attempt has been made to characterize these soils in the US soil taxonomy and the FAO - Unesco legend. In the end some information on the nutrient status of these soils have been provided.

Seven soil profiles of Brahmaputra floodplains each representing an extensive soil series along with the associated natural environmental features were studied in situ as well as in the laboratory. Soil samples were collected from the appropriate horizons from each of the profiles.

A. The soils were studied morphologically in the field and their detailed profile descriptions were recorded according to the procedures of USDA. The prominent morphological features are as follows :

- ◆ The top soils were generally grey to dark grey in colour when moist.
- ◆ The subsoil colours were usually olive to grey when moist.
- ◆ The soils were characterized by the presence of flood coatings and variously coloured mottles along the old root channels and pores.
- ◆ Prismatic to angular blocky structure developed in the subsurface horizons of all the profiles, whereas massive structure was found in the surface soils.
- ◆ The soil reaction were slightly acidic in the surface to mildly alkaline in the subsurface with a tendency to increasing pH with depth.

Chapter - VI Summary and Conclusion

- ◆ The soils have poor drainage conditions and remained flooded for various periods during the monsoon season.

B. Physical investigations of the collected soil samples were carried out and the results obtained therefrom might be summarized as follows :

- ◆ Silt was by far the dominant fraction in the soils and played a significant role in moulding the textural character of these soils.
- ◆ The irregular vertical distribution pattern of sand/silt ratio as well as the clay content in all the profiles indicated the heterogeneous nature of the parent materials from which these soils have developed.
- ◆ The soil moisture retention at 0.01, 0.33, and 15 bars pressure were determined.
- ◆ Most of the soils were found to have higher bulk density in the Ap₂ horizons (ploughpan) due to compaction resulting from rice cultivation. In most cases, particle density showed higher values in the subsoil's than in the top soils.

C. Results of chemical analysis may be summarized as follows :

- ◆ The organic matter contents of these soils were low and showed more or less a gradual decrease with depth. The C/N ratio of the soils varied from 4 to 11. The vertical distribution pattern of C/N ratio in the pedons was irregular.
- ◆ All Δ pH values were negative and ranged from -0.56 to -1.60 pH unit. The Δ pH values showed a significant and a positive relationship with the pH values of the soils.
- ◆ The cation exchange capacity (CEC) showed a significant positive correlation with percent clay and also with the organic matter, but the CEC is more strongly correlated with clay.
- ◆ The base saturation was high and showed a tendency to increase with depth in the profiles. Calcium and magnesium were the dominant cations in all the soils.

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Calcium alone occupied more than 60% of the exchange positions. Base saturation had a positive relationship with pH (H_2O).

- ◆ Free oxides of iron, aluminium and manganese in the soils studied were low. Free Fe_2O_3 content had a significant positive correlation with the free MnO_2 content. Acid oxalate extractable iron, aluminium and manganese in the soils were also determined.
- ◆ From the fusion analysis of the whole soils, it was clear that the distribution pattern of SiO_2/R_2O_3 ratios throughout the profiles was non-uniform. This suggested that the parent materials were heterogeneous and were of mixed origin.
- ◆ The higher K_2O content suggested that the soils were rich in illitic type of clay minerals. The TiO_2 content of the colloidal fraction of the soils was around 1.27 percent. The distribution pattern of TiO_2 content from the surface downward was irregular in nature.
- ◆ Mineralogical composition of clay fraction in topsoil, subsoil's and substratum from each of the profiles were determined. All the soils contained high amount of mica and kaolinite but mica was the dominant clay mineral. Other minerals were vermiculite, chlorite and some interstratified type.
- ◆ The presence of vermiculite in all the soils indicated that mica is possibly being transformed to vermiculite.
- ◆ Relatively higher amounts of available nitrogen, phosphorus and potassium were found in the surface horizons of the soils.
- ◆ DTPA extractable micronutrient elements (Fe, Mn, Cu, Zn) were determined. The DTPA extractable Zn was marginal in all the soils.
- ◆ On the basis of morphological, physical, chemical and mineralogical properties, the following conclusions are drawn:
 - * Of the soils studied, only one pedon was found to fit in the Entisol order and the rest six pedons in the Inceptisol order.
 - * Gleization appeared to be the dominant pedogenetic process.

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- * The present soils have moderate nutrient status, which are renewed every year by siltation during flooding in the monsoon season.
- ♦ The soils have been characterized at the family level, according to the US soil taxonomy as follows :

Soil Series	Family name*
Melandaha	Loamy over sandy, Mixed, Nonacid, Hyperthermic, Typic Fluvaquents.
Dhamrai	Loamy, Mixed, Nonacid, Hyperthermic, Typic Endoaquepts
Sonatala	Loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquepts.
Silmandi	Loamy, Mixed, Nonacid, Hyperthermic, Typic Endoaquepts.
Lokdeo	Loamy, Mixed, Nonacid, Hyperthermic, Aeric Endoaquepts.
Ghatail	Clayey over loamy, Mixed, Non acid, Hyperthermic, Aeric Endoaquepts.
Sherpur	Loamy, Mixed, Nonacid, Hyperthermic, Aquic Dystric Eutrochrepts.

* According to USDA soil taxonomy.

CHAPTER-7

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APPENDICES

APPENDIX-I

Correlation coefficient between different parameters of the studied soils.

Parameters	Calculated Correlation Coefficient (r)	Level of Significance (%)
Clay content Vs Soils moisture (hygros)	+0.84**	1
Clay content Vs Oven dry/ Air dry (OD/AD)	- 0.64**	1
Clay content Vs Loss on ignition (L.O.I)	+0.67**	1
Organic matter Vs Loss on ignition	+0.48**	1
Bulk density Vs porosity	- 0.97**	1
Clay content Vs n-Value	-0.54**	1
Clay content Vs 15 bar tension	+0.76**	1
pH (H ₂ O) Vs Δ pH	-0.40**	1
pH(H ₂ O) Vs pH KCl	+0.86**	1
Organic matter Vs Total nitrogen	+0.93**	1
Clay content Vs Cation exchange capacity (CEC)	+0.87**	1
Organic matter Vs CEC	+0.30*	5
Total iron Vs Free iron	+0.57**	1
Free iron Vs Free Mn	+0.58**	1
Organic matter Vs Available nitrogen	+0.56**	1
Total nitrogen Vs Available nitrogen	+0.52**	1

APPENDIX-2

Correlation coefficient between the total and available micronutrients and some properties of the studied soils.

Soil Properties	DTPA extractable				Total			
	Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Clay content	0.27*	0.28*	0.40**	0.33*	0.40**	+	0.30*	0.64**
Organic matter	0.27*	0.76**	0.51**	0.55**	0.36**	+	+	0.37**
pH (H ₂ O)	+	0.27*	+	+	+	0.43**	0.28*	+
CEC (soil)	+	0.23	0.38**	0.22*	0.48**	+	0.29*	0.63**
Total micronutrient elements in soil								
Zn	0.30*	0.23	+	0.31*	1.00	-	-	-
Cu	+	+	+	+	0.70**	1.00	-	-
Mn	0.61**	+	+	+	0.22	+	1.00	-
Fe	0.43**	0.31*	0.27*	0.23	0.38**	+	0.61**	1.00

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

* Significant at 5% level.

** Significant at 1% level.

APPENDIX-3 :

Values used for classification soil acidity and alkalinity (BARC, 1989).

Class	Ranges
Extremely acid	Below 4.5
Strongly acid	4.5 - 5.5
Moderately acid	5.6 - 6.5
Neutral	6.6 - 7.3
Moderately alkaline	7.4 - 8.4
Strongly alkaline	8.5 - 9.0

APPENDIX-4 :

Values used to classify organic matter content and cation exchange capacity (BARC, 1989).

Class	Organic matter (%)	Cation Exchange Capacity (Meq/100g)
Very high	> 5.5	> 30
High	3.4 - 5.5	15 - 30
Medium	1.7 - 3.4	7.5 - 15
Low	1.0 - 1.7	3 - 7.5
Very low	< 1.0	< 3

APPENDIX-5 :

Approximate values of plant nutrients used to interpret soil test results (BARC, 1989).

For Loam and Clay Soils for Upland Crops.

Element	Low (upto)	Medium	Optimum
N $\mu\text{g/g}$ soil	65.00	66.00 - 130.00	131.00 - 260.00
P $\mu\text{g/g}$ soil	10.00	11.00 - 22.00	23.00-65.00
S $\mu\text{g/g}$ soil	10.00	11.00- 22.00	23.00-65.00
B $\mu\text{g/g}$ soil	0.17	0.18-0.44	0.45-1.00
Cu $\mu\text{g/g}$ soil	0.85	0.86-2.50	2.60-8.00
Fe $\mu\text{g/g}$ soil	17.00	18.00-35.00	36.00-175.00
Mn $\mu\text{g/g}$ soil	4.00	4.10-8.50	8.60-40.00
Zn $\mu\text{g/g}$ soil	1.80	1.81-3.50	3.60-10.00
Ca cmol/kg soil	1.80	1.81-3.50	3.60-15.00
Mg cmol/kg soil	0.70	0.71-1.75	1.76-8.00
K cmol/kg soil	0.18	0.19-0.35	0.36-1.20
Ca/Mg	0.12	1.30-1.70	1.80-3.10
Mg/K	0.16	1.70-2.00	2.10-7.00